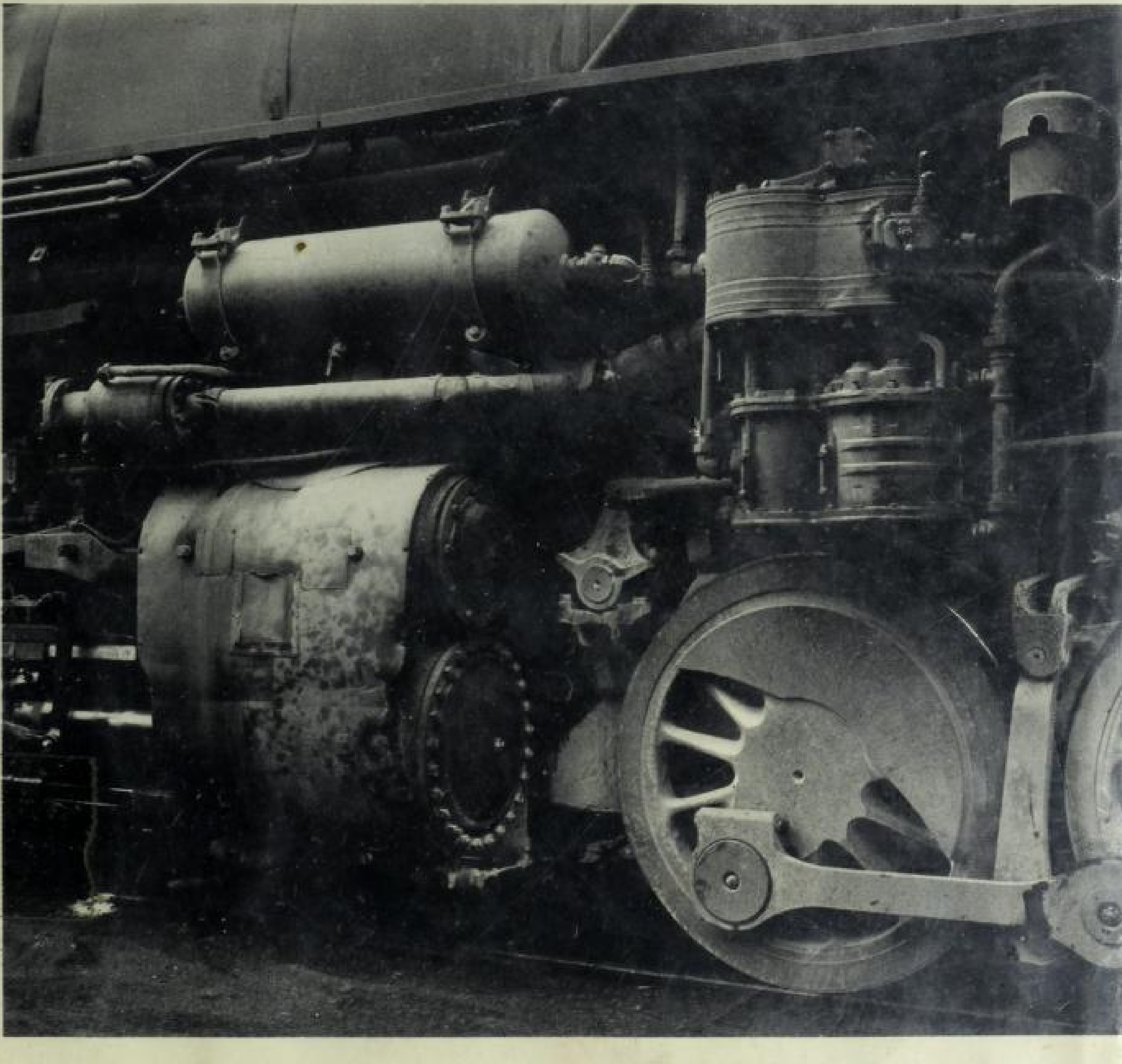
ARTICULATED LOCOMOTIVES

By LIONEL WIENER

Introduction and epilogue by Robert A. Le Massena



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By LIONEL WIENER

BY the author's estimate, articulated steam locomotives existed around the world in "a couple of hundred variations." By the estimate of contemporary authority Robert A. Le Massena, Lionel Wiener's volume ranks as one of four landmark books on steam locomotives and the only one to deal comprehensively with the principles of articulation. Professor Wiener approaches his subject expansively. He regards a locomotive with a trailing-truck booster as being temporarily articulated when the booster is operating, the Mallet as being only semi-articulated because its rear engine is rigid with respect to the boiler. He embraces Garratts, Climaxes, Shays, Fairlies, and a host of little-remarked types in his chronicle of how the concept of articulation was applied from Semmering to Sand Patch. ARTICULATED LOCOMOTIVES was first published in the United States in 1930. Articulateds would be constructed for another generation after that, but only as refinements of designs already established. So Wiener's work covers the field. Original editions of his book are virtually nonexistent. Kalmbach's republication is as faithful to the original as Wiener himself was faithful to his subject. Le Massena relates Wiener's text to the latter-day scene and discusses the articulateds of the North American continent.

MILWAUKEE, WISCONSIN

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BY

LIONEL WIENER

Professor at the University of Brussels

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INTRODUCTION

AMONG the fascinating lore of railroad motive power, four English-language volumes have towered above all others. The first was Angus Sinclair's *Development of the Locomotive Engine,* a nearly 700-page documentary of steam locomotion prior to 1907. Twenty-five years were to pass before another comparable work appeared. This was Ralph Johnson's *The Steam Locomotive,* a comprehensive (500 pages) treatise on the theory and design of fuel-burning, steam-driven self-propelled machinery. Just a decade later, Alfred Bruce recorded the 20th century evolution of steam power in a 400-plus-page tome entitled *The Steam Locomotive in America.* The subject would seem to have been adequately covered in these 1600 pages of fairly detailed discussion and illustration; nevertheless, there was a gap in the chronicle, a vacancy which has been filled admirably by *Articulated Locomotives.*

Prof. Lionel Wiener at the University of Brussels in Belgium compiled the data and wrote the book which, after translation into English, was published in 1930. As with Sinclair's masterpiece, Wiener originals are rare; and fortunate indeed is the railfan who can point to a copy in his private library.

In his research, Professor Wiener enjoyed personal contacts with men of varied experience and wide background: Anatole Mallet, Lawford Fry, George Henderson, and Francois de St.-Phalle (Baldwin's manager of foreign sales). From his central location Wiener was close to European locomotive plants and overseas offices of American builders, which provided him with their published catalogs and periodicals. Railroad companies in remote corners of the globe were probed for data, although Wiener may not have received altogether adequate replies from the United States, as a discerning reader perceives. Industrial and professional publications from the United States, England, France, Belgium, and Germany formed an important proportion of foundation material. The search, particularly when one appreciates the enormous scope of the subject in both design and location, has been remarkably thorough; and although the author made no claim for absolute completeness, the omissions (Davenport, Dunkirk, and Price) are not significant in an undertaking of such magnitude.

Differing from the other three volumes, *Articulated Locomotives* acknowledges no earthly restraint; jointed engines seem to have been used everywhere except in Antarctica. Naturally, much of the book is devoted to articulateds in the United States, but U.S. railfans will experience a refreshing perspective of accomplishments elsewhere. A 3′-6″ 4-6-2+2-6-4 Union-Garratt is a formidable piece of machinery. American readers will be amused at some infrequent trivialities, the result of distance and double translation (American to French to English); Baltimore & Ohio's Sand Patch appears as Saint Pitch, for example.

Professor Wiener's monumental opus appeared at a significant time in railroad motive-power history. Super-Power locomotives were beginning to replace the compound Mallet in the United States. Lima was very close to assembling its final Shay, and last rites were being pronounced at Climax. The last Erie Triplex had just become a part of railroad history; the Duplex was yet to flourish, and the first U. S. 4-6-6-4 was six years and the Great Depression away. The internal-combustion locomotive was making its timid debut, and the Pennsylvania was about to commence a gigantic electrification program. With the delivery of Northern Pacific 2-8-8-4 No. 5000 in February 1929, the articulated steam locomotive had been approaching some sort of zenith. It was high time *someone* said *something* about a subject that had been virtually untouched for 100 years. Professor Wiener did precisely that; his Foreword is dated January 1, 1930.

Many a motive-power expert somewhat hazily regards Mallet and articulated as mutually interchangeable adjectives. The Professor dispels this presumed synonymity by enumerating a hundred different varieties of articulated locomotives, of which the Mallet is but one. Moreover, his definition of "articulated," embracing everything from tender boosters to McCloud River back-to-back Vauclain compound double 0-6-0's and steam-devouring Baldwin Triplexes, conceivably could include many an all-electric and oil-electric configuration. But Professor Wiener is the hero of the 100 per cent pure steam fraternity; he eliminates such a possibility without the slightest acknowledgment of any competitor to the steam articulated locomotive. Which is just as well, anyway; the book embraces 600 pages as it is.

The fact that Mallets form a single class of articulateds does not imply a six-page treatment. Instead, one-third of the book is devoted to them, true ones as well as those masquerading under that title. Garratts, of ordinary, Beyer, and Union variants, require some 60 pages filled with such unlikely arrangements as four-, six-, and eight-cylinder compounds and a proposed 2-6-6-2+2-6-6-2 Mallet-Garratt. Roughly 40 pages apiece are devoted to the mechanical intricacies of Fairlie; Meyer and Meyer-Kitson; and Shay, Climax, Heisler, and Baldwin jointed locomotion. Forty pages also are devoted to powered tenders, and boosters receive 25 pages of detailed discussion. All of the other articulateds — some with only one pivoted driven axle, others of nigh-hopeless mechanical complexity — fill the remainder of this wonderful compilation. Many of the designs were practical, and the locomotives constructed to them worked well and long. But then, too, others appeared to be more the product of an overly complicated mind than a useful servant of man. The English Harrison locomotives were of this caliber; the boiler and driving machinery were carried on completely separate vehicles. And the Mexican Central operating between El Paso and Mexico City seemed to have a singular affinity for peculiar locomotives, among which were Mason's single-Fairlie and Johnstone's double-Fairlie, which had to be partly dismantled before it would pass through the Santa Fe's Raton Pass tunnel. A more sensible mechanism was the Swiss meter-gauge 0-6-6-0 simple-Meyer locomotive whose construction included a rotary snowplow.

For the uninitiated, some concept of the boundaries of articulation might be illuminating. Mallet, Fairlie, and Garratt (2-6-2+2-6-2) engines were built to 1′-11½″ gauge, while the 5′ 6″-gauge railroads operated 2-6-6-2 Mallets, 2-8+8-0 Meyer-Kitsons, and 4-8-2+2-8-4 Garratts. There were Shays and U. S.-built 2-8-8-2's in China, and Russia was using 0-6-6-0 Mallets as early as 1896. In fact, Mallets were running in Europe in 1888, some 16 years before they were employed in the United States, a country which never adopted the versatile Garratt locomotive.

The depth of U. S. revelations is astonishing; otherwise obscure information is presented in exceptional detail. One learns, for example, that Horatio Allen's 2-2-0+0-2-2 machine (1832) was the world's first articulated (a double-Fairlie), and that an

English-built double-Fairlie ran on the Denver & Rio Grande. Shays were used on Canadian Pacific and on Lake Superior & Ishpeming, and C&O, Western Maryland, and Southern had rare four-truck models. The Pennsylvania's one-of-a-kind 2-8-8-0 and 2-8-8-2 simple "Mallets" are included in the book, as are Southern's tractor-tenders, Canadian Pacific 0-6-6-0 experiments, and the Sinnamahoning Valley's backward-running eight-cylinder Vauclain-compound 0-6-6-0T Meyer-Kitson monstrosities.

An unusual feature of the work is the multiple index which enables one to locate a particular locomotive with minimal input information. Two hundred photos and drawings are indexed, as are all the many types of articulateds and their dimensional tabulations. Builders are listed; so are railroads; and there is even a chronology of articulated developments.

When Professor Wiener's book was published it was part of the then current motive-power landscape; it portrayed what had been done, what was being done, and what could be done. Just a quarter-century later, all of it was history insofar as the United States was concerned. Yet this was primarily a local affair. Mallets, Garratts, and Fairlies continued to be built and operated in other parts of the earth. Many, of course, have been replaced since by all-electric or oil-electric units, but the ultimate demise of the last remaining articulated is not in sight. Was it not Chapelon who claimed that a steam locomotive was a machine which could consume anything burnable, which could run through any kind of impediment, which could be operated (or abused) by untrained personnel, and which could be maintained and repaired in a primitive environment?

ROBERT A. LE MASSENA

Denver, Colo.
May 1970

FOREWORD

SINCE the inception of railways, articulated locomotives have been to the fore whenever conditions became too severe or too specialised for the proper employment of rigid locomotives. The Semmering Competition (1851) marks the first important step towards the establishment of the modern systems, most of which owe something to their forerunners of this period. But it was not until a score of years later that the present types were evolved, and, from that day to this, constant improvements have been brought to them.

Indeed, during the last quarter of a century articulated locomotives have not only invaded most colonial and overseas railways; they have extended their sphere of usefulness to the home roads. This is why a study of articulated locomotives is useful.

The present edition is not a simple elaboration of the author's former books; the entire subject has been gone into again, and two-thirds of this book are new.

Before presenting it to our readers, we would like to emphasize a few points :—

(1) We have tried to establish a clear system of classification of the numerous types we quote and to state our facts methodically, so as to faciliate reference, obviate confusion and show what has been done heretofore, what has been left undone—and why.

(2) We have given some information concerning a number of obsolete types, not only because we have been requested to do so, but because in many instances these types have not been successful as they were premature. Either new conditions or, in several instances, improvements in engineering have rendered possible the designing, and the building of so-called new modern types which are but up-to-date designs of much older systems.

Of course in such cases the information we give concerning these ancestors of the newer systems is much less elaborate than that which concerns their progenitors, but it is none the less indispensable, and may save time, research and, in some cases, useless applications for new patents.

(3) We have only quoted such characteristics of the articulated locomotives as distinguish them as such. It would be a waste of time to give detailed descriptions of elements which they have in common with rigid locomotives.

(4) REFERENCES.—We have quoted a large number of references of each type, because it is the best way to show to what extent any given system of articulated locomotive has—or has not—been used, and also because it indicates where to apply for further information, should such be needed.

(5) TABLES.—We have given numerous tables of principal dimensions of all types of articulated locomotives, both for immediate use and for the sake of comparison.

When the locomotives work in countries where the metrical system is prevalent, we have given the dimensions both in metrical measurements and in their British equivalents ; in other cases, in the latter dimensions only.

LIONEL WIENER.

January 1st, 1930.

ACKNOWLEDGMENT

It is a pleasant duty for us to thank the many people who have helped us :—

Our late friends Anatole Mallet and George Henderson, for much valuable information and personal opinions.

Mr. Leopold Fry, Mr. de Saint-Phalle, Mr. Hamilton, Mr. Whitelegg, and the numerous firms of locomotive builders who have so courteously replied to the outrageous number of queries we have put to them and supplied us with data and information, and to all of whom we are most grateful.

Also the many railway companies who have been good enough to send us the information we applied for.

We must also thank the managing editors of several technical magazines who have printed earlier portions of our works, and who have given us the necessary authorisations to make use of them, and particularly Mr. Kay (*Railway Gazette*) ; Mr. Bell (*The Locomotive*) ; Mr. Godfernaux (*Revue Générale des Chemins de fer*, of Paris) ; Mr. Baes (*Bulletin de la Société des Ingénieurs et des Industriels*) ; Major Pirot (*Bulletin de l'A.I.A.*, Brussels) ; the *Bulletin of the International Railway Congress*, and others.

The three latter have been good enough to lend us some blocks for illustrations.

Finally, we want to express our appreciation of the able way in which Mr. Wright has translated a considerable part of our manuscript into English, and of the pleasant intercourse we have had with him.

L. W.

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ARTICULATED LOCOMOTIVES

INTRODUCTION

Reasons for Using Articulated Locomotives

FORMERLY, articulated locomotives were confined to a few railways, but, for some time past, their use has been greatly extended. This is due to several causes which have constrained engineers to employ them, namely :—

(*a*) The need for more powerful locomotives.

(*b*) The need for using heavy locomotives on lines with permanent way of insufficient strength.

(*c*) The demand for locomotives of sufficient flexibility to negotiate curves of small radius.

Let us consider these points in order :—

(*a*) POWER OF LOCOMOTIVES.—The continued development in the power of engines is due both to the constant increase of traffic, and to the fact that large locomotives are relatively more economical, both in running and maintenance than smaller ones.

But in order to use greater engine power, the adhesive weight must be increased in like measure. Hence, when the load on the coupled axles reaches the limit which the permanent way and bridges can support, further adhesion can only be supplied by increasing the number of driven axles.

In practice, five coupled axles, and—exceptionally—six seem to be the maximum for rigid locomotives.* If these are insufficient, either double heading must take place (and this is unjustifiable as a regular practice), or, alternatively, articulated locomotives must be used.

(*b*) WEAKNESS OF THE PERMANENT WAY.—If a locomotive's adhesive weight, when distributed over the maximum number of axles permissible in a rigid locomotive, is still too great for the

* There are six-coupled locomotives on standard gauge and five-coupled ones on narrow gauge lines; there is even a six-coupled one on the latter (in Java).

permanent way, the number of coupled axles must obviously be increased, and this is only possible by the use of articulation. This is the case on many European and American railways. Sometimes, as in the case of the San Paulo Ry. (Brazil) a single structure imposes a limit of axle load.

(*c*) Flexibility of Locomotives on Curves.—Rigid locomotives give trouble on curves of small radius. Therefore, if a larger number of coupled axles than will give satisfactory running on the curves of a railway must be used, articulated locomotives should be employed. For many years this was indeed supposed to be their only advantage. But it has gradually been realised that there are other good reasons for using them. Hence they are no longer exceptions, but are frequently to be found not only in the Colonies, but also in North and South America, and, though to a lesser degree, in Europe. Even conservative countries, such as England, have tried them, and there is no doubt that railway administrations, such as the Belgian National Rys. and the P.L.M., who have hitherto been opposed to them, would find them advantageous in certain definite cases.

Since, therefore, articulated locomotives have a field of utility which is both important and increasing, it has seemed useful to deal with them comprehensively, and with this object the present work has been undertaken.

The Semmering Contest (1851)

Although the Semmering Contest did not have such immediate results as the Rainhill Contest, nevertheless it is an important landmark in locomotive history. For it was at the Semmering that there appeared in embryo most systems of locomotive articulation which have since been satisfactorily developed.

The Semmering railway crosses the Noric Alps. On the $37\frac{1}{2}$ km. section ($23\frac{1}{3}$ miles) between Payerbrack and Murzzuschlag, gradients reached $2\frac{1}{2}$ per cent., one bank being 3,581 m. ($1\frac{1}{2}$ miles) long. The minimum radius of curvature was 190 m. (623 ft.), except on the gradients, where it was 285 m. (935 ft.).

At the present day, these conditions would not be considered extraordinary, but in those early days engineers were at a loss to know how to cope with them. Therefore, in 1850, the Austrian Ministry of Commerce and Public Works issued an invitation for designs of locomotives capable of dealing with the traffic on the above section.

The conditions to be met with were that the locomotives should be able to draw trains of 140 tons up a gradient of 2½ per cent. at a speed of 11½ km. (7¼ miles) per hour. The boiler pressure was not to exceed 8·5 kgs. per square centimetre (121 lb. per square inch). The axle load was limited to 14 tonnes (13 tons, 18 cwt.).

Many designs were submitted and also four actual locomotives :—

(1) The " Bavaria," built by Maffei, a locomotive with three trucks, and transmission by chains.

(2) The " Wiener-Neustadt," built by the engineering firm of that name. It had two trucks and transmission by coupling bars. It was the prototype of the *Meyer* locomotives.

(3) The " Seraing," built by the Société John Cockerill (Belgium), a prototype of the *Fairlie* group of locomotives.

(4) The " Vindobona," built at the *Wien Glognitz Bahn* Works, a tank engine with four coupled axles of which the last was behind the firebox. It was not articulated. Tables 1 and 1A give the leading dimensions of these locomotives, the descriptions of which are given hereafter in the appropriate chapters.

All these locomotives fulfilled the conditions of the competition, but, in subsequent regular service, none of them gave satisfaction. The prize of 240,000 francs was awarded to the " Bavaria." But the Semmering section was actually worked by *Engerth* locomotives, the dimensions of which are also given in Tables 1 and 1A.

The Evolution of the Articulated Locomotives

Before the Great War, finality seemed to have been reached in regard to the types of articulated locomotives. But those of to-day are as different from those of the year 1913 as were the latter from earlier types. This is chiefly due to the continual progress in locomotive construction, resulting in increased power and economy for the same axle load. It has become

TABLE 1.—PRINCIPAL DIMENSIONS OF THE LOCOMOTIVES WHICH TOOK PART IN THE SEMMERING CONTEST.

Locomotive		Bavaria.	Seraing.	Wiener-Neustadt.	Vindobona.	Engerth.
Type		**4 + 4 + 6**	**4 + 4**	**4 + 4**	**0-8-0**	**6 + (4)**
Cylinders, number		2	4	4	2	2
,, diameter	m.	0·51	0·41	0·33	0·42	0·48
,, stroke	m.	0·76	0·69	0·63	0·58	0·62
Boiler pressure	kg./sq. cm.	7	7	7·8	8	8·5
Tubes, number		250	340	180	288	189
,, length	m.	4·26	3·19	6·38	3·25	4·80
Heating surface	m.c.	158	170	175	160	155
Grate area	m.c	1·80	2·20	1·70	—	1·17
Wheels, diameter	m.	1·07	1·06	1·11	0·95	1·11
Wheelbase, rigid	m.	2·95	2·14	2·21	4·50	2·29
,, total	m.	11·00	8·24	8·12	4·50	6·06
Weight in service	t.	68·30	55·28	61·00	47·26	56·10
,, per axle	t.	9·70	13·80	15·25	11·80	11·20
Tractive effort	t.	8·27	9·80	6·40	5·60	7·15
Adhesive factor		8·2	5·6	9·5	8·5	7·8

TABLE 1A

Locomotive		Bavaria.	Seraing	Wiener-Neustadt	Vindobona	Engerth.
Type		**4 + 4 + 6**	**4 + 4**	**4 + 4**	**0-8-0**	**6 + (4)**
Cylinders, diameter		20⅛″	16¼″	13″	16½″	18⅞″
,, stroke		29⅞″	27⅛″	24¾″	22¾″	24¾″
Boiler pressure	lb./sq. in.	100	100	111	114	120
Tubes, number		250	340	180	288	189
,, length		14¼′	10′ 5½″	20′ 11¼″	10′ 6¾″	5′ 8⅞″
Heating surface	sq. ft.	1,700·8	1,829·9	1,883·8	1,722·3	1,668·5
Grate area	,,	1,937·0	2,368·0	182·9	—	125·9
Wheels, diameter		3′ 6⅛″	3′ 5¾″	3′ 7¾″	3′ 1⅜″	3′ 7¾″
Wheelbase, rigid		9′ 8⅛″	7′ 0¼″	7′ 3″	—	7′ 6⅛″
,, total		36′ 0¼″	7′ 0⅜″	26′ 3¼″	14′ 9¼″	19 10¼″
Weight in service	t.	7·3	54·7	60·3	46·7	55·3
,, per axle	t.	9·6	13·6	15·0	11·6	11·0
Tractive effort	t.	8·2	9·7	6·3	5·5	7·1
Factor of adhesion		8·2	5·6	9·5	8·5	7·8

possible to use rigid locomotives in cases where articulated locomotives were formerly indispensable. But, on the other hand, the demands of the traffic department continue to increase. It is, therefore, necessary to improve articulated locomotives in like measure, so that when displaced from one service they may be used elsewhere.

At the present time, even *Mallet* locomotives, which had seemed to be finally standardised, are undergoing development. Engines with four simple expansion cylinders are acceptable in practice, and six-cylinder *Mallets* may follow.

The *Garratt* locomotives were but little used until ten years ago, but they are now undergoing rapid development and have attained a prominent place. Their progress should be closely observed, the more so that the *Fairlie* engines are being modified, and new types (*e.g.* the *Golwé* and the *Hanomag*) are being evolved so as to incorporate the good qualities of the *Garratt* type without abandoning their own.

The Minimum Number of Coupled Axles for Articulated Locomotives.—An interesting problem, in connection with the use of articulated locomotives, has arisen during the last few years. It deals with what we may call the limit of their use, or the point above which they should, logically, be employed.

An articulated locomotive can readily negotiate sharp curves, but it should be remembered that it is more complicated than a rigid locomotive and that there is a slight loss of force due to the articulation. On the other hand, five-coupled locomotives are common on standard gauge lines, while even six-coupled ones have made their appearance. Hence, on the standard gauge, it is only when a minimum of six coupled axles is required that an articulated locomotive is indicated. This kind of evolution is general. During the last few years the efficiency of all mechanical appliances has been developed, with the result that the fields for their use are widened.

Thus, by increased all-round efficiency several American railways have been able to replace *Mallet* locomotives of moderate power (for U.S.A.) by rigid locomotives.

The conclusion to be drawn from this is that the lower limit of power above which it is desirable to use a *Mallet* locomotive has risen, and it is remarkable to observe that this advance has been effected within a period of scarcely five years, and that locomotives with five coupled axles handle heavy traffic over more or less crooked lines.*

Their rigid wheelbase is often small. This is achieved by giving lateral play to the first, third and fifth of the coupled axles ($\pm$ 25 mm. = 1 in. approximately on the Serbian State Ry.) or to the two extreme axles only ($\pm$30 mm. = $1\frac{3}{16}$ ins.) on the Royal Mining Administration of Zabrze Rys., where 2-10-0 locomotives are in use fitted with Flamme, Helmholz, or Zara types of bogies. These locomotives can thus negotiate curves of 180 m. (590 ft.) radius, or even less. The same considerations apply to narrow gauge lines with many curves, where (thanks to the Klien-Lindner, and to geared axle systems) locomotives with four, and even five coupled axles can easily be used, and even this number has been exceeded.

Locomotives with six coupled axles 2-12-2 have been introduced on the Java State Rys. (3 ft. 6 ins. gauge), and 4-10-2 locomotives in South Africa, for the purpose of comparing operating results with those of *Mallet* engines. This shows that the general tendency is to use rigid locomotives as far as possible. Maintenance costs per ton-mile will show whether this is justified.

In the meantime, articulated locomotives should be used whenever more than five coupled axles are needed, in order to employ powerful units without exceeding the permissible load per axle. For locomotives with five coupled axles or less, other arrangements are available which allow of the use of the rigid type. Exceptions occur, particularly on narrow gauge lines, in cases where a large evaporative surface is necessary, and the rigid wheelbase must be small, or else when the load per foot-run of track is restricted to a low figure.

The Influence of the Gauge

Articulated locomotives differ considerably whether constructed for standard or for narrow gauge railways and they can be grouped accordingly. But the influence of the loading

* Among locomotives of the 0-10-0 type, those of the Serbian State Rys. have a rigid wheelbase of 2·84 m. (9 ft. 4 ins.) and a total wheelbase of 5·60 m. (18 ft. 4½ ins.), while those of the Saxon State Rys. have 2·80 m. (9 ft. 2 ins.) and 5·60 m. (18 ft. 4½ ins.) respectively.

Similar dimensions are met with elsewhere, as the following table shows :—

Railway.	Number of Locomotive.	Wheelbase. Rigid. M.	Wheelbase. Rigid. Ft. Ins.	Wheelbase. Total. M.	Wheelbase. Total. Ft. Ins.
Decapod Locomotive with Separate Tender.					
Serbian State Rys.	21	2·84	9 4	5·00	16 6
Italian State Rys.	470	3·00	9 9¾	6·00	19 8¼
Ch. de fer Orientaux	201	3·00	9 9¾	4·50	14 7
Prussian State Rys.	5,101	3·00	9 9¾	6·00	19 8¼
Saxon State Rys.	701	2·80	9 2½	5·60	18 3
Bavarian State Rys.	—	3·20	10 5	6·00	19 8¼
Ofoden Ry.	—	3·35	10 10¾	5·80	18 11
Decapod Tank Engines.					
Saxon State Rys.	1,325	2·80	9 2½	5·60	18 3
Prussian State Rys.	8,123	2·00	6 6¾	5·80	18 11
Ch. de fer Paris-Orleans	2 503	3·70	12 1	6·20	20 1½
Ch. de fer du Midi	5,002	3·19	10 0	6·20	20 1½

gauge is at least as considerable as the track gauge. Thus the difference between standard gauge *Mallets* for American and for European use is at least as great as the difference between either of them and a corresponding narrow gauge locomotive. To proceed on these lines would therefore introduce useless subdivision and complication. We shall, therefore, abstain from such classification, leaving it to be understood that the locomotives referred to hereafter fall into three general groups :

Standard gauge, American practice.
Standard gauge, European practice.
Articulated locomotives for other gauges.

Tender and Tank Locomotives

Owing to the tendency to use the entire available weight for adhesion, that of the stores has been called upon as well. This has been accomplished either in extending tanks and bunkers of tank locomotives back of the cab, or else in providing the tender with steam-driven sets of wheels. In some cases, the extension back of the cab has grown so much that it has the appearance of an ordinary tender ; hence it is sometimes difficult to properly classify these transition types.

We consider that a " tender locomotive " has a tender which is joined to the locomotive proper by means of buffing and draw-gear. When such gear does not exist and the tender portion is carried on the same frame as the locomotive proper, it is a " tank locomotive," even if its general appearance is similar to the former type. In this case, it is advisable to designate the rear portion by the appellation " pseudo-tender."

Designation of Types of Articulated Locomotives

Whyte's classification designates locomotives according to their wheel arrangement. In the case of articulated locomotives a *plus* sign (+) is placed between each separate set of wheels. Thus the symbols 2-6-0 + 0-6-2 designates an engine with two sets of wheels, each consisting of three coupled axles with an additional carrying axle at each end (more briefly such an engine may be described 2-6 + 6-2).

But this method of representation is rather unwieldy, especially when locomotives have three separate sets of wheels. We shall therefore often make use of designations similar to those which have been adopted for certain types of rigid locomotives.. According to this method, the above locomotive would be simply a double Mogul, and an engine of the 2-8-0 + 0-8-2 type, a double Consolidation.

When the tender is steam driven, whether provided with cylinders or not, the tender's wheel disposition should be added, between brackets.

There is yet another case to be considered, though it is exceptional; that is when auxiliary driven axles are occasionally brought into use, as in the *Krauss* locomotive. The least complicated way is to designate this extra axle as the denominator of a fraction, whose numerator concerns the locomotive's ordinary axles.

A *Krauss* 4-4-0 locomotive, with auxiliary driving axle to the front bogie, would be a $\frac{4}{0\text{-}2\text{-}0}$-4-0 locomotive.

Principal Dimensions of Locomotives

When comparing locomotive dimensions it is not sufficient to "translate" English into metric measures or *vice versâ*, because a number of factors are computed differently in different countries.

The heating surface is usually measured externally in England and U.S.A. and internally in France and in Belgium, though there are exceptions.

The equivalent heating surface is, in America, the sum of the measured surface and of one and a half times the surface of the superheater,* but it is better practice not to make this addition. *Combined heating surface* is the sum of total and superheated surfaces.

The tractive force is variously computed. In France and Belgium the usual formula is:

$$\text{Tractive force} = \cdot 65\,\frac{pc^2s}{D}.$$

p = steam pressure—in pounds per square inch.
c = cylinder diameter—in inches.
s = stroke—in inches.
D = diameter of driving wheels—in inches.

* In England one and a third is usually taken.

This formula certainly gives results which are too low for the tractive force at starting and at low speeds, but subject to this reservation, it can be used.

In ENGLAND the constant ·80 is often used instead of ·65. In the U.S.A. *the American Locomotive Co.* uses ·85 and *the Baldwin Locomotive Works*, ·90. For German locomotives with Schmidt superheaters ·75 is used. *Messrs. Beyer, Peacock & Co.* use ·75 for their *Garratt* locomotives.

There is even more variation in the case of formulas for compound locomotives. The most usual of these are given below. The same notation is employed, except that diameters of high and of low pressure cylinders are denoted c and C respectively.

Formulæ used by the Baldwin Locomotive Works:

Vauclain compounds $\frac{2}{3}(c^2 \times C^2)\frac{pS}{D}.$

Four cylinder cross compounds $\frac{2}{3}\left(\frac{pc^2S}{D}\right).$

Mallet compounds: see hereafter, chapter dealing with this class of locomotive.

The *American Locomotive Co.* uses the following formula:

$$\text{Two cylinder compounds, } T_1 = \frac{Kpc^2S}{2D},$$

in which K is a constant given in tables and is a function of the ratio between the volumes of the cylinders.*

$$\text{Four cylinder compounds, } T_2 = \frac{KpC^2S}{D}.\dagger$$

* When live steam is admitted into the cylinders, K being 0·52 and the ratio of the columns of the cylinders 2·5, the formula becomes:—

$$\text{Tractive force} = \frac{0{\cdot}85\ c^2Sp}{D} = 1{\cdot}3\ T_1$$

† On the same assumption as the previous one, this formula becomes:

$$\text{Tractive force} = \frac{(2 \times 0{\cdot}85)\ C^2\ Sp}{D} = 1{\cdot}3\ T_2$$

This formula and the one quoted in footnote (*) give the tractive force at starting, when live steam is admitted into all the cylinders.

If compound locomotives are provided with superheaters the admission to the L.P. cylinders ought to be retarded by 5 per cent. in com-

The Scheme of this Work

In our study of articulated locomotives we shall confine ourselves to those special characteristics which are due to the use of the system of articulation, and we shall not deal with those features which are also found in ordinary locomotives, unless their use is necessitated by the choice of the articulated system itself.

We will first summarise the characteristics of each system. In order to make a clear distinction between them, we have to consider :

(*a*) Whether there are one or two (movable) trucks.

(*b*) The manner in which the boiler is supported on the trucks.

(*c*) Whether the buffing and drawgear is carried by the trucks or by the main frame.

We shall also give tables of the leading dimensions of the locomotives under consideration. This will avoid a succession of monotonous detailed descriptions. Finally, we shall draw attention to the features which distinguish certain of these locomotives, and we shall give some information concerning the lines on which they run and the services for which they are employed.

The Principal Types of Articulated Locomotives

An articulated locomotive is a locomotive in which one or more of the driven axles are able to take up positions where they do not remain parallel to the others and may take angular positions in curves. The axles may be driven by two separate engines or by a single one.

The number of cylinders or the type of boiler (whether simple or double), do not in themselves distinguish special types of articulated locomotives. Thus a double boiler has actually been utilised in conjunction with a rigid frame and group of wheels.*

parison with that to the H.P. cylinders if the ratio of the volumes of the cylinders is 2·5 : 1.

If this ratio is 2·75 : 1, there should be no retardation.

Conversely, if the ratio is 2·2 : 1, there should be a relative advance of 10 per cent.

* On the Nocera-Salerno Ry.

Conversely, the fact that a locomotive has two sets of cylinders and two groups of driving wheels does not constitute an articulated locomotive unless some of the coupled axles can take angular displacements in curves. For this reason, the well-known Pettiet locomotives do not fall within the scope of this book.

Among the multiplicity of proposed systems, some have never got beyond the stage of designs on paper, while others have received practical trial. But only some half-dozen of these have persisted down to the present day ; and although the number of types has been reduced, many examples of each type have been produced.

In order to systematise our study, we shall examine these locomotives in —

Book I.—Articulated locomotives proper.

Book II.—Semi-articulated locomotives.

Book III.—Partially articulated locomotives, in which we include those which have an auxiliary engine.

Book IV.—Locomotives with steam tenders, in which one or more axles are driven.

These groups may be subdivided according to the means adopted for transmitting the tractive force, by gear, by rod, or by other connections.

This leads to a multiplicity of types and systems—we have quoted a couple of hundred—and unless a great deal of method be brought into our examination, this would constitute but a dry and absolutely useless enumeration or compilation of types.

To obviate this, we have classed this mass of information into divisions, which have been clearly divided and subdivided yet again.

Thus each of our " BOOKS " comprises a certain number of " SECTIONS " according to there being one engine and one driven set of wheels ; one engine and two sets ; two engines and—occasionally—an auxiliary engine.

Each " section " in turn is divided into " SUB-SECTIONS " concerning the method of transmission of the cylinder's action.

Each " sub-section " comprises a certain number of " GROUPS " of articulated locomotives, each of which embraces the " TYPES " which concern it.

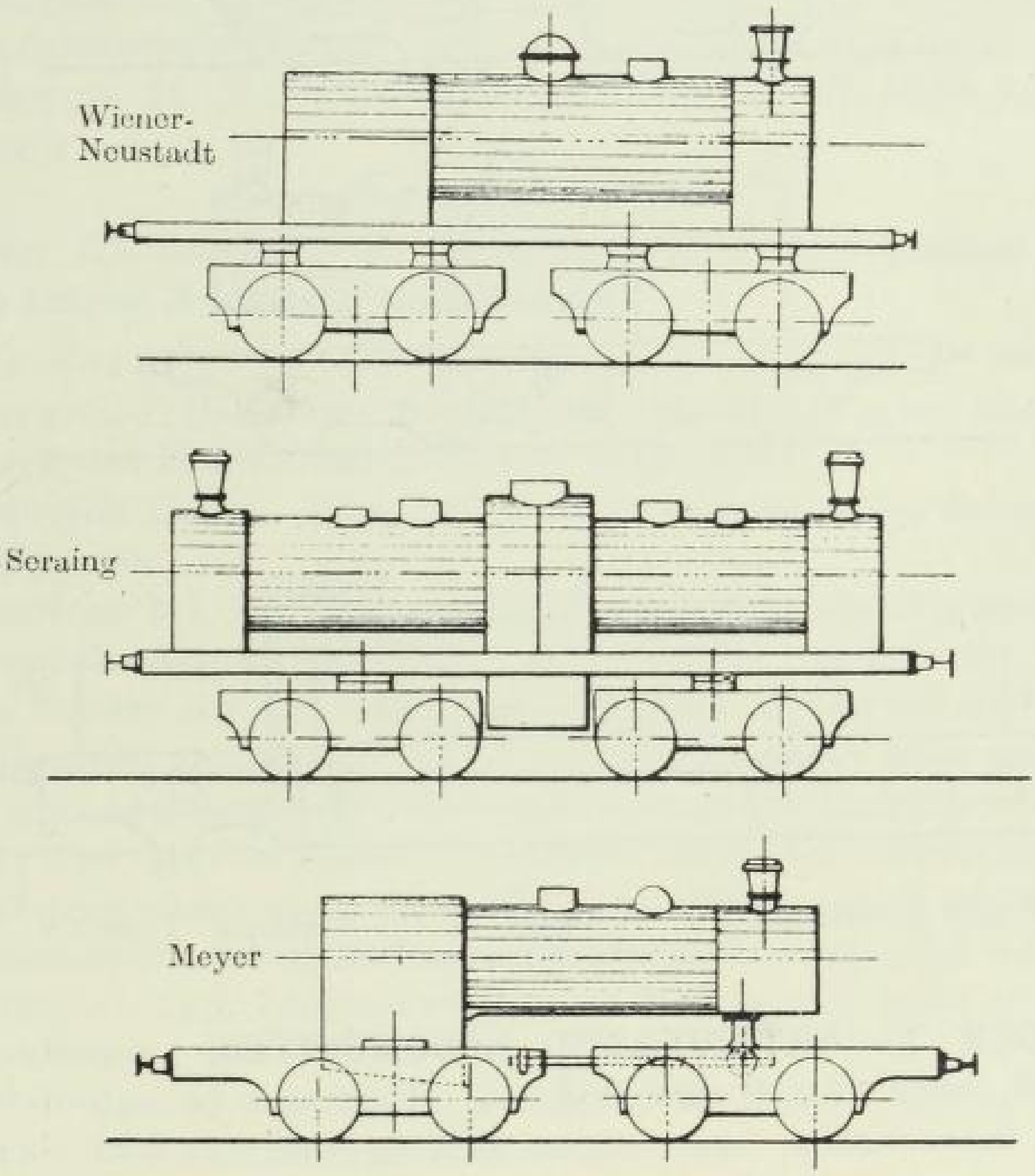
And, lastly, the disposition of the axles is taken into account in a number of "CLASSES."

Occasionally, of course, some modification of these divisions has been introduced, so as to simplify matters, but, generally speaking, it has remained as stated above.

This enables any type to be easily distinguished, placed and appreciated. This grouping also makes it easy to grasp the distinguishing features of each type, also its advantages or the reverse, and analysis of each of them is facilitated.

Finally, it shows their variations, how one can pass by easy stages from one to another and how it is possible to invent new features for dealing with any special condition.

Applying the above principles, all types of articulated locomotives fall within the following classification :



For continuation of Fig. 1 see next page.

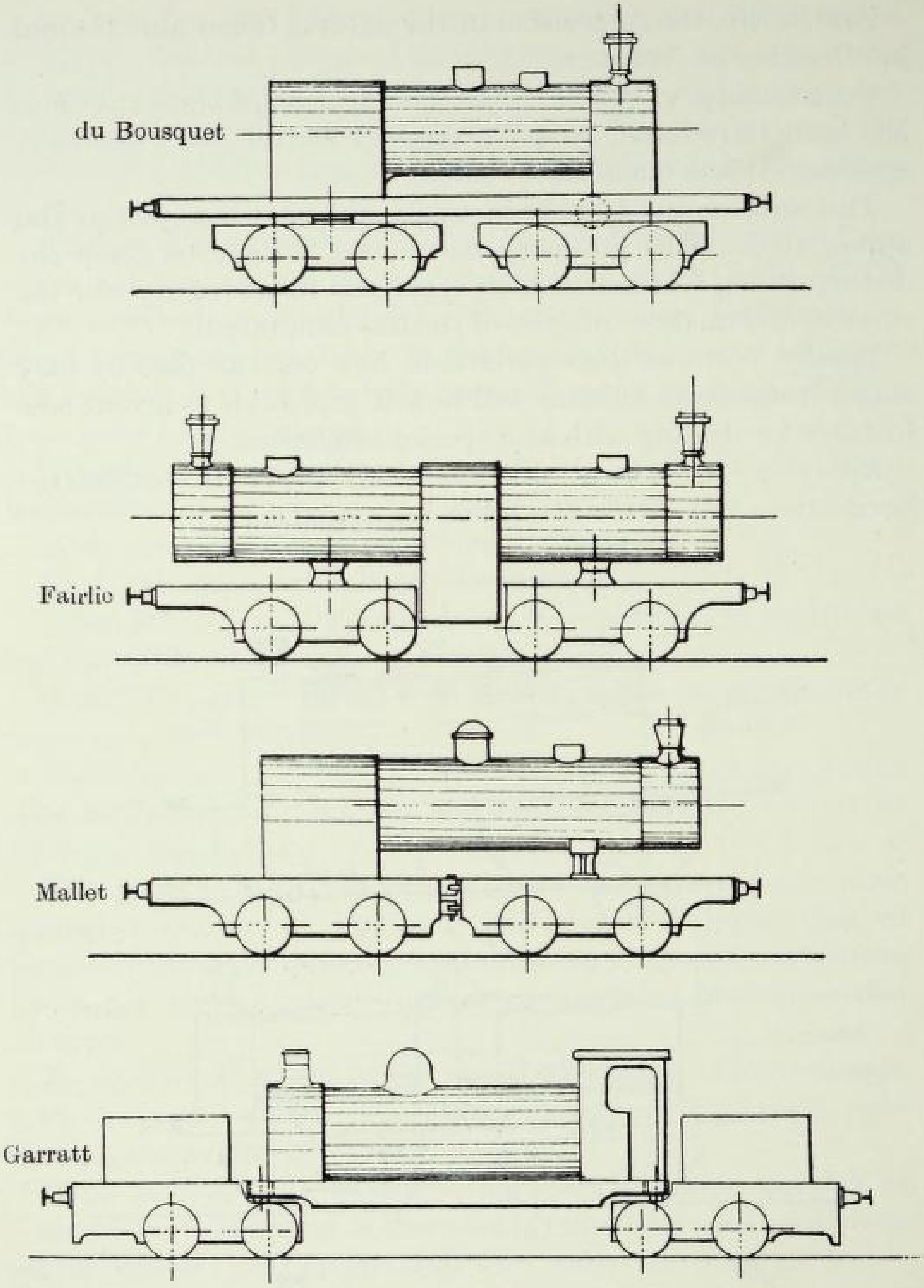


Fig. 1.—Schematical Drawings of the Principal Types of Articulated Locomotives.

BOOK I.—ARTICULATED LOCOMOTIVES, properly so-called, have two bogies (Fig. 1). They can be sub-divided into three heads, one engine driving one or both bogies or two engines for the two bogies.

Part I.—Articulated Locomotives with a Single Engine and but One Driven Bogie.

These comprise single *Fairlies* and *Mason-Fairlies,* the second bogie of which is undriven.

Part II.—Articulated Locomotives with a Single Engine Driving both Bogies.

These locomotives have but one pair of cylinders whose action is transmitted by various means to the bogies.

Section II. A.—Transmission by Gearing.—This comprises the *Shay*, the *Climax*, and the *Baldwin types.*

Section II. B.—Transmission by Rods and Gearing.—First tried on the *Neath Abbey* locomotive and later by the *Winterthur Works*, the only successful type is the *Heisler*, in which the axles of each bogie are rod connected.

Section II. C.—Transmission by Ball and Socket or Quill Joints.—The only type worth quoting is *Cowles's.*

Section II. D.—Transmission by Rods.—A single type: *Behne's.*

Part III.—Articulated Locomotives with Two Engines and Two Driven Bogies.

Section III. A.—Transmission by Gearing.—Nil.

Section III. B.—Transmission by Ball and Socket Joints.—A *Krauss* locomotive is of interest.

Section III. C.—Transmission by Chains.—The *Schwartzkopff* system.

Section III. D.—Transmission by Rods.—Quite a number of types have been successful and are still in regular use. The best known are the *Meyer*, the *Fairlie*, the *Garratt* and the *du Bousquet* groups. To avoid complications, we have quoted the less important ones at the same time as the above.

(1) The Meyer Group of Articulated Locomotives has two bogies which carry the buffing and drawgear and which are connected by a rod or bar. The boiler is supported on the front truck by a spherical support and on the rear truck by side brackets.

This type of locomotive, as altered by Messrs. *Kitson,* is to be found on a number of railways.

(2) The Fairlie Group of Articulated Locomotives has

also two bogies to which the buffing and drawgear are attached. It has, generally, a double boiler which is carried on the trucks by circular seatings which provide a certain amount of lateral elasticity.

The Horatio Allen locomotive was a progenitor of this type which achieved a certain amount of success as the *Seraing locomotive* in the Semmering Contest. It differed from the *Fairlie* type in that the boiler rested on a main frame which carried the buffing and drawgear. This frame rested on side brackets on the bogies.

The *Thouvenot*, the *Péchot-Bourdon*, and the *Johnstone* locomotives also belong to the same group, which has recently been revived with single boilers under the name of the *modified Fairlie* and to which can be added the *Golwé* locomotive.

(3) THE GARRATT group of articulated locomotives has two bogies. The boiler, in effect, forms a girder and rests on two pivots fixed to the inner extremities of the bogies.

The *Union* locomotive is a recent modification of the same type.

(4) The DU BOUSQUET locomotive has bogies similar to those of the *Meyer* type, but the boiler is carried on a main frame to which the buffing and drawgear is fitted.

The *Wiener-Neustadt* locomotive, which had appeared at the Semmering Contest in 1851, was of the same general type, except that the bogies carried the frame by circular saddles.

BOOK II.—SEMI-ARTICULATED LOCOMOTIVES.—These have one rigid group of driving wheels and one motor truck. They have either one or two engines.

Part I.—Semi-articulated Locomotives with One Engine and Two Driven Trucks.

As with articulated locomotives proper, it is convenient to group the various systems into groups according to the means used for transmitting the cylinder's action.

SECTION I. A.—CHAIN TRANSMISSION.—The *Bavaria*, which competed at the Semmering, and a *Winterthur* type deserve a passing mention.

SECTION I. B.—GEARED SEMI-ARTICULATED LOCOMOTIVES.—Originally tried with scant success by *Baldwin* and *Engerth*, and recently successfully revived in Germany by *Henschel* and by

Orenstein and Koppel for coupling up the extreme driving axles with their neighbours.

SECTION I. C.—RECIPROCATING MECHANISM TRANSMISSION IN SEMI-ARTICULATED LOCOMOTIVES :—Transmission occurs in various ways :

FIRST GROUP.—Those types where transmission takes place by rods located on the longitudinal axis of the locomotive comprises such designs as those of *Maffei, Thouvenot, Weidknecht, Roy, Rarchaert, Dredge and Stein.*

SECOND GROUP, wherein the convergent axles are coupled by means of oscillating levers, such as were used in another *Rarchaert* system, and in those of *Gouin* and *Larpent*, of *Maffei* and, more especially, of *Hagans*, which alone was successful.

The THIRD GROUP utilises driven countershafts for coupling up convergent driving axles. It comprises designs by *Maffei*, by *Weidknecht*, by *Köchy*, by *Gouin and Boutmy*, by *Aliger*, by *Kirchweger*, and by *Rarchaert.*

Fink's system was put to practical tests.

FOURTH GROUP.—The convergent axles are coupled by means of coupling bars of variable length.

Fretel, Vogel and *Neuhaus's* systems deserve but a passing mention. That of *Klose* was used with success.

FIFTH GROUP.—Ball and socket (quill) transmission in semi-articulated locomotives.

The axle is able to move radially inside a sleeve, to which it is joined by a central ball and socket connection, and the sleeve is coupled to the other axles. First used by *Heywood*, this system was again tried by Messrs. *Klien* and *Lindner*, and achieved a durable success.

Part II.—Semi-Articulated Locomotives with Two Engines and Two Driven Sets of Wheels.

Of the two sets of wheels, either may be rigid. We will group the types accordingly.

SECTION II. A.—TWO MOTOR SETS OF WHEELS, OF WHICH THE REAR ONE IS MOBILE.—A number of patents have been taken out, but none have been put into practice. The most interesting are those of *Tourasse* and *Hardery*, of *Cockerill* (also for the Semmering), of *Boutmy*, of *Rimrott* and, quite recently, of the *Esslingen*, and of the *Hanover* Locomotive Works.

SECTION II. B.—TWO MOTOR SETS OF WHEELS, OF WHICH THE FORE ONE IS MOBILE.—Apart from the *Koechlin* patent, there is but one type to quote, but this has been the most successful of all articulated locomotives ; it is the *Mallet* compound.

In these locomotives, the front set of wheels is articulated with the rear frames by means of a vertical pivot. The boiler rests on seatings on this truck, to which the drawgear and buffers are attached.

There are several modified forms of the *Mallet* locomotives, including the *Triplex*, where a third truck has been added at the rear and is connected to the middle set of wheels in the same way as is the fore truck.

SECTION II. C.—TWIN OR DUPLEX LOCOMOTIVES.—Occasionally, two locomotives have been coupled back to back so as to combine sufficient power with the desirable flexibility. They can be considered under this head, as each unit is mobile in relation to the other, considered as rigid.

Several types, such as the *Weidknecht*, the *Lange and Livesey*, and the *Stephenson*, have been patented.

BOOK III. — TEMPORARILY ARTICULATED LOCOMOTIVES OR LOCOMOTIVES WITH AN AUXILIARY ENGINE.

These are rigid locomotives in which a special device has been incorporated so as to momentarily use for adhesion the weight normally borne by the leading or trailing trucks.

Auxiliary cylinders drive at will either the leading carrying axle (*Krauss* system and *Esslingen* mixed track and adhesion locomotive), or the trailing axle or axles (the *Booster*). The latter device has been entirely successful and is much used in America, but is likely to invade other countries as well.

Of course when not in use, the locomotive is an ordinary rigid one, but when working, the locomotive becomes a semi- or partially articulated one.

BOOK IV.—UTILISATION OF THE TENDER'S WEIGHT FOR ADHESION.

The idea of using part or all of the tender's weight for increasing the total adhesion is so old and has been so successfully renovated that it is necessary to examine it separately. We will class the various systems, according to their using, for the tender, no engine, a permanently working engine or an intermittently operating one.

Part I.—No Separate Engine on the Tender.

SECTION I. A.—PART OF THE TENDER'S WEIGHT IS TRANSFERRED TO THE LOCOMOTIVE.—Originally tried by *Miller*, then renewed by *Behne-Kool*, and again by *Thouvenot* in the modified *Engerths*, and more recently by *Beugniot* and by *Stutz*, none of these types have achieved any measure of success.

SECTION I. B.—THE LOCOMOTIVE'S ENGINES DRIVE BOTH ITS OWN WHEELS AND SOME OF THE TENDER'S, motion being transmitted by chains or cinematic contrivances.

Unsuccessful, from the prototype (Maffei's *Bavaria*), through *Dredge and Stein's* system down to *de Bergues's*.

Part II.—A Steam Tender with its Own Engine.

For many years, all systems provided the tender with an engine which worked continuously. Success has been achieved since the tender has been provided with auxiliary engines only.

SECTION II. A.—A STEAM TENDER WITH ITS OWN PERMANENT ENGINE working in a similar fashion to the locomotive's. First tried by *Verpilleux*, this idea has been frequently revived, the best known system being *Sturrock's*. The most recent one is *Poultney's*, which it is still too early to judge.

SECTION II. B.—THE TENDER IS PROVIDED WITH AUXILIARY ENGINES which are cut in or out at the driver's convenience.

This, the contemporary practice, is entirely successful ; two types are in use ; *Bethlehem's auxiliary engine*, and *Flanklin's tender booster*.

BOOK I

ARTICULATED LOCOMOTIVES
(Properly so called)

BOOK I

ARTICULATED LOCOMOTIVES, PROPERLY SO CALLED

By this title, we mean locomotives which have two separate trucks capable of radial movement so that the axles of the two sets of wheels are not constrained to remain parallel to one another.

Before going further, it is desirable to define what is meant by the terms used, for they are often inaccurately employed.

The axles of a locomotive are grouped in one or more "groups" or "sets" of wheels which support either a fixed frame or a mobile frame, the latter with its group of wheels, being called a "truck." This can move radially around a real or a virtual pivot situated at a point either inside the truck (bogie) or outside it (bissel). As, obviously, any locomotive truck is mobile, the term "mobile truck" is a pleonasm.

We now proceed to our examination of the different types of these locomotives, which we divide into three heads according to their having—

(1) One engine (and pair of cylinders) driving one bogie, the other bogie being undriven.

(2) One engine driving both bogies.

(3) Two engines, one for each bogie.

Each of these has suitable sub-heads.

PART I

ARTICULATED LOCOMOTIVES HAVING ONE DRIVEN AND ONE UNDRIVEN BOGIE

These locomotives differ from rigid tank locomotives with trailing bogie, such as the *Forney* type and others, in that the driving wheels are set in a driven truck. This system is usually the outcome of another, wherein both bogies are driven, and its utility is questionable as other types are more simple.

Be that as it may, a certain number of single *Fairlies* and *Mason-Fairlies* which have been used belong to this group, and others have been designed, notably by *Johnstone*.

Type 1.—Single Boiler Fairlie Locomotives, with one Driven and one Undriven Truck

The well-known *Fairlie* locomotive, which is described in detail further on, has usually a double boiler carried by two steam-driven bogies. But each of the *Fairlie's* distinctive features has been modified separately or simultaneously, in many cases by the inventor himself. Thus, in some instances, a single boiler has been used instead of a double one, and in others, one of the two bogies only is driven, instead of both. Locomotives embodying these latter alterations will be dealt with here, though they appeared later than did the double *Fairlies* (about the year 1869).

Bogies.—The two bogies could take up any position independently of each other and of the boiler. The latter was riveted to a casting at the front end which had a recessed socket into which a flat-faced pivot carried by the leading steam bogie worked. Excessive pitching or lateral motion was checked by front and side springs. The non-driven (rear) bogie was of the Adams type with the usual lateral play.

Steam Piping.—Steam was carried from the front of the dome to beneath the centre of the boiler by outside piping and by a tee tube and curved pipes to the steam chest ; these pipes had sufficient elasticity for the purpose and no articulated joints were used. The steam exhausted into the petticoat of a blast pipe in the way often found in locomotives of this period.

ALTERATIONS.—In several instances, early single *Fairlies* have been rebuilt with the driving wheels supported in bearings in the main frames instead of being carried by a swivelling bogie, thus doing away with the *Fairlie* principle altogether.

Utilisation of Single Fairlies

0-4-0 + (4) *Fairlies* were to be found on several railways in Ireland, in England, and especially in Wales; 0-6-0 + (4) *Fairlies* in New Zealand.

Class a.—0-4-0 + (4) Single Fairlies

0-4-0 + (4) Single Fairlie, Gt. Southern and Western Ry.—Gauge, 5 ft. 3 ins. (1m.60).

Two of these locomotives were built in 1869–70 to the designs of Mr. MacDonnell, the railway's chief engineer.

The pivot of the steam bogie had a flat face which rested in a recessed socket. India-rubber check springs controlled pitching or rolling; the former were fixed to a central bracket fixed on a transverse stay in front of the firebox, and the latter in cup brackets attached on each side to the main carrying frame.

The steam pipes were quite simple and their elasticity was relied upon to provide sufficient flexibility. In front of the dome, they divided so as to pass externally around the boiler to a tee joint underneath it, and from here a bent pipe conveyed the steam to the valve chest between the cylinders.

Subsequent locomotives of the same class were outwardly identical with the above, but instead of a steam bogie, the coupled axles were arranged with bearings in the main frame.

0-4-0 + 4 Swindon, Marlborough and Andover Ry., Single Fairlie.*—Standard gauge.

This passenger locomotive was built by the Avonside Engine Co., to the order of the Fairlie Engine Co., and was exhibited in

* This locomotive has sometimes been erroneously described as having one driven bogie and a double boiler. This would have been quite feasible but it was not the case.

It could negotiate curves of very small radius.

TABLE 2.—PRINCIPAL DIMENSIONS OF SINGLE FAIRLIE LOCOMOTIVES.

Gauge	5′ 3″	Standard.	—	—	1′ 11½″	1′ 11½″	1′ 11½″
Railway	Gt. Southern and Western.	Swindon, Marlborough and Andover.	New Zealand.	New Zealand.	Festiniog Ry.	N. Wales Narrow Gauge.	N. Wales Narrow Gauge.
Builder	—	Avonside.	Avonside.	Avonside.	Vulcan.	—	Hunslet.
Date	1869/1870.	1878.	1878/79.	—	1876.	1876.	1908.
Type	**0-4 + (4).**	**0-4 + (4).**	**0-4 + (4).** Class R.	Class S.	**0-4 + (4).**	**0-6 + (4).** "Snowdon."	**0-6 + (4).**
Cylinders, diameter	15″	16″	12¼″	13″	9″	8½″	9½″
,, stroke	20″	22″	16″	—	14″	14″	14″
Boiler, diameter	—	4′ 2⅜″	—	—	2′ 7″ × 7′ 7″	—	2′ 5″ × 8′ 10″
,, pressure . lbs. per sq. in.	—	—	—	—	120 to 140	—	160
Tubes, number	—	181	—	—	94	—	65
,, diameter	—	2″	—	—	1⅝″	—	1⅝″
Heating surface, firebox sq. ft.	—	72	—	—	29·5	—	30·0
,, ,, tubes ,,	—	1,022	—	—	313	—	252
,, ,, total ,,	—	1,094	—	—	342·5	366	282
Grate area ,,	—	15·5	—	—	6·3	5·9	5·0
Wheels, diameter	5′ 7½″	5′ 6″	3′ 0½″	3′ 0½″	2′ 8″	2′ 6″	2′ 4″
,, diameter	2′ 11″	4′	—	—	1′ 7″	1′ 7″	1′ 10″
Wheelbase, bogie	6′ and 5′	6′ 6″ and 6′	—	—	4′ 6″	6′ 0″	5′ 6″
,, total	20′ 6″	21′ 7″	—	—	13′ 11″	14′ 11½″	14′
Bogie centres	14′ 7″	15′ 4″	—	—	—	—	—
Overall length	—	33′ 2″	—	—	21′ 6¾″	—	—
Water capacity . gall.	800	1,200	—	—	380	350	400
Coal capacity . t.-cwt.	1—10	—	—	—	12 cwt.	—	1—2
Weight, adhesive . t.-cwt.	22	—	—	—	—	—	11—6
,, total . t.-cwt.	35·7	44	—	—	9	14—10	18—10

Paris in 1878. It appeared on this railway in 1881.* It was similar to the former ones, but had outside cylinders. Water was carried partly in short side tanks and partly behind the cab, where the fuel was also stored.

It was the first English locomotive to be fitted with the Walschaert valve gear,† but this was not properly understood and was never in proper order so that coal consumption was enormous (40 lb. per mile) and the locomotive considered unsatisfactory. This was unfortunate as its high operating costs were erroneously attributed to the principle of the Walschaert gear, which was only reproduced in the British Isles many years later, by Beyer, Peacock & Co., in 1890.

Single Fairlie Locomotive of the East and West Junction Ry.—Standard gauge.

There is nothing of special interest in regard to these locomotives, the last of which was taken out of service in 1892.‡

Festiniog Ry. 0-4-0 + (4) Single Fairlies.—1 ft. $11\frac{1}{2}$ ins. gauge (0m.60).

The Vulcan Foundry Co. built some engines of this type for two Welsh narrow gauge lines. It is interesting to compare their dimensions with those of the double-boiler *Fairlies* referred to hereafter.

Class b.—0-6-0 + (4) Single Fairlies

Single 0-6-0 + (4) Fairlie Locomotives for the New Zealand Government Rys.—3 ft. 6 ins. gauge.—Fig. 2.

After a satisfactory trial with double *Fairlie* locomotives, this railway ordered two sets of single *Fairlies*. They were even used for express trains,§ and some of them are still working.

* It has been stated that this locomotive was subsequently purchased by a French railway company. We have been unable to trace it in France, and, on the other hand, the British railway's single *Fairlie* was identical with it. We believe, in fact, that it was the original locomotive.

† Walschaert was a Belgian mechanic who invented the valve gear which bears his name in 1844.

‡ The line became, later, the Midland and South-Western Junction Ry., and is now part of the Great Western system.

§ The "Class R" engines, of which eighteen were supplied by the Avonside Engineering Co. in 1878–79, had cylinders $12\frac{1}{4}$ ins. diameter,

0-6-0 + (4) Single Fairlies of the North Wales Narrow Gauge Ry.—1 ft. $11\frac{1}{2}$ ins. gauge (0m.60) (Fig. 2).

The main line, from Dinas Junction to Snowdon (Rhyd-Dhu), is 10 miles long ; there are, besides, some short branches.

Three locomotives of this type have been in use since the railway's inception and have given satisfaction. They have been re-built without much alteration by Messrs. Davis and Metcalfe in 1902–3, and by the Hunslet Locomotive Co. in 1908.*

The conditions to which they conform are severe. With an

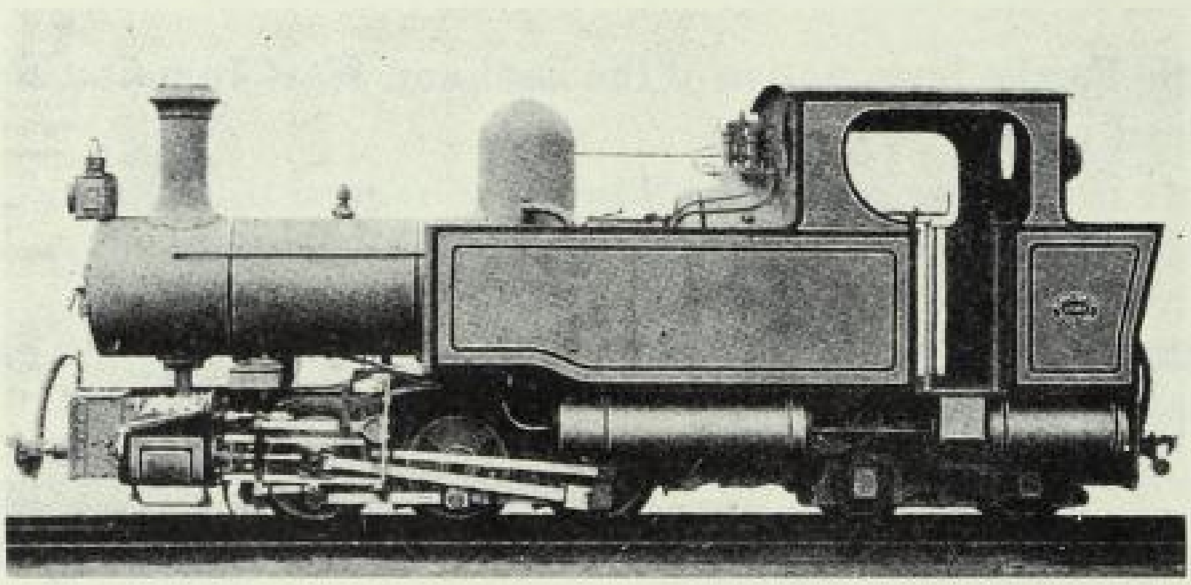


Fig. 2.—0-6 + (4) Tank Fairlie, Single Boiler Locomotive, North Wales Narrow Gauge Ry.
(1 ft. $11\frac{1}{2}$ ins. Gauge).
Built by the Hunslet Locomotive Works.

axle-load of 4 tons 5 cwt. they haul 280 tons on the level, 140 up 1 per cent. grades and 75 up 1 in 50. Minimum radius of curves, 60 ft.

Type 2.—The Mason-Fairlie Locomotives

After having built for the Lehigh Valley R.R. a modified

and 16 in. stroke (0m.32 and 0m.41) and driving wheels 3 ft. $0\frac{1}{2}$ in. diameter (0m.92).

The "Class S" engines, seven in number, had the same size of driving wheels, but cylinders of 13 ins. diameter (0m.33). Four of them were sold to the Western Australian Government Rys. The other twenty-one locomotives were still in service in 1925.

* The extreme height of these locomotives is 8 ft. 9 ins. ; their extreme width, 6 ft. 6 ins. They weigh empty, 14 tons 19 cwt.

Tractive effort at 75 per cent. boiler pressure is 5,415 lbs. ; factor of adhesion, 4·7.

form of *Fairlie* locomotive, which met with little success,* Mason designed some locomotives of the *Fairlie* type, in which the cab, the fuel and the water tanks were carried on a six-wheel, non-driven bogie.

The first of these locomotives was built in 1878 and sold to a railway in Colorado.† It was followed by some others in which the rear bogie had sometimes two and sometimes three axles, and some of them had a bissel on the leading (driven) truck.

The 2-6-0 + (6) Mason-Fairlie Locomotives of the Mexican Central Ry.—Standard gauge.

This railway forms the Mexican section of the direct line from Denver to Mexico City *viâ* El Paso.‡ Its construction was inferior from an engineering point of view and this necessitated the employment of articulated locomotives. *Mason's* were first tried,§ then *Johnstone's*, and, finally, *Mallet* locomotives.||

This was the most important application of the *Mason-Fairlie* locomotives which had been made up to that time, but they did not respond to the expectations which had been entertained and the type was soon discontinued.

Type 3.—The Johnstone Singles

Like both Fairlie and Mason before him, Johnstone built double-boiler locomotives and, like the former, he afterwards sought to simplify them.

He did so in two stages ; in the first he substituted a single for his double boiler ; in the second, he placed ordinary un-driven bogies under the tender portion of his locomotive, and

* The "Janus," built in 1871, had two six-wheel bogies, and cylinders 15 ins. by 22 ins. (0m.381 by 0m.559).

† This locomotive had cylinders 12 ins. by 16 ins. The diameter of the drivers was 2 ft. 10 ins. (0m.863).

‡ The distance from Mexico City to El Paso is 1,225 miles (1,971 km.). The American and Mexican sections were united in the year 1884. The line has many sharp curves and heavy gradients and was originally constructed almost without earthworks or ballast.

§ This locomotive had cylinders 16 ins. by 24 ins. (0m.406 by 0m.609). The driving wheels were 4 ft. 6 ins. (1m.371) diameter. Weight in working order, 69,400 lbs. (31,500 kg.).

|| The *Mallets* of this railway are double-Moguls whose principal dimensions are given hereafter.

maintained a steam-driven bogie worked according to his special device under the fore portion.

But as it never got beyond the projected stage we shall not further describe it here, referring our readers to the double-boiler *Johnstone* locomotive hereafter, which alone was constructed.

PART II

ARTICULATED LOCOMOTIVES WITH ONE ENGINE AND TWO GROUPS OF DRIVING WHEELS

In the early days of railways, numerous attempts were made to facilitate the passage of locomotives around curves, but as increased power became imperative, a larger number of axles were necessary for adhesion than was possible in rigid locomotives, and articulated locomotives appeared.

The early types had only two cylinders, which necessitated the employment of complicated transmission systems, until it was realised that it was more simple to fit a pair of cylinders to each truck. In spite of this it is desirable to make a brief reference to these early designs for, in railway matters, it can never be assumed that any system is definitely abandoned—it may always reappear in a modified form. And this is what has actually happened in several instances.

When a single engine is used, the drive has to be transmitted to both wheel groups, which introduces difficulties of design. The simplest method is to use gear transmission, and this was adopted as early as the year 1838, in the *Neath Abbey* locomotive. Since the year 1880 it has been widely and successfully employed in America, where the *Climax*, the *Baldwin*, the *Heisler*, and above all, the *Shay* designs are successful applications of gear transmission.

Other solutions of the problem have been tried, but the complications which they introduce are so great that they have been abandoned in favour of the simpler plan of providing the second truck with its own engine and pair of cylinders.

We will examine articulated locomotives having but one engine and two driven bogies under three heads :—

(1) Those using gear transmission between the trucks.
(2) Those using ball and socket joints between them.
(3) Those using rod connections only.

SECTION II. A.—SINGLE ENGINE ARTICULATED LOCOMOTIVES WITH TRANSMISSION BY GEARING

These locomotives are dealt with in a separate group because, although they have two or more motor trucks, the method of gear transmission distinguishes them sharply from other types.

Though some of the oldest locomotives had gear transmission, its use was abandoned at an early date in locomotive history, and it was not until the eighties that it was reintroduced in various forms adapted to special services. In this shape, they were nearly entirely confined to the continent of America; they are, however, worthy of detailed study and fitly occupy an important place in any work dealing comprehensively with articulated locomotives.

As will be seen hereafter, owing to the progress automobile gearing has made, gearing has recently been reintroduced in locomotive practice in Germany, usually in conjunction with coupling rods. These locomotives are dealt with in Book II., which deals with semi-articulated locomotives. It was revived for the purpose of reducing the rigid wheelbase of ten-coupled rigid locomotives, the four leading axles being coupled by side rods in the usual way, while the fifth was driven therefrom by gearing.

Comparison of Geared and Rod Locomotives.—Geared locomotives have the advantage that their entire weight is available for adhesion, even when the fuel and water are carried, in whole or in part, in a separate tender. Furthermore, the fact that this weight is distributed over a large number of axles and that the turning moment is approximately uniform, owing to the number of impulses per revolution of the wheels, allows these locomotives to be used on lines of inferior formation and road bed. They are also used in construction lines.

As the driving wheels have no counter-weights, there is no hammer action on the rails, and the load per axle can be higher than in the case of an ordinary reciprocating locomotive. The rails wear less and track maintenance is reduced.

Articulated locomotives, with transmission by gearing, have been used for a number of years in the U.S.A. In some instances, extra water and fuel space is provided in a tender, which is carried by one or two bogies, and these are driven like the bogies of the locomotive proper, bringing the total number of bogies up to three and even four.

General Features of American Geared Locomotives.—These locomotives are well adapted for the special services in which they are employed and furnish an economic solution of the problem of steam traction on those lines of particular difficulty which are often met with on the American continent.

The system on which geared locomotives are constructed permits them readily to climb gradients of 6, 10 and even 14 per cent. and to negotiate very sharp curves. Of course electric traction can also deal with similar conditions, but the capital expenditure required for the installation of electric traction is generally greater than the traffic in such cases can justify.

These geared locomotives are successfully used on plantation railways, on forest and on mining lines, where the road bed is far inferior to the standard of public railways. They have also been used on special lines in hilly districts constructed for tourist traffic. And in America they are also used in cases where European engineers would install aerial rope-ways. It would be interesting to have comparative figures of the cost of these two systems under approximately similar conditions.

Hauling capacities are based on a figure of 8 lbs. per short ton for rolling friction and a M.E.P. of 75 per cent. of the full boiler pressure. The following formula can be used :

$$\text{Hauling pressure} = \frac{0{\cdot}75\,p \times 1{\cdot}5\,c^2 s \mathrm{R}}{\mathrm{D}},$$

where p is the boiler pressure in pounds per square inch ;
c is the diameter of the cylinders in inches ;
s the stroke ;
R the gear ratio ;
D the diameter of the driving wheels, in inches.

American Types of Geared Locomotives.—There are four distinct types of American geared locomotives.

The most widely used system is the *Shay*, the product of the Lima Locomotive Works. But other systems in use are the *Climax*, the *Baldwin*, and the *Heisler*.

The *Shay* locomotive has a longitudinal transmission shaft running along the right-hand side of the boiler. It is actuated by a vertical engine and drives the wheels through bevel gears.

The *Climax* locomotive has a central transmission shaft. This drives the axles through gears located alternately on the right and left of the shaft. The engine is vertical or horizontal, according to the class.

The *Baldwin* geared locomotive has two longitudinal transmission shafts, one actuating the leading bogie and the other the trailing bogie or bogies.

The *Heisler* locomotive has a central transmission shaft, but this shaft drives only one axle of each bogie, the other axles of the bogie being driven from the latter by coupling bars.

GROUP I.—THE SHAY GEARED LOCOMOTIVES

§ 1.—General Features

The first *Shay* locomotive was built in 1880. Since then the Lima Locomotive Works (U.S.A.) have built them in large numbers.

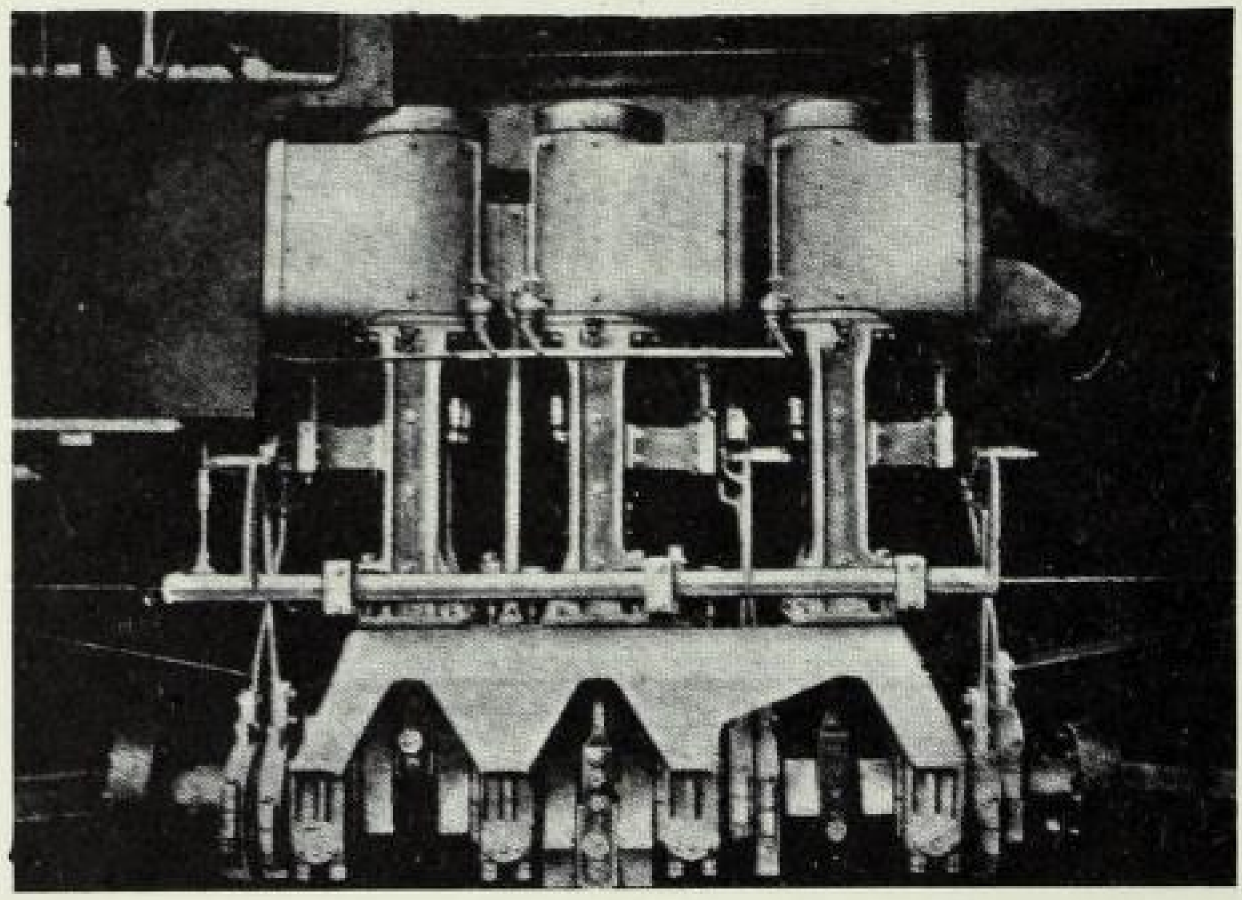


Fig. 3.—Arrangement of Cylinders and Valve Motion of Shay Geared Locomotives.

The boiler with its firebox, the cab, the fuel and water are carried on a single rigid frame, which rests on two bogies. A vertical engine, situated on the right-hand side of the boiler, transmits its action to a horizontal shaft, which in turn is connected by gearing with each axle of every bogie.

In the larger classes of *Shay* locomotives, a pseudo-tender or even a tender is added, and the one or two bogies on which it rests, as the case may be, are driven in the same as those of the locomotive proper.

TRANSMISSION.—The engine (Fig. 3) is a three-cylinder vertical one and is fixed to the boiler, above the frames. It drives a horizontal shaft which runs along the whole length of the locomotive, on the right-hand side at the level of the centres of the wheels and outside of them. Pinion shafts carry the pinions which engage with the bevel wheels fastened to each wheel. These gears are secured both to the axles and to the outer periphery of the wheels themselves. The driving stresses are communicated from the bogies to the superstructure through the weight-bearing pivots.

GEARS.—The ratio of gear reduction varies from 2 : 1 to 3 : 1.

FIG. 4.—Steel and Timber Frame, Shay Geared Locomotive.

FIG. 5.—Steel Frame Shay Geared Locomotive.

With a three-cylinder engine whose cranks are set at 120 degrees, there are therefore from 12 to 18 impulses per revolution of the wheels. This gives a much more even turning moment than is the case in an ordinary two-cylinder engine driving a crank shaft direct, in which case there are only four impulses per revolution of the driving wheels.

FLEXIBILITY.—The crank shafts are connected to the pinion shafts by universal joints, so that the driving mechanism is flexible in any direction, but rigid in revolution. These joints are always used in pairs to correct any variation in velocity due to one of them.

The driving shaft has slip joints consisting of a cast steel square shaft and sleeve.

RUNNING SPEED.—These locomotives can climb banks at speeds of from 4 to 7½ miles (6 to 12 km.) per hour. On the level or down-hill their maximum speed is from $9\frac{1}{2}$ to 19 miles (15 to 30 km.) per hour. They are, therefore, only suitable for dealing with heavy loads at low speeds.

Trucks (Fig. 6).—All trucks are four-wheeled; they are connected with the main frame through centre plates. Above them, the main frames are provided with cross-bolsters bearing centre plates, which rest on the trucks' centre plates.

Driving Wheels.—All the wheels are driven and the power developed by the engine is equally divided between them. The diameter of the wheels is generally 3 ft. (0m.91) and never

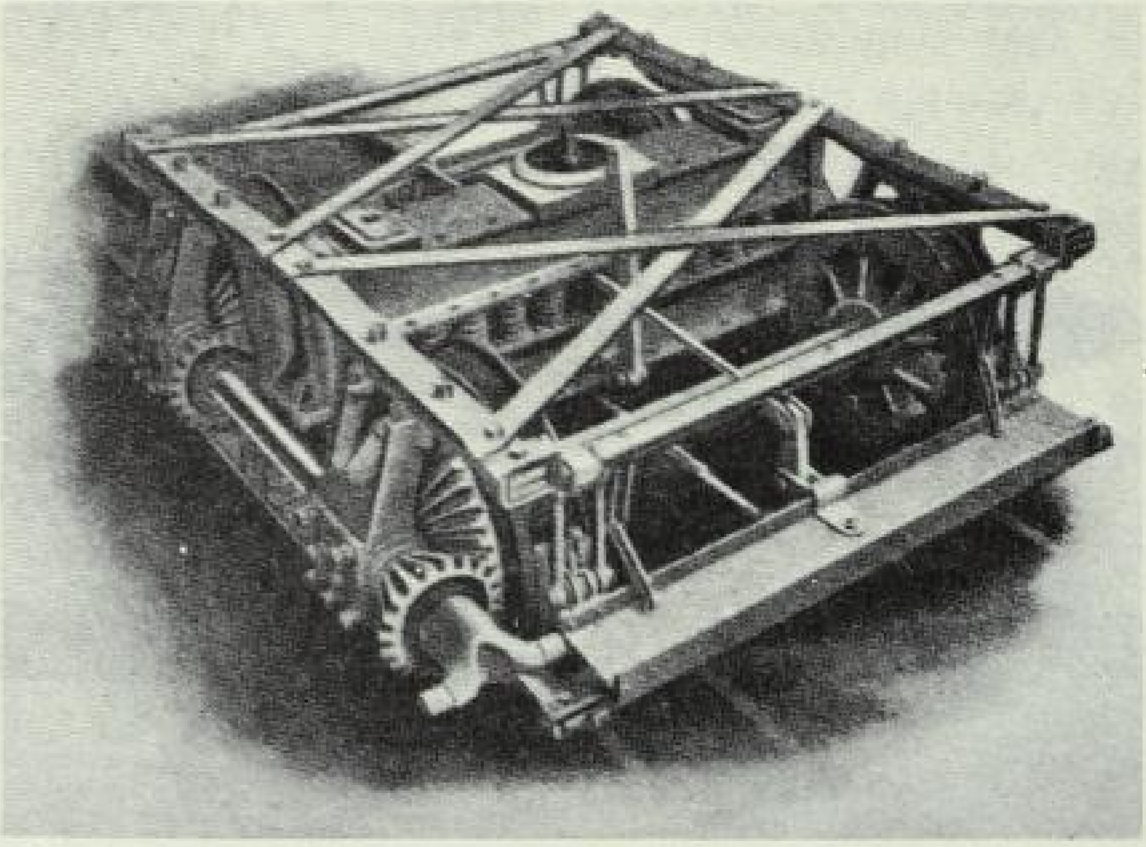


Fig. 6.—Truck and Gearing, Shay Locomotive.

exceeds 4 ft. (1m.22). The rigid wheelbase varies from 4 ft. 4 ins. (1m.32) to 4 ft. 8 ins. (1m.42), although, in some of the most powerful locomotives, it may reach a maximum of 5 ft. 8 ins. (1m.72).

Articulation.—The transmission shaft between the engine and the bogies is of square section and provided with sliding sockets at the joints to facilitate running through curves. Universal joints are provided at each end of each section of the transmission shaft.

Valve Gear.—Stephenson link motion is fitted.

Boiler.—The boiler is set over to the left of the centre line of the locomotive in order to balance the weight of the vertical engine fixed on the opposite side. The usual pressure is

TABLE 3.—COMPARISON OF SHAY LOCOMOTIVES WITH OTHER LOCOMOTIVES OF THE SAME TRACTIVE FORCE.

	Shay. 2 trucks.	Prairie.	Shay. 3 trucks.	Mikado.	Shay. 2 trucks.	Mallet 2-4 + 4-2.
Weight:						
Total . . . . . lbs.	78,111	111,000	308,000	497,000	124,000	240,000
Adhesive . . . . ,,	78,000	58,000	308,000	240,000	124,000	130,000
Dead weight . . . ,,	None.	53,000	None.	257,000	None.	110,000
Average per pair of drivers ,,	19,500	19,330	51,350	60,000	31,000	32,500
Wheelbase:						
Rigid	4′ 2″	8′ 0″	5′ 8″	16′ 9″	4′ 8″	5′ 4″
Total	26′ 5″	42′ 4″	49′ 0″	71′ 9½″	33′ 4″	53′ 6″
Rated tractive effort . . lbs.	14,320	14,280	59,740	60,000	24,000	24,000
Drawbar pull on grades:						
2 per cent. grade . . lbs.	12,450	11,100	52,450	56,000	22,250 (1 per cent.)	18,700 (1 per cent.)
6 per cent. grade . . lbs.	9,330	6,670	40,000	26,150	16,000	6,700
10 per cent. grade . . lbs.	6,210	2,220	33,850	16,500	—	—
Sharpest curve (radius). . .	75′	140′	179′	300′	—	—
Lightest rail advised .lbs. per yd.	30	40	80	90	55	60

200 lbs. per square inch (14·1 kg. per square centimetre). Recent types are fitted with superheaters.

CYLINDERS.—These are usually secured to the boiler barrel (which is reinforced by a large plate inside) by brackets to which the cylinders are bolted. In a recent and improved type (the Pacific Coast locomotive) they are fixed to the frame and not to the boiler. The cylinders in this type have piston valves.

FIRE-BOX.—The length of the fire-box is generally 6 ft. $\frac{1}{2}$ in. (1m.88), but in some cases reaches 9 ft. 6 ins. (2m.90). The width of the fire-box varies from 3 ft. $8\frac{3}{8}$ ins. (1m.14) to 5 ft. $1\frac{1}{4}$ ins. (1m.55). Arch tubes are sometimes used, which is surprising in a locomotive of this kind, according to European ideas.

FUEL AND WATER.—The water capacity is as much as 247 cub. ft. (7 cub. m.) for locomotives with two bogies, 460 cub. ft. (13 cub. m.) for those with three bogies, and 812 cub. ft. (23 cub. m.) for tender locomotives with four bogies. These last can take 8 tons 18 cwt. (9 metric tons) of coal.

COMPARISON WITH ORDINARY LOCOMOTIVES.—In Table 3 some results of comparative tests of *Shay* locomotives with others of the same rated tractive force, together with certain dimensions and weights, are shown.

The Mikado locomotive in the table is a standard type of the United States Rys. Administration. The *Shay*, with which it is compared, is one of those in use on the Greenbrier, Cheat and Elk R.R.

The *Mallet* (2-4 + 4-2) is a type in which this system of articulation is at a disadvantage.

TYPES OF SHAY LOCOMOTIVES.—*Shay* locomotives may have two, three or four motor trucks.

Utilisation of Shay Geared Locomotives

Besides their use for special purposes, such as industrial construction work, *Shay* locomotives are regularly employed both for passenger and goods service and also as banking engines.

Particulars of some of the applications of these locomotives will be given later, but they are also in use on the following railways :—

CANADA, U.S.A. AND MEXICO.—The Canadian Pacific Ry.,

TABLE NO. 4.—PRINCIPAL DIMENSIONS OF SHAY GEARED LOCOMOTIVES BUILT BY THE LIMA LOCOMOTIVE WORKS.

Type	4 + 4 Class 50–2	4 + 4 Class 60–2	4 + 4 Class 60–2	4 + 4 + 4 Class 70–3	4 + 4 + 4 Class 70–3	4 + 4 + 4	4 + 4 Class 80–2	4 + 4 + 4 Class 80–3	4 + 4 + 4 Class 90–3	4 + 4 + 4	4 + 4 + 4 Class 150–3
Railway or Company	Columbus, Railway Power & Light Co.	New York Central Railroad.	Sugar Pine Lumber Co.	Mt. Shasta Power Corp.	Oeste de Minas Ry.	Pacific Coast.	Cleveland Electric Illuminating Co.	Clear Lake Lumber Co.	Cascade Timber Co.	Pekin-Kalgan Ry.	Greenbrier Cheat & Elk Railroad.
Gauge	Standard.	Standard.	Standard.	Standard.	Metre.	Standard.	Standard.	Standard.	Standard.	Standard.	Standard.
Cylinder diameter	11"	12"	12"	12"	12"	13"	13"	13½"	14½"	15"	17"
,, stroke	12"	12"	12"	15"	15"	15"	15"	15"	15"	17"	18"
Boiler diameter	44⅜"	46½"	46½"	50⅛"	50"	50⅛"	56"	49⅞"	58⅛"	58"	62⅜"
,, pressure lbs. per sq. in.	220	200	200	200	200	200	200	200	200	200	200
Tubes, number	82	155	78	97	97	97	210	97	129	246	166
,, diameter	2"	2"	2"	2"	2"	2"	2"	2"	2"	2"	2"
Flues, number	10	—	12	15	15	15	—	15	20	—	26
,, diameter	5⅜"	—	5⅜"	5⅜"	5⅜"	5⅜"	—	5⅜"	5⅜"	5⅜"	5⅜"
,, length	8' 11"	10' 11$\frac{5}{16}$"	10' 11$\frac{5}{16}$"	11' 0'	10' 11¼"	11' 0"	11' 0"	12' 5¼"	11' 11¼"	15' 6"	13' 6"
Firebox, length	72½"	89¼"	72½"	72½"	72½"	89¼"	72½"	72¼"	84"	96"	114"
,, width	46¼"	46¼"	46¼"	44¾"	44¾"	44¾"	50¼"	54¼"	58¼"	58½"	61¼"
Heating surface:											
Firebox sq. ft.	110	125	105	105	102	122	110	115	135	—	207
Tubes and flues ,,	504	880	626	783	779	783	1,198	887	1,037	—	1,656
Total ,,	614	1,005	731	888	881	905	1,308	1,002	1,172	—	1,882
Superheater ,,	91	—	139	189	189	189	—	208	253	—	411
Grate area ,,	23·3	28·5	23·3	22·53	22·53	27·75	25·3	27·2	33·9	38·8	48·5
Wheels, diameter	32"	36"	36"	36"	34"	36"	40"	36"	36"	40"	48"
Wheelbase, rigid	4' 4"	4' 8"	4' 8"	4' 4"	4' 4"	4' 4"	5' 0"	4' 8"	4' 8"	4' 10"	5' 8"
,, total	28' 10"	33' 3⅜"	33' 0"	40' 2"	40' 2"	41' 2"	34' 10"	44' 8⅜"	43' 2¾"	45' 6"	49' 0"
Water galls.	1,750	2,200	3,000	3,000	2,300	3,000	3,000	3,500	3,500	4,000	6,000
Fuel t. or galls.	3¼ t.	2¼ t.	1,200 g.	1,200 g.	3 cords (wood)	1,200 g.	5 t.	1,200 g.	1,500 g.	5 g.	9 t.
Maximum tractive power lbs.	22,580	27,400	24,000	30,350	36,150	38,200	32,480	35,100	40,400	—	59,700
Factor of adhesion	5·18	5·09	6·34	5·75	4·03	4·74	5·15	5·82	5·2	—	5·16
Weight in service lbs.	117,000	139,400	152,300	174,700	146,000	181,000	167,300	204,600	209,800	—	308,000

The Class 150, 3-truck Shay Locomotive for the Greenbrier, Cheat and Elk Railroad Company has an arch tube heating surface of 19 square feet. This is not shown on the table, but is included in the total heating surface of this locomotive.

the Lake Superior and Ishpeming Ry., the Argentine Central Ry. (3 ft. gauge), the Chesapeake and Ohio R.R., the Southern Utah Ry., the Uintah Ry., the Quintal Ry., and the Mexican North-Western Ry.

Central America.—The Northern and Central Rys. of Guatemala.

South America.—The Guayaquil-Quito Ry. (Ecuador), the Chilian Nitrate Ry., the Arica La Paz Ry. (Chile and Bolivia), the Transandine Ry. (Chile).

Asia.—The Pekin-Kalgan Ry. (China) and the Imperial Government Ry. (Formosa).

Australia.—The Wolgan Valley Ry.

Class A.—Shay Locomotives with Two Motor Trucks (4 + 4)

There are two classes of this type of locomotive.

The smaller type has a two-cylinder engine and weighs from

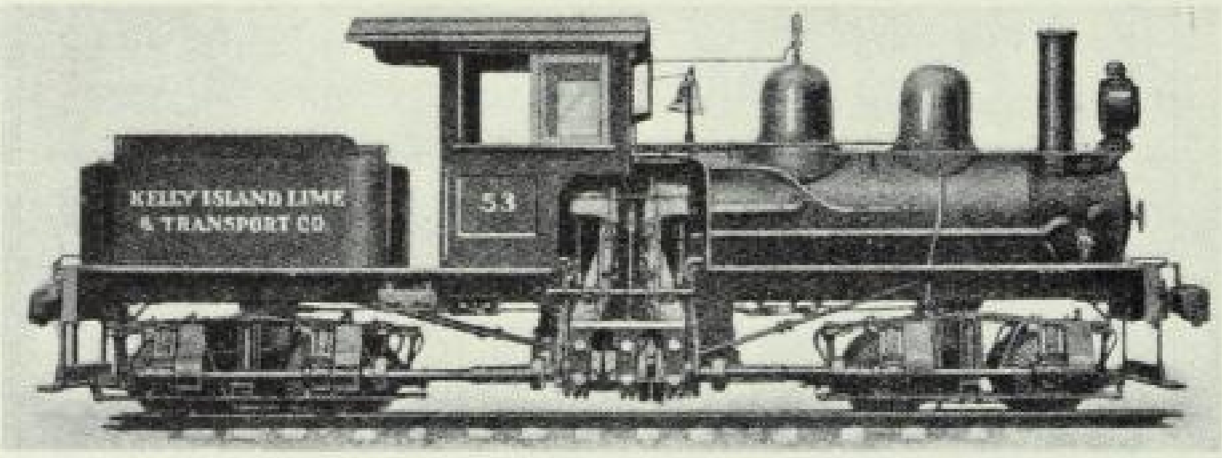


Fig. 7.—4 + 4 Shay Geared Locomotive.

12 to 18 tons (Fig. 7). The larger has a three-cylinder engine and weighs from 22 to 53 tons.

4 + 4 Shay Locomotives of the Argentine Central Ry. (U.S.A.). —3 ft. gauge.

This line was built for tourist traffic. It runs from Silver Plume * to Waldorf and to the summit of Mt. MacClellan. A branch line, from Waldorf, will be carried under the Argentine Pass by a tunnel 2,507 yards (2,293 m.) in length in order to serve a region which is rich in copper mines. It will connect at Keystone with the systems of the Denver and Rio Grande

* Silver Plume is 54 miles (87 km.) from Denver, by the Denver and Rio Grande Western R.R.

Western R.R. and the Colorado Southern Ry. which run to Leadville.*

The branch from Waldorf to Leadville is owned by the Montezuma and Western Ry., a subsidiary company of the Argentine Central Ry. This line ascends a height of 5,150 ft. (1,572 m.) from Silver Plume, altitude 8,850 ft. (2,697 m.), to Mt. MacClellan, altitude 14,000 ft. (4,269 m.). This is only 139 ft. (42 m.) below the top of the rack railway from Manitou to Pike's Peak, which is not far distant. The difference in level is surmounted on a development of 16 miles (26 km.) by almost continuous grades of 6 per cent. non-compensated and 8 per cent. compensated. The minimum radius of curvature is 145 ft. (44 m.). There are five reversing stations between Waldorf, and mile $8\frac{1}{2}$ (km. 14), altitude 11,250 ft. (3,556 m.), and two others not far from Silver Plume.

The line is closed during the winter months, but even in summer snow causes trouble to the track.

The *Shay* locomotives used weigh 44 tons 5 cwt. (45 metric tons). The trains consist of three passenger coaches weighing 8 tons 4 cwt. (8·3 metric tons) empty.

4 + 4 Shay Locomotives of the La Paz-Yungas Ry. (Bolivia). —Metre gauge.

This railway is situated in one of the most mountainous regions in the world. The town of La Paz lies in a narrow valley 1,473 ft. (450 m.) below the level of the plateau which surrounds it.

In November 1914, the Bolivian Government decided to build a railway to the tropical region of Yungas, *viâ* the Cumbre Pass. For this work a loan of £500,000 was raised in the United States in 1917.

The first 16 miles (26 km.) from La Paz to La Cumbre were opened for traffic on October 20th, 1919.

From La Paz, altitude 11,800 ft. (3,600 m.), the line ascends the valley of the River Chuquiaquillo in order to reach the Cumbre Pass by which the Cordilleras are crossed at an altitude of 15,180 ft. (4,640 m.). Up to this point the ruling gradient

* The distance from Denver to Leadville *viâ* Waldorf will be $121\frac{3}{4}$ miles (196 km.) by the 3-ft. gauge lines. The distance *viâ* Colorado Springs, by the standard gauge lines, is 276 miles (444 km.).

is 4 per cent. (1 in 25), but beyond this the line descends for some 31 miles (50 km.) of track length with 6 per cent. grades. Thus the line descends 1,473 ft. (450 m.) in a distance, as the crow flies, of scarcely 1 km. (·62 mile). After the fiftieth kilometre, the descent of the valley is less steep, and the maximum gradient is 3 per cent. and subsequently 2 per cent. only.

The traffic is handled by *Shay* locomotives weighing 37 tons 7 cwt. (38 metric tons) which haul train loads of 57 tons up the 6 per cent. grades. The rails are very light, weighing only 36 lbs. per yard (18 k. per metre). It is intended to replace them with 50-lb. rails at a later date. The minimum radius of curvature is 200 ft. (61 m.).

Apart from the difference of gauge, these locomotives differ but little from those of the Columbus Ry., 4 + 4 type, of which we give some particulars.*

4 + 4 Shay Locomotives of the Wolgan Valley Ry.—Standard gauge.

This line is situated in the Blue Mountain district of New South Wales. It connects with the Government Ry. at Newnes Junction, 85½ m. (128 km.) from Sydney, altitude 3,610 ft. (1,100 m.), whence it runs to Newnes, altitude 1,758 ft. (536 m.), which is the centre of the oil-well district. The total length of the line is 31¾ miles (51 km.). The summit level is 3,957 ft. (1,207 m.) at mile 7.

For the first 18½ miles from the junction the maximum grade is 3 per cent. It rises to 4 per cent. for the next 8¾ miles.

The minimum radius of curvature is 328 ft. (100 m.).

The line has four *Shay* locomotives, three weighing 62 tons (63 metric tons),† and one weighing 74 tons 15 cwt. (76 metric tons).

* They have the same cylinders and trucks, but they carry less water (1,450 U.S. galls.) and fuel (3 short tons), and have a lower boiler pressure (180 lbs. per square inch). They weigh 99,500 lbs. in working order.

† These locomotives have cylinders 12 ins. × 15 ins. (0·31 m. × 0·38 m.). Boiler pressure, 200 lbs. per square inch (14·1 k. per square centimetre). Trucks, 4 ft. 4 ins. (1·32 m.). Total wheelbase, 40 ft. 2 ins. (12·24 m.). Water, 2,500 U.S. galls. (11·4 cub. m.). Coal, 4·4 short tons (4 metric tons).

4 + 4 Shay Locomotives of the Mt. Tamalpais Ry.—Standard gauge.

This is a remarkable example of the use of simple adhesion on a tourist line with very severe gradients. European engineers have usually adopted rack railways for such lines as this, but it is worth considering whether geared locomotives working by adhesion only would not be a better solution of the problem, in many cases.

Mt. Tamalpais dominates the Golden Gate, the entrance to the Bay of San Francisco. The mountain is distant $11\frac{1}{4}$ miles (18 km.) from the city and rises to a height of 2,595 ft. (790 m.). The railway which climbs the mountain is of standard gauge and was built in 1896.* The mean gradient is 6 per cent. with a maximum grade of 7 per cent. The line is a veritable cork-screw, having no less than 281 curves, some of only 69 ft. (21 m.) radius. Among these is the famous Double Bow Knot, composed of five successive loops by means of which the line climbs a height of 88 ft. (27 m.) in a point to point distance of 270 ft. (90 m.). The longest portion of straight alignment is only 412 ft. (126 m.).

The locomotive is always placed at the rear of the train. In order to diminish the friction between wheel flanges and rails when running through curves, a small jet of water is played on each wheel flange. The brake shoes are cooled by the same means.

These locomotives have feed-water heaters located in the smokebox.†

The Placerville and Lake Tahoe Ry. (**U.S.A.**) uses *Shay* locomotives to handle mixed trains up the 8 miles of 3 per cent. grade between Camino and Placerville.

4 + 4 Shay Locomotives of the Chilian Trans-Andine Ry.—Metre gauge.

Particulars of this line are given in the section dealing with *Meyer-Kitson* and *Esslingen* locomotives.

* It starts at Mill Valley and climbs to a height of 2,508 ft. (762 m.). There is also a branch line which runs to the Muir Woods.

† Among the coaching stock, there are some passenger trollies with cross-benches which are used for the descent of the line by gravity. These trollies have hand-brakes only. They are hauled back to the summit by locomotive power.

The *Shay* locomotives are similar to those of the Wolgan Valley Ry. and, as in the case of all the earlier locomotives, the boiler pressure is 180 lbs. per square inch only.*

4 + 4 Shay Geared Locomotives, New York Central R.R.—Standard gauge (Fig. 8).

This locomotive is of particular interest as illustrating another curious application of the geared principle under very peculiar circumstances.

The N.Y.C. operates a switching service in New York City, between Thirtieth Street Yard and the St. John's Park freight station, a distance of some $2\frac{1}{2}$ miles located in the streets. This entails compliance with the city traffic regulations, slow

FIG. 8.—4 + 4 Shay Geared Locomotive, New York Central R.R. (Standard Gauge).

running with frequent stops and accelerations, rails in poor condition and sharp gradients.

All these conditions are against the proper operation of direct-connected steam locomotives, but well within the possibilities of the geared locomotives, which have been giving good service.

Owing to street traffic, they are entirely closed in and a horseman rides in front of the trains with a flag—which certainly adds picturesqueness.

The locomotive can be controlled from both ends.

4 + 4 Shay Geared Locomotive, Cleveland Electric Illuminating Co.—Standard gauge.

In Table 4 we have given dimensions of this two-truck

* Other dimensions are : Cylinders, 12 ins. diameter × 15 ins. stroke. Heating surface : firebox, 89 sq. ft. ; tubes, 897 sq. ft. ; grate area, 21·1 sq. ft. Weight in working order, 137,000 lbs.

locomotive to show an instance where better track has enabled the railway to call for a locomotive giving the same service which many other lines obtain from three-truck *Shays*.

Class B.—Shay Locomotives with Three Motor Trucks (4+4+4).

When the main frame cannot accommodate sufficient fuel and water space, a tender is added. The front of the tender rests with its centre on the locomotive frames and is carried by a bogie which is in effect a double bissel truck with its point of application at the centre of the rear of the locomotive frame.

The axles of this truck are driven from the longitudinal shaft in the same way as the locomotive axles.

The three-truck *Shays* weigh from 62 to 110 tons in working order. The boiler pressure is 200 lbs. per square inch.

4 + 4 + 4 Shay Locomotives of the West of Minas Ry. (Brazil).—2 ft. 6 ins. gauge.

This railway has two straggling lines, the first of 1 m., the other of 2 ft. 6 ins. gauge. The *Shay* locomotive of which dimensions are given in Table 4 is similar to the standard gauge *Shay* of the Mt. Shasta Power Corporation.

4 + 4 + 4 Shay Locomotives of the Baltimore and Ohio R.R.—Standard gauge.

These locomotives, which weigh 133 tons, are allotted to the Thurmond section in West Virginia. The gradient is 4½ per cent. The *Shays* are used for goods traffic, and occasionally for passenger traffic as well.

4 + 4 + 4 Shay Locomotives of the Pekin-Kalgan Ry.—Standard gauge.

This railway uses both *Shay* and *Mallet* locomotives on the ascent through the Nankow Gorge to Kalgan, 2,500 ft. (762 m.)* The alignment of this railway was a matter of difficulty, and it was impossible to avoid some gradients of 2½ and 3·3 per cent., and curves of 590 ft. (180 m.) radius. In the gorge, the

* The distance from Pekin is about 124 miles (200 km.). From Kalgan westward to Ta-Tung-Fou is another 121 miles (195 km.), and thence to Feng Chen about 31 miles (50 km.).

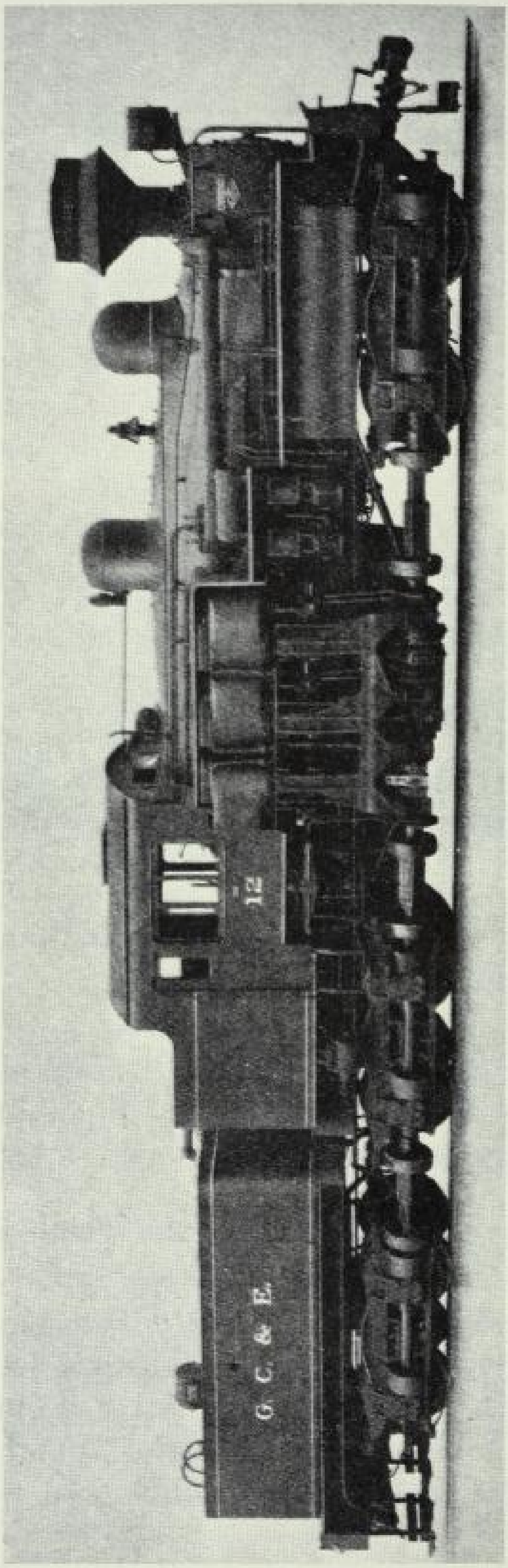


FIG. 9.—4 + 4 + 4 Shay Geared Locomotive, Greenbrier, Cheat and Elk R.R. (Standard Gauge).
Built by the Lima Locomotive Works.

line rises 1,640 ft. (500 m.) in a length of 12 miles. There are some heavy banks and cuttings, four tunnels and one reversing station.

4 + 4 + 4 Shay Locomotives of the Greenbrier, Cheat and Elk R.R.—Standard gauge (Fig. 9).

These are the most powerful geared locomotives which have yet been constructed by the Lima Locomotive Works. They were built in 1921. They are used on the section from Cass to Elk, which is 85 miles in length and is laid with 84- and 100-lb. rails, also on some branch lines aggregating about 31 miles in all. The maximum grade is 7 per cent., and the minimum radius of curvature 180 ft. (55 m.).

These locomotives have the comparatively large heating surface of 1,882 sq. ft. (170 sq. m.), and are provided with superheaters of 441 sq. ft. (41 sq. m.). In addition there are arch tubes giving a heating surface of 19 sq. ft. (1·76 sq. m.). In other respects, these locomotives are comparable to large reciprocating locomotives.*

The drawbar pull (with 85 per cent. of full boiler pressure) on various gradients is as follows :—

Grade.		Drawbar pull. Lbs.		Kgm.
1 per cent.	...	56,000	...	25,150
2 ,,	...	51,600	...	23,300
4 ,,	...	46,400	...	21,000
6 ,,	...	40,200	...	18,150
8 ,,	...	34,000	...	15,400

Class C.—Shay Locomotives with Four Motor Trucks (4 + 4 + 4 + 4)

This type has been designed in order to provide still more water and fuel capacity. It is similar to the preceding type in all respects, except that there are two motor trucks under the tender instead of one.

Shay Four-truck Locomotives, Chesapeake and Ohio R.R.—Standard gauge (Fig. 10).

Though this type is obsolete, we quote it as being an example

* The overall height of these *Shay* locomotives is 14 ft. 11 ins. (4m.86). The maximum load per axle is 22 tons 18 cwt. (23,200 kg.).

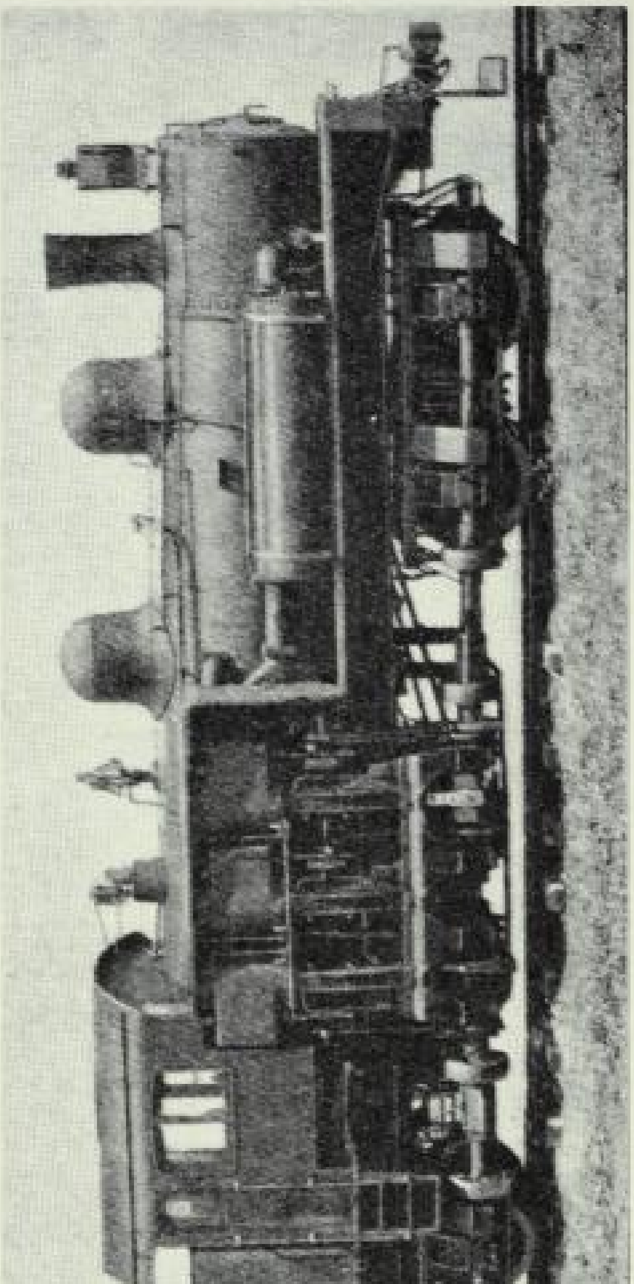


FIG. 10.—4 + 4 + 4 + 4 Shay Geared Locomotive, Chesapeake and Ohio R.R. (Standard Gauge).
Built by the Lima Locomotive Works.

of the adaptation of the *Shay* geared principle to an eight driving axle locomotive.

Its principal dimensions were as under :—

Cylinders, diameter	...	17 ins.
,, stroke	...	18 ins.
Boiler pressure	...	200 lbs.
Wheels, diameter	...	46 ins.
Wheelbase, rigid	...	5 ft. 1½ ins.
,, total	...	58 ft. 4 ins.
Water	...	3,300 U.S. gallons
Fuel	...	8 short tons
Weight in service	...	297,500 lbs.

Class D.—The Willamette Geared Locomotives

These locomotives were built by the Willamette Iron and Steel Works, Portland, Oregon, and follow the *Shay* design.

For various reasons, such as ease in delivery and facility for repairs, it was thought desirable to have an establishment for the building and repair of these locomotives on the Pacific coast.

The first Willamette locomotive was supplied to the Coos Bay Lumber Co., Marshfield, Oregon, in November, 1922. It had three motor trucks actuated by the usual side shaft, which was driven by a three-cylinder vertical engine developing 900 h.p. at the boiler pressure of 200 lbs. The engine had Walschaert valve gear.

The weight of the locomotive in working order was 18 tons approximate.

The water capacity was 4,000 U.S. gallons. It was oil fired and carried 1,500 U.S. gallons of fuel oil. The cab was built of steel.

GROUP II.—THE CLIMAX LOCOMOTIVES

General Characteristics

The *Climax* locomotive is built by the Climax Manufacturing Co., Corry, Pa. (U.S.A.). Its outstanding difference from the *Shay* type is that the transmission shaft is located on the centre line of the locomotive, in a position immediately above the axles, all of which are driven therefrom.

Engines.—In the horizontal type, each locomotive has two longstroke horizontal engines, one on each side.

Transmission.—A transverse crankshaft is driven by the engine through the intermediary of connecting rods with universal joints. This shaft has a master gear which transmits the power through the longitudinal shaft. This latter further transmits it to each axle gear through the truck pinions.

Gearing.—A bevel gear is keyed to each axle, which meshes

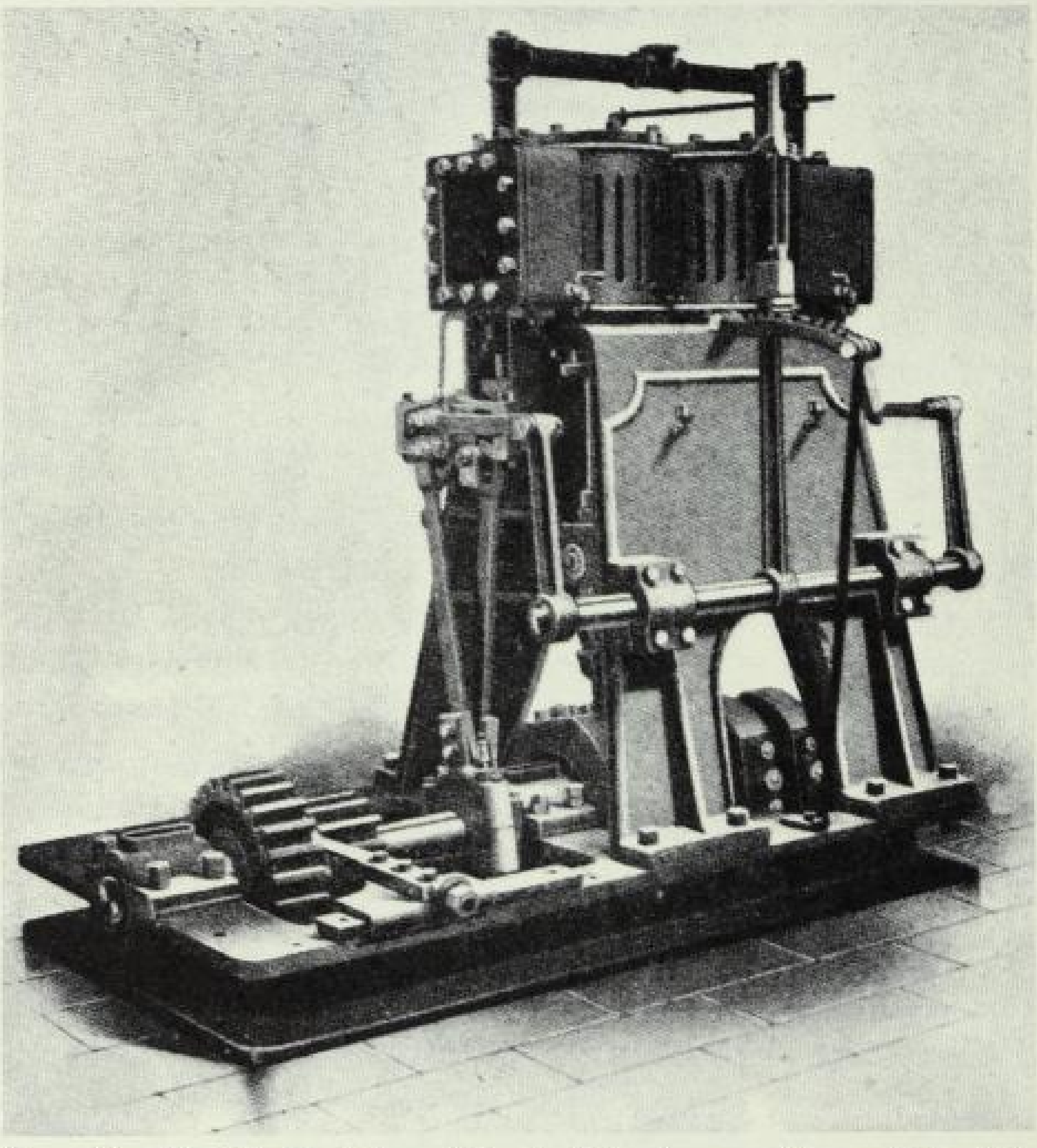


Fig. 11.—Double High Speed Vertical Engine, used in upright style, Climax Locomotive.

with a corresponding pinion on the transmission shaft. The gears are located alternately to the right and left of the transmission shaft, as shown in Fig. 12. Special attention has been given to the springing of the bogies so as to overcome difficulties which may be caused by irregularities in the permanent way. There are springs under the ends of the bolster as well as the usual springing of the axles.

The transmission system is not designed for high speeds

The gear ratio for freight service allows a maximum speed of 12 miles (19 km.) per hour. A ratio of 2 : 1 is used for locomotives intended for passenger service, which permits a maximum speed of 20 miles (32 km.) per hour.

FRAME.—The main frame carries the boiler and the cab, with the fuel bunker and water tank at the rear. It is secured at its ends to the two bogies.

FIREBOX.—This can descend freely between the bogies, but very deep fireboxes are not needed in this type of locomotive.

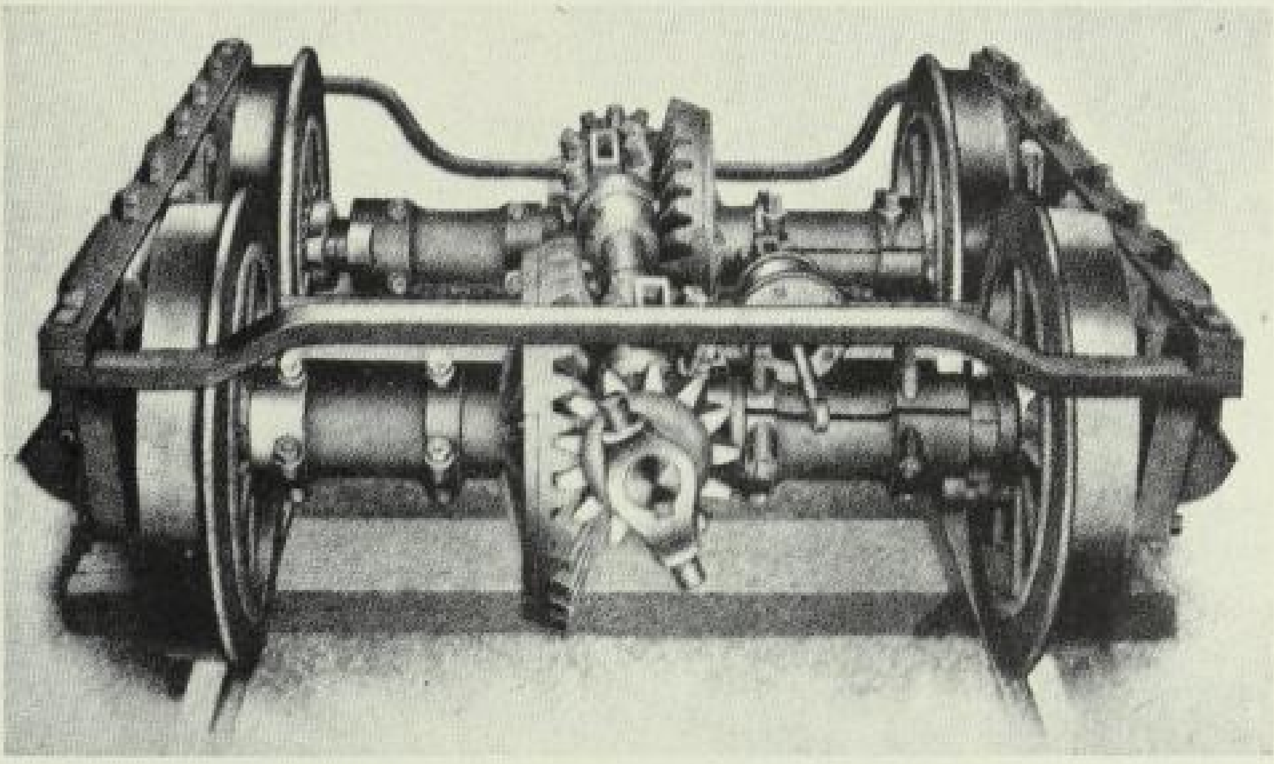


FIG. 12.—End View of Truck with Bolster removed, showing Gears, Climax Locomotive.

VALVE GEAR.—Walschaert valve gear is used on locomotives weighing 45 tons and more.

TYPES OF CLIMAX LOCOMOTIVES

There are two types of *Climax* locomotives, one with vertical, and the other with an inclined horizontal engine.

Type A.—Climax Locomotives with Vertical Engines (Upright Type). FIG. 11

This type is used for the smaller locomotives, up to 20 tons.

The engine is of the two-cylinder vertical double acting type and drives the transmission shaft through a two-speed gear. The engine is located behind the boiler, which is of the wagon-top type.

TABLE 5.—PRINCIPAL DIMENSIONS OF CLIMAX LOCOMOTIVES.

Type No. of Bogies Railway		4 + 4 2 Nome Arctic Ry.	4 + 4 2 Licking River R.R.	4 + 4 2 N. W. Branch Eldorado R.R., Col.	4 + 4 2 Yeon and Pelton R.R. (Oregon).	4 + 4 2 Northern Pacific Victoria Co.	4 + 4 + 4 3 Caspear, S. Fork and Eastern R.R.	4 + 4 + 4 3
Cylinders, diameter	ins.	7¾	9⅛	12¾	12⅞	12⅞	15	16½
,, stroke	,,	11	12¼	14¼	14¼	16¼	16¼	18⅛
Boiler pressure	lbs./sq. in.	160	160	160	172	172	172	200
Wheels, diameter		2′ 5¼″	2′ 4″	2′ 7¼″	2′ 7¼″	2′ 7¼″	2′ 7¼″	3′ 0¼″
Wheelbase, bogie		2′ 3¼″	3′ 8¼″	4′ 0⅛″	4′ 0⅛″	4′ 3¼″	4′ 3¼″	4′ 7¼″
,, total		19′ 0″	20′ 4″	26′ 0″	26′ 7″	26′ 11″	42′ 4″	44′ 3″
Overall length		29′ 8″	26′ 11″	32′ 4″	33′ 6″	34′ 6″	46′ 2″	54′ 10″
,, height		10′ 10″	11′ 3″	12′ 3″	12′ 0″	13′ 6″	13′ 9″	14′ 2″
Water capacity	cub. ft.	67	81	159	187	201	350	537
Coal capacity	tons-cwt.	1–0	1–0	1–10	1–19	2–9	4–18	5–7
Wood capacity	cub. ft.	32	64	95	110	127	138	148
Weight, empty	tons-cwt.	17–16	16–17	28–16	34–12	39–12	48–10	—
,, in service	,,	17–16	17–16	31–12	40–11	44–10	58–8	90–0
Loads drawn :								
On level		970	880	1,580	2,030	2,260	2,940	4,840
2 per cent. grade		142	130	230	300	330	428	810
4 per cent. grade		59	63	110	146	158	197	346
6 per cent. grade		33	34	67	86	92	122	210
8 per cent. grade		23	22	45	56	62	80	135
10 per cent. grade		17	17	30	38	42	50	90

The data as to loads drawn are those furnished by the builders.

The transmission shaft is provided with universal joints.

These locomotives can be used on wooden rails if required.

Type B.—Climax Locomotives with Inclined Cylinders (Horizontal Type)

This type is used for all the larger locomotives, which reach 54 tons for those with two four-wheeled bogies, and 90 tons for those with three such bogies. It more closely resembles an ordinary locomotive, than the previous type.

BOILER.—The boiler is of the wagon-top type. The water level is sufficiently high to insure that the fire tubes are not uncovered on any gradient.

The steam dome is located at the centre of the boiler so

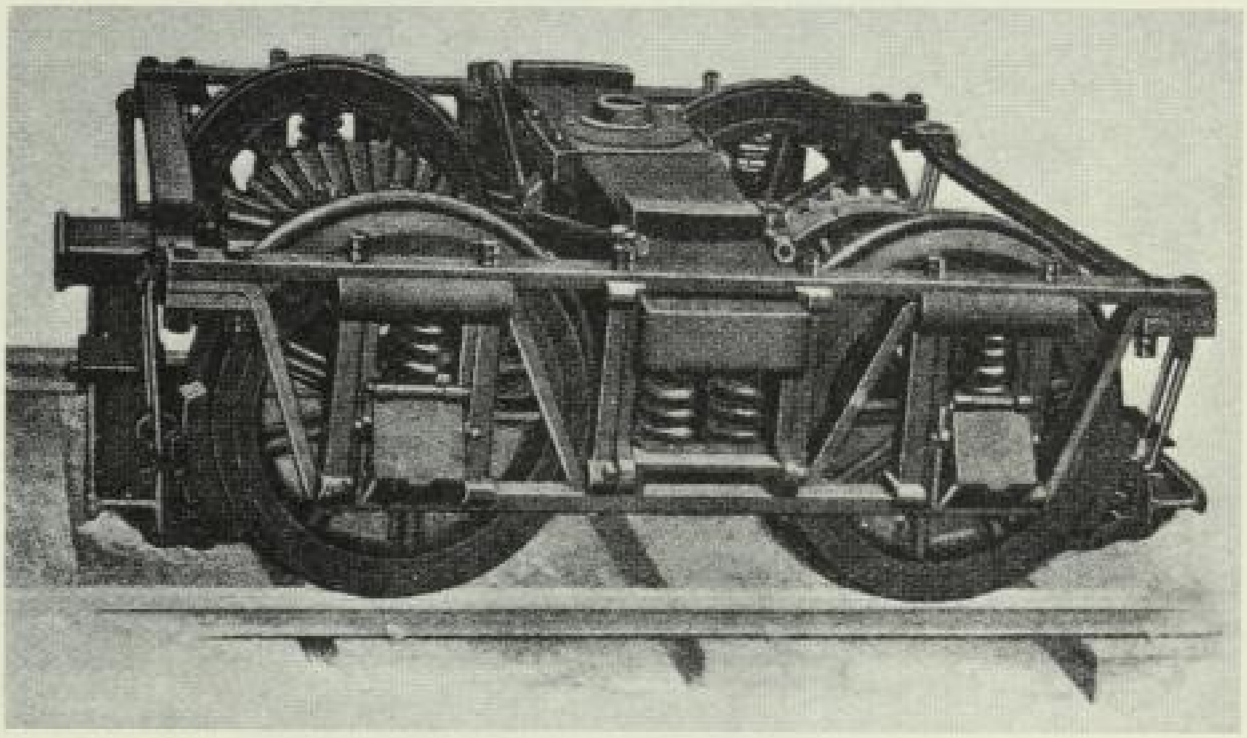


FIG. 12A.—Side View of Geared Truck, Climax Locomotive.

that a supply of dry steam is given whether the locomotive is running in forward or reverse gear.

STEAM PIPING.—The live steam pipes leading from the dome to the cylinders have universal joints and pass through the smoke-box saddle. The exhaust pipes have similar joints.

Utilisation of Climax Locomotives

Like the *Shay* locomotives, the *Climax* are much used for logging railways, as also for other services where the gradients are severe, the curves sharp and the permanent way inferior.

Class A.—Climax Locomotives with Two Motor Trucks (4 + 4)

This is the most familiar type, and is built to a series of standard designs ranging from 20 to 60 (short) tons. They are used on the following railways :—

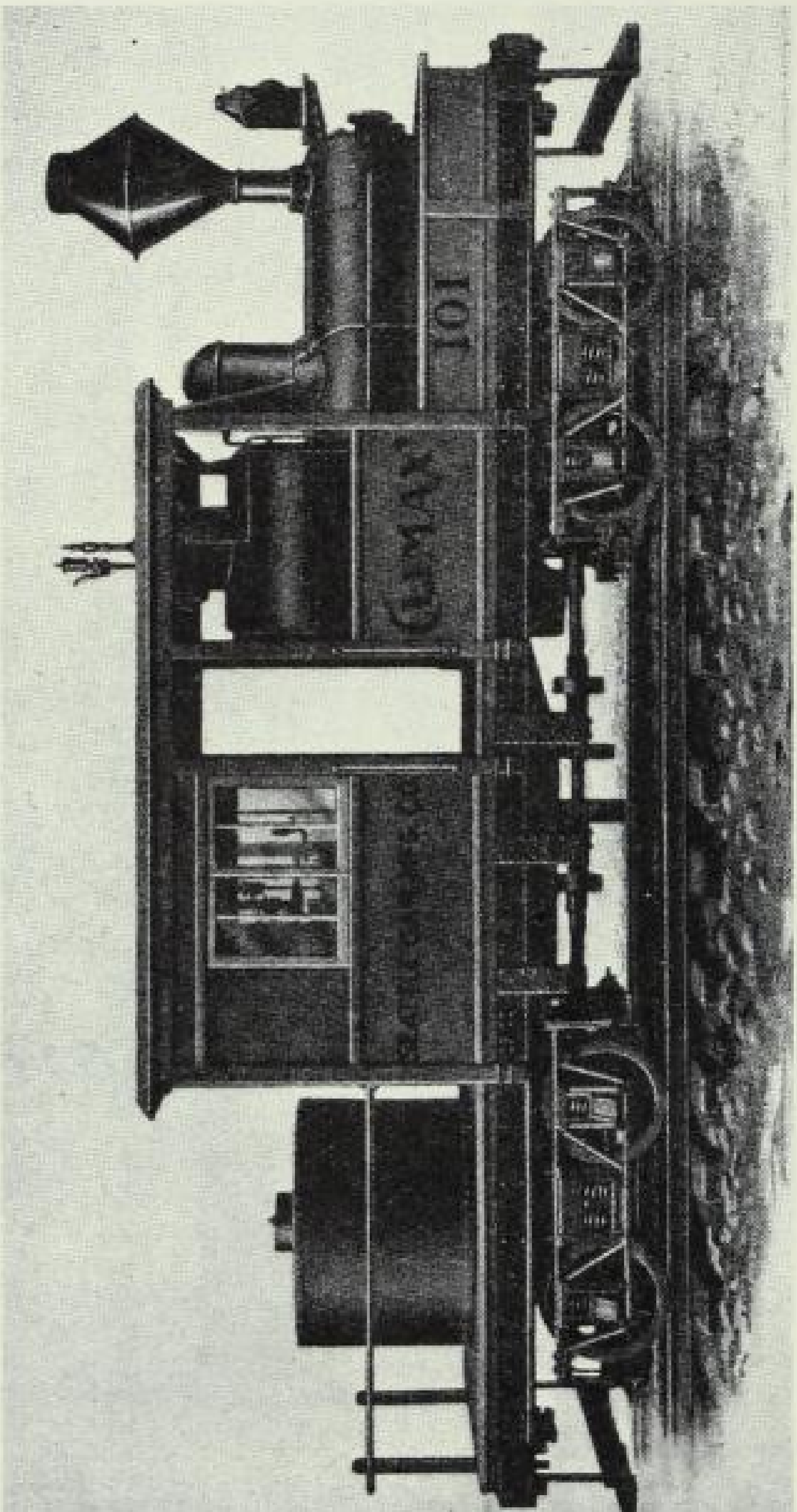


FIG. 13.—4 + 4 Climax Geared Locomotive, Seattle Car Manufacturing Co.

THE NOME ARCTIC RY. (Alaska).—3 ft. gauge. The gradients are as steep as 12 per cent.

THE LICKING VALLEY R.R. (Kentucky).—This railway has some 17-ton *Climaxes*. The maximum grade is 8 per cent.

THE ELDORADO R.R. uses *Climaxes* on grades of 10 per cent. (uncompensated) with curves of 157 ft. (48 m.) radius.

The Columbia and Nehalem Valley R.R., has some 32-ton *Climax* locomotives which run on sections with 8 per cent. grades, and curves of 157 ft. (48 m.) radius.

The Williamsport and North Branch R.R. is a tourist line,

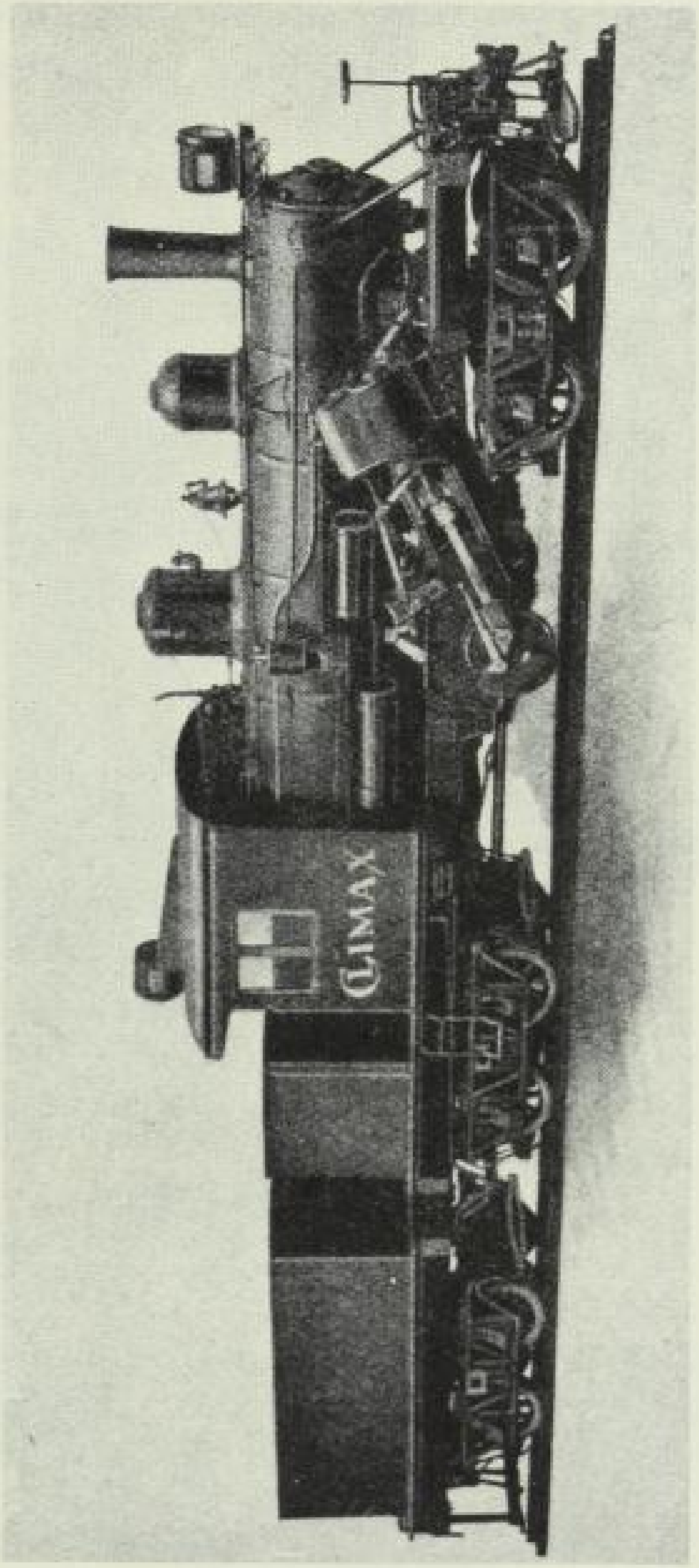


Fig. 14.—4 + 4 + 4 Climax Geared Locomotive.

running from Sonestown to Eagle's Mere Lake (Pennsylvania). It has 4 per cent. grades and curves with a minimum radius of 140 ft. (43 m.). *Climax* locomotives with 2 : 1 gear ratio have handled the passenger traffic since 1904.

The White Deer and Loganton Ry. is another tourist line running from Sunbury. It has used *Climax* locomotives for its passenger trains since 1908.

Class B.—Climax Locomotives with Three Motor Trucks (4 + 4 + 4). Fig. 14

This type is built to a series of standard designs of 70, 80, 90 and 100 (short) tons (67 tons 14 cwt. to 89 tons 6 cwt.).

The Jerome Ry. (Arizona), a mineral line, uses the most powerful *Climax* locomotives yet built, which weigh 90 (short) tons (80 tons 7 cwt.).

GROUP III.—BALDWIN GEARED LOCOMOTIVES

General Characteristics

The increasing use of geared locomotives has caused some of the great locomotive works to undertake their construction.

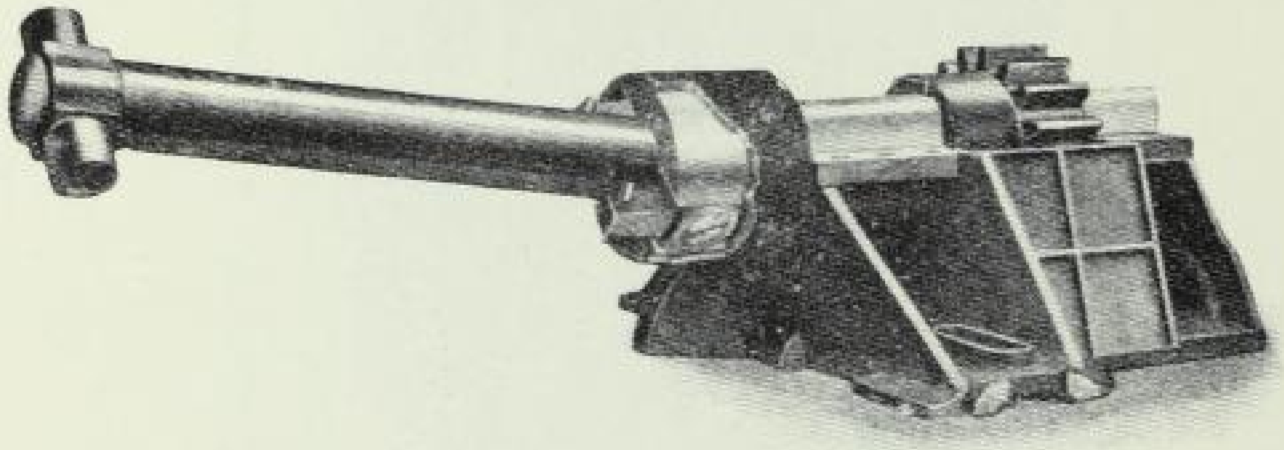


Fig. 15.—Longitudinal Shaft showing Universal Joint, Baldwin Geared Locomotive.

Thus the Baldwin Works have built some geared locomotives to a design which approximates, more closely than other designs, to the normal locomotive. Like the above examples, the Baldwin products have two four-wheeled bogies and all axles are driven ; but this branch of their output has since been abandoned.

Cylinders.—These occupy the usual position (as in the larger *Climax* type) and are inclined. They have Hackworth valve gear.

Transmission.—The cylinders drive a countershaft placed transversely under the waist of the boiler. This countershaft is bevel geared to two longitudinal shafts, one of which actuates the leading trucks wheels and the other the rear truck; both are provided with universal joints; when a third truck is used, power is transmitted to it through a third longitudinal shaft.

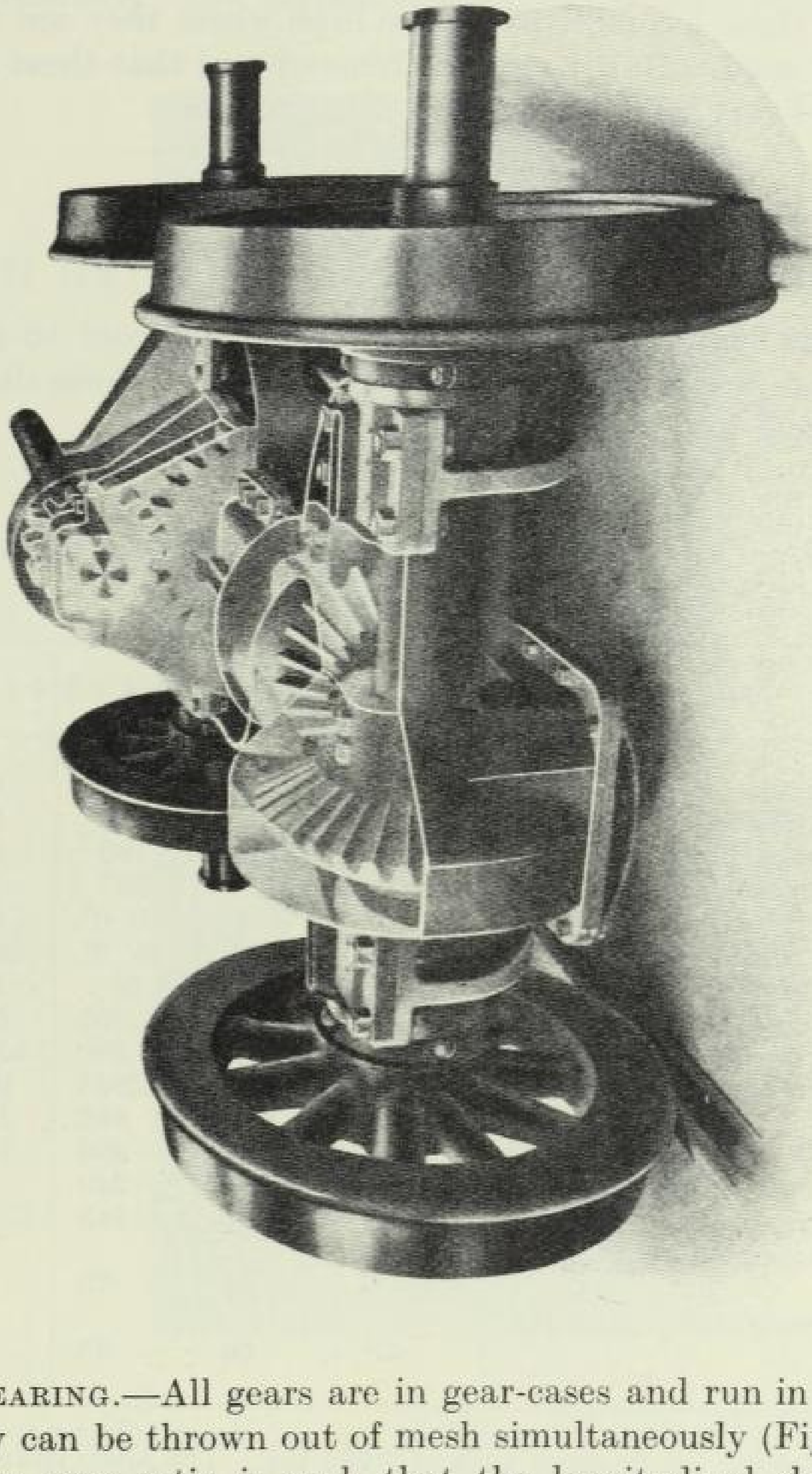


FIG. 16.—Truck with Gear and Gear Housing in Place, Baldwin Geared Locomotive.

GEARING.—All gears are in gear-cases and run in lubricant. They can be thrown out of mesh simultaneously (Fig. 16).

The gear ratio is such that the longitudinal shafts make two and a half revolutions for each revolution of a wheel.

This gives a very even turning moment and a steady drawbar pull. There are about ten exhausts for every wheel revolution, which should result in fuel economy.

TRUCKS.—These are of the equalised pedestal type; the weight is carried on elliptic springs.

TRAIN LOADS.—There is nothing remarkable about the loads drawn by these locomotives on the lines where they are most frequently used. But it must be remembered that these lines are often of very weak and inferior construction.

Utilisation of Baldwin Geared Locomotives

Locomotives with Two Motor Trucks (4 + 4). FIG. 17

These are built to standard designs ranging from 10 to 60 (short) tons (8 tons 18 cwt. to 53 tons 12 cwt.). Some dimensions of these locomotives will be found in Table 6.

TABLE 6.—PRINCIPAL DIMENSIONS OF BALDWIN GEARED LOCOMOTIVES

Type.	4 + 4	4 + 4	4+4+4	4+4+4
Cylinders, diameter	9″	12″	12″	18″
,, stroke	14″	16″	14″	18″
Boiler pressure, lbs. per sq. in.	180	180	180	180
Wheels, diameter	30″	36″	30″	42″
Wheelbase, rigid	5′ 0″	5′ 6″	5′ 0″	6′ 4″
,, total	23′ 6″	28′ 0″	38′ 0″	52′ 6″
Weight in service, short tons	30	60	60	125
Water capacity, U.S. galls.	800	1,600	2,000	6,000
Tractive force, lbs.	13,350	27,000	26,500	55,800
Loads drawn (short tons) level	1,470	2,980	2,935	6,170
,, ,, 1% grade	415	905	885	1,870
,, ,, 2% ,,	245	500	490	1,035
,, ,, 4% ,,	120	245	240	510
,, ,, 6% ,,	70	150	145	310
Minimum radius of curvature, ft.	70	75	70	90
Minimum weight of rail, lbs. per yard	30	60	35	70

N.B.—Weights are in short tons of 2,000 lbs. The loads drawn are calculated on a resistance to traction due to rolling friction of 8·7 lbs. per ton.

Fig. 17 illustrates one of these locomotives which was in use at the Baldwin Works at Eddystone.

Locomotives with Three Motor Trucks (4 + 4 + 4)

In this type there are two trucks behind the transverse countershaft. The motion is transmitted from the second to

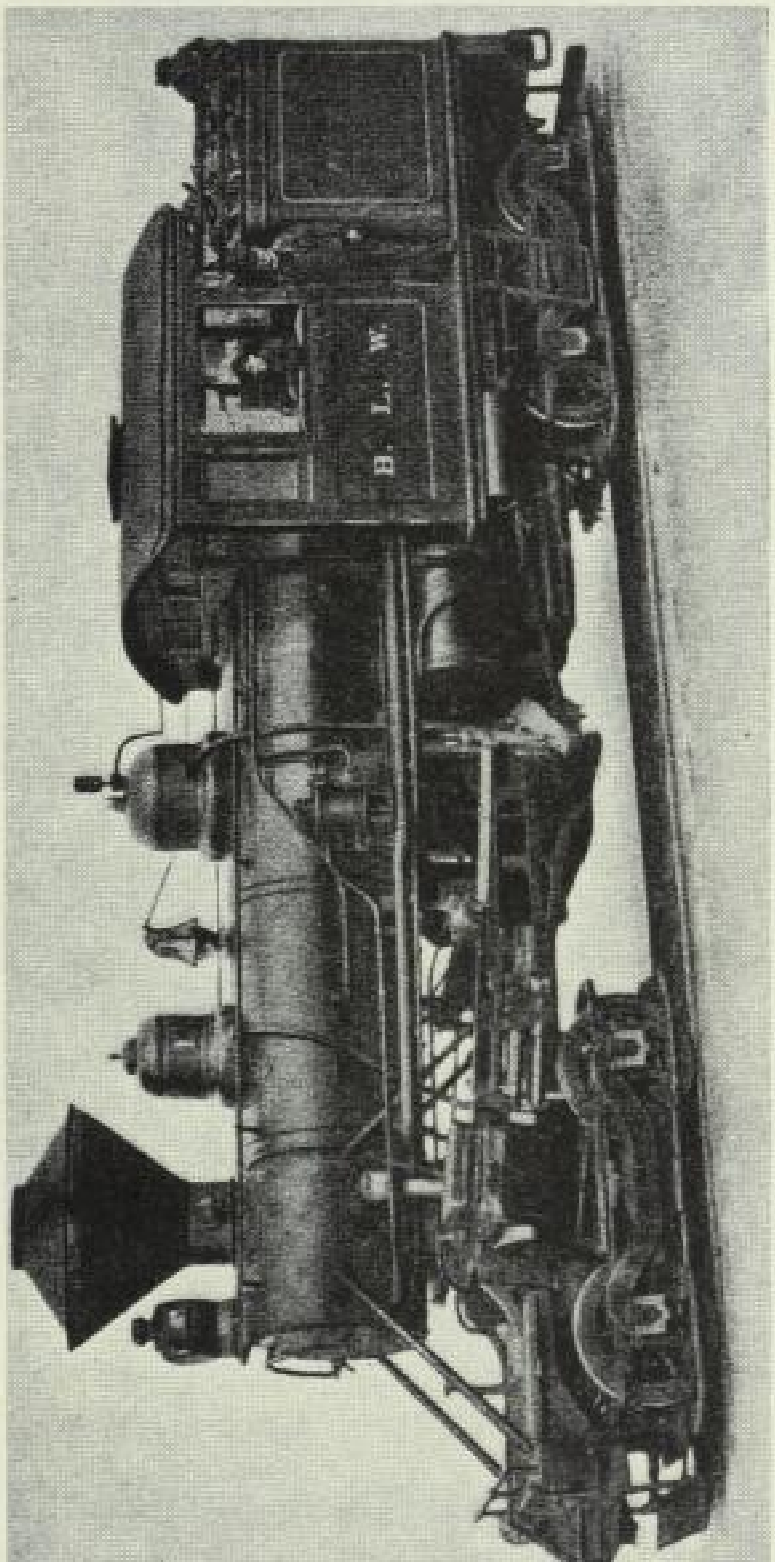


FIG. 17.—Eight-wheel (4 + 4) Baldwin Geared Locomotive.

the rearmost truck by an additional longitudinal shaft, provided like the others with universal joints. An example of this type is shown in Fig. 15.

The rearmost truck supports the water tank and coal bunker. In order to equalise the load taken by the various axles, the

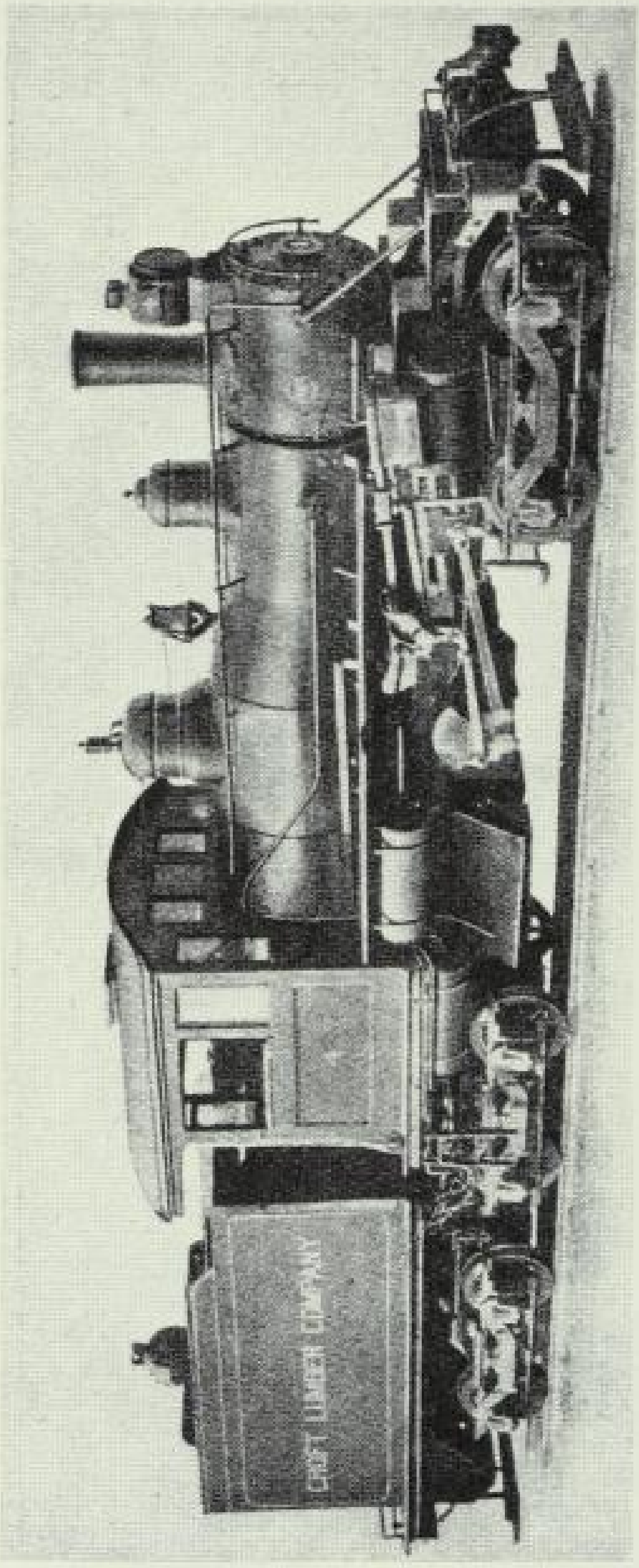


FIG. 18.—Twelve-wheel (4 + 4 + 4) Baldwin Geared Locomotive for the Croft Lumber Co.

third truck is articulated with the main frame in such a way that part of its load is transmitted to the second truck.

SECTION II. B.—LOCOMOTIVES WITH TRANSMISSION BY RODS AND GEARING IN COMBINATION

As in the case of the geared locomotives already described, an advantage of this arrangement is that the locomotive cylinders can be rigidly fixed to the main frame. Flexible steam and exhaust pipes are therefore not needed.

Locomotives of this type have been designed on two different methods. But the object of both designs is the same, namely, to transmit the motion by gearing to one axle of each bogie, the other axle of the bogie being driven therefrom by coupling rods.

In the first design, the locomotive has one- or two-cylinder engines which drive one or two countershafts, carrying gears which mesh with pinions on the driven axle of the bogies. This design has been often tried but has not given satisfaction in practice.

In the second design the crankshaft of the engine is coupled to a longitudinal shaft which is geared to the driven axles of the bogie. The *Heisler* locomotive is the best known example of this type.

TRANSMISSION BY RODS AND GEARING THROUGH A COUNTERSHAFT

Type 1.—The Neath Abbey Locomotive.—Standard gauge.

The earliest application of this method was in a locomotive built by the Neath Abbey Works, in 1839, for use on the private line of the Rhymney Forge (Wales).* It was indeed the adoption of a method which is as old as the locomotive itself,† but it was the first application of that method to an articulated locomotive.

Each truck had two axles coupled together by side rods. A countershaft placed between them was driven by two inclined cylinders at the front of the locomotive. A spur wheel on the countershaft geared with pinions on the adjacent axles of the two trucks.

This application was made ninety years ago. Until quite recently it has received very little subsequent development.

Type 2.—The Winterthur Geared Locomotive.—Gauge 0·90 m. (2 ft. 11½ ins.).

This was built, about 1885, for a line in the south of France.

* *Engineering*, November 15th, 1867.

† Headley's contemporary locomotive at the Wylam Colliery was generally similar to the Neath Abbey locomotive except that the two trucks were rigidly fixed to the frames. It was not, therefore, an articulated locomotive.

It had four axles in two groups and weighed 22 metric tons (21 tons 15 cwt.) in service. The countershaft was driven by a vertical engine.*

No further use was made of this system in Europe until quite recently, when it has been renewed by some German locomotive builders for the purpose of reducing the rigid wheelbase of locomotives with five coupled axles.

The three central axles or, sometimes, the four leading axles, are coupled by side rods in the ordinary way. The one or two other axles receive their motion through gearing.

As this is an example of partial rather than total articulation, these locomotives will be dealt with under the former head later in this book.

TRANSMISSION BY RODS AND GEARING WITH A LONGITUDINAL SHAFT

Our classification requires us to deal with this system under a separate heading, although locomotives in this paragraph differ but little either in their design or use from the geared locomotives already described.

GROUP IV.—THE HEISLER GROUP OF GEARED LOCOMOTIVES

General Characteristics

Transmission.—These locomotives differ from the other geared types in that the transmission is effected both by gears and coupling bars. The wheels of each motor truck are connected by side rods in the usual manner. One axle only of each truck is actuated through bevel gears from the central transmission shaft, the other axle receiving its motion through the aforementioned side rods. This arrangement reduces the number of gears to half that in other designs without loss of flexibility (Fig. 19).

The axle to which the bevel gear is fixed is the outermost of each truck. The longitudinal transmission has therefore to pass above the other axle of the bogie. The shaft therefore runs

* See *Organ*, 1885, p. 4, pl. 1. This locomotive had a heating surface of 303 sq. ft. (30 sq. m.). The wheels were 2 ft. 11½ ins. (0·90 m.) diameter.

horizontally to a point above the inner axles and then inclines downward to the outer axles. Universal joints are provided between the various sections of the shaft. The arrangement is clearly shown in Figs. 21 and 23.

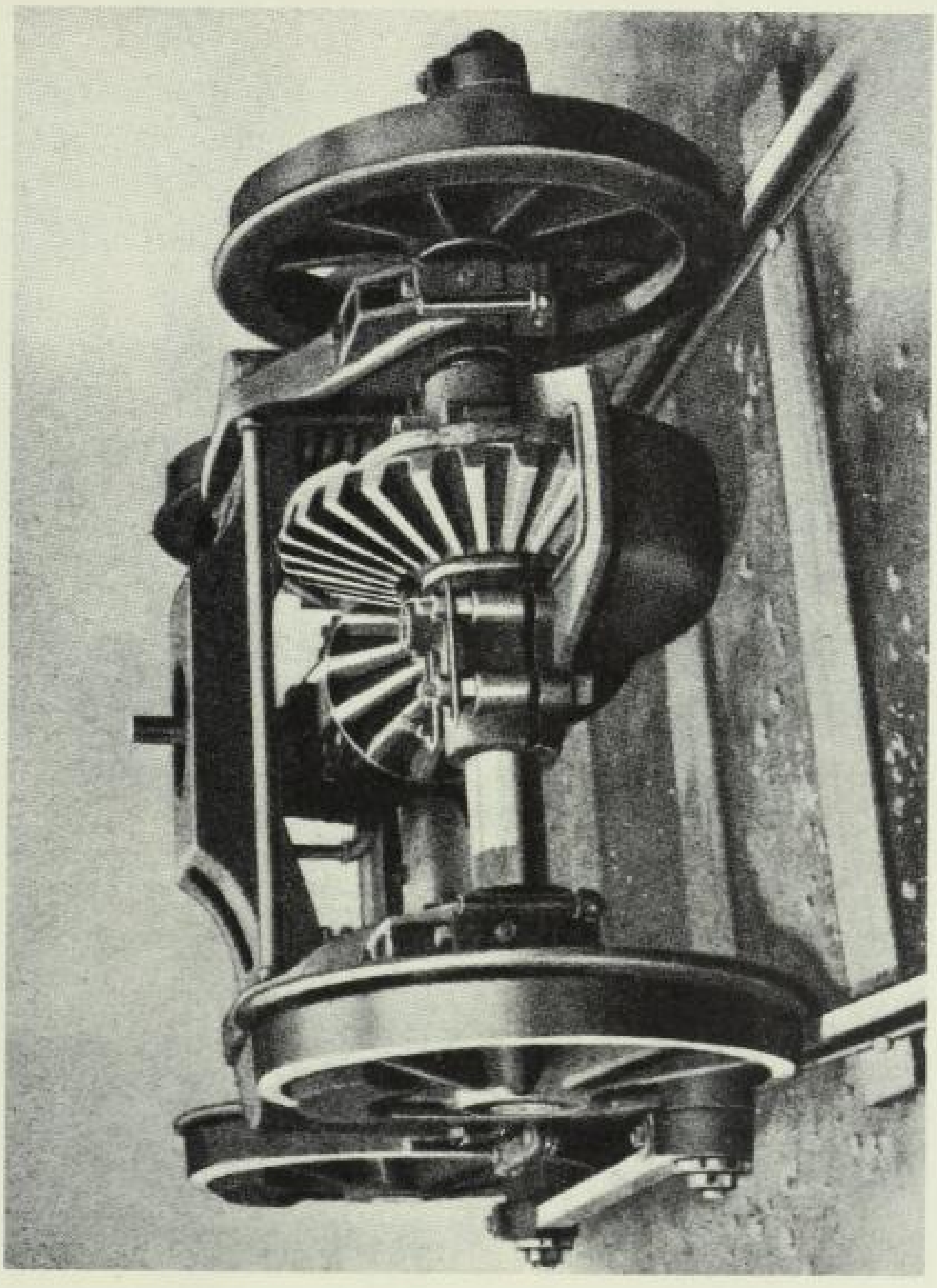


FIG. 19.—Heisler Geared Swivel Steel Truck with Gear Cover Removed.

FLEXIBILITY.—The longitudinal shaft is fitted with four pairs of universal couplings, two of which are telescopic.

GEARING.—The bevel gears are in gear-cases and run in oil. Those on the axles are located respectively to the right and left of the central transmission shaft (Fig. 19).

The engines (Figs. 20 and 21) are mounted on the main frame, clear of the boiler. They are set at an angle of 90 degrees to each other, both engines driving on to a single-throw crankshaft, the power being transmitted through the centre longitudinal driving shaft.

The valve gear is mounted on brackets bolted to the engine frames.

BOILER.—The boiler is of the extended wagon-top type.

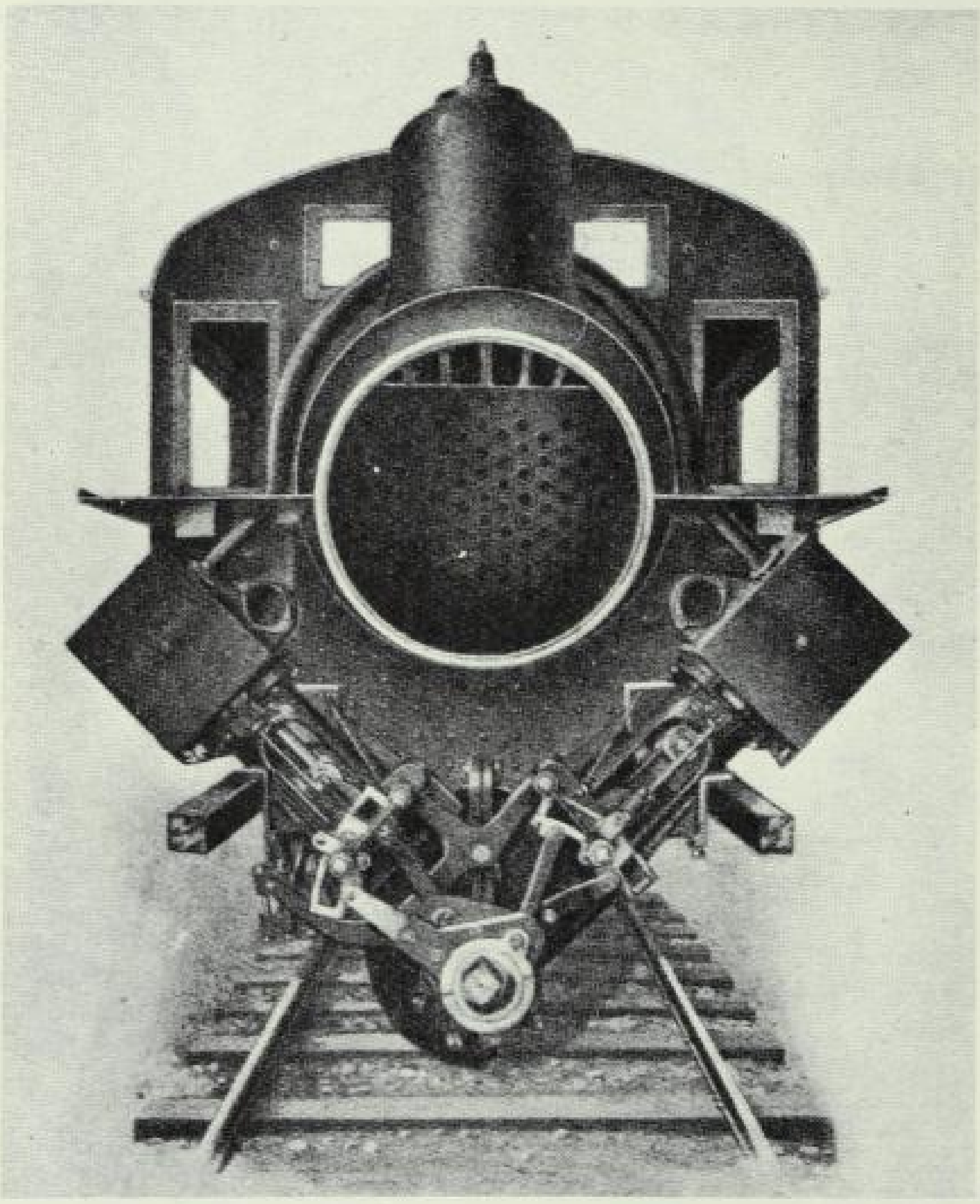


FIG. 20.—Heisler Geared Locomotive showing Construction and Location of Motor Engines on Main Frame, and which are free from the Boiler.

The dome is mounted towards its rear end. The steam pipes from the dome to the cylinders are carried outside the boiler barrel. The exhaust pipes between the cylinders and the smoke-box are also external.

MAIN FRAME.—Locomotives of 37 tons and over have diamond frames built up of square section bars.

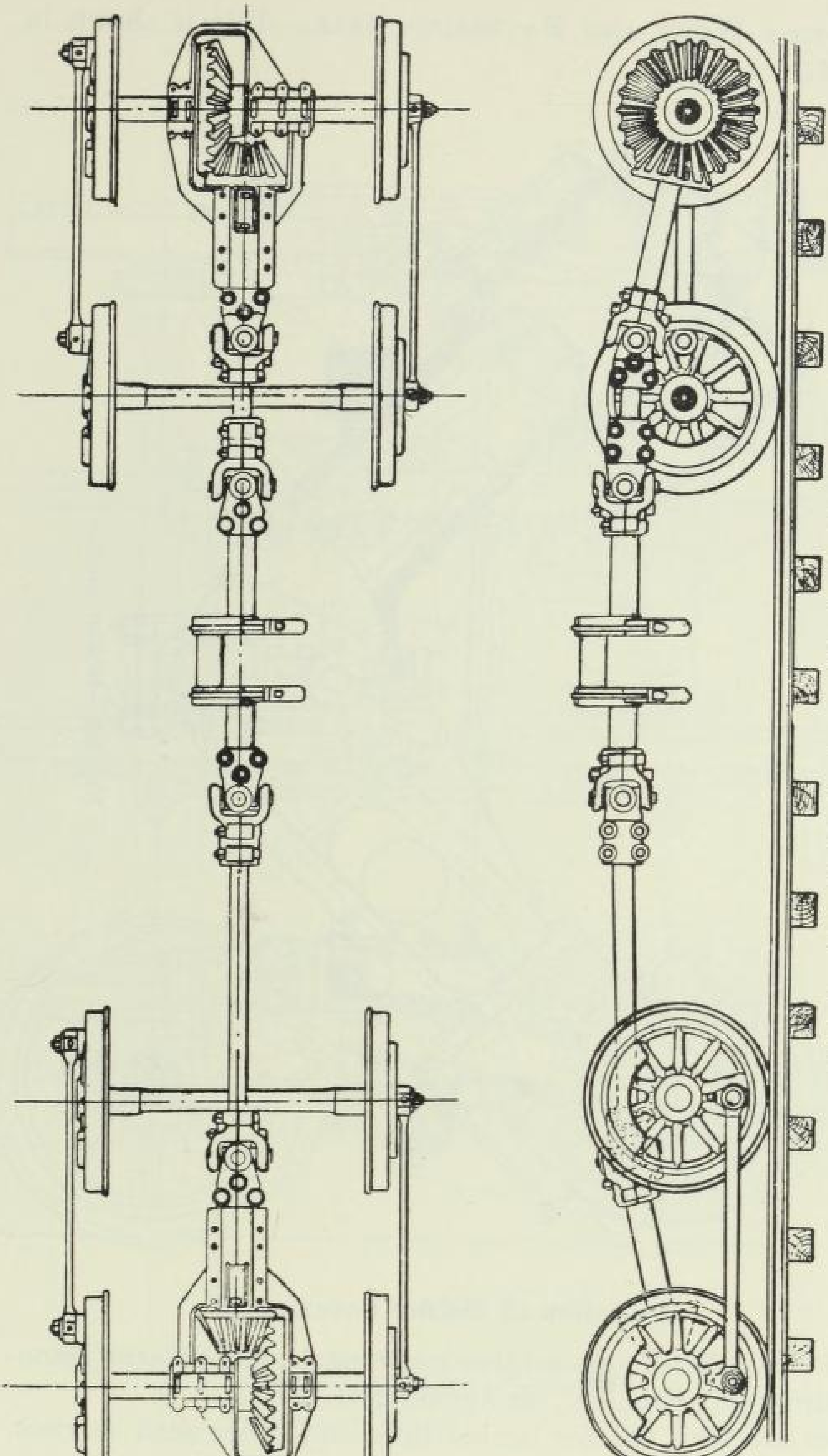


FIG. 21.—Main Shaft, Gearing and Trucks, Heisler Locomotive.

Motion Work and Reversing Gear.—This is shown in Fig. 21.

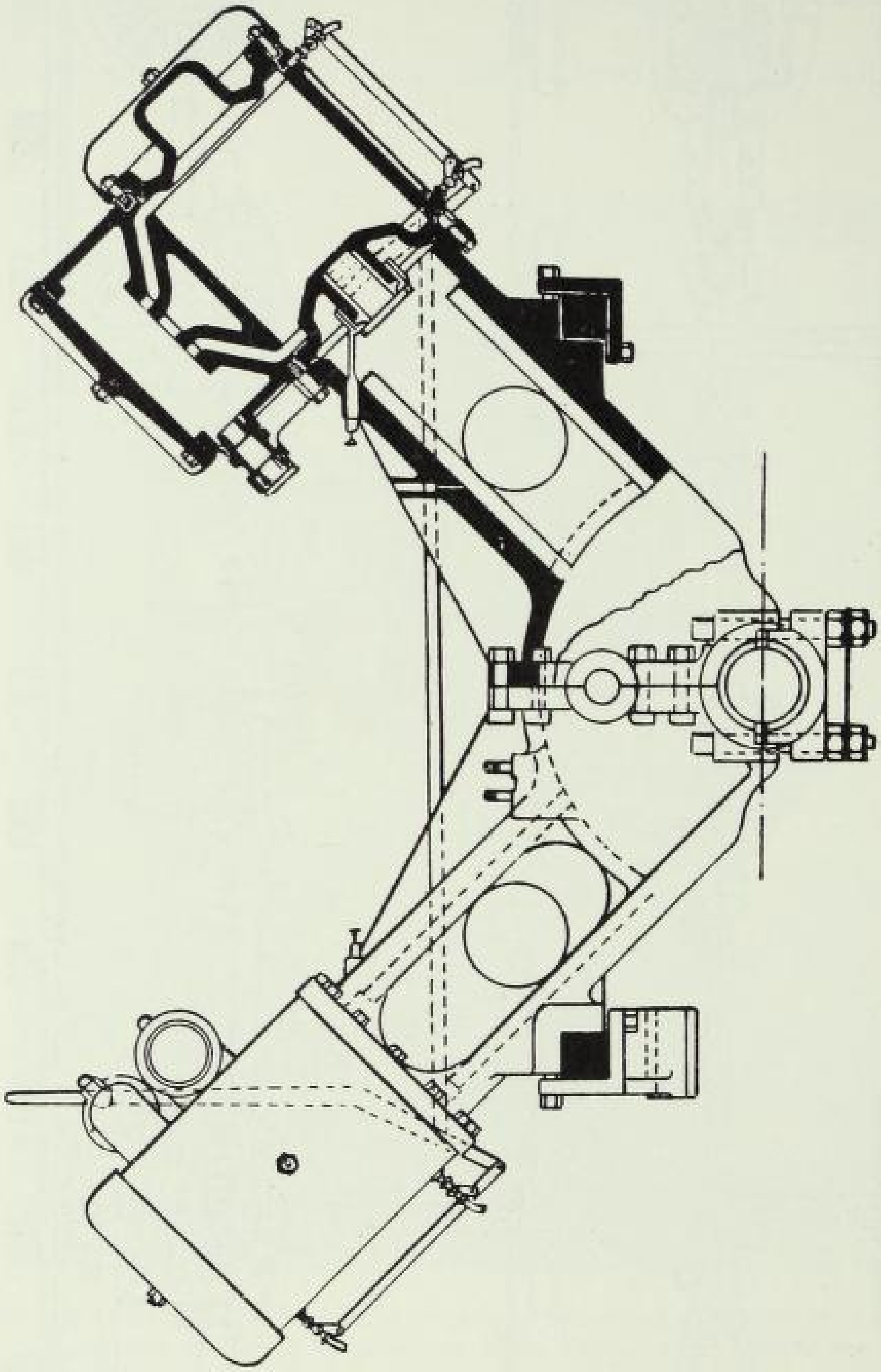


Fig. 22.—Heisler Engine.

Utilisation of Heisler Locomotives

The first *Heisler* locomotive was built by the Stearns Manufacturing Co., Erie, Pa., on August 20th, 1894.*

Besides their use for timber lines and other such services,

* It was shipped to Read and Campbell, Patzcuaro, Mexico.

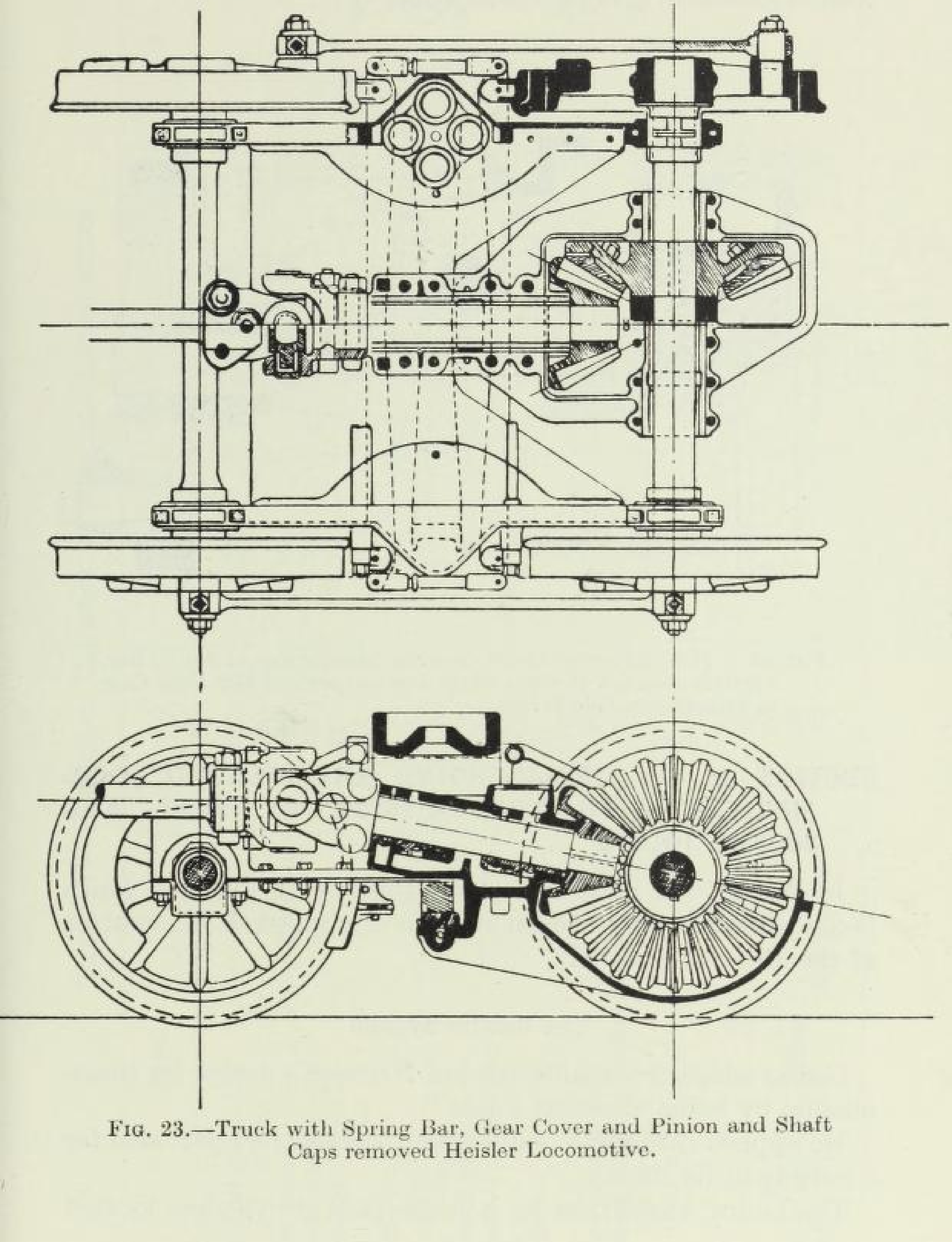


Fig. 23.—Truck with Spring Bar, Gear Cover and Pinion and Shaft Caps removed Heisler Locomotive.

these locomotives are in use on various branches of railway systems, notably on the Northern Pacific Ry.

The principal dimensions of the standard types of *Heisler* geared locomotives are given in Table 7.

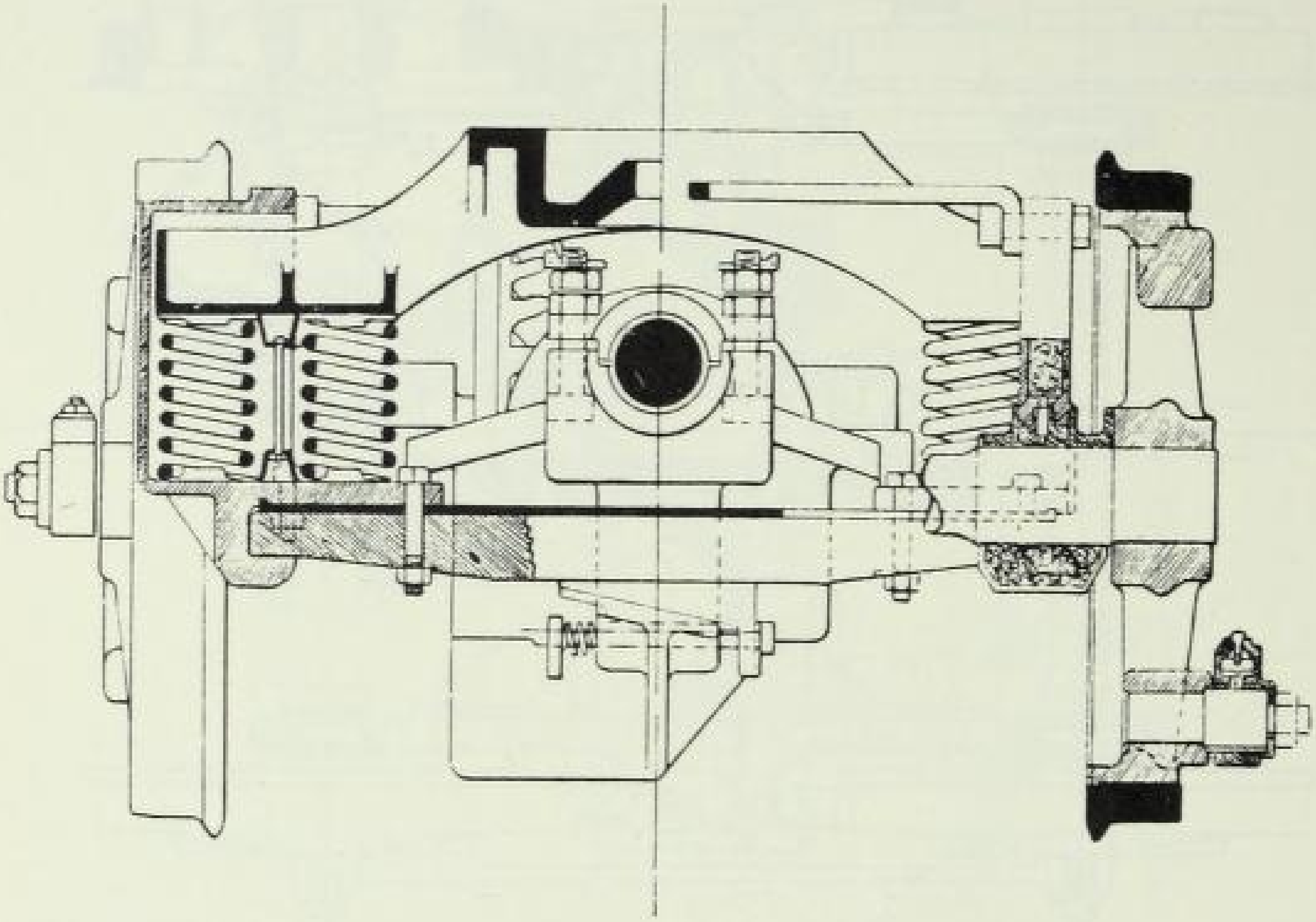


FIG. 24.— Heisler Geared Truck showing Construction of Spring Bar, Flexible-tongued Bottom Plate and Supporting Bar Gear Case as attached to Side Frames.

SECTION II. C.—SINGLE-ENGINE ARTICULATED LOCOMOTIVES WITH TRANSMISSION BY BALL AND SOCKET JOINTS

In this section there is but one type worth quoting, which is a modification of *Heywood's* design as applied to locomotives of the Duffield Bank Ry.

The Cowles System

Cowles adopted a modification of *Heywood's* design for transmission by ball and socket joints.*

He applied it to some double-bogie locomotives provided for a railway in Kentucky.

The motor was driven by a single pair of cylinders located

* See the *Engineering News*, February 9th, 1893, pp. 129 and 130.

TABLE 7.—PRINCIPAL DIMENSIONS HEISLER LOCOMOTIVES

Type.		4 + 4	4 + 4	4 + 4	4 + 4	4 + 4 + 4
Cylinders, diameter		11″	12½″	14″	15½″	17″
,, stroke		10″	12″	12″	14″	15″
Boiler pressure	lbs. per sq. in.	160	160	180	180	200
Wheels, diameter		30″	30″	33″	38″	38″
Wheelbase, rigid		44″	44″	56″	61″	61″
,, total		20′	21′ 4″	25′	27′ 1″	40′ 3″
Overall height		10′ 3″	10′ 10″	11′	11′ 10″	12′ 6″
,, width		7′ 11″	8′ 11″	9′ 5″	9′ 11″	10′ 3″
,, length		28′ 8″	30′ 4″	35′ 5″	36′ 6″	48′ 1½″
Tractive effort	lbs.	11,290	15,230	19,350	24,160	31,940
Water	U.S. galls.	750	1,075	1,375	1,800	3,000
Coal	lbs.	2,700	4,000	5,000	7,300	9,350
Wood	cords	3¼	1½	1½	2	2½
Oil	U.S. galls.	310	450	500	716	1,280
Weight in service	lbs.	55,000	70,000	92,000	121,000	177,000
Hauling capacity in short tons:						
On level		1,387	1,871	2,339	2,965	3,972
On 1 per cent. grade		379	511	655	807	1,070
2 ,, ,,		211	285	365	448	595
3 ,, ,,		142	192	245	300	399
5 ,, ,,		80	109	138	168	225
10 ,, ,,		30	41	51	61	82
Minimum curve, radius		50′	50′	80	85′	100′
Weight of rails	lbs. per yard	20	25	35	45	45

between the two trucks. The pistons were provided with tail rods so as to drive both sets of wheels simultaneously. Each bogie had three axles. The middle axle passed through a hollow sleeve and the middle pair of wheels were keyed to this

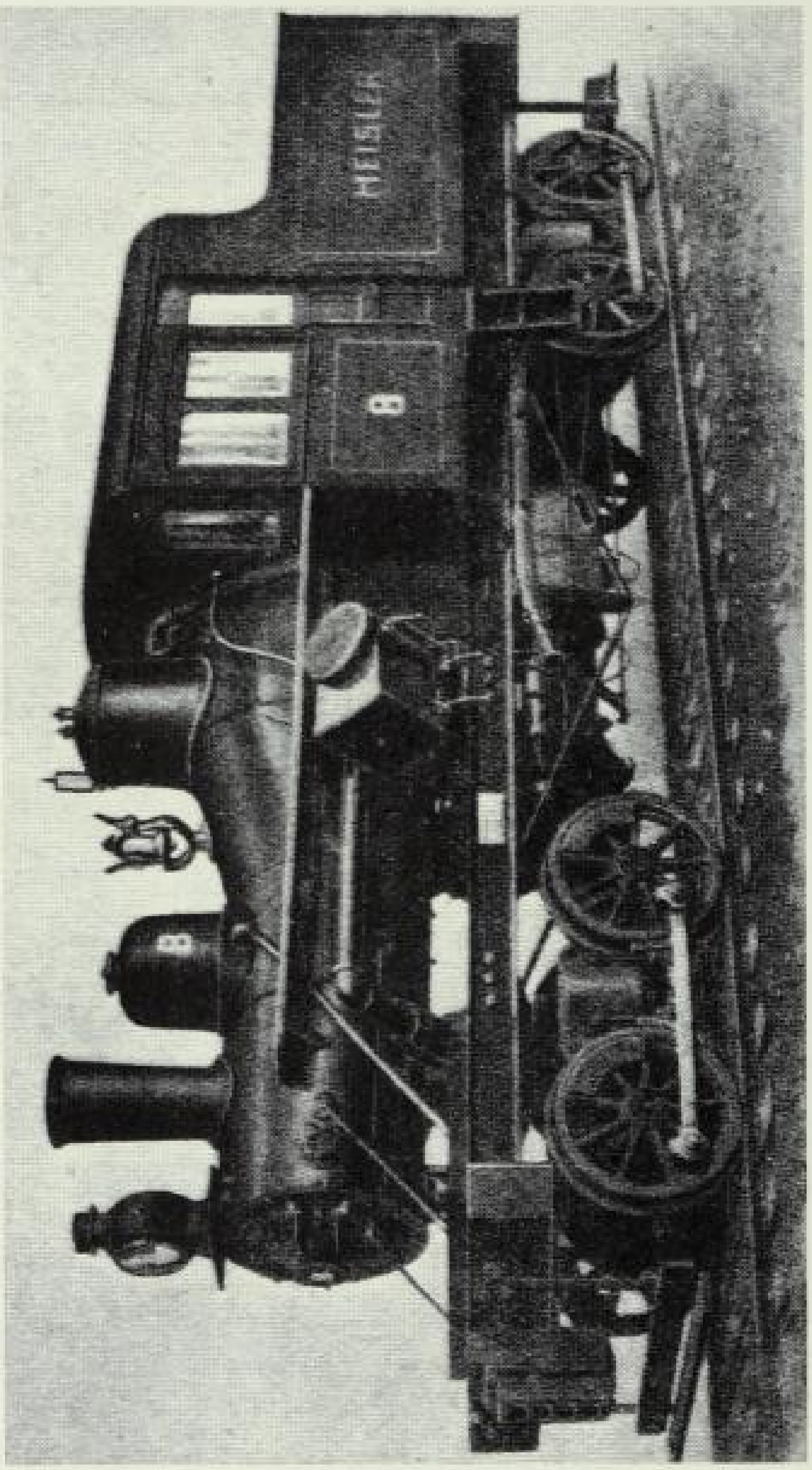


FIG. 25.—4 + 4 Heisler Locomotive showing Trussed I beam Frame Construction.

sleeve and not to the axle itself. Connection was made between this sleeve and the axles on either side of it by coupling bars. The sleeve was connected to the central axle, which lay within it, by a ball and socket joint located at the centre. The sleeve and the axle were, therefore, free to move relatively to one another.

This central axle had outside bearings. It had outside cranks and the brasses of the connecting rods had some lateral play on the crank pins.

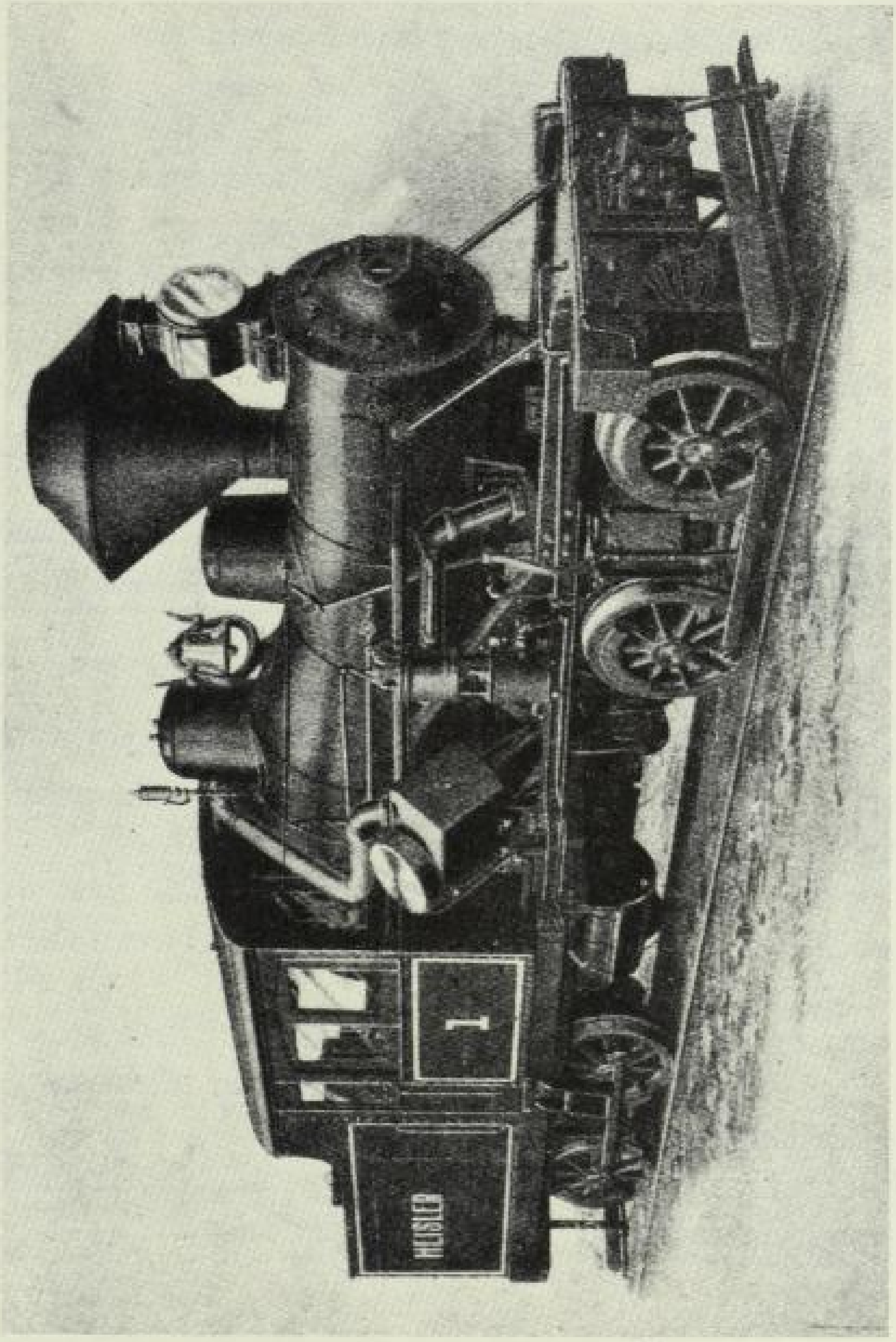


FIG. 26.—Heisler Geared Locomotive, showing Diamond Frame Construction and Diamond Stack.

No further examples of this type of locomotive have been built.

SECTION II. D.—SINGLE ENGINE ARTICULATED LOCOMOTIVES WITH TRANSMISSION BY RODS

Little enough has been realised in this connection and the only system worth quoting is due to Behne.

Behne's Patent

In 1860, Behne took out a patent in Hamburg, and in France (No. 26,978, November 8th, 1860) for a very curious locomotive of this class. This locomotive had two independent boilers, of which the smoke-boxes faced each other. The main frame was carried on two eight-wheeled bogies. The bunkers were at the outer ends of the frame. The water was carried in side tanks located near the ends of the frame (Fig. 27).

There were two vertical cylinders attached to the main frame at the centre of the locomotive. Each cylinder had two

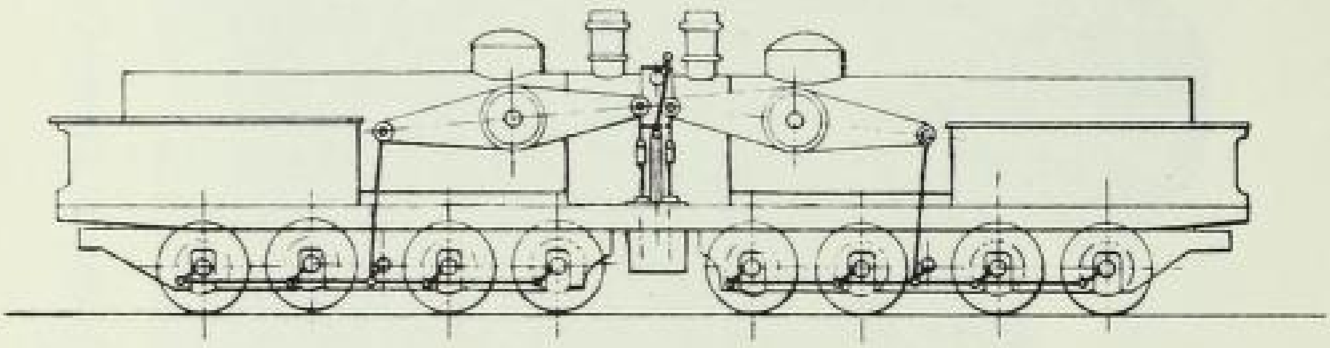


Fig. 27.—Behne Patent Articulated Locomotive (1860).

pistons working upwards and which were connected by a short rod which, in turn, bore a vertical rod to give action to an upper shaft which controlled the steam distribution.

The side rods were connected not only to the four axles of each truck but also to a countershaft located between the second and third axles.

This countershaft was driven by a vertical link attached to one end of a lever, the other end of which was connected to the piston rod of the vertical cylinder.

The locomotive was estimated to weigh about 100 tons. The design never received practical application.

PART III

ARTICULATED LOCOMOTIVES WITH TWO ENGINES AND TWO GROUPS OF DRIVING WHEELS

This is the most important group of articulated locomotives properly so called and contains several types which have been entirely successful and which survive until this day.

It is also the oldest group. The first example was the "Horatio Allen" locomotive, of 1832, but its success dates from the time of the Semmering Contest, at which both the "Seraing" and the "Wiener-Neustadt" locomotives appeared. These have been the ancestors of a numerous progeny.

We will examine them in the following order :—

(A) Articulated locomotives with transmission by gearing.

(B) Articulated locomotives with ball and socket transmission.

(C) Articulated locomotives with chain transmission.

(D) Articulated locomotives with transmission by connecting rods.

The two first have been unsuccessful; not so the latter, which comprises :—

Group I.—The *Meyer* locomotive and its modifications including the *Meyer-Kitson* ; also the *Golwé*.

Group II.—The *Fairlie* locomotive and its modifications ; also the *Péchot-Bourdon* and the *Johnstone* locomotives.

Group III.—The *Garratt* locomotive and its modifications ; also the *Union*.

Group IV.—The *du Bousquet* locomotive.

Locomotives with two engines, one of which is only used as an occasional auxiliary are examined elsewhere.

SECTION III. A.—ARTICULATED LOCOMOTIVES WITH TWO ENGINES AND TRANSMISSION BY GEARING

No types have been sufficiently successful either in design or in practice, to deserve a notice here.

SECTION III. B.—ARTICULATED LOCOMOTIVES WITH TWO ENGINES AND TRANSMISSION BY BALL AND SOCKETS

An articulated locomotive of this type has actually been built by Messrs. Krauss, of Munich. It embodied a number of novel features, some of which have reappeared more recently.

The Krauss System of Locomotive Articulation

This most interesting locomotive, which was built in 1889, is practically unknown. And yet, in view of subsequent

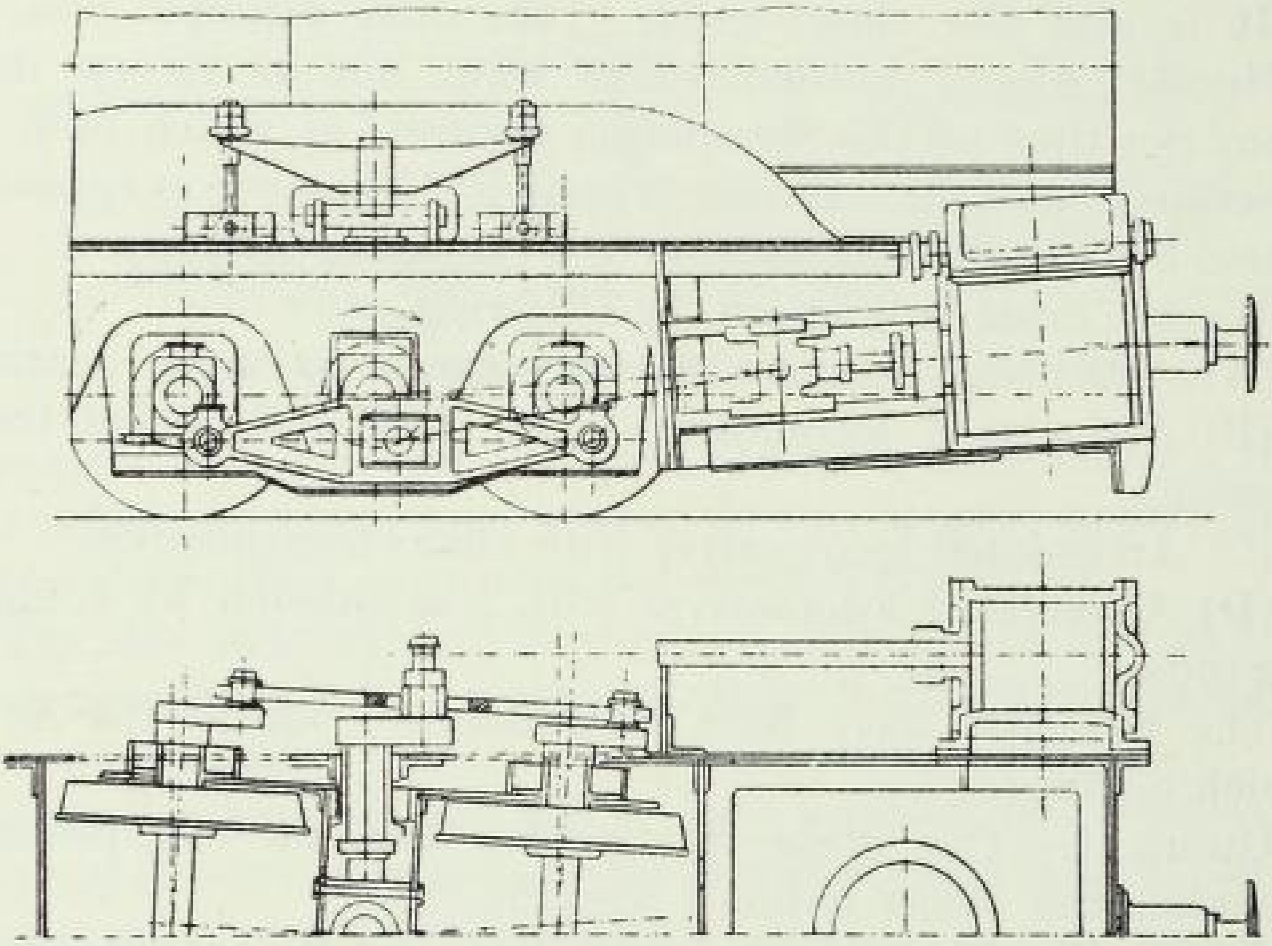


FIG. 28.—Krauss Articulated Locomotive.

developments, it presents many a point that deserves more than a cursory notice.

Through the courtesy of the builders, we are able to furnish some data concerning it. It was designed to meet exceptionally hard conditions. The gauge was 0·60 m. (1 ft. $11\frac{5}{8}$ ins.), the curves had a radius of 20 m. (66 ft.) only and the axle load was limited to 2·5 tonnes (2 tons 9 cwt.) per axle. The only other conditions were that particular care should be taken to provide against mishaps in case of derailment, and that the tractive effort should be as large as possible.

An entirely new type of articulated locomotive was therefore designed. The wheel arrangement was 0-6 + 6-0, each group of coupled wheels constituting a driven bogie.

It is also notable that these bogies were located in the manner since adopted in the *Garratt* locomotive, the boiler resting on their inner ends. This was done so that the builders could place the boiler at 1·05 m. (3 ft. 5⅜ ins.) above rail level, and yet have water tanks beneath, thus bringing the centre of gravity very low indeed.

The four cylinders were at the extremities of the locomotive, above the main frame to which they were fixed. They were inclined and drove the same crank-pin of a vertical connecting rod situated above the middle axle, which it drove by means of gearing.

This eliminated all articulated steam joints.

Fig. 28 shows an earlier design on the same principle.

TABLE 8.—PRINCIPAL DIMENSIONS OF THE KRAUSS ARTICULATED LOCOMOTIVE

Cylinders, diameter	0m.16	6¼″
,, stroke	0m.20	7⅞″
Gear ratio	1 : 2	1 : 2
Boiler pressure	12 kgm. per sq. cm.	171 lbs. per sq. in.
Heating surface	23 sq. m.	246 sq. ft.
Grate area	0·53 sq. m.	6·7 sq. ft.
Wheels, diameter	0m.58	1′ 10¾″
Wheelbase, rigid	2m.50	8′ 2½″
,, total	5m.85	19′ 2″
Distance between pivots	4m.55	14′ 11″
Water	2·1 cub. m.	453 galls.
Fuel	0·64 cub. m.	22·6 cub. ft.
Weight in service	14·6 metric tons	14 tons 8 cwt.
Overall, width	1m.90	6′ 3″
,, length	7m.32	24′ 0″

SECTION III. C.—LOCOMOTIVES WITH CHAIN TRANSMISSION

Since 1851, when the locomotive " Bavaria " achieved such poor success, transmission by chains has been abandoned for locomotives. It is therefore all the more noteworthy that owing, on the one hand, to technical improvements, and, on the other, to the variety of economical conditions that have to be provided for, locomotives with chain transmissions should have survived.

In this instance, their reappearance is due to the necessity of substituting mechanical for bovine traction on Peruvian 3 ft. gauge lines, situated in sugar-cane plantations. The track is laid without earthworks and consists of 18 lb. rails. The shortest radii of the curves are 20 and even 15 m. only (about 65 and 49 ft.). Locomotives operating under such strenuous conditions must therefore be exceptionally robust and simple and all machinery and delicate organs must be adequately protected.

The Schwartzkopff System

This system has been established to cope with these conditions. Mining locomotives with chain transmission had long

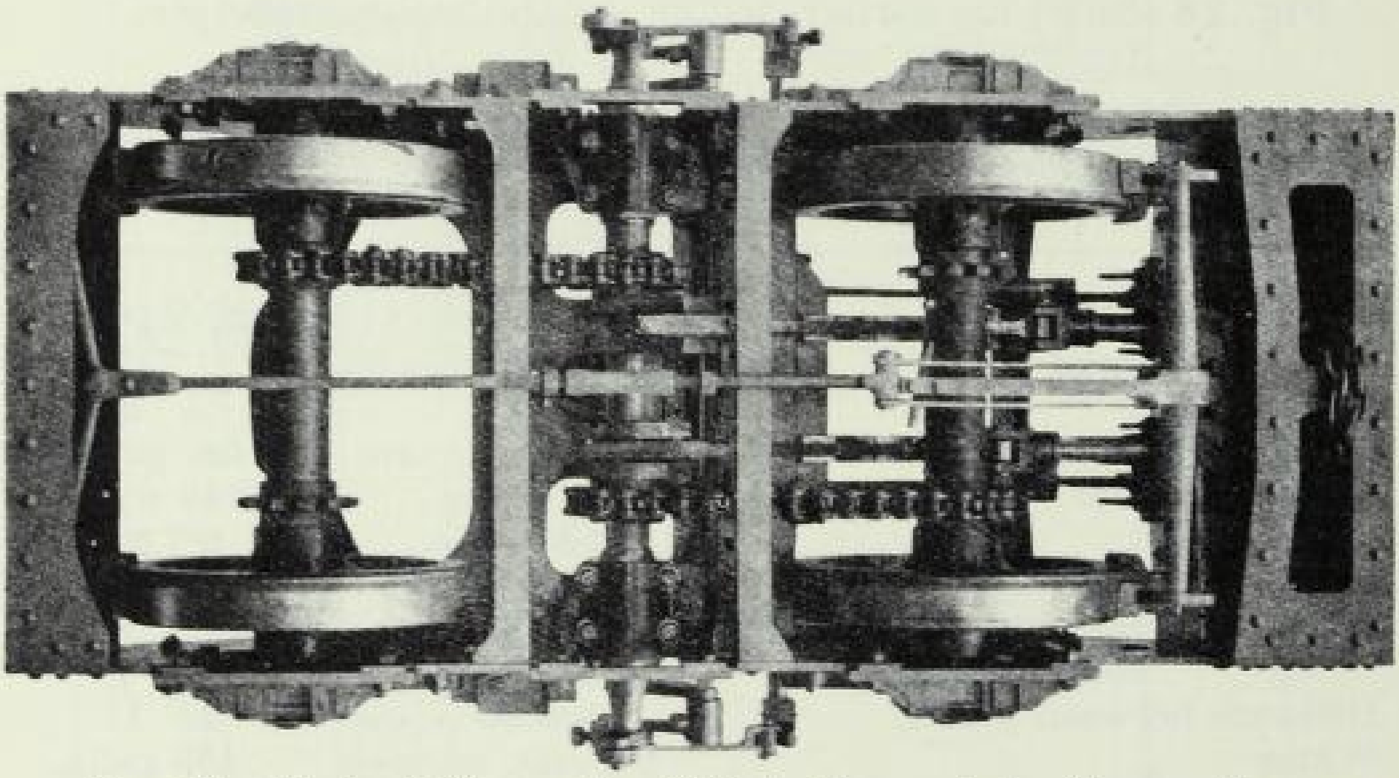


FIG. 29.—Bogie of Schwartzkopff Chain Transmission Locomotive.

been satisfactory, hence the idea of using the same method of transmission on locomotives for Peru (Figs. 29 and 30).

The locomotive consists of a main frame which carries the boiler, the cab, water and fuel, and of two steam bogies each provided with two cylinders whose pistons transmit the motion to a crank axle situated between the coupled axles. The coupling is effectuated by chains whose maintenance and replacement are easy even with unqualified labour. They last from nine to twelve months in practice.

The bogies have a very short wheelbase, 1·20 m. only (3 ft. 11¼ ins.), and the pivots are 3·50 to 4 m. apart (11 ft. 5⅝ ins. to 13 ft. 1½ ins.).

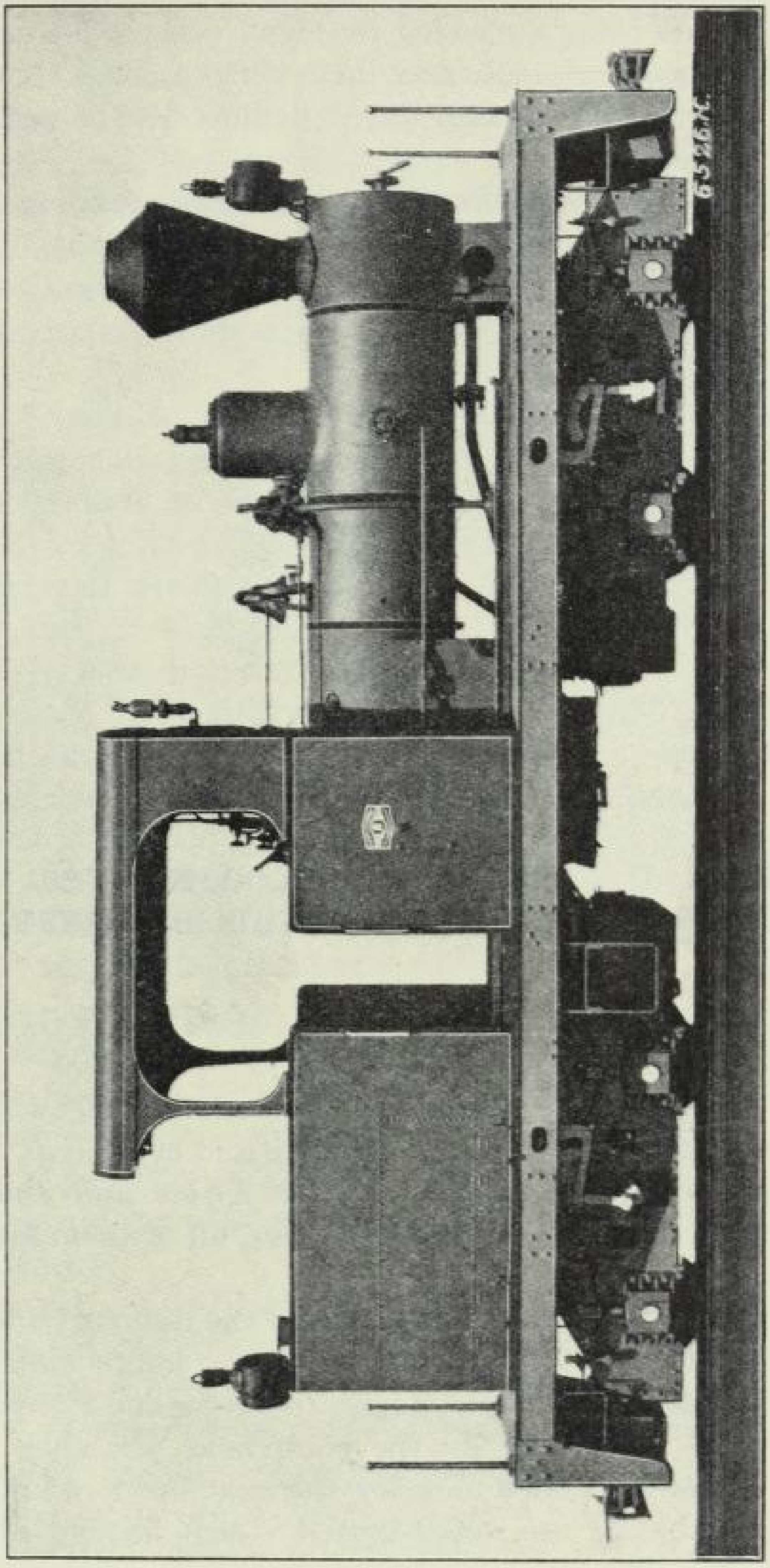


FIG. 30.—Chain Transmission Locomotive, Schwartzkopff System.

The centre of gravity has been kept low. The framework is robust and the wheels are outside the bogie frames.

The usual types produced by the builders * weigh 10 to 12 tons, the former being somewhat too light. These locomotives are hardly known abroad, and their performances should be followed with interest, as they have a definite field of usefulness.

TABLE 9.—PRINCIPAL DIMENSIONS OF SCHWARTZKOPFF CHAIN LOCOMOTIVES

Gauge		3′	2′ 3½″	1′ 11½″	1′ 11½″
Cylinders, diameter		6⅜″	6⅜″	6¾″	6¾″
,, stroke		$9\frac{1}{16}$″	$9\frac{1}{16}$″	$9\frac{1}{16}$″	$9\frac{1}{16}$″
Boiler, pressure	lb./sq. in.	142	170	170	170
Heating surface, firebox	sq. ft.	12·0	—	—	—
,, tubes	,,	87·0	—	—	—
,, total	,,	99·0	132·4	174·4	174·4
Grate area	,,	2·5	6·4	7·1	7·1
Wheels, diameter		35⅝″	35⅝″	35⅝″	35⅝″
Wheelbase, rigid		3′ 11¼″	3′ 11¼″	3′ 11¼″	3′ 11¼″
,, total		17′ 0⅜″	17′ 0⅜″	17′ 0⅜″	17′ 0⅜″
Water tanks	galls.	88	220	176	264
Fuel	tons-cwt.	0–7	0–13	1–3	1–3
Weight, empty	,,	8–11	10–12	9–16	9–16
,, in service	,,	9–16	12–15	11–16	12–6
Max. tractive force	,,	1–9	1–14	1–19	1–19

SECTION III D.—ARTICULATED LOCOMOTIVES WITH TWO ENGINES AND TRANSMISSION BY CONNECTING RODS

This is far the most important group—if we except the *Mallet* semi-articulated locomotives.

In all of them, the boiler, firebox and cab rest on two steam bogies, each of which has its own engine and cylinders.

With the exception of a few *Meyer-Kitson* and *Johnstone* locomotives which have separate tenders, all of them are tank locomotives.

Compounding is exceptional owing to the difficulty formerly experienced in keeping articulated steam joints sufficiently tight. In spite of this, some *Meyer*, *Johnstone* and *Fairlie* locomotives have been built on the compound principle. More recently it has been tried on a few *Garratts*, but it would seem more reasonable to use super-heated steam instead of compounding.

The cylinders were grouped in the centre of the locomotive,

* Messrs. Schwartzkopff & Co., Berlin.

facing each other in the early *Meyer* and the first *Garratt* locomotives. They are situated at the back end of each truck in the *Meyer-Kitson* early designs, in the *Sinnemahoning* and in the *Golwé*.

Finally, in more recent designs of the *Meyer-Kitson* locomotives, the cylinders are at the outer ends of the bogies, as in the *Johnstone*, the modified *Fairlies* and the *Garratts*.

The steam from the rear cylinders usually serves to heat the feed water and often exhausts up an auxiliary chimney at the rear.

The Krauss Locomotive Works were the first to spread out the bogies, thus providing easy access to the centre part of the locomotive and allowing the designers free scope in the provision of an efficient boiler and firebox. This feature was retained and developed in the *Garratt* locomotives, and other types, such as the North British modified *Fairlie* and the *Union-Garratts*, have embodied it since then. Reaction has taken place, as it always does, and the *Golwé* type features a shorter wheelbase.

Double boilers have only been used in connection with the *Fairlie* and *Péchot-Bourdon* types, and have in turn been ousted by two-boiler locomotives. Eventually, these also have disappeared, and recent *Fairlies* have the usual single boiler like all other types of articulated locomotives.

So as not unduly to multiply the number of types and to have a general view of articulated locomotives, we have grouped those of them which do not differ in essentials from each other, under a few headings only, as follows :—

Group I.—The *Meyer* and *Meyer-Kitson* articulated locomotives, which we have subdivided according to the position of the cylinders.

Group II.—The *Fairlie* group, beginning with *Horatio Allen's* locomotives and continuing with the "*Seraing*," the *Thouvenot* system and the various kinds of double-boiler and two-boiler *Fairlie*, *Mason-Fairlie*, *Péchot-Bourdon* and *Johnstone* locomotives, and finishing with the North British type of single *Fairlie* and the *Golwé* locomotives.

Group III.—Comprising the *Garratts* and locomotives, such as the *Union*, derived therefrom.

Group IV.—The *du Bousquet* locomotives with their predecessor, the *Wiener-Neustadt*.

GROUP I.—THE MEYER GROUP OF ARTICULATED LOCOMOTIVES

On March 15th, 1861, Jean-Jacques Meyer, of Mulhouse * (France), and his son, Adolphe, took out a French patent (No. 48,993) "for a system of complete articulation for tank engines." This system comprised the use of several individually rigid "motor-trucks" connected to one another in such a manner as to form a flexible whole.

Classification of the Meyer Locomotives

It is hardly surprising that in locomotives whose use has extended during three-quarters of a century, there should be great variety of types. It is all the more necessary to classify these in a simple fashion and we shall do so, taking as a basis the arrangement of their cylinders, which has been altered as the designs were improved.

Sub-Group I. A.—The Original Meyer Locomotives.—These had four cylinders located at the centre.

These early locomotives did not differ in essentials from each other, and were either of the 0-4 + 4-0 or of the 0-6 + 6-0 classes.

Type 1.—Simple *Meyer* locomotives with which we have grouped a more recent example built by the *Winterthur Works* for meeting special conditions (Type 2).

Type 3.—So-called *Mallet-Meyer* locomotives; these were compounds and few of them have been built.

Sub-Group I. B.—The Meyer-Kitson Locomotives with Cylinders at the Rear End of each Bogie.—A number of alterations were embodied in these locomotives, whose arrangements varied considerably.

* J. J. Meyer was born in 1804 and obtained his diploma of mechanical engineer at the "Ecole des Arts et Métiers," Paris. In 1831, he established the Mulhouse Works, where he built locomotives for German and Austrian railways, and built the first bogies to be used in France. But owing to financial trouble, he was obliged to sell his concern, which was the origin of the "Société Alsacienne de Constructions Mécaniques."

He invented a number of locomotive appliances, and died in Vienna in 1877.

His son was associated with his work and contributed to the invention of the system which bears his name.

Type 1.—Compound tank locomotive built in America.

Type 2.—Simple tank locomotives, all of the 0-6 + 6-0 class.

Type 3.—Locomotives of the 0-6-0 + 0-6-0 or of the 0-6-2 + 0-6-2 class, with separate tenders.

SUB-GROUP I. C.—THE MEYER-KITSON LOCOMOTIVES WITH CYLINDERS AT THE OUTER ENDS OF THE BOGIES.—These include :—

Type 1.—Tank engines of the 0-6 + 6-0 ; 2-6 + 6-2 ; 2-6-2 + 2-6-2 classes.

Type 2.—Tank locomotives of the 2-6 + 6-4 class, with three bogies of which two are driven.

Type 3.—Combined rack and adhesion 0-8 + 6-0 class.

SUB-GROUP I. A.—THE ORIGINAL MEYER LOCOMOTIVES WITH CYLINDERS LOCATED AT THE INNER ENDS OF THE BOGIES

General Characteristics

These locomotives comprise a boiler and frame, and two steam-driven bogies.

Bogies.—They have a single boiler which is supported on the rear truck by special bearings, on sliding plates, carried by brackets on the frames, at either side of the firebox, and on the front truck, by a spherical pivot working in a socket fixed to the boiler.

Connection between the Bogies.—The motor-trucks are connected to one another by means of tie-rods, the ends of which embrace the pivot castings, " a new and advantageous system which gives to the whole arrangement a flexibility not hitherto obtained." *

It is by this feature, in particular, that these locomotives are distinguished from their predecessors.

Stradal drawgear was originally used outside and between the bogies.

Buffing and Drawgear.—The drawgear and buffers are attached to the bogies. The stresses are therefore confined to

* Text of patent.

TABLES 10 and 11.—PRINCIPAL DIMENSIONS, SIMPLE AND COMPOUND MEYER LOCOMOTIVES.

Gauge	Standard.	Standard.	Standard.	Standard.	0m.75.	0m.60.
Railway	Various and Ch. de fer du Grand Luxembourg	Ch. de fer du Hérault (France).	Grand-Central Belge.	Saxony State Rys.	Saxony State Rys.	Osnabrück Ry.
Builder	Fives-Lille.	Cail.	Evrard. Brussels.	Chemnitz.	Chemnitz.	Jung.
Date	1868.	1870.	1873.	1892.	1891.	—
Type	**0-4 + 4-0**	**0-6 + 6-0**	**0-6 + 6-0**	**0-4 + 4-0** Compound.	**0-4 + 4-0** Compound.	**0-4 + 4-0.** Compound.
Cylinders, diameter	$13\frac{3}{8}''$	$13\frac{3}{4}''$	$17\frac{5}{16}''$	$13\frac{3}{4}''$ / $18\frac{1}{8}''$	$8\frac{7}{16}''$ / $14\frac{3}{8}''$	$9\frac{1}{16}''$ / $13\frac{3}{8}''$
,, stroke	$21\frac{5}{8}''$	$21\frac{5}{8}''$	$23\frac{1}{2}''$	$20\frac{3}{4}''$	$14\frac{1}{2}''$	$13\frac{3}{4}''$
Boiler, pressure	142	128	114	170	199	170
Heating surface, total sq. ft.	1636·2	1291·7	2216·3	925·7	538·2 *	473·6
Grate area ,,	18·3	22·6	355·2	15·1	10·8	10·8
Wheels, diameter	$4'\ 3\frac{3}{16}''$	$3'\ 11\frac{3}{16}''$	$3'\ 11\frac{1}{4}''$	$3'\ 3\frac{3}{8}''$	$29\frac{7}{8}''$	$27\frac{1}{2}''$
Wheelbase, rigid	$9'\ 6\frac{1}{8}''$	$8'\ 7\frac{15}{16}''$	$8'\ 8\frac{1}{4}''$	$5'\ 8\frac{7}{8}''$	$4'\ 7\frac{1}{8}''$	$3'\ 3\frac{3}{8}''$
,, total	$28'\ 10\frac{7}{16}''$	$28'\ 8\frac{1}{2}''$	$28'\ 7\frac{5}{16}''$	$22'\ 1\frac{1}{16}''$	$20'\ 4\frac{1}{16}''$	$19\frac{5}{8}''$
Water galls.	—	—	16,500	—	10,900	8,800
Coal tons.	—	—	2·95	—	0·88	0·88
Weight, empty ,,	—	—	—	48·7	22·0	15·7
,, in service ,,	51·1	49·6	70·8	59·6	27·4	19·6
Overall height	—	—	$14'\ 3\frac{1}{4}''$	$13'\ 7\frac{3}{8}''$	$10'\ 4''$	$9'\ 2\frac{1}{4}''$
,, width	—	—	$9'\ 10''$	$9'\ 11\frac{11}{16}''$	$6'\ 8\frac{1}{4}''$	$6'\ 2\frac{3}{4}''$
,, length	—	—	$41'\ 11\frac{1}{8}''$	$38'\ 1''$	$29'\ 6\frac{5}{16}''$	$20'\ 8\frac{13}{16}''$ †

* These locomotives have a firebox heating surface of 46·3 sq. ft., and 491·9 sq. ft. contributed by the tubes.
† Buffers excluded.

TABLES 10A and 11A.—PRINCIPAL DIMENSIONS, SIMPLE AND COMPOUND MEYER LOCOMOTIVES.

Gauge / Railway	Standard. Various and Ch. fer du Grand Luxembourg.	Standard. Ch. de fer du Hérault (France).	Standard. Grand-Central Belge.	Standard. Saxony State Rys.	0m.75. Saxony State Rys.	0m.60. Osnabrück Ry.
Builder	Fives-Lille.	Cail.	Evrard, Brussels.	Chemnitz.	Chemnitz.	Jung.
Date	1868.	1870.	1873.	1892.	1891.	—
Type	**0-4 + 4-0**	**0-6 + 6-0**	**0-6 + 0-6**	**0-4 + 4-0** Compound.	**0-4 + 4-0** Compound.	**0-4 + 4-0** Compound.
Cylinders, diameter . . m.	0·34	0·35	0·44	0·35—0·46	0·24—0·37	0·23—0·34
,, stroke . . m.	0·55	0·55	0·60	0·53	0·38	0·35
Boiler, pressure . . kg./sq. cm.	10	9	8	12	14	12
Heating surface total . sq. m.	152	121	205·9	86	50 *	44
Grate area . . sq. m.	1·6	2·1	3·3	1·4	1·0	1·0
Wheels, diameter . . m.	1·30	1·20	1·22	1·00	0·76	0·70
Wheelbase, rigid . . m.	2·90	2·64	2·66	1·75	1·40	1·00
,, total . . m.	8·80	8·75	8·72	6·75	6·20	5·00
Water . . . cub. m.	—	—	7·5	—	2·40	1·95
Coal . . . . . t.	—	—	3·0	—	0·90	0·90
Weight, empty . . . t.	—	—	—	49·5	22·4	16·0
,, in service . . t.	52	50·5	72	60·5	27·9	20·0
Overall height . . . m.	—	—	4·35	4·15	3·15	2·80
,, width . . . m.	—	—	3·00	3·04	2·04	1·90
,, length . . . m.	—	—	12·78	11·62	9·00	6·32 †

* These locomotives have a firebox heating surface of 4·3 sq. m., and 45·7 sq. m. contributed by the tubes.

† Buffers excluded.

them and are in no way transmitted to the boiler or its supports.

This is not the case in the *Fairlie* engine. In the *Seraing*, the *Wiener-Neustadt* and the *du Bousquet types*, the buffers and drawgear are fixed to a main frame, which in turn supports the boiler.

BOGIES.—The method of supporting the boiler on the bogies allows the latter to move freely in reference to each other.

CYLINDERS.—*Meyer* locomotives have four cylinders, all H.P., though compounding has been tried. In the earlier types, the cylinders were all located at the centre of the locomotive, where they were overhung. In recent types they are usually located at the rear of each of the two bogies.

In the original *Meyer* locomotives (as represented by the obsolete Belgian Grand Central Ry.'s type), steam was taken to the cylinders by copper pipes provided with sliding joints. These, owing to the elasticity due to their curves, gave sufficient flexibility.

The exhaust pipes of the rear cylinders were provided with flexible joints at their ends. Like the front cylinders' exhausts, they opened in the hollow ball of the front bogie, whence the steam passed up the chimney.

All operating levers were provided with suitable universal joints.

The reversing gears of both engines could be worked simultaneously or separately.

FUEL AND WATER.—Coal bunkers and water tanks were situated at the rear of the locomotive. Additional water capacity was provided by side tanks, which often ran the full length of the boiler.

Type 1.—Simple Meyer Locomotives

Utilisation of the Meyer Locomotives

EARLY MEYER LOCOMOTIVES.—Meyer exhibited the drawings of his articulated locomotive at the Exhibitions of 1862, in London, and of 1867, in Paris. But the first locomotive of this type was not actually put in hand until the following year, and that by the help of a State subsidy.

It was built by the "Cie. de Fives-Lille" and christened "L'Avenir." It was tested on several main railways and

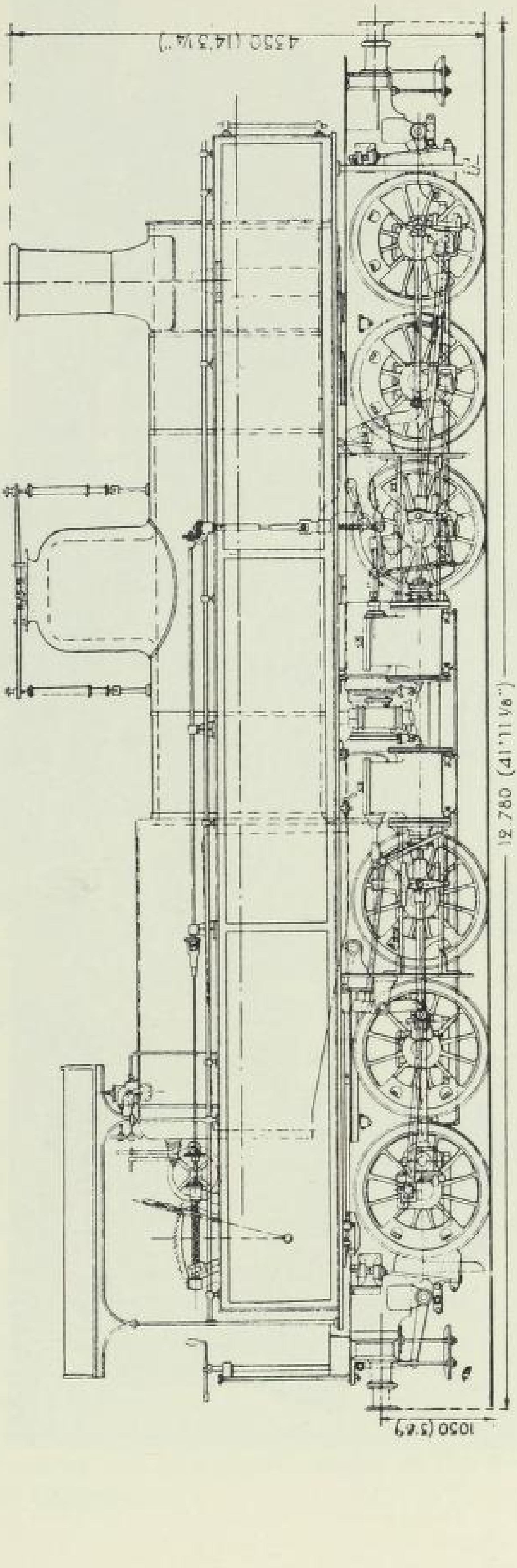


FIG. 31.—Meyer Locomotive, Ch. de fer du Grand Central Belge.
(Standard Gauge.)
Built by Charles Evrard, Brussels.

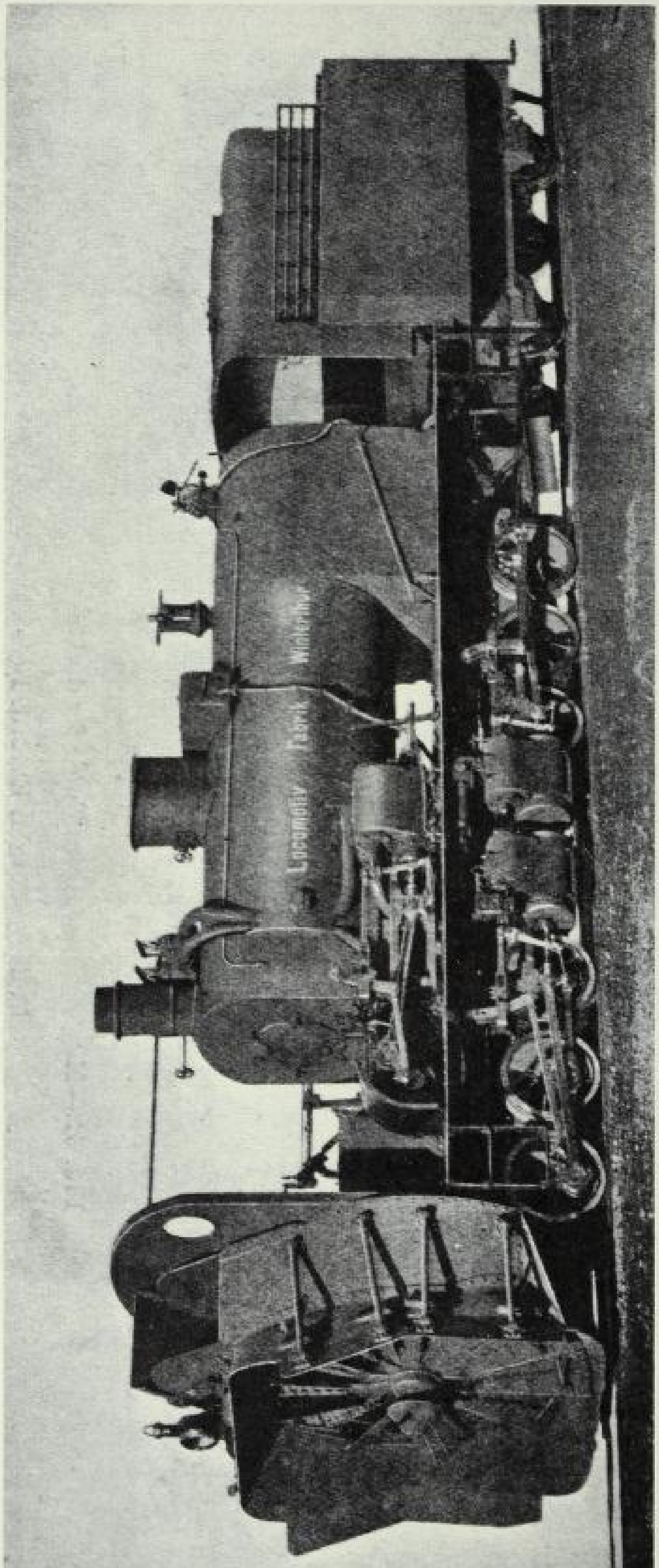


FIG. 32.—Winterthur Articulated Rotary Snow Plough Locomotive, Bernina Ry. (Switzerland).
(Metre Gauge.)

finally disposed of to a secondary standard gauge line in France.*

It was followed, in the year 1870, by two 0-6 + 6-0 locomotives, built for the " Ch. de fer de l'Hérault," by the Société Cail. They weighed 50 tons (French) each.

The 0-6 + 6-0 Meyer Locomotive of the Ch. de fer du Grand-Central Belge.†—Standard gauge (Fig. 31).

It was not until this locomotive (which was exhibited at the Vienna Exhibition) was built by Charles Evrard, of Brussels,‡ that the *Meyer* system reached its full development.

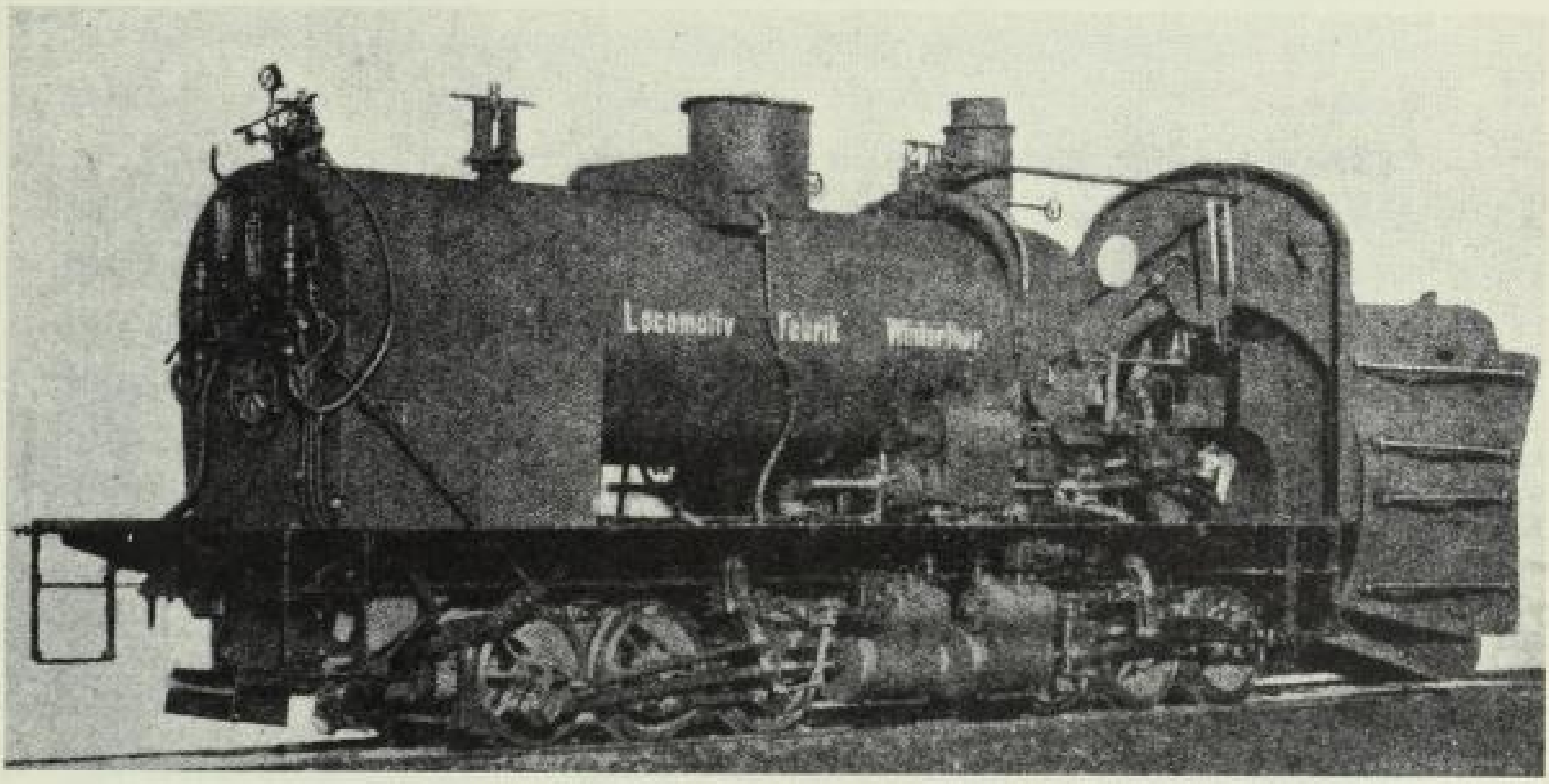


Fig. 33.—Boiler of Winterthur Snow Plough Locomotive.

Type. 2—The Winterthur Articulated Locomotive

Rotary Snow Plough Locomotive of the Ch. de fer de la Bernina.—Metre gauge (Figs. 32 and 33).

This line connects Tirana (altitude 1,407 ft.), *viâ* the Bernina Pass and Pontresina, with St. Moritz (altitude 5,833 ft.). The summit level of the line, at the Bernina Hospice, is 7,400 ft.

* This engine worked on several French lines, notably on the *Ch. de fer du Nord.* It was afterwards used on the *Ch. de fer du Grand Luxembourg* (Belgium), on the *Jura-Neufchâtelois* line and on the *Hauenstein* section of the *Central Swiss Ry.* It was finally purchased by the *Ch. de fer des Charentes* (France).

† This railway is now incorporated in the Belgian State Rys system.

‡ These works are now incorporated in the Société Anglo-Franco-Belge, of La Croyère.

above sea level, which is the greatest altitude reached by any ordinary railway in Europe. Traffic is liable to be greatly impeded by snow, and special arrangements are needed to deal with snowdrifts. It was found that the electric locomotives employed on the line could not push the ordinary type of rotary snow ploughs with satisfactory results. An articulated steam locomotive was therefore designed in which the rotor of the snow plough was actuated by a separate pair of cylinders independent of those used for the propulsion of the locomotive itself. It was supplied to the railway by the Winterthur Works, and is an excellent example of the applicability of the principle of articulation to locomotives for special services.

The locomotive has two bogies, each with three driven axles. The four simple admission cylinders are located between the bogies.

The rotor of the snow plough is driven by a horizontal engine through Citroën double helical gears having a reduction of 1 : 1·9. The cylinders of this engine are placed one on either side of the boiler above the cylinders used for propulsion.

The whole locomotive, including the tender, is enclosed in a wooden covering for the protection of the *personnel*. The locomotive is controlled from the front, the driver and his assistant being between the smoke-box door and the rotor casing. The fireman is in the usual place behind the firebox.

This locomotive can climb grades of 7 per cent. and run through curves of 40 m. (131 ft.) radius. The speed with the snow plough in action is 5 km. (3 miles) per hour.

TABLE 12.—PRINCIPAL DIMENSIONS, WINTERTHUR ROTARY SNOW PLOUGH

Diameter of all cylinders	0·30 m. (11 3/16″).
Stroke of locomotive cylinders	0·35 m. (13¾″).
Stroke of snow plough cylinders	0·45 m. (17¾″).
Gear ratio	1 to 1·9.
Revolutions per minute	170.
Wheels, diameter	0·75 m. (2′ 5½″).
Wheelbase, rigid	1·70 m. (5′ 7″).
,, total	5·74 m. (18′ 10″).
Snow plough, external diameter	2·50 m. (8′ 2″).
Boiler pressure	12 k./cm.² (176 lbs./in ²).
,, heating surface	110 sq. m. (1184 sq. ft.).
Superheater heating surface	17·5 sq. m. (183⅓ sq. ft.).
Grate area	1·6 sq. m. (18⅓ sq. ft.).
Weight of locomotive empty	41·5 t. (91,500 lbs.).
,, ,, in working order	45 t. (99,200 lbs.).
,, ,, and tender	61 t. (134,500 lbs.).

Type 3.—Compound Meyer Locomotives

The Mallet-Meyer Locomotives.—In 1877 Anatole Mallet, who was the first successfully to apply compounding to locomotives, suggested its application to *Meyer* and to *Fairlie* locomotives, hence the above title, by which these locomotives are often designated. They have not, however, achieved any great success.

Meyer Compound Locomotives of the Saxon State Rys. (Gauges, standard and 75 cm.—2 ft. 5½ ins.).

Part of the railway system of Saxony traverses hilly country which necessitates special methods of traction. Thus compound *Meyer* locomotives are used both on the standard and on the narrow gauge lines.*

This railway has tried many systems both of articulated locomotives and of others with convergent axles, such as the *Klose* and *Klien-Lindner* types. It is therefore of interest to quote comparative leading dimensions, which will be found in Table 13.

SUB-GROUPS I. B AND I. C.—THE MEYER-KITSON LOCOMOTIVES

General Characteristics

Messrs. Kitson & Co., of Leeds, England, have introduced numerous modifications of the original *Meyer* engine, with the result that it has acquired a new lease of life, and many specimens have been built for various railways, under diverse working conditions, right down to the present time.

The superstructure is carried by a pair of girders supported by the steam bogies, which carry the load on pivots placed as near as possible to the centre of the adhesive wheelbase. Rolling is checked by plates concentric with each centre and pitching, by slides at the end of each bogie.

Position of Cylinders.—While on the earlier *Meyer* locomotives the cylinders were always located at the centre of the locomotive, in the *Meyer-Kitson* locomotives they are placed at the rear of each bogie or at the ends of the locomotives. All these engines use H.P. steam for all four cylinders.

Fuel and Water.—In some cases (*e.g.*, in the locomotives

* See the *Engineer*, October 23rd, 1891, pp. 340–346.

Table 13.—Principal Dimensions of Various Types of Articulated Locomotives used by the Saxon State Rys.—(0m.75 (2′ 5½″), Metre and Standard Gauges)

Type		0-4 + 4-0	0-4 + 4-0	0-4 + 4-0	0-6-2	0-8-0	2-8-0	0-4 + 4-0
System		Fairlie.	Meyer.	Meyer.	Klose.	Klien-Lindner.	Klien-Lindner.	Mallet.
Builder		Chemnitz.	Chemnitz.	Chemnitz.	Chemnitz.	Chemnitz.	Chemnitz.	Chemnitz.
Date		1902	1910	1890	1891—1910	1901	—	1899
Gauge		1·00 m.	1·435 m.	0·75 m.	0·75 m.	0·75 m.	1·435 m.	1·435 m.
Cylinders, diameter	m.	0·28	0·35	0·24	0·32	0·34	0·53	0·45
,, diameter	m.	0·43	0·36	0·37	—	0·50	0·77	0·65
,, stroke	m.	0·38	0·38	0·38	0·40	0·40	0·63	0·60
Boiler, centre line	m.	1·90	2·55	1·62	—	1·80	2·40	2·30
,, diameter	m.	1·00	1·26	0·95	—	0·95	1·60	—
,, pressure	k./sq. cm.	14	12	12 then 14	10	14	15	12
Heating surface, firebox	sq. m.	7·8	6·9	4·1	3·6	4·2	2·2	10·7
,, ,, tubes	,,	71·3	99·3	45·7	42·7	45·7	142·7	130·4
,, ,, total	,,	79·1	106·2	49·8	46·2	50·0	154·8	141·1
,, ,, superheater	,,	None	None	None	None	None	42·2	None
Grate area	,,	1·9	1·4	1·0	0·9	0·96	3·2	2·0
Wheels, diameter	m.	None	None	None	0·86	—	1·05	None
,, diameter	m.	0·76	1·00	0·76	0·76	0·86	1·24	1·24
Wheelbase, rigid	m.	1·10	1·75	1·40	2·80	1·50	2·86	1·70
,, driving	m.	7·60	6·75	6·20	—	—	—	5·75
,, total	m.	7·60	—	—	5·75	3·90	7·76	7·76
Overall height	m.	3·75	4·15	3·15	3·00	3·15	4·57	4·15
,, width	m.	2·90	3·04	2·04	2·00	2·30	3·05	3·15
,, length	m.	10·48	11·62	9·00	9·00	8·38	11·02	11·02
Weight, adhesive	t.	0·7	51	27·9	19	27·8	60·1	59·6
,, empty	t.	33·2	49·5	22·4	20·2	22·1	64·1	53·6
,, in service	t.	40·7	60·6	27·9	25·6	27·8	70·8	59·6
Water tanks	cub. m.	3·2	5·0	2·4	2·0	2·4	Tender	Tender
Coal bunkers	t.	1·2	1·8	1·0	1·2	1·0	,,	,,
		(*)	(¶)		(‖)	(†)	(‡)	(§)

* Tractive effort, 6·3 tons, 270 tubes, 35 mm. diameter, and 2m.40 long

‡ Tractive effort, 10·7 tons. 259 tubes, 45/50 mm. diameter and 4·60 m. long.

‖ 97 tubes, 45 mm. diameter and 3m.05 long.

† Tractive effort, 4·1 tons. 104 tubes, 45/40 mm. diameters and 3·50 m. long.

§ 205 tubes, 45 mm. diameter, and 4m.50 long.

¶ 199 tubes, 45/40 mm. diameter and 3·70 m. long.

TABLE 13A.—PRINCIPAL DIMENSIONS OF VARIOUS TYPES OF ARTICULATED, SEMI-ARTICULATED AND PARTIALLY ARTICULATED LOCOMOTIVES OF THE SAXON STATE RYS.

Type System Builder Date Gauge	**0-4 + 4-0** Fairlie Compound. Chemnitz. 1902 Metre.	**0-4 + 4-0** Meyer Compound. Chemnitz. 1910 Standard.	**0-4 + 4-0** Meyer Compound. Chemnitz. 1890 2′ 5$\frac{1}{2}$″	**0-6-2** Klose. Chemnitz. 1891—1910 2′ 5$\frac{1}{2}$″	**0-8-2** Klien-Lindner. Chemnitz. 1901 2′ 5$\frac{1}{2}$″	**2-8-0** tender Klien-Lindner. Chemnitz. — Standard.	**0-4 + 4-0** Mallet. Chemnitz. 1899 Standard.
Cylinders, diameter	11″	13$\frac{6}{8}$″	9$\frac{1}{16}$″	12$\frac{9}{16}$″	13$\frac{3}{8}$″	20$\frac{3}{4}$″	17$\frac{11}{16}$″
,, diameter	16$\frac{7}{8}$″	14$\frac{1}{8}$″	14$\frac{9}{16}$″	—	19$\frac{5}{8}$″	30$\frac{5}{16}$″	25$\frac{9}{16}$″
,, stroke	14$\frac{7}{8}$″	14$\frac{7}{8}$″	14$\frac{7}{8}$″	15$\frac{3}{4}$″	15$\frac{3}{4}$″	26$\frac{3}{4}$″	23$\frac{1}{2}$″
Boiler, centre line	6′ 2$\frac{3}{4}$″	8′ 4$\frac{3}{8}$″	5′ 2$\frac{3}{4}$″	—	5′ 10$\frac{7}{8}$″	7′ 10$\frac{1}{2}$″	7′ 0$\frac{5}{8}$″
,, diameter	3′ 3$\frac{3}{8}$″	4′ 1$\frac{5}{8}$″	3′ 1$\frac{3}{8}$″	—	3′ 1$\frac{3}{8}$″	5′ 3″	—
,, pressure . . lbs./sq. in.	199	171	171 then 199	142	199	213	171
Heating surface, firebox . sq. ft.	84·0	74·3	44·1	38·8	45·2	131·3	115·2
,, ,, tubes ,,	767·5	1068·9	491·9	459·6	491·9	1536·0	1403·2
,, ,, total ,,	851·5	1143·2	536·1	497·3	538·2	1666·3	1518·8
,, ,, superheater ,,	None	None	None	None	None	454·3	None
Grate area ,,	20·5	15·1	10·8	9·7	9·7	34·4	21·5
Wheels, diameter	None	None	None	33′ 0$\frac{7}{8}$″	33′ 0$\frac{7}{8}$″	3′ 0$\frac{3}{8}$″	None
,, diameter	2′ 5$\frac{7}{8}$″	3′ 3$\frac{3}{8}$″	2′ 5$\frac{7}{8}$″	2′ 5$\frac{7}{8}$″	—	4′ 0$\frac{13}{16}$″	4′ 0$\frac{13}{16}$″
Wheelbase	3′ 7$\frac{5}{16}$″	5′ 8$\frac{7}{8}$″	4′ 7$\frac{1}{8}$″	9′ 2$\frac{1}{2}$″	4′ 11$\frac{1}{16}$″	9′ 4$\frac{1}{2}$″	5′ 6$\frac{7}{8}$″
,, driving	24′ 11$\frac{3}{16}$″	22′ 1$\frac{11}{16}$″	20′ 4$\frac{1}{8}$″	—	—	—	18′ 10$\frac{3}{8}$″
,, total	24′ 11$\frac{3}{16}$″	22′ 1$\frac{11}{16}$″	20′ 3$\frac{1}{8}$″	18′ 10$\frac{3}{8}$″	12′ 9$\frac{1}{2}$″	25′ 5$\frac{1}{2}$″	18′ 10$\frac{3}{8}$″
Overall height	12′ 3$\frac{5}{8}$″	13′ 7$\frac{3}{8}$″	10′ 4″	9′ 10$\frac{1}{8}$″	10′ 4″	14′ 11$\frac{7}{8}$″	13′ 7$\frac{3}{8}$″
,, width	9′ 6$\frac{1}{8}$″	9′ 11$\frac{1}{16}$″	6′ 8$\frac{1}{4}$″	6′ 6$\frac{3}{4}$″	7′ 6$\frac{1}{2}$″	10′ 0$\frac{1}{8}$″	10′ 4″
,, length	34′ 4$\frac{5}{8}$″	38′ 1$\frac{1}{2}$″	29′ 6$\frac{3}{8}$″	29′ 6$\frac{3}{8}$″	27′ 5$\frac{7}{8}$″	36′ 1$\frac{7}{8}$″	36′ 1$\frac{7}{8}$″
Water tanks . galls.	1,450	2,270	1,100	900	1,100	Tender	Tender
Coal bunkers . t.-cwt.	1–4	1–5	1–0	1–3	1–0	,,	,,
Weight, adhesive ,,	40–0	51–0	26–11	18–14	27–5	59–2	58–15
,, empty ,,	32–14	48–14	22–1	19–0	21–16	63–2	52–15
,, in service ,,	40–0	59–12	27–9	24–13	27–5	69–14	58–15
	(*)			(‖)	(†)	(‡)	(§)

* Tractive effort, 13,900 lbs., 270 tubes, 1$\frac{3}{8}$ in. diameter, 7 ft. 1 in. long.
† Tractive effort, 9,000 lbs.
‡ Tractive effort, 22,500 lbs.
§ 205 tubes, 1$\frac{3}{4}$ in. diameter, 14 ft. 9$\frac{1}{4}$ ins. long.
‖ 97 tubes, 1$\frac{3}{4}$ ins. diameter and 10 feet long.

supplied to the *Leopoldina Ry.*) a semi-tender is provided by increasing the rear tanks, this extension being supported by a four-wheeled bogie (not driven).

TENDERS.—Some of these locomotives have been built with separate tenders (*e.g.*, on the engines for the *Central South African Rys.*). In one type built for the *Antofagasta* (*Chile*) *and Bolivia Ry.*, the locomotive is arranged to run cab forward in order to improve the driver's view of the road, the tender being attached to the smoke-box end of the engine.

NUMBER OF AXLES.—All the types have six coupled axles in two groups, except those built for the great Southern of Spain Ry., which have eight. Some of these locomotives have a bissel truck in front, or at either end, of each bogie.

STEAM PIPES.—Ball and socket joints are used for the steam and exhaust pipes, the centre of the ball coinciding with that of the spherical pivot casting. The exhaust of the rear cylinders passes back to the smoke-box by a similar ball and socket joint again installed close to the twisting joint. In cases where a reheater is provided, the exhaust passes through piping placed in the water tanks and, after heating the water, escapes through an auxiliary chimney at the back.

THE CYLINDERS are provided with cylinder covers of special design so that the cylinders can be dismantled without interfering with the side tanks above them.

The reversing and hand brake gear are necessarily provided with universal joints ; they can, therefore, be operated with equal ease on curves or on the straight.

SUB-GROUP I. B.—MEYER-KITSON AND SIMILAR LOCOMOTIVES WITH CYLINDERS AT THE REAR OF EACH MOTOR TRUCK

For a time, this was the most familiar class of these locomotives and was in use on about a dozen railways, but in recent years a type more nearly approaching the *Garratt* has superseded it.

All of these locomotives had two three-axle steam bogies, their entire weight being available for adhesion. Those of the Central South African Rys. and one class of the Antofagasta (Chile) and Bolivia Ry. had separate tenders, all the others being tank-engines.

The first of the series was supplied by the Baldwin Locomotive Works, in the year 1892, to an unimportant American railway. It was unsuccessful, and was speedily forgotten.

Next came those built by Kitson & Co., and these have been much used in South America, and especially in Chile. It will suffice to supplement the information we give in Table 15 by some data concerning the railways on which these locomotives are used.

Type 1.—Articulated Locomotives of the Sinnemahoning Valley

In the year 1892, the Baldwin Locomotive Works supplied to this railway a couple of 0-6 + 6-0-T locomotives (Fig. 34),

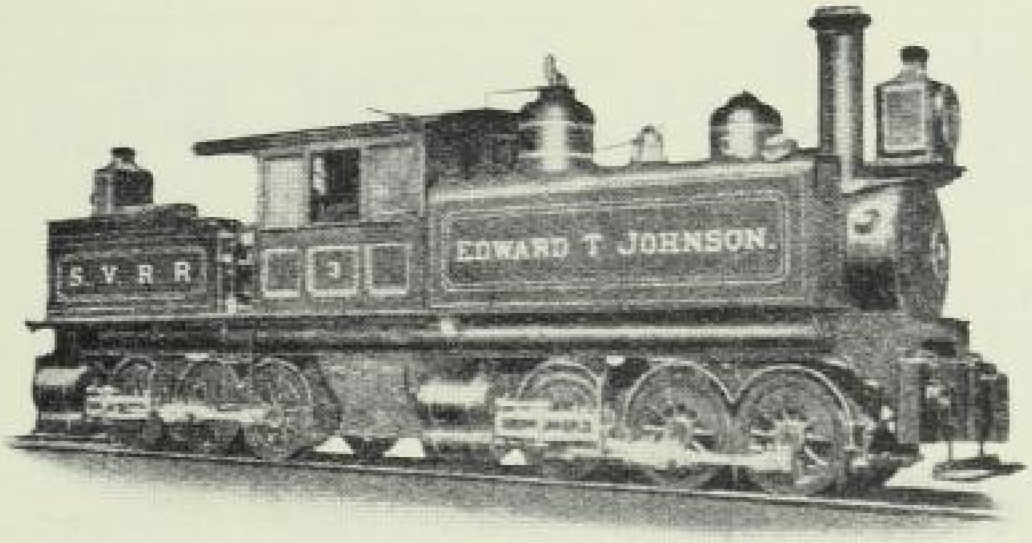


FIG. 34.—Articulated Compound Locomotive of the Sinnemahoning Valley R.R.
(Standard Gauge.)

with two driven bogies. They were four-cylinder compounds, and the cylinders were located at the rear end of each bogie.

The fuel was stocked back of the cab, the water in side tanks.*

* TABLE 14.—PRINCIPAL DIMENSIONS OF THE SINNEMAHONING VALLEY RY.'S ARTICULATED LOCOMOTIVES

Name of Locomotive	Edward T. Johnson
Gauge	Standard
Cylinders, diameter	0·24 and 0·41 m. ($9\frac{1}{2}$ ins. and 16 ins.)
,, stroke	0·46 m. (18 ins.)
Wheels, diameter	1·22 m. (4 ft. 0 in.)
Wheelbase, rigid	2·29 m. (7ft. 6 ins.)
,, total	8·23 m. (27 ft.)
Weight in working order	68·0 tonnes (67 tons 6 cwts.)

TABLE 15.—PRINCIPAL DIMENSIONS OF MEYER LOCOMOTIVES WITH CYLINDERS AT THE BACK END OF EACH BOGIE

Gauge		0·75	0·91	1·067	1·067	1·067	1·067	Standard.	Standard
Railway		Anglo-Greek Magnesite.	National (Colombia).	Taltal Ry. (Chile).	South African Rys.	Anglo-Chilian Nitrate Ry.	Anglo-Chilian Nitrate Ry.	Nitrate Rys.	Jamaica. Govt. Rys.
Builder		Barclay.	Kitson.	Kitson.	Kitson.	Kitson & Kerr Stuart.	Kitson.	Yorkshire.	Kitson.
Date		1903	1909	1907	1904	1909	1910	1912	1904
Type		**0-4 + 4-0**	**0-6 + 6-0**	**0-6 + 6-0**	**0-6 + 6-0**	**0-6 + 6-0**	**2-6 + 6-2**	**0-6 + 6-0**	**0-6 + 6-0**
Cylinders, diameter	m.	0·23	0·36	0·36	0·41	0·36	0·38	0·43	0·33
,, diameter	m.	0·38	0·46	0·46	0·61	0·46	0·53	0·56	0·56
Boiler, centre line	m.	1·51	1·85	2·07	2·18	2·07	2·13	2·52	2·36
,, diameter	m.	1·04	1·32	1·37	1·52	1·32	1·55	1·67 ext.	1·55
,, pressure	kg./sq. cm.	11·6	11·3	11·3	13·2	11·3	12·66	12·7	12·7
Tubes, number		115	206	192	239	206	281	262	226
,, diameter	mm.	44 ext.	44	48	51	44	44	51	48
,, length	m.	2·98	3·37	3·37	4·21	3·37	3·62	4·71	3·65
Heating surface, firebox	sq. m.	4·5	9·5	9·9	12·6	9·7	11·7	15·9	12·1
,, ,, tubes	sq. m.	42·7	96·8	96·8	160·4	96·8	142·1	198·3	123·4
,, ,, total	sq. m.	47·2	106·3	106·7	173·1	106·5	153·8	214·3	135·5
Grate area	sq. m.	0·8	2·4	2·3	3·2	2·4	3·2	3·6	2·4
Wheels, diameter	m.	0·98	0·88	0·88	1·22	0·88	0·97–62	1·14	1·07
Wheelbase, 1st group	m.	1·22	1·89	1·92	2·59	1·89	3·96	2·59	2·36
,, 2nd group	m.	1·22	1·89	1·92	2·59	1·89	3·96	2·59	2·36
,, Total	m.	5·18	7·95	7·79	10·36	7·79	8·76	10·87	9·07
Water tanks	cub. m.	3	7·8	8·6	0	9·3	11·3	18	11·4
Coal bunkers	t.	1·5	2·5	3	7	3·2	5	4	4
Oil tanks	cub. m.	None.	None.	None.	None.	2·3	95 c.f.	None.	None.
Overall height	m.	2·99	3·70	3·91	3·91	3·91	3·91	4·12	4·19
,, width	m.	2·28	2·54	2·60	2·74	2·69	2·69	3·05	3·05
,, length	m.	7·92	11·30	10·80	13·64	11·00	14·18	15·16	12·32
Weight, adhesive	t.	30·4	61·9	61·8	84·5	63·6	62·4	120·0	82·0
,, empty	t.	18·8	47·9	47·1	70·0	48·8	58·9	91·4	60·9
,, in service	t.	30·4	61·9	61·8	84·5	63·6	78·7	120·0 *	82·0

* There is a feedwater heater 144 sq. ft. (13·4 sq. m.). The firebox is 9 ft. by 5 ft. 8⅝ ins. (2m.74 × 1m.74), and the rated tractive effort 43,222 lbs. (19·6 t.).

These locomotives are only referred to as a curious application of compounding to locomotives of this class.

Type 2.—Meyer-Kitson Tank Locomotives with Cylinders at the Rear of Each Truck

These locomotives, all of the 0-6 + 6-0 class, have been—and still are—widely used and deserve a somewhat detailed notice.

Class A.—0-6 + 6-0 Meyer-Kitson Locomotives

0-6 + 6-0 Locomotives, Anglo-Chilian Nitrate Ry.—3 ft. 6 ins. gauge.

These locomotives, which were built in 1903, are, we believe, the prototypes of the new *Meyer* engines and their success is directly responsible for their reinstatement in public favour.

This company's system of 75½ miles (122 km.), extends from the Chilian port of Tocopilla into the nitrate zone, and on the main line, no less than 17 miles (27·3 km.) have gradients of 1 in 25 combined with 181 ft. (53 m.) radius curves.*

Working trains on this section has always been a difficult problem, and in 1894 Robert Stirling ordered some *Meyer* locomotives from Messrs. Kitson & Co. A modified form was elaborated, and the *Meyer-Kitson* locomotives appeared.

Instead of being all grouped in the centre of the locomotive, two of the cylinders were carried behind the rear bunkers, all cylinders thus being symmetrically placed on the bogies, which are identical with each other.

Further locomotives were supplied by Kerr, Stuart & Co., and some later locomotives were provided with bissels.

0-6 + 6-0 Meyer-Kitson Locomotives, Colombian National Rys.—Gauge, 3 ft.

This system, which is situated in a mountainous district, has

* Tocopilla (km. 0) is at a height of 17 m. (56 ft.); Ojeda (km. 53, mile 33) is at + 1,494 m. (4,920 ft.).

TABLE 15A.—PRINCIPAL DIMENSIONS OF MEYER LOCOMOTIVES WITH CYLINDERS AT THE REAR OF EACH MOTOR TRUCK

Type	0-4 + 4-0	0-6 + 6-0	0-6 + 6-0	0-6 + 6-0	2-6 + 6-2	0-6 + 6-0	0-6 + 6-0	0-6 + 6-0
Railway	Anglo-Greek Magnesite.	Colombian National Rys.	Taltal Ry. (Chile).	Anglo-Chilian Nitrate Ry.	Anglo-Chilian Nitrate Ry.	South African Rys.	Jamaica Goverment Rys.	Nitrate Rys.
Gauge	2′ $5\frac{1}{2}$″	3′	3′ 6″	3′ 6″	3′ 6″	3′ 6″	4′ $8\frac{1}{2}$″	4′ $8\frac{1}{2}$″
Builder	Barclay.	Kitson.	Kitson.	Kerr Stuart.	Kitson.	Kitson.	Kitson.	Yorkshire.
Date	1903.	1909	1907	1909	1903-1904	1904	1904	1912
Cylinders, diameter	9″	14″	14″	14″	15″	16″	14″	17″
„ stroke	15″	18″	18″	18″	21″	24″	22″	22″
Boiler, centre line	4′ $11\frac{1}{2}$″	6′ 1″	6′ $9\frac{3}{8}$″	6′ $9\frac{3}{8}$″	7′	7′ 2″	7′ $9\frac{1}{2}$″	8′ 3″
„ diameter	3′ $5\frac{1}{8}$″	4′ 4″	4′ 6″	4′ 4″	5′ $1\frac{1}{4}$″	5′ 6″	5′ $1\frac{3}{4}$″	5′ 6″
„ pressure lbs./sq. in.	165	160	160	160	180	185	180	180
Tubes, number	115	206	192	206	281	239	226	262
„ diameter	$1\frac{3}{4}$″	$1\frac{3}{4}$″	$1\frac{7}{8}$″	$1\frac{3}{4}$″	$1\frac{3}{4}$″	2″	$1\frac{7}{8}$″	2″
„ Length	9′ $9\frac{5}{16}$″	11′ $0\frac{5}{8}$″	11′ $0\frac{3}{4}$″	11′ $0\frac{5}{8}$″	11′ $10\frac{5}{8}$″	11′ $11\frac{5}{8}$″	11′ $11\frac{11}{16}$″	15′ $5\frac{11}{16}$″
Heating surface, firebox sq.ft.	48	106·6	106·6	112	110	135·6	130·9	171
„ „ tubes	460	1,119·9	1,119·9	1,526·6	1,726·6	1,726·6	1,328·3	2,135
„ „ total	508	1,226	1,226	1,231·9	1,654·9	1,862·2	1,458·6	2,306
Grate area	8·5	25·5	25·5	25·5	34·0	34·0	26·1	39·3
Wheels, diameter	2′ $3\frac{1}{2}$″	2′ $10\frac{3}{4}$″	2′ $10\frac{3}{4}$″	2′ $10\frac{3}{4}$″	3′ $2\frac{1}{2}$″	4′	3′ 6″	3′ 9″
„ diameter	None	None	None	None	2′ $0\frac{1}{2}$″	None	None	None
Wheelbase, 1st group	4′	6′ $2\frac{3}{8}$″	6′ $3\frac{9}{16}$″	6′ $2\frac{3}{8}$″	13′	8′ 9″	7′ $8\frac{11}{16}$″	8′ 6″
„ 2nd „	4′	6′ $2\frac{3}{8}$″	6′ $3\frac{9}{16}$″	6′ $2\frac{3}{8}$″	13′	8′ 9″	7′ $8\frac{11}{16}$″	8′ 6″
„ total	17′	26′ 1″	25′ 6″	25′ $6\frac{15}{16}$″	38′ 9″	34′	29′ $8\frac{11}{16}$″	35′ 8″
Overall height	9′ $6\frac{1}{16}$″	12′ $1\frac{5}{8}$″	12′ 10″	12′ 10″	12′ 10″	12′ 10″	13′ 9″	13′ 6″
„ width	7′ $5\frac{3}{4}$″	8′ 4″	8′ $6\frac{1}{4}$″	8′ 10″	8′ 10″	9′	10′	10′
„ length	25′ $11\frac{13}{16}$″	37′ 11″	35′ 5″	36′ 11″	46′ 7″	13′ 6″	40′ 5″	49′ 9″
Water tanks . galls.	666	1,700	1,900	2,040	2,500	0	2,500	4,000
Coal bunkers t.-cwt.	1–10	2–10	3	110 cub. ft.	130 cub. ft.	7	4	4
Oil tanks	—	—	—	80 cub. ft.	95 cub. ft.	—	—	—
Weight, adhesive t.-cwt.	30	61	61	62	61–10	84–5	80–8	117–2
„ empty	18–3	47–2	46–4	48–8	58–6	70	60	90
„ in service	30	61	61	62	77–18	84–5	80–8	117–2

tried several types of articulated locomotives. The above * have been followed by others of the 2-6 + 6-2 class, and by 58-ton *Mallets* as well.

0-6 + 6-0 Meyer-Kitson Locomotives of the Taltal Ry. (Chile). —Gauge, 3 ft. 6 ins.

This railway system, the length of which is 272 km. (169 miles), is situated in the Chilian nitrate zone, and gives access to the interior by a line which has grades of 4·8 per cent.† The radius of the curves is 130 m. (426 ft.). The rails formerly weighed 20·3 kg. per metre (41 lbs. per yard), but have now been replaced with rails of 28 kg. per metre ($56\frac{1}{2}$ lbs. per yard).

The boilers of the *Meyer* locomotives ‡ are practically identical with those of the Colombian National Rys., and are also similar to those of the other metre-gauge *Meyer-Kitson* locomotives (such as those of the Leopoldina Ry.), and of other 3 ft. 6 ins. gauge locomotives.

0-6 + 6-0 Meyer-Kitson Locomotives of the Nitrate Rys.— Standard gauge.

This railway system is more important than those described above. It has a length of some 600 km. (373 miles). Access to the ports served by the system (Iquique and Pisagua), is

* Loads drawn by these locomotives :—

On a level	2,750 tons.
1 per cent. grade	719 ,,
2 per cent. grade	392 ,,
4 per cent. grade	185 ,,

† Taltal (the starting-point) is at an altitude of 12 m. (39 ft.). Bianca-Estella, at 134 km. (83·3 miles) is at an altitude of 2,809 m. (9,217 ft.) above sea-level.

‡ The following are the loads drawn at the usual speed of 13 to 16 km. an hour (8 to 10 miles) :—

On a level	2,964 tons
1 per cent. grade	734 ,,
2 per cent. grade	397 ,,
4 per cent. grade	186 ,,

as difficult as to the ports of the other lines in this region.* It has gradients of 4·47 per cent. compensated, and curves with a radius of 91·5 m. (300 ft.). These figures fully justify the employment of articulated locomotives which can ascend banks 31 km. (19¼ miles) in length, at a speed of 13·6 km. an hour (8·5 miles), with loads of 202 tons without replenishment of fuel or water.

These locomotives are provided with feed-water heaters, which consist of twenty-seven longitudinal elements located in the lower part of the rear water tank. The exhaust steam from the rear cylinders passes through the feed heater. The heating elements have an external diameter of 1·04 m. (3 ft. 4 ins). The length between the tube plates is 3·636 m. (11 ft. 6 ins.).

0-6 + 6-0 Meyer-Kitson Locomotives of the Jamaica Government Rys.—Standard gauge.

In these locomotives the exhaust from the rear cylinders was originally led through the rear tanks to a separate chimney. Subsequently the exhaust from these cylinders was led forward to the smoke-box, but this caused excessive draft.

Type 3.—Meyer-Kitson Locomotives with Separate Tender

Two railways only have introduced locomotives of this type.

0-6-2 + 0-6-2 Locomotives, Antofagasta (Chile) and Bolivia Ry.—Gauge, 2 ft. 6 ins. (0m.76) (Fig. 35).

This railway, which already owned some *Kitson-Meyer* six-coupled total adhesion locomotives, put into service a more powerful type of a new design. These have no side tanks,

* The following figures give an idea of the profile of the main lines :—

	Altitude.
Iquique	8 m. (26 ft.)
Santa-Rosa	876 m. (2,875 ft.)
Montevideo	1,161 m. (3,809 ft.)
Pisagua	2 m. (6½ ft.)
Nevel	1,101 m. (3,612 ft.)

TABLE 16.—PRINCIPAL DIMENSIONS OF MEYER-KITSON LOCOMOTIVES WITH CYLINDERS AT THE REAR OF EACH BOGIE AND WITH SEPARATE TENDERS

Gauge	2 ft. 6 ins.	3 ft. 6 ins.
Railway	Antofagasta (Chile) and Bolivia Ry.	South African Rys.
Builder	—	Kitson.
Date	1911	1904
Type	**0-6-2 + 0-6-2**	**0-6-0 + 0-6-0**
Cylinders, diameter	18″	16″
,, stroke	20″	24″
Boiler, centre line	6′ 10″	7′ 2″
,, diameter	5′ 6½″	5′ 0″ int.
,, pressure . lbs./sq. in.	160	180
Tubes, number	—	239
,, diameter	—	2″
,, length	—	13′ 9⅝″
Heating surface, firebox . sq. ft.	153	136
,, ,, tubes . ,,	1,725	1,727
,, ,, total . ,,	1,878	1,863
Grate area . ,,	3·95	—
Superheater surface ,,	40	None
Wheels, diameter	2′ 4″	None.
,, diameter	3′ 8″	4′
Wheelbase, one group	9′	8′ 6″
,, total locomotive	45′	34′
,, total locomotive and tender	—	58′ 4½″
Water tanks	0	(3,000)
Fuel bunkers	6	6
Overall height	13′ 3″	12′ 10″
,, length	—	66′ 5¼″
Weight, adhesive . t.-cwt.	—	83–3
,, in service ,,	94–14	83–3

which facilitates access to the mechanism of the engine. A separate tender, carried on two four-wheeled bogies, is provided and carries the total water supply and some 4 tons of coal in bags. The remainder of the coal (6 tons) is carried in a bunker behind the cab. The total weight of fuel carried is therefore 10 tons which is a large amount for a locomotive of so narrow a gauge.

In view of the high altitudes which the line reaches, the cab is completely enclosed and the engine runs cab foremost, the tender being attached to the smoke-box end of the locomotive.

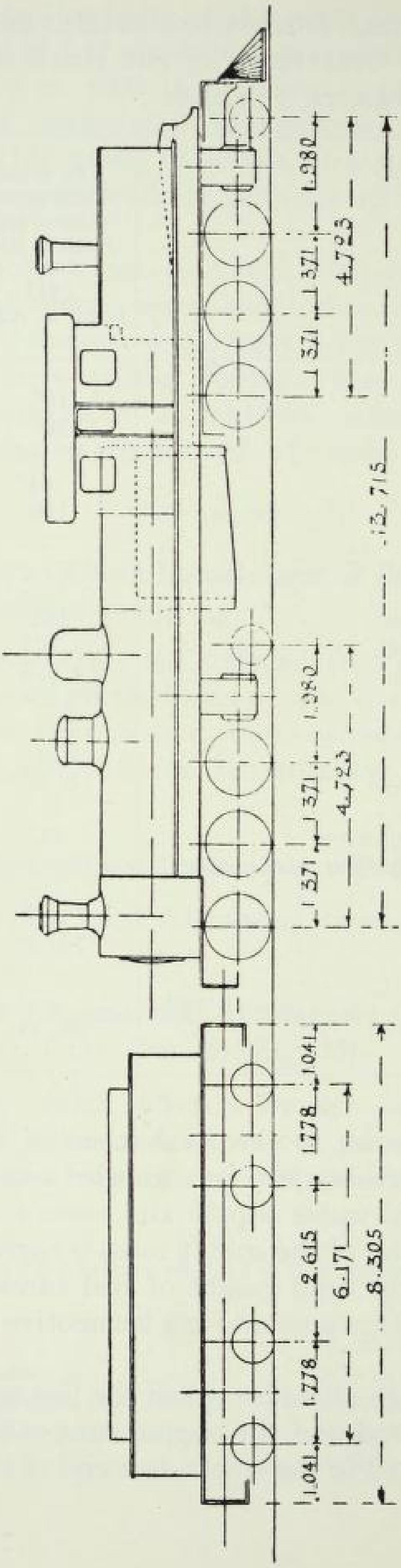


Fig. 35.—Meyer-Kitson 0-6-2 + 0-6-2 Tender Locomotive, Antofagasta (Chile) and Bolivia Ry. (2 ft. 6 ins. Gauge).

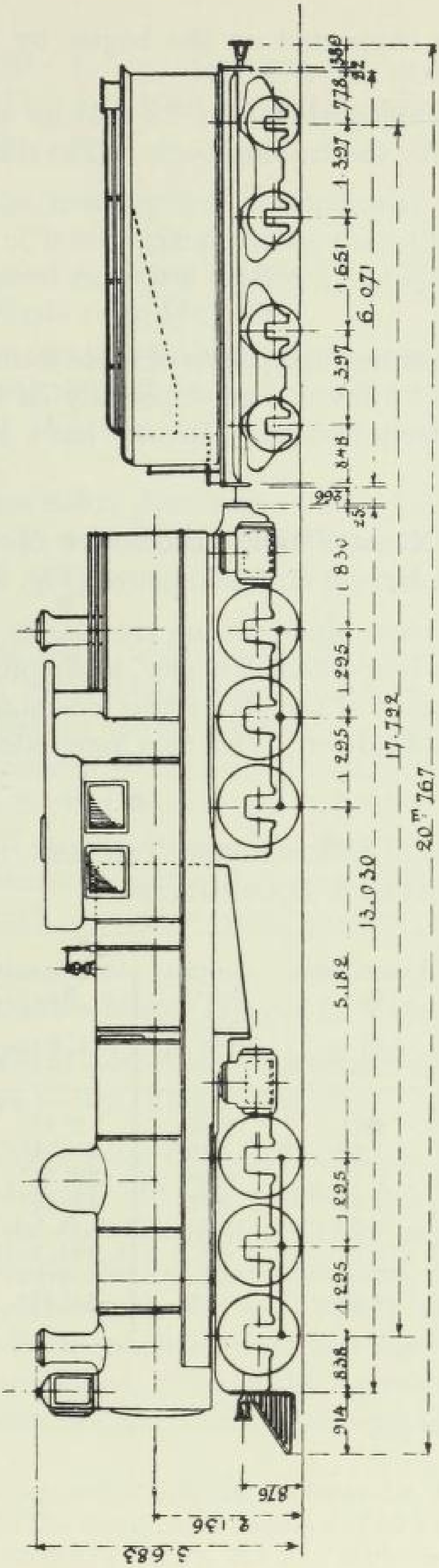


FIG. 36.—Meyer-Kitson 0-6 + 6-0 Tender Locomotive, Central South African Ry. (3 ft. 6 ins. Gauge).

The main frame is supported on the bogies by pivots and side and end slides.

The loads on the coupled wheels are 12 tons for the leading, and 12 tons 17 cwt. for the trailing bogie. The dimensions of the firebox are :—

Length	9 ft. (2m.74).
Depth	4 ft. 3 ins. to 4 ft. 9 ins. (1m.30 to 1m.45).

It will be noticed that the dimensions of these locomotives are exceptional for a 2 ft. 6 ins. gauge, especially as the loading gauge is not particularly liberal. *Garratts* have now superseded them.

0-6 + 6-0 Tender Meyer-Kitson Locomotive of the former Central South African Ry.—3 ft. 6 ins. gauge (Fig. 36).

As in the previous case, there are no side tanks, a separate tender, carried on two four-wheeled bogies, being provided.

The leading dimensions of the above two locomotives will be found in Table 16, and those of the tenders hereunder.

TABLE 17.—PRINCIPAL DIMENSIONS, TENDERS OF MEYER-KITSON LOCOMOTIVES

Railway . . .	Antofagasta Ry.	Central South African Ry.	Antofagasta Ry.	Central South African Ry.
Gauge . . .	0·61 m.	1·067 m.	2 ft. 6 ins.	3 ft. 6 ins.
Wheels, diameter . m.	0·71	0·85	2′ 4″	2′ 9½″
Wheelbase, bogie . m.	1·78	1·40	5′ 10¾″	4′ 7⅛″
,, total . m.	6·17	4·45	20′ 2⅞″	14′ 7¼″
Distance pivots . m.	4·39	3·05	14′ 4⅞″	10′ 0⅞″
Water tanks . cub. m.	5·2	13·7	cub. ft. 1,115	3,000
Coal bunkers . . t.	4·0	6·1	t.-cwt. 3–19	6
Weight in service . t.	27·4	38·5	t.-cwt. 27	38
Length of frame . m.	6·48	6·07	21′ 3⅛″	19′ 11″

SUB-GROUP I. C.—MEYER-KITSON LOCOMOTIVES WITH CYLINDERS AT THE OUTER ENDS OF EACH BOGIE.

This is the most recent development of the system, and, as such, is of more interest than the others. The two latest examples were supplied to the Colombian National and to the Kalka-Simla railways.

The bogies are thrown yet further apart than in the previous types, showing the influence of the *Garratt* type, which demonstrated that this was no drawback and has indeed, certain advantages.

Special provision has been made for ensuring maximum flexibility, not only in the horizontal, but also in the vertical direction, as the locomotives are apt to take a most twisted position.

The water space is proportionally increased, and in recent types, so as to maintain easy access to the firebox and the central portion of the locomotive, the tanks have been severed midway, a portion being carried well forward, and another one kept at the back of the cab and extended.

The use of guiding bissels has been rationally extended.

Other features do not call for special comment and include all items which constitute sound modern practice.

Class A.—Double-Mogul (2-6 + 6-2) Meyer-Kitson Locomotives

Double-Mogul Locomotive Ferrocaril de Girardot (Colombian National Rys.)—3 ft. gauge (Fig. 38).

This line runs from Girardot (altitude 325 m.; 1,066 ft., to Facativa (altitude 2,614 m.; 8,576 ft.). The summit which is situated at the 125th km. (78th mile), is at + 2,729 m. (9,088 ft.) above sea level. Grades of 1 in 25 are frequent and lengthy, together with curves of 260 ft. radius.*

Care has been taken to maintain easy access to all organs, and this is obtained, despite the narrowness of the gauge, by the use of exterior bar framing and by a special disposition of

* These locomotives operate between La Mesa (altitude, 961 m.; 3,153 ft.), and the terminus, a distance of 53 km. (33 miles).

Minimum radius of curves, 213 ft. Rails weigh 60 lbs. per yard.

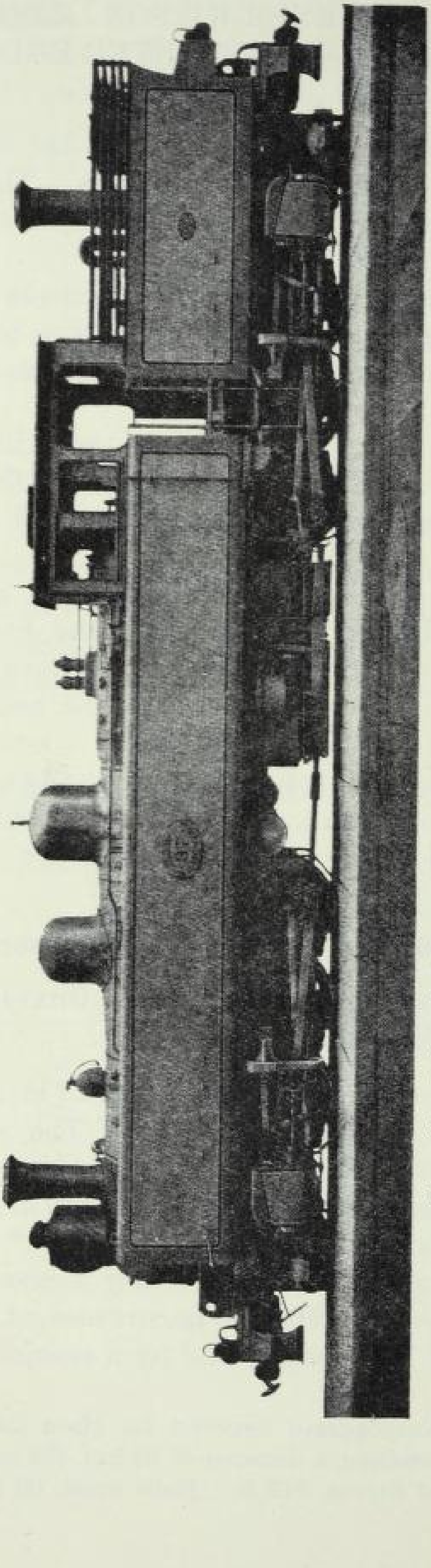


Fig. 37.—2-6 + 6-2 Meyer-Kitson Locomotive, Antofagasta (Chile) and Bolivia Ry. (2 ft. 6 ins. Gauge.)

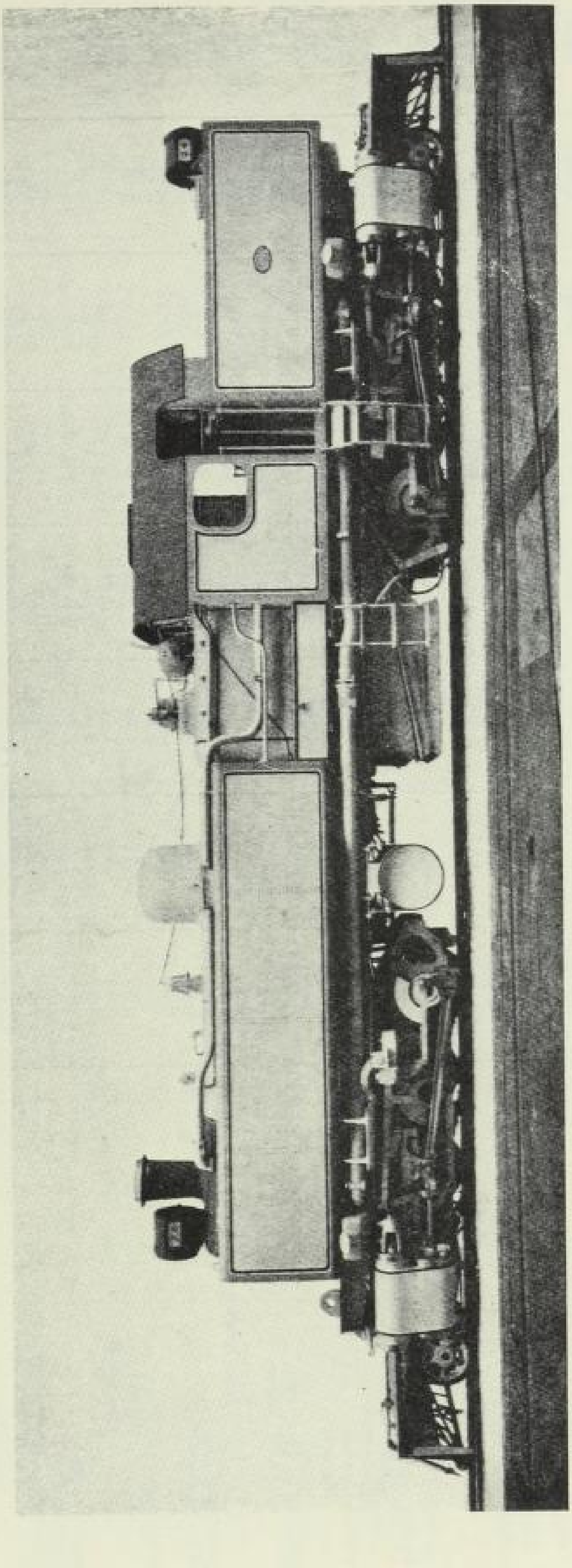


FIG. 38.—2-6 + 6-2 Meyer-Kitson Locomotive, F. C. de Girardot (Colombian National Fys.). (3 ft. Gauge.)

Table 18.—Principal Dimensions of Meyer-Kitson Locomotives with Cylinder at Extreme Ends

Gauge	0·76	0·76	2′ 6″	3′	1 m.	1 m.	1·067	1·672
Railway	Antofagasta.	Antofagasta.	Kalka-Simla Ry.	F. C. de Girardot.	Trans-andine Ry.	Leopoldina Ry.	Manila Ry.	Gt. Southern of Spain.
Builder	Kitson.	Kitson.	Kitson.	Kitson.	Kitson.	Kitson.	Kitson.	Kitson.
Date	1911.	1908.	1928.	1927.	1909.	1908.	1913.	1908.
Type	**2-6 + 6-2**	**2-6 + 6-4**	**2-6-2 + 2-6-2**	**2-6 + 6-2**	**1-8 + 6-0** *	**2-6 + 6-4**	**2-6 + 6-2**	**2-8 + 8-0**
Cylinders, diameter . . . m.	0·36	0·36	0·34	0·39	0·42 × 0·48 Rack :	0·36	0·41	0·38
„ stroke . . . m.	0·46	0·46	0·36	0·51	0·33 | 0·46 0·36 | 0·48	0·46	0·51	0·61
Boiler, centre line . . . m.	1·83	1·67	1·73	2·10	2·13	2·07	2·13	2·59
„ diameter . . . m.	1·52	1·32 ext.	1·32	1·65	1·52 ext.	1·57	1·67	1·68
„ pressure . . . kg./sq. cm.	12·1	cm. 12·1	12·7	13·4	14·1	12·3	11·3	12·7
Tubes, number . . .	242	179	16–86	26–166	292	192	193 + 24 + 38	218
„ diameter . . . mm.	44	48	140–51	136–51–380	48	48	133	51
„ length . . . m.	4·57	3·66	4·11	4·04	3·76	3·83	3·85	4·70
Heating surface, firebox . . . sq. m.	12·0	12·5	10·2	14·4 + 1·0	12·1	10	13·4	13
„ „ tubes . . . „	166·5	154·5	84·1	152·0	164·3	109·7	149·7	163·6
„ „ total . . . „	166·5	167	94·3	167·4	176·4	119·7	163·1	176·6
„ „ superheater . . . „	27·9	None.	19·7	35·3	None.	None.	33·6	None.
Grate area . . . „	2·8	2·8	2·5	3·3	2·9	2·3	3·3	3·2
Wheels, diameter . . . m.	0·69	0·69	0·53	0·66	None.	0·66	0·62	0·84
„ „ . . . m.	0·95	0·95	0·76	0·95	0·91	0·88	0·99	1·22
Wheelbase, rigid . . . m.	—	3·89	1·83	2·52	—	—	2·74	4·57
„ first group . . . m.	3·89	5·14	4·57	3·04	3·20	4·15	3·94	6·79
„ second group . . . m.	3·89	5·14	4·57	3·04	2·72	5·54	3·94	4·57
„ total . . . m.	12·35	12·47	13·66	14·31	9·51	12·85	12·09	15·01
Water tanks . . . cub. m.	14·1	17	6·1	11·36	8·3 + 0·5	13·6	13·6	10·5
Coal bunkers . . . t.	4·1	4·5	3·1	3·7	2·5	5·1	4·1	2·5
Weight, adhesive . . . t.	61·3	60·5	49·0	—	51·4	56·1	72·5	91·7
„ empty . . . t.	67·0	61·1	—	—	83·6	57·1	70·4	82·1
„ in service . . . t.	90·6	86·3	69·7	—	92·2	80·3	96·2	102·6
Overall height . . . m.	3·74	3·50	3·25	3·77	3·76	3·85	3·91	4·27
„ width . . . m.	2·53	2·54	2·26	—	2·87	2·44	2·67	2·97
„ length . . . m.	15·34	15·16	15·30	16·09	14·30	14·51	14·73	18·32

* Mixed rack and adhesion locomotive.

TABLE 18A.—PRINCIPAL DIMENSIONS, MEYER-KITSON LOCOMOTIVES WITH CYLINDERS AT EXTREME ENDS

Gauge	2′ 6″	2′ 6″	2′ 6″	3′	Metre.	Metre.	3′ 6″	5′ 6″
Railway	Antofagasta (Chile) and Bolivia Ry.	Antofagasta (Chile) and Bolivia Ry.	Kalka-Simla Ry.	F. C. de Girardot (Colombia).	Transandine Ry.*	Leopoldina Ry. (Brazil).	Manila Ry.	Gt. Southern of Spain Ry.
Builder	Kitson.	Kitson.	Kitson.	Kitson.	Kitson.	Kitson.	Kitson.	Kitson.
Date	1911.	1908.	1928.	1927.	1909.	1908.	1913.	1908.
Type	**2-6 + 6-2**	**2-6 + 6-4**	**2-6-2 + 2-6-2**	**2-6 + 6-2**	**0-8 + 6-0**	**2-6 + 6-4**	**2-6 + 6-2**	**2-8 + 8-0**
Cylinders, diameter	14″	14″	13½″	15¼″	16½″ 13″ 18″	14″	16″	14¾″
,, stroke	18″	18″	14″	20″	19″ 14″ 19″	18″	20″	24″
Boiler, centre line	6′	5′ 6″	5′ 6″	6′ 10½″	7′	6′ 9⅜″	7′	8′ 6″
,, diameter	5′	4′ 4″	4′ 4″	5′ 5″	5′	4′ 6″	5′ 6″	5′ 6″
,, pressure . lbs./sq. in.	180	180	180	190	200	175	160	180
Tubes, number	242	179	16–86	166–26–104	292	192	24–193	218
,, diameter	1¾″	1¾″	5¼″–2″	2″–5⅜″–1½″	1⅞″	1⅞″	5¼″–1⅞″–1½″	2″
,, length	15′	12′	13′ 6″	13′ 3″	12′ 4″	12′ 6¾″	12′ 7½″	15′ 5¼″
Heating surface, firebox . sq. ft.	129	104·3	110	155-11 arch †	130·2	107·3	136·5	139·9
,, ,, tubes ,,	1,663	1,054·7	904·7	1,636·5	1,767·8	1,183·9	1,612·2	1,759·9
,, ,, total ,,	1,792	1,159	1,014·7	1,802·5	1,898·0	1,291·1	1,748·7	1,890·2
,, ,, superheater ,,	None.	None.	212·0	380·0	None.	None.	352·0	None.
Grate area ,,	30	25·2	27	35·5	31·0	25·2	35·0	36·2
Wheels, diameter	2′ 3″	2′ 3″	2′ 6″	2′ 2″	None.	2′ 2″	2′ 2½″	2′ 9″
,, ,,	3′ 1½″	3′ 1½″	1′ 9″	3′ 1½″	3′	2′ 10¾″	3′ 3″	4′ 0″
Wheelbase, rigid	—	—	6′ 0″	8′ 3″	—	—	9′ 0″	—
,, first group	12′ 9″	12′ 9″	15′ 0″	13′ 3″	10′ 6″	13′ 7½″	12′ 11″	22′ 3″
,, second group	12′ 9″	16′ 10½″	15′ 0″	13′ 3″	8′ 11″	18′ 2″	12′ 11″	13′ 16½″
,, total	40′ 6″	40′ 1½″	44′ 10″	44′ 3″	31′ 2¼″	42′ 2″	39′ 7″	52′ 6⁵⁄₁₆″
Pivot-centres	—	—	26′ 3″	—	—	—	—	—
Overall, height	12′ 3″	11′ 6″	10′ 8″	12′ 4½″	13′ 10″	12′ 5¼″	12′ 10″	14′ 10″
,, width	8′ 3¼″	8′ 4″	7′ 5″	—	9′ 5¼″	8′	8′ 9″	9′ 9¼″
,, length	50′ 3¾″	49′ 9″	52′ 8¾″	52′ 9¾″	46′ 11″	47′ 11″	48′ 4″	60′ 10″
Water tanks . galls.	3,100	3,750	1,350	2,500	1,800	3,000	3,000	2,300
Fuel bunkers . t.-cwt.	4	4–10	3	3–10	2–10	5	4	2–10
Weight, adhesive ,,	60–14	59–15	48–12 empty	91 & 62	50–12	56–1	71–9	90–12
,, empty ,,	66–0	60–15	—	73–0	82–8	56–1	69–13	80–16
,, in service ,,	89–12	85–0	68–12	94–8	90–16	80–0	92–4	101–10

* Mixed rack and adhesion locomotive.

† Two-brick arch tubes, 2 ins. diameter.

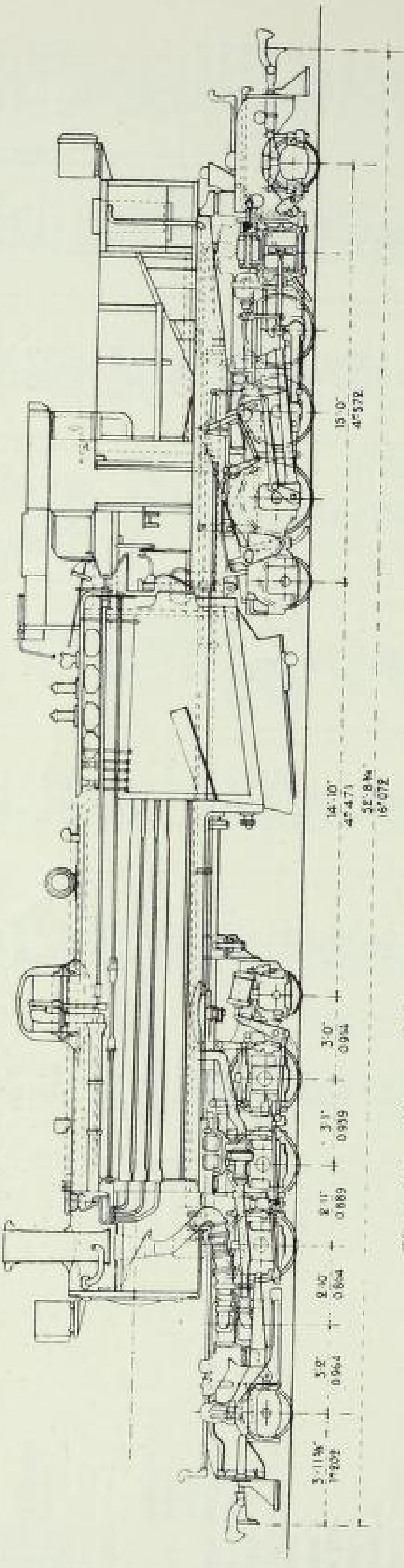


Fig. 39.—Meyer-Kitson 2-6-2 + 2-6-2, Kalka-Simla Ry. (British India).
(2 ft. 6 ins. Gauge.)
Built by Kitson & Co., Leeds.

the tanks, which is also found in other types of articulated locomotives. They are severed above the firebox, a portion of them being well forward, and another and not inconsiderable one, behind the cab.

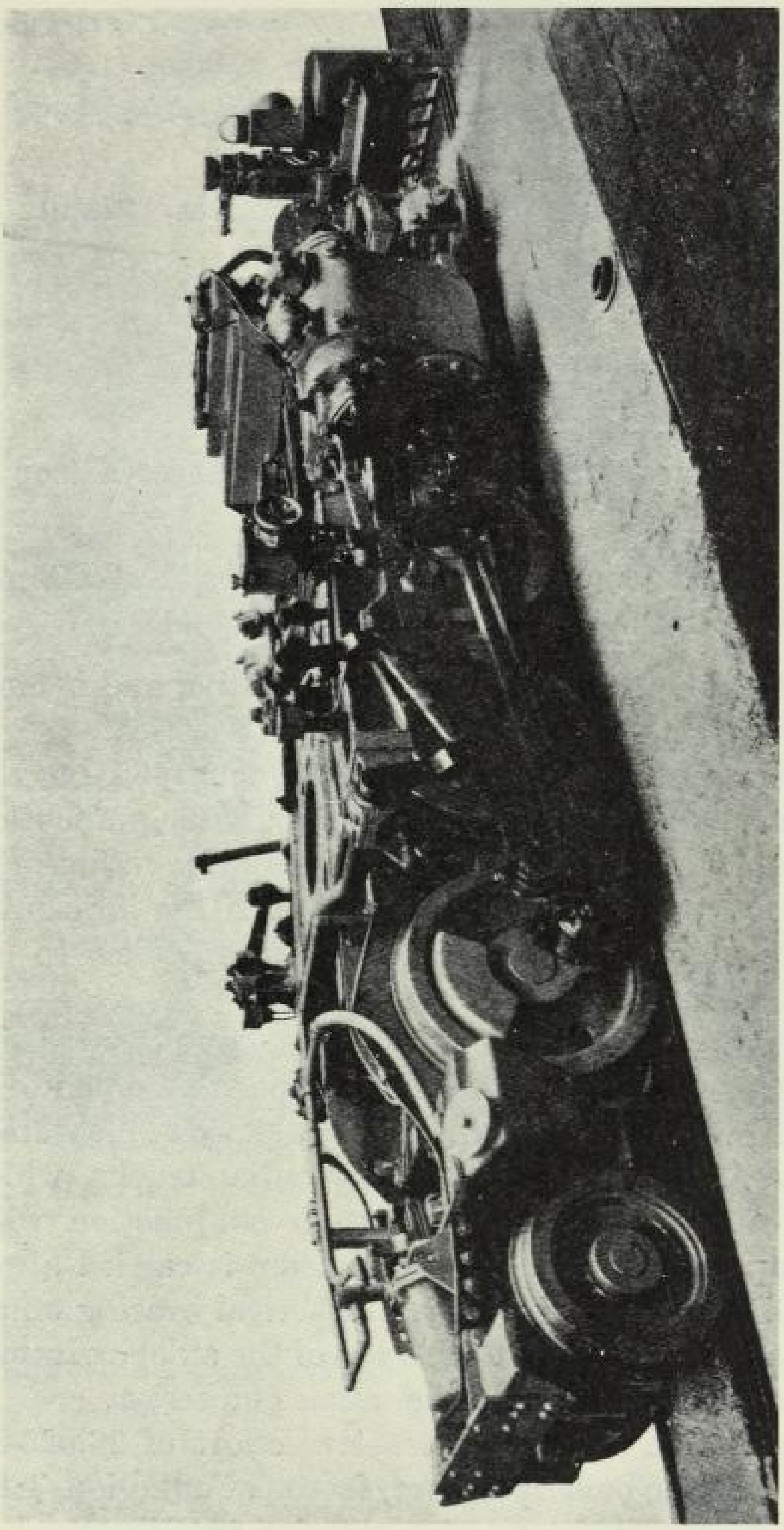


FIG. 40.—Steam Bogie of Meyer-Kitson Locomotive, Kalka-Simla Ry.

Two arch tubes, 3 ins. in diameter, partly support the brick arch.

The second pair of coupled wheels of each bogie is flangeless.

These locomotives develop 40,000 lbs. tractive effort, interesting ratios being as under :—

$\frac{\text{Adhesive weight (fully loaded)}}{\text{85 per cent. L.P. tractive force}}$	. .	4·53
$\frac{\text{Rated tractive force (85 per cent.)}}{\text{Equivalent (1·33) heating surface}}$	. .	17·3

Double-Mogul Meyer-Kitson Locomotives, Manila Ry.—3 ft. 6 ins. gauge.

These locomotives have Robinson superheaters. They call for no comment.

Class B.—Double-Prairie (2-6-2 + 2-6-2) Meyer-Kitson Locomotives

Double-Prairie Meyer-Kitson Locomotives, Kalka-Simla Ry. (India).—2 ft. 6 ins. gauge (Figs. 39, 40 and 41).

This is, so far, the latest *Meyer* locomotive and it embodies all the features making for sound modern practice.

The Kalka-Simla Ry. rises from altitude 2,143 ft. to altitude 6,870 ft. in the course of its 60 miles, maximum gradients reaching 4 per cent., with curves having a minimum radius of 120 ft. To meet such tortuous conditions (both in the horizontal and in the vertical plane) especial care has been taken to provide extreme flexibility in all directions.

On each bogie the spring gear is compensated in two groups. The contour of the tyres has been modified owing to the excessive wear that is expected, and special measures have been taken in connection with the radial trucks, which are arranged with vertical movement, in conjunction with the spring compensation, whose central beam is carried above the axle of a pivot. This pivot has a spherical bearing on a loose rubbing plate, which slides on the top of the axlebox frame.

The illustrations show the other items of interest.

This locomotive develops a tractive effort of 26,025 lbs. at 85 per cent. of the boiler pressure, factor of adhesion, 4·17. It is destined to haul 160 tons at a speed of 10 miles per hour on the steep gradients. It should also be remembered that the longest of these is no less than 24 miles long (save for short stretches through the stations).

Class C.—Meyer-Kitson 2-8 + 8-0 Locomotives

2-8 + 8-0 Meyer-Kitson Engines for the Gt. Southern Ry. of Spain.—Gauge, 1·672 m. (5 ft. 6 ins.).

These locomotives are the only ones hitherto built with eight coupled axles. It is also believed that they are the only ones which have been supplied to a broad gauge railway.

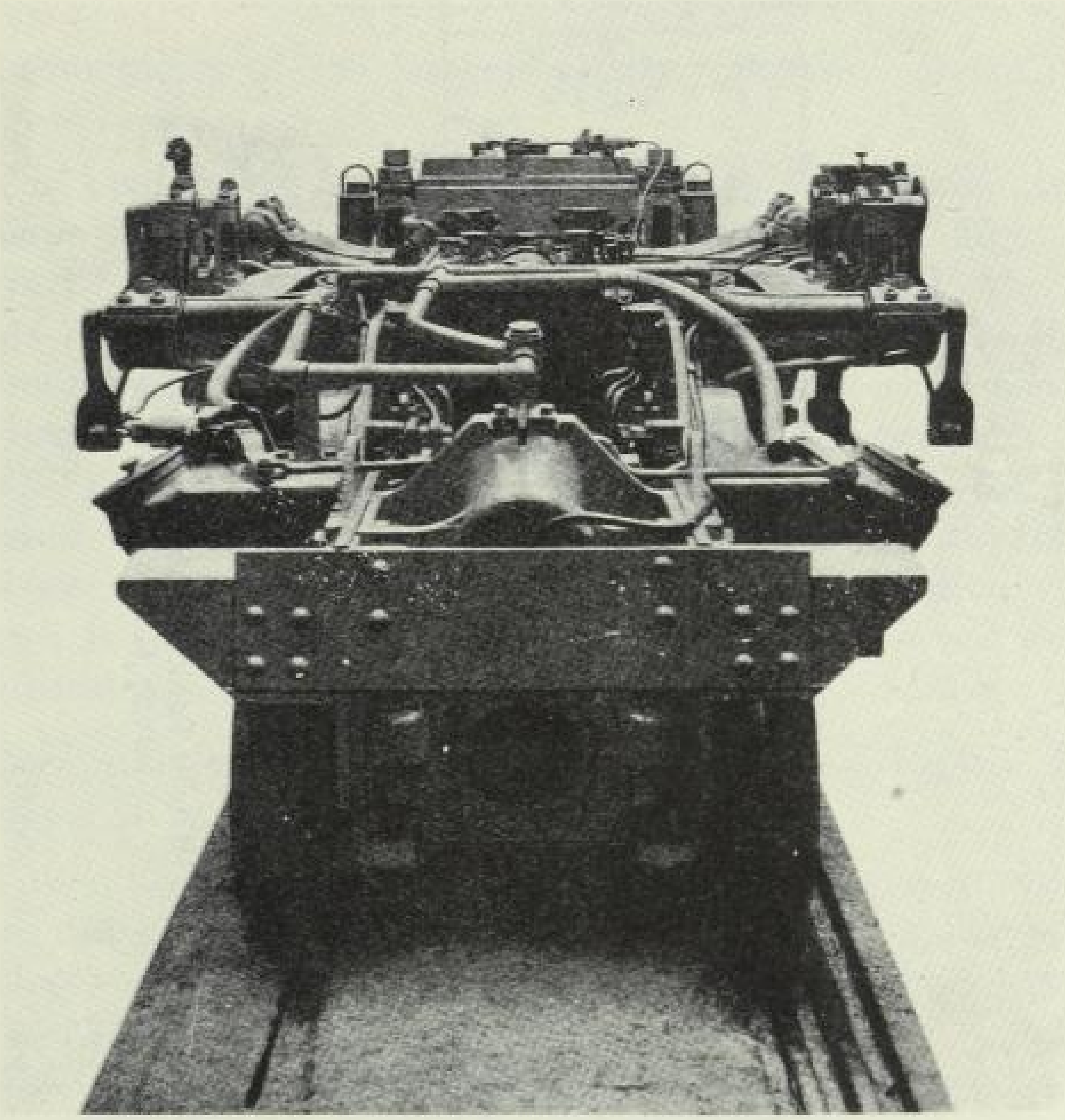


Fig. 41.—Front View of Bogie, Meyer-Kitson Locomotive, Kalka-Simla Railway.

The Meyer type was selected in order to handle heavy mineral traffic on a relatively light road bed.* Although the total

* The following table gives the loads hauled by these locomotives at speeds of 13 to 16 km. (8 to 10 miles) per hour :—

Level	3,584	metric tons
1 per cent. grade	865	,,
$1\frac{1}{4}$ per cent. grade	677	,,
2 per cent. grade	456	,,
4 per cent. grade	198	,,

These data, as also other particulars regarding the loads drawn by these engines, have been furnished by their builders.

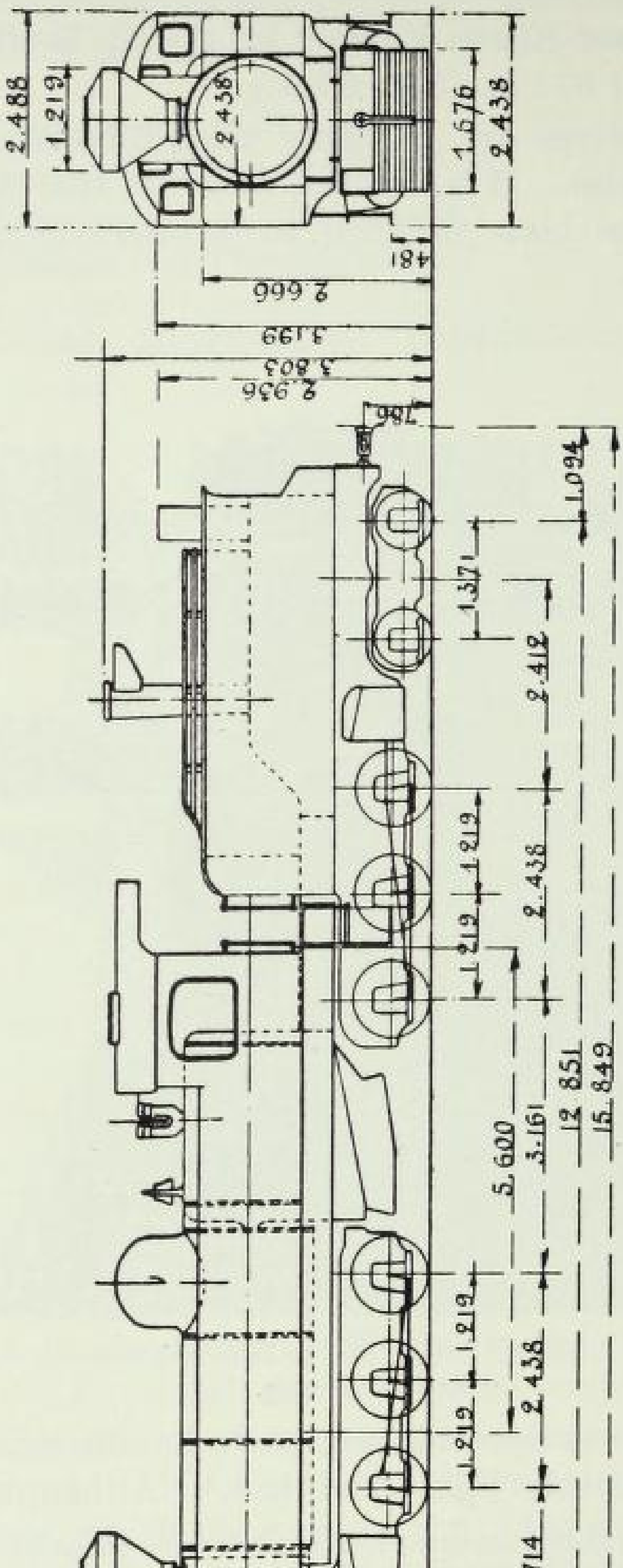


FIG. 42.—2-6 + 6-4 Meyer-Kitson Tank Locomotive, Leopoldina Ry. (Brazil). (Metre Gauge.)

weight available for adhesion is no less than 90 tons 16 cwt., the average load per axle is only 11 tons 7 cwt. This justifies the adoption of articulated locomotives for this service. The driven axles are the third of each coupled group.

Type 2.—The 2-6 + 6-4 Meyer-Kitson Locomotive with Two Driven and One Undriven Bogies

Locomotives of the Leopoldina Ry. (Brazil).—Metre gauge (Fig. 42).

The Leopoldina Ry. introduced this type of locomotive on its lines with heavy grades, where very powerful engines were needed.* Also the majority of the weight which the road could carry was absorbed by the locomotive itself. The frames therefore extended backwards so that fuel and water could be carried in a sort of pseudo-tender located behind the cab.

The second set of driving wheels is located in the usual position and supports the rear end of the locomotive, the cab and the front part of the tender. The rear portion of the tender is carried by an additional bogie which is not driven. The arrangement of the axles is therefore 2-6-0 + 0-6-4.

Locomotives of the Antofagasta (Chile) and Bolivia Ry.—Gauge 0·76 m. (2 ft. 6 ins.).

This railway ascends the Cordillera of the Andes in order to reach the elevated plateau of Bolivia and La Paz, the capital of that state. It thus rises to a height of more than 4,000 m. (over 13,000 ft.) above sea level.†

The lines are 76 cm. (2 ft. 6 ins.) gauge up to Oruro, km. 924 (mile 574), altitude 3,694 m. (12,120 ft.). Beyond this point they are of metre gauge. The gradients are as steep as 3·2 per

* The following are the loads hauled by these locomotives at speeds of 13 to 16 km. (8 to 10 miles) per hour :—

Level	3,026 tonnes
1 per cent. grade	781 ,,
1¼ per cent. grade	614 ,,
2 per cent. grade	420 ,,
4 per cent. grade	192 ,,

† Ollagüe, at km. 435 (mile 270½), is 3,696 m. (12,126 ft.) high. Viacha is at km. 1,126 (mile 710), and is 29 km. (18 miles) from La Paz. The maximum height is at Punte-Alto, 4,788 m. (15,710 ft.), on the Conchi branch.

cent. on the main line,* and the radius of some curves is as small as 100 m. (328 ft.). All these circumstances favour the use of articulated locomotives.

Special measures had to be taken to counteract the effects of the extreme dryness of the country. When *Meyer* engines were adopted, the ordinary capacity of the water tanks was increased. Besides side tanks running the full length of the boiler, the first of these locomotives was provided with additional water tanks located behind the cab and supported by a supplementary bogie, not driven.† Subsequent locomotives had separate tenders.

Type 3.—The Meyer-Kitson Combined Rack and Adhesion Articulated Locomotives

Owing to their flexibility and to the fact that they have two engines driving two separate trucks, it would seem, at first sight, that articulated locomotives would be particularly adaptable to mountain railway traffic. But so far, the data that have been collected are insufficient for us to form a definite opinion on the subject.

0-8 + 6-0 Meyer-Kitson combined Rack and Adhesion Locomotives with Auxiliary Engine, Transandine Ry.—Metre gauge.

This line crosses the Cordillera of the Andes,‡ whose slopes have steep declivities which are surmounted by stretches of

* There are gradients of 4·7 per cent. on the Conchi branch.

† The following are the loads hauled by the two locomotives above referred to, at speeds of 13 to 16 km. (8 to 10 miles) per hour :—

Railway Gauge	Antofagasta. 76 cm. (2 ft. 6 ins.).	Leopoldina. Metre.
Level	2,800 tonnes	3,026 tonnes
1 per cent. grade	737 ,,	781 ,,
2 per cent. grade	392 ,,	420 ,,
4 per cent. grade	174 ,,	192 ,,

The overall length of these locomotives is 18·29 m. (60 ft.).

‡ The distance from Valparaiso to Los Andes by the broad gauge line of the Chilian State Rys. is 139 km. (84·5 miles). Then come the metre gauge sections of the Chilian Transandine Ry., 70 km. in length

rack railway. The gradients are 2·5 per cent. on the ordinary sections of the line, and as much as 8 per cent. on the Chilian side and 6·5 per cent. on the Argentine side, for the rack-rail sections.

The minimum radius of the curves is 120 m. (6 chains) on the ordinary sections, and 200 and 180 m. respectively (10 and 9 chains) on the rack sections.

The weight of the rails is only 25 and 27·5 kg. per metre (50·5 and 55·5 lbs. per yard).

Combined locomotives of various kinds have been tested, amongst them being a *Meyer-Kitson* articulated, and an *Esslingen* semi-articulated locomotive.

The first *Meyer-Kitson* locomotive was delivered in 1907. The idea was that the front bogie should constitute an ordinary adhesion engine capable of hauling the locomotive up the steepest gradient (8 per cent.) and that the rear bogie, with its two geared pinions and adhesion carrying wheels, should haul the weight of the train.

An auxiliary engine was added on the front bogie, with the object of driving a third pinion. This necessitated a reduction of the heating surface so as to find room for it.

The front unit had outside frames, 3 ft. diameter (0m.91) wheels, and cylinders 16½ ins. by 19 ins. (0m.42 by 0m.48).

The rear bogie's wheels were ordinary carrying wheels, whose axle bearings carried inside frames. These served in turn as outside frames for the two rack pinions. These were operated by the means of two cylinders, 18 ins. by 19 ins. (0m.46 by 0m.48), which operated the first rack pinion, to which the other was coupled.

As it was feared that the wheels of the front bogie might slip on the 8 per cent. grades when these were icebound and have insufficient adhesion, an auxiliary rack engine was added. It consisted of a pair of outside inclined cylinders, 13 ins. by 14 ins. (0m.33 by 0m.36), which drove a single rack pinion of different diameter to the others. The boiler was unable to furnish steam to six cylinders, so when travelling on the rack

(43·5 miles), and of the Argentine Transandine, 161 km. (100 miles); and, finally, the broad gauge line of the Buenos Ayres and Pacific Ry., 1,045 km. (649·5 miles) in length, from Mendoza to Buenos Ayres.

The summit level is in the Las Cuevas international tunnel at a height of 3,190 m. (10,466 ft.) above sea level.

section, those cylinders which correspond to the rack engines were alone employed.

One of the main difficulties resided in the fact that the line had been built for 40-ton locomotives hauling 60-ton trains. The track was too light for heavy work, yet traffic demanded that greater power be provided, hence one of the reasons for having recourse to locomotives such as these, with a large number of wheels grouped into two sets.

The *Shay* type of geared locomotive * was already in use and had given satisfactory results, especially during construction work, but it was too slow on the adhesive sections, where it ran at a speed of 15 km. an hour only (9 miles).

The new locomotives were to haul a maximum of 140 tons up 8 per cent. gradients, at a speed of 10 km. an hour (6·2 miles) and 15 km. an hour downwards (9·3 miles), and at a speed of 30 km. an hour (18·6 miles) on the adhesive sections where gradients reached 2·5 per cent. and the radius of curves was 100 m. (5 chains) only.

A locomotive of the first type of *Meyer-Kitson* locomotive, provided with an auxiliary engine, was put into service in 1907, and was followed by others in 1908 and 1909.

Several improvements were then made with a view of reducing maintenance of locomotives and track, and the 1911 type had no longer any auxiliary engine.

It was in this same year that the *Esslingen* type of semi-articulated locomotive was put into service and the performance of the various types was closely checked.

The 1911 Altered Type, without Auxiliary Engine

Experience extending over several years had shown the weak points of these locomotives.

The auxiliary engine's pinion worked too fast and suffered a good deal, and as its use precluded that of the adhesion bogie's driving wheels the small rack engine was bodily removed, and the working of the locomotive greatly improved thereby.

The rack pinions of the rear engine were fixed to the main frame and not to a suspended frame, as is more usual, so that

* This was a 59-ton 4 + 4 + 4 locomotive with a gear ratio of 1 : 2·21. It hauled 80 tons up the 8 per cent. gradients ; a repression brake helped to check the load on the descent.

springs should be able to counterbalance the action caused by inequalities of the rails and rack. Whether this alteration is advisable or the reverse remains to be proved.

The 1912 Type, Argentine Transandine Ry.

This locomotive embodied all the above, and other alterations.*

Principal dimensions :—(Table 19.)

Cylinders, adhesion	16½ ins. by 19 ins.
,, rack	18½ ins. by 19 ins.
Boiler pressure	200 lbs. per sq. in.
,, diameter	5 ft. 3 ins.
Tubes, number	292
,, diameter	1⅞ ins.
Heating surface, firebox	140 sq. ft.
,, tubes	1,900 sq. ft.
,, total	2,040 sq. ft.
Grate area	30 sq. ft.
Overall height	13 ft.
,, length	47 ft. 7 ins.
Wheels, diameter	3 ft.
Wheelbase, each bogie	10 ft. 6 ins. and 8 ft. 11 ins.
,, between bogies	12 ft. 5½ ins.
Tractive force, adhesion	20,000 lbs.
,, rack	34,000 lbs.

* See Henderson, *Proceedings Institute Civil Engineers*, Vol. CXCV.; and Lucy, Vol. CCII.

GROUP II.—THE FAIRLIE GROUP OF LOCOMOTIVES

SUB-GROUP II. A.—THE EARLY TYPES

As always happens, a certain number of unsuccessful types on this principle were tried before *Fairlie* made it a practical success. Indeed, early examples go back to the very beginnings of railways.

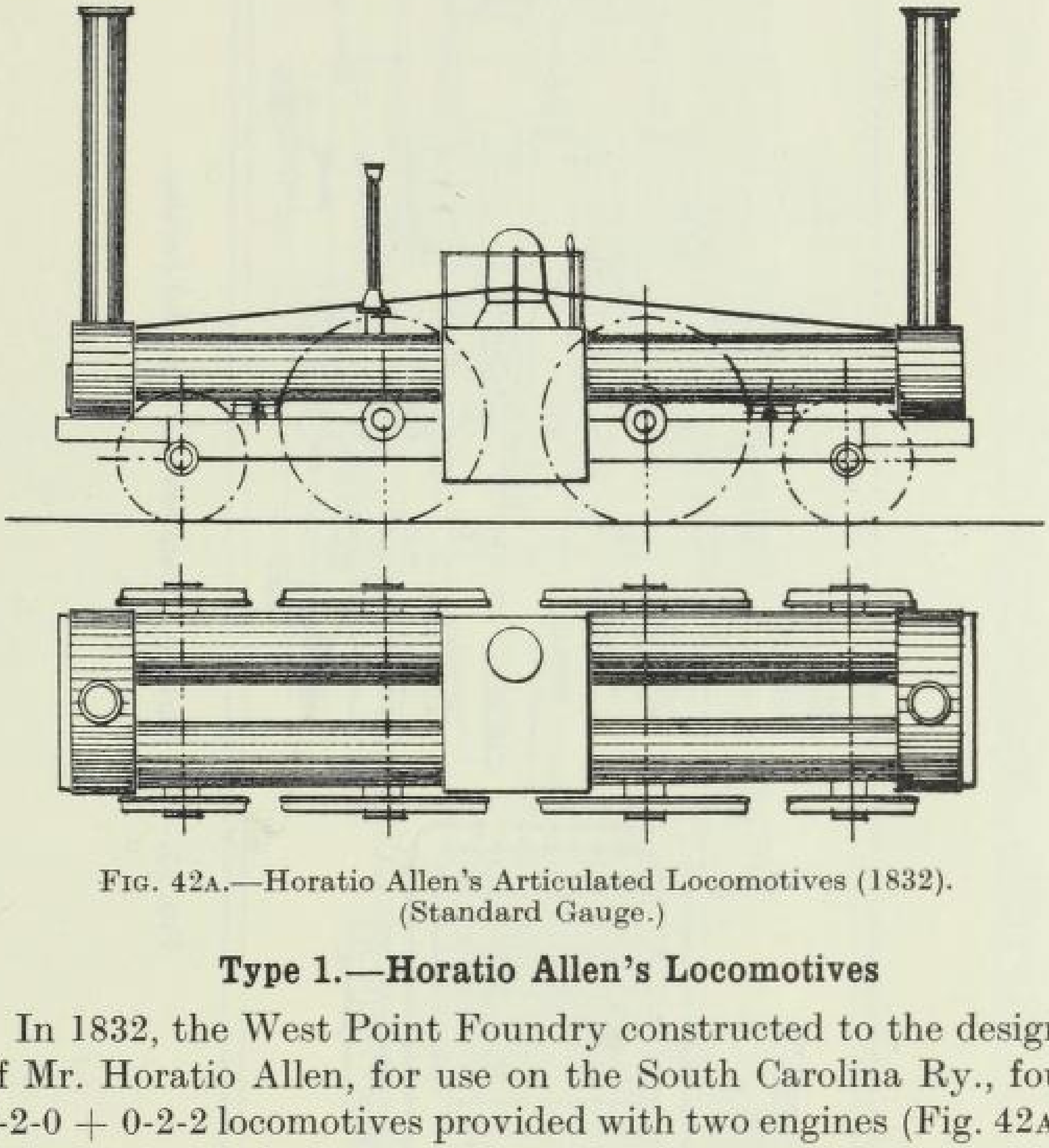


FIG. 42A.—Horatio Allen's Articulated Locomotives (1832). (Standard Gauge.)

Type 1.—Horatio Allen's Locomotives

In 1832, the West Point Foundry constructed to the designs of Mr. Horatio Allen, for use on the South Carolina Ry., four 2-2-0 + 0-2-2 locomotives provided with two engines (Fig. 42A). It had a double boiler, on either side of a central firebox which descended between the bogies.

Each half of the double boiler had two barrels set side by side, with a free space between them. Each of the two driving axles formed a bogie connected to the boiler by a centre pin. Each boiler barrel rested on rollers secured to the side frames of the bogies. There were only two cylinders, one at each end, located on the centre line of the locomotive ; each exhausted into a chimney at the same end. The connecting rods driving the

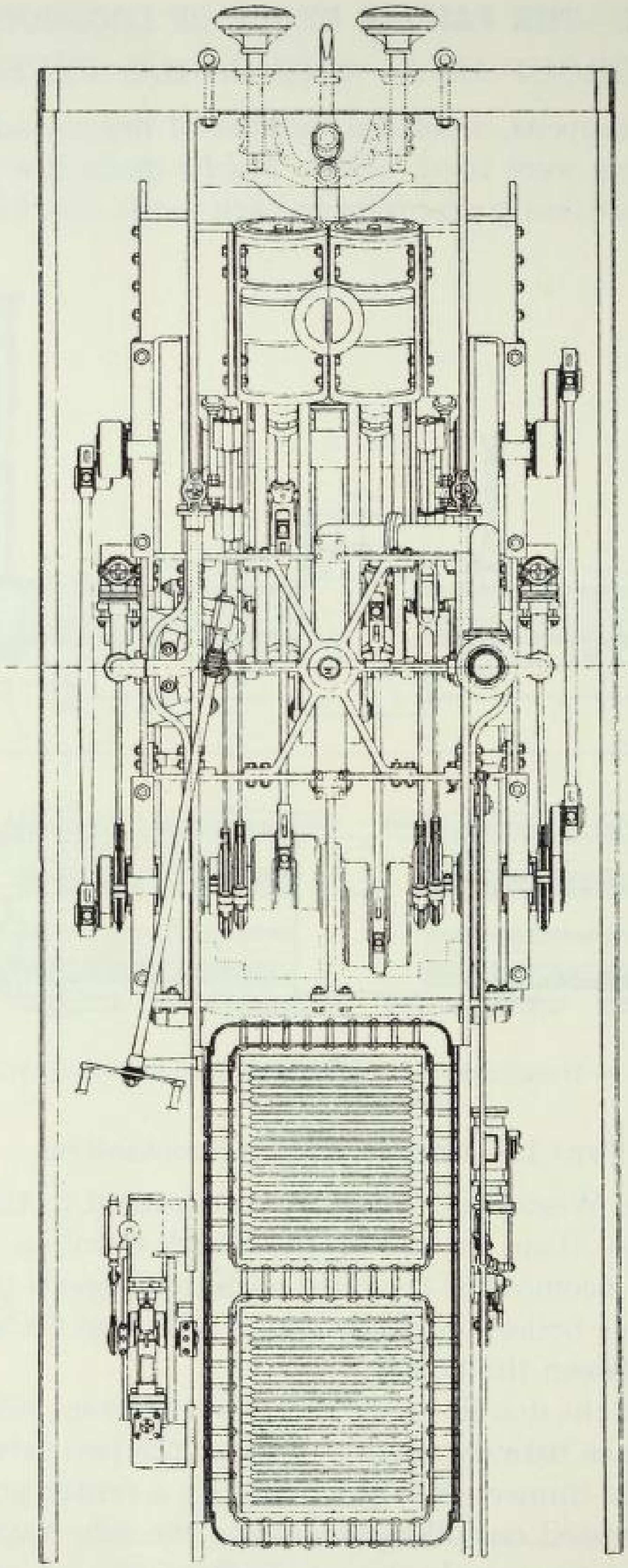
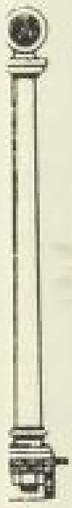


Fig. 43.—The Seraing Locomotive, Horizontal Section.

crank axles had spherical seated big end brasses and a vertical joint, which enabled the bogie (and the axle) to move radially.



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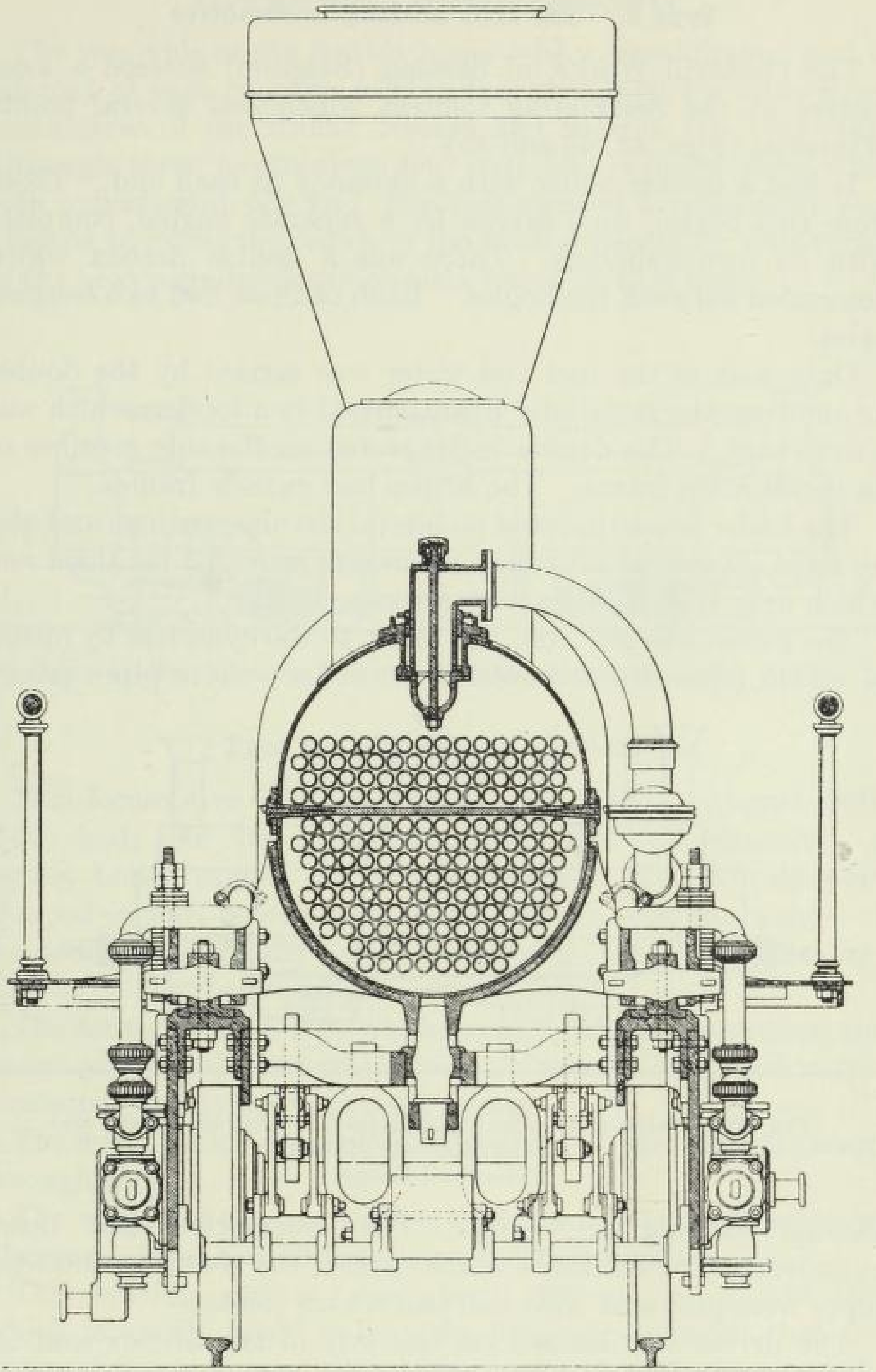

FIG. 44.—Locomotive "Seraing," Cross Section.

These locomotives were not found to be of practical value, but the basic ideas on which they had been designed were revived later at the Semmering Contest.

Type 2.—The 1851 Seraing Locomotive

The Cockerill Works, of Seraing (Belgium) entered a locomotive at the Semmering Contest which had several points of interest (Figs. 43, 44 and 45).

It had a double boiler with a chimney at each end. There were two bogies, each driven by a separate engine, complete with its own cylinders. There was a double firebox which descended between the bogies. Each of these had two coupled axles.

Only part of the fuel and water was carried by the double locomotive, the remainder being carried in a tender, which was a drawback. The double boiler rested on the side member of an inside main frame. The bogies had outside frames.

The boiler was supported on lateral circular seatings and also by fixed pivots, which rested in sockets provided for them and which only sustained tractive stresses.

The steam was led from the boiler to the cylinders by means of steam pipes situated outside the boiler; these pipes passed

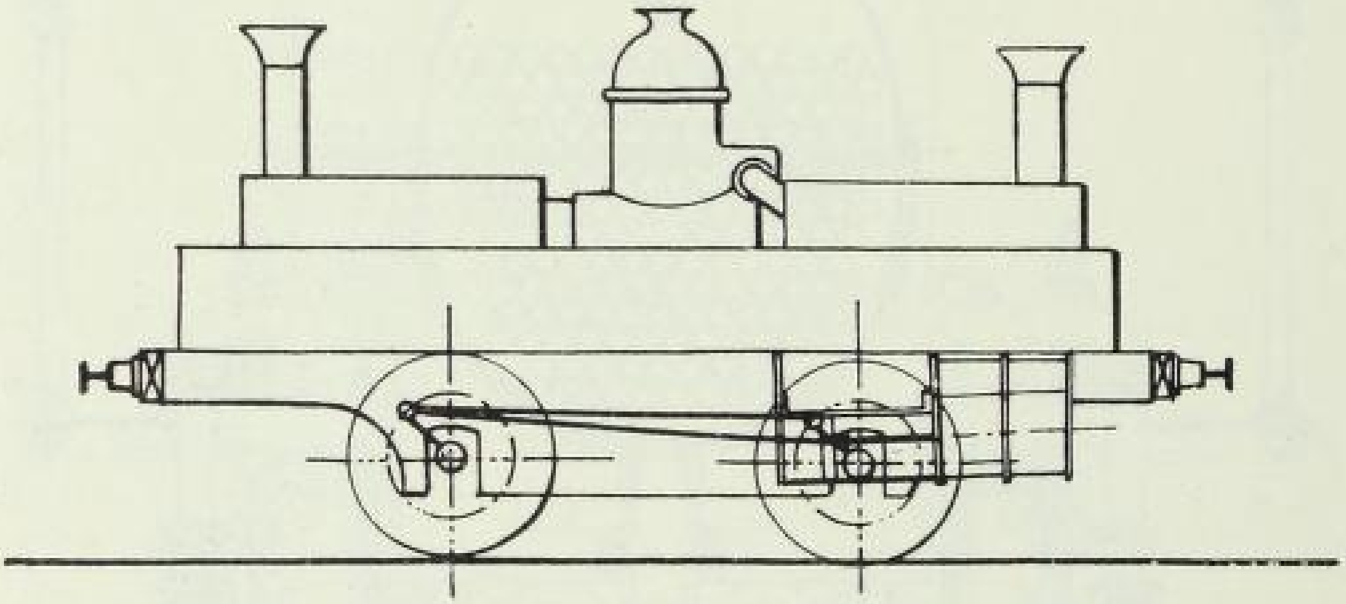

Fig. 46.—Pattison Double-boiler Rigid Locomotive, Nocera and Salerno Railway (1861).
(Standard Gauge.)

through stuffing box joints. The locomotive had inside cylinders. The exhausts which carried the steam to the blast pipes were provided with ball and socket joints.

The driver was located on one side of the firebox and the fireman on the other, the coal being carried on a sort of lateral platform within his reach. The water tanks were carried on a small tender attached to one of the ends of the locomotive. The buffing and drawgear was not attached to the bogies, but to a main frame which ran the whole length of the locomotive.

Type 3.—The Pattison Locomotive*

The principle of the double boiler with central firebox and a chimney at each end was used in the year 1860, for some rigid locomotives of the Italian Nocera and Salerno Ry. (Fig. 46). Although these locomotives had only two coupled axles with both cylinders at one end, this complicated arrangement was adopted to avoid the crown of the firebox becoming uncovered on the heavy gradients which were found on that line.

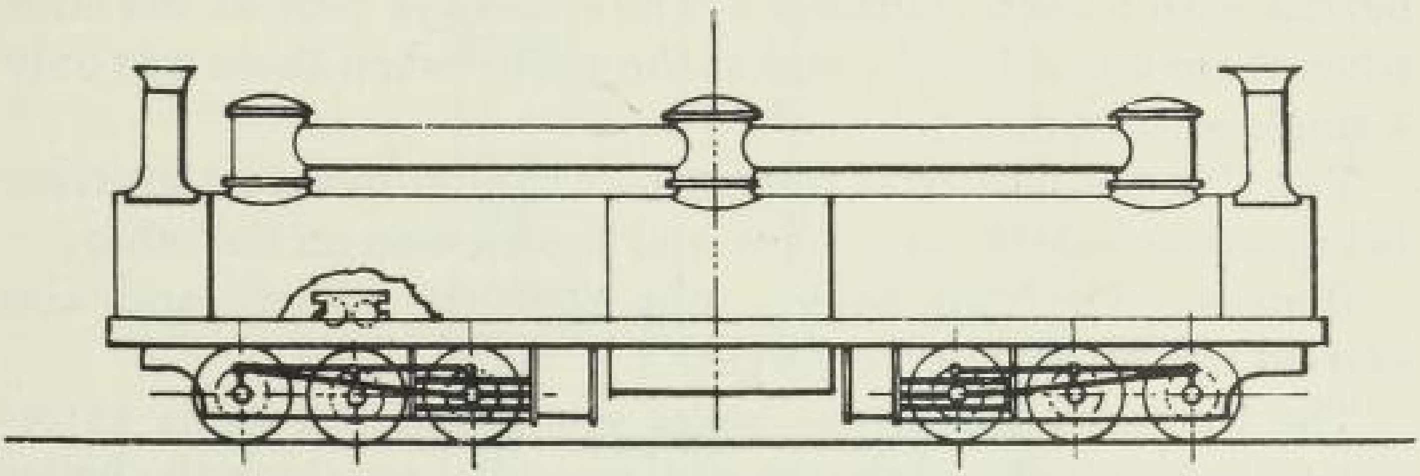

FIG. 47.—The Thouvenot System of Articulated Locomotive (1863).

Type 4.—Thouvenot's System

This locomotive (French Patent No. 59,773, August 20th 1863) had, like the *Seraing* and the *Fairlie* locomotives, a double boiler carried by a main frame. The wheels were grouped in two bogies with central pivots, but the weight of the boiler rested on the bogie frames by means of lateral rollers (Fig. 47).

The four cylinders were at the centre of the locomotive, the steam pipes had universal telescopic joints. An outside flue connected the domes with each other.

The water tanks were below the boiler and the exhaust passed through them.

The weight of the locomotive, which was designed for use on Alpine sections, was 83 tons 12 cwt. (85 tonnes).

The heating surface was about 500 sq. m. (5,380 ft.), which is hardly credible, but the inventor intended that the locomotive should eventually drive certain wagon axles as well, but this is outside the scope of our book.

* This locomotive had outside cylinders 33 cm. by 66 cm. (13 ins. by 26 ins.). Boiler pressure, 118 lbs. per square inch.

SUB-GROUPS II. B, C AND D.—THE FAIRLIE LOCOMOTIVES

General Characteristics

Fairlie took out an English patent (dated May 12th, 1863) and a French patent (dated November 23rd, 1864) for a new system of articulated locomotive, which differed in several details from the *Seraing* locomotive (Fig. 48).

Boiler.—Like the *Seraing* locomotive, the boiler had two barrels with a central firebox. The chimneys were at the ends when there was a double, and at the centre when there was only a single set of tubes.*

The Cab was located in the centre of the locomotive, the driver being on one side of the firebox and the fireman on the other.

Bogies.—The two bogies supported the boilers and also carried the buffing and drawgear.†

The frame by which the boiler was supported at its extremities had a pivot under each of the saddles to which the boiler was attached. These pivots worked in bearings which formed part of the bogie frames. The latter were provided at their rear ends with radial slides,‡ and centralising gear.

The pivots were fixed to the boiler shell and no longer to brackets, as in the *Seraing* locomotive. These pivots were placed approximately midway between each rigid wheelbases. It was contended—rightly—that added to the other features of these locomotives, wear of rails and flanges was considerably reduced and the adhesive weight on each axle, under varying conditions of weight of supplies, was evenly redistributed. Since 1869 circular bogie centre castings were substituted to the pivot pins.

Axles.—The leading axles of each bogie were set slightly behind the smokebox to allow the cylinders, which were overhung, to be placed at the same height as the latter.

Generally, all the weight of the *Fairlie* was available for adhesion.

* This latter type has never been used, though it is described in the original patent.

† In the *Seraing*, the buffing and drawgear was attached to a main frame which ran the full length of the locomotive.

‡ The arrangements described are those of recent *Fairlies*. There is no object in giving earlier ones.

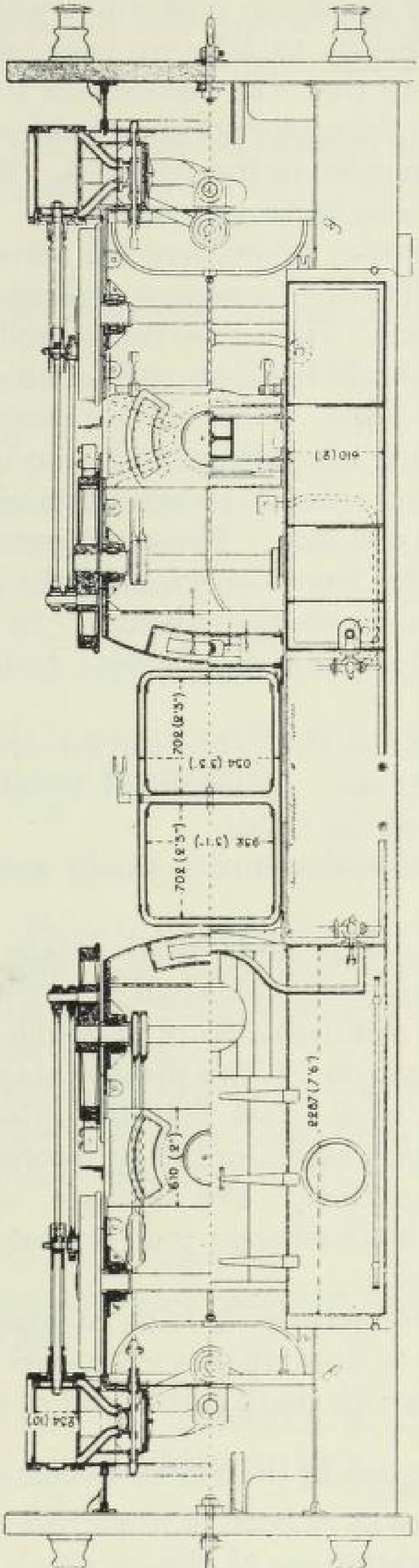

Fig. 48.—Horizontal Section, old Fairlie Locomotive, Nassjo and Osearsham Railway (Norway).

Steam Pipes.—In the original *Fairlie* locomotive, the natural elasticity of the steam pipe which was coiled inside the smokebox was sufficient to take up such movements as the bogie caused, and all that was needed was to provide suitable slotted apertures in the under portion of the smokebox through which these pipes were led to the cylinders. But this happy-go-lucky system was soon to prove inadequate.

Since 1869, the steam pipes were led across the front tube plate, into a special fitting forming a prolongation of the lower part of the smokebox. Here a swivelling and sliding joint was provided, though which the steam passed to the cylinders by the centres of the bogies where these pipes were articulated. Ball and socket joints were also provided on the exhaust pipes.

The Firebox (and ash pit) passes down clear of the bogies and was fired from one side. The arrangement of the firebox in the centre of the locomotive lessens the risk of the crown becoming uncovered on steep gradients. In contradistinction to the " Seraing " locomotive, *Fairlie's* had a single firebox instead of two.

Fuel and Water.—These are carried on the locomotive, the water in side tanks. When wood is burnt, the logs are stacked on the top of the boiler.

These locomotives take curves easily and have sufficient stability.

Disadvantages.—The first disadvantage is the limited quantity of water and fuel which can be carried.

Also repairs and maintenance of a double boiler are more costly than for a single one. This disadvantage is compensated for to some extent by the fact that the tube heating surface is more efficient than in an ordinary locomotive having an equivalent heating surface. For example, two sets of tubes each 10 ft. long are more efficient than one set 20 ft. long of the same heating surface.

Lastly the locomotive lacks stability at high speeds.

This limits its use to lines where such speeds are not required, and specially to lines with sharp curves and steep gradients.

Classification of the Fairlie Locomotives

Fairlie locomotives have been in use for the past sixty years, and a number of variations of the original type have been introduced.

All *Fairlies* have two bogies, but some have a double boiler (which was included in the original type), whilst "modified *Fairlies*" have two separate boilers, and some, a single boiler only.

In each group, some of the locomotives have two engines and sets of cylinders, and others one only. They may be classed as follows.

Sub-Group II. B.—Double-Boiler Fairlie Locomotives

Type 1.—Double-boiler *Fairlies* (0-4 + 4-0 ; 0-6 + 6-0 ; 2-6 + 6-2 classes).

Type 2.—*Mason-Fairlie* locomotives.

Type 3.—*Péchot Bourdon* locomotives.

Those using compounding :—

Type 4.—Compound *Fairlies.*

Sub-Group II. C.—Two-Boiler Fairlie Locomotives

Type 1.—*Fairlie* locomotives (0-6 + 6-0 class).

Type 2.—*Johnstone* locomotives.

Sub-Group II. D.—Single-Boiler Fairlies

Type 1 (*ante*).—These have one engine and one driven and one undriven truck, and have been dealt with *ante.* They comprise 0-4 + 4-0 and 0-6 + 6-0 *Fairlies* and 0-6 + 6-0, 0-6 + (4), and 2-6 + (6) *Mason-Fairlies.*

Type 2.—Single *Fairlie* locomotives, with two driven bogies.

Type 3.—Modified *Johnstone* locomotive.

Type 4.—Modified *Fairlies,* built by the North British Locomotive Co.

Type 5.—The *Golwé* locomotives.

The leading dimensions of examples of each class are given in appropriate tables.

SUB-GROUP II. B.—DOUBLE-BOILER FAIRLIE LOCOMOTIVES

Patents taken out by some other inventors concern locomotives so akin to the *Fairlie* that no object would be served in considering them separately.

We will therefore consider, in due order, the following classes of locomotives.

First those using saturated steam and which comprise :—

Type 1.—*Fairlie* double-boiler locomotives.

Class A. 0-4 + 4-0 locomotives.
Class B. 0-6 + 6-0 locomotives.
Class C. 2-6 + 6-2 locomotives.
Class D. *Fairlie* express locomotives.

Type 2.—*Mason-Fairlie* double-boiler locomotives.

Type 3.—The *Péchot-Bourdon* locomotives.

Next those using compounding :—

Type 4.—Compound *Fairlie* double-boiler locomotives.

Type 1.—The Fairlie Double-boiler Locomotives

These comprise simple and compound locomotives. We will take the former first.

Class A.—0-4-0 + 0-4-0 Fairlie Locomotives.

0-4 + 4-0 Fairlies of the Neath and Brecon Ry.—Standard gauge.

The first *Fairlie* locomotive, called the "Progress," was built in 1865 by Messrs. Cross & Co., of St. Helens, to Robert Fairlie's designs and supplied to the Neath and Brecon Ry.

As per the original patent, the steam pipes were situated in the lower part of the smokebox, where they were coiled, so that their elasticity should be sufficient to compensate the movements due to the action of the curves on the bogies. Appropriate slotted apertures were provided for them in the smokebox and covered with sliding plates. As might have been expected, this system gave trouble after a very short time, and a pendulum steam pipe was substituted.

Fortunately, these drawbacks were rightly attributed to defects in the particular locomotive which had been built and not to the system itself (as has too frequently happened in other types of articulated locomotives). The deficiencies were made good, and *Fairlie* locomotives were tried by other roads.

TABLE 20.—PRINCIPAL DIMENSIONS OF EARLY FAIRLIE LOCOMOTIVES

Gauge	Standard.	Standard.	3 ft. 6 ins.	Standard.		3 ft.	Standard.	Metre.
Railway	Neath and Brecon Ry.	Anglesea Ry.	Queensland Rys.	Burry Port and Gwendreath Ry.		Denver and Rio Grande.	East and West Junction Ry.	Nilgiri Ry.
Builder	Cross & Co.	Cross & Co.	Cross & Co.	Fairlie.	Yorkshire.	—	Yorkshire.	—
Date	1865.	1866.	1867.	1870.	1873.	1873.	1873.	1880.
Type	**0-4 + 4-0**	**0-4 + 4-0**	**0-4 + 4-0**	**0-4 + 4-0**	**0-6 + 6-0**	**0-4 + 4-0**	**0-4 + 4-0**	**0-4 + 4-0**
Cylinders, diameter	15″	10″	11″	10″	11″	10″	11″	10″
„ stroke	22″	16″	18″	18″	18″	18″	16″	16″
Boiler pressure . lbs. per sq. in.	—	—	110	—	140	—	—	—
Heating surface, firebox .sq. ft.	—	—	72	—	—	—	151	151
„ „ tubes . „ „	—	—	1,037	—	—	—	1,578	1,578
„ „ total . „ „	—	—	1,087	—	—	—	1,729	1,729
Grate area . „ „	—	—	17·2	—	—	—	29	29
Wheels, diameter	4′ 6″	4′	3′ 0″	3′ 6″	2′ 9″	3′ 6″	3′ 6″	3′ 6″
Wheelbase, rigid	—	5′	6′ 6″	—	—	—	—	—
„ total	—	19′ 11″	22′ 6″	—	23′ 0″	—	—	—
Water tanks . galls.	—	—	—	—	1,000	800	2,100	2,100
Coal bunkers t.-cwt.	—	—	—	—	—	—	1–10	1–10
Weight in service t.-cwt.	42	—	30 *	—	37	28	57	57

* Boilers each contain 113 tubes.

0-4-0 + 0-4-0 Fairlie Locomotives, Anglesea Central Ry.— Standard gauge.

The original locomotives were shortly followed by others which this railway ordered from the same builders in 1866.

For the first time the boilers were carried on forgings riveted to their under side, the lower part of which consisted of pivots of 5 ins. (13 cm.) diameter. Later, circular bogie centre castings were substituted.

The defects which had shown themselves in the previous locomotive were remedied by the provision of a water space partition in the firebox, and ball and socket joints on the steam pipes. A connecting frame encircling the firebox casing was established between the bogies.

Other Early Fairlie Locomotives.—In 1867 a model of a *Fairlie* locomotive built for the Queensland Rys. was exhibited at the Paris International Exhibition, and shortly afterwards several builders undertook the construction of these locomotives,* of which a number were supplied to home and foreign railways.

They usually had cylinders 10 ins. or 11 ins. by 18 ins. (0m.25 or 0m.28 by 0m.46).

Their tanks held 750 to 890 galls. of water (3,400 to 4,000 litres).

Their weight in working order ranged from 63,000 to 77,000 lbs. (28·5 to 35 tonnes), with an axle load of 16,000 to 18,000 lbs. (7,250 to 8,000 kg.).

They were all built from similar designs and presented no special features.

A number of early *Fairlies* were built by Messrs. Hawthorn, Leslie & Co., who have been good enough to furnish the following particulars :—

* In 1870 the Fairlie Engine and Steam Carriage Co. took over Messrs. England's Works at Hatcham.

Since 1871 the Avonside Co. started exporting *Fairlies* to India, New Zealand and South America.

Others were built by the Yorkshire Engine Co. and the Vulcan Foundry.

Type	0-6 + 6-0	0-4 + 4-0	0-6 + 6-0	0-4 + 4-0	0-4 + 4-0	0-4 + 4-0
Number of locomotives	1	4	2	1	1	—
Railway	Quebrada (S. America.)	Nassago Ascar-hamn.	Bolivia Ry.	A Norwegian Railway.	—	Saxon State Rys. *
Gauge	2′	Standard.	2′	3′ 6″	Standard.	2′ 6″
Date	—	1872.	1875.	1878.	1878.	1884.
Cylinders, diameter	9″	10″	9″	10″	16″	8¼″
,, stroke	14″	18″	14″	18″	22″	14″
Wheels, diameter	2′ 6″	3′ 6″	2′ 6″	3′ 3″	4′	2′ 8″
Wheelbase, bogie	6′	—	—	—	5′ 6″	4′ 6″
,, total	22′ 8″	—	—	—	—	18′ 8″
Overall length	32′ 2″	29′ 6″	33′ 3″	31′ 0″	33′ 2″	27′ 10″
Weight, empty . tons-cwt.	23	27–2	—	—	—	22–0

Fairlie Locomotives of the Burry Port and Gwendreath Ry.—Standard gauge.—A western Welsh colliery railway.

This company's first *Fairlie* locomotive, "The Mountaineer," had been built in 1870 for New South Wales. It was a 0-4 + 4-0. Next came "The Victoria," a 0-6 + 6-0 locomotive, built in 1873 by the Yorkshire Engine Co. and rebuilt in 1896.

0-6 + 6-0 Fairlies, East and West Junction Ry.—Standard gauge.

In 1873 some *Fairlies*, originally built by the Yorkshire Engine Co. for a Mexican Ry. of standard gauge, appeared on this home line.

In 1876 this railway also acquired a single boiler *Fairlie* locomotive.

The Fairlie Locomotives of the Festiniog Ry.—1 ft. 11½ ins. gauge (0m.60).

There have never been a large number of *Fairlies* in use in England, and of these, the greater number have been employed in Wales.

* Besides the dimensions quoted above, the following items of the Saxon State *Fairlie* may be of interest :—

Heating surface, fireboxes	70·4 sq. ft.
,, tubes	622·2 sq. ft.
,, total	692·6 sq. ft.
,, grate area	13·5 sq. ft.
Water tanks	40 galls.
Fuel capacity	40 cub. ft.
Boiler pressure	140 lbs. per sq. in.
,, outside diameter	2 ft. 7 ins.

At an early date they made their appearance on the Festiniog Ry., where some of them are still to be found.

This narrow gauge line is 13¼ miles (22 km.) in length; its chief traffic is the conveyance of slates from Blaenau Festiniog to Portmadoc. The gradient is fairly constant and the curves are of 115 ft. (35 m.) radius.* When the line was first opened in the year 1832, the wagons were pulled up by horses and let down by gravity. In 1863, the horses were replaced by ordinary rigid locomotives. In the year 1870 a *Fairlie* double-boiler locomotive was tried; it was immediately successful and was followed by others. The type attracted much favourable notice and many others were built for various countries.

Indeed, the remarkable financial results at first obtained on the Festiniog Ry. were attributed to the narrowness of the gauge, other factors being overlooked. This was the immediate cause of the introduction of narrow gauge lines in many countries, notably in the U.S.A., for services for which they were not really adapted. This justifies a somewhat extended reference to the locomotives of this little railway.

Its first *Fairlie* was named " The Little Wonder." It could deal with a train of seventy-two slate wagons which weighed 206 tons and was 648 ft. in length. The locomotives previously employed could only draw twenty-six wagons at most.

The second *Fairlie* differed but little from the first.† It was in service for a long time and was rebuilt in 1889 and in 1908.

It had a double firebox like the older " Seraing " locomotive. The single boiler *Fairlie*, to which we have previously referred, was rebuilt in 1900.

The latest *Fairlies* deal with trains of 190 tons.

The leading dimensions of these locomotives are given in Table 21. They are of interest since their initial success led to the introduction of the *Fairlie* type on many railways.

* Blaenau Festiniog is at a height of + 1,027 ft. (313 m.). The maximum gradient is 1·66 per cent.

† The centre line of the boiler was 4 ft. ½ in. (1m.23) above the rail-head. The length of the boiler between tube plates was 25 ft. 6 ins. (7m.77).

TABLE 21.—PRINCIPAL DIMENSIONS OF FAIRLIE LOCOMOTIVES OF THE FESTINIOG RY. (WALES).

Railway	Festiniog Railway			
Gauge	1 ft. 11½ ins.			
Type	**0-4 + 4-0**	**0-4 + 4-0**	**0-4-4**	**0-4 + 4-0**
Boiler	Double.	Double.	Single.	Double.
Date	1870.	1872.	1876.	1879 and 1885.
Name of Loco.	Little Wonder.	James Spooner.	Taliesin.	—
Builder	Fairlie Co.	Avonside Works.	Vulcan Works.	Boston Lodge. Works.
Cylinders, diameter	8¾″	8½″	9″	9″
,, stroke	13″	14″	14″	14″
Boiler, diameter	2′ 6″	2′ 7″	2′ 7″	2′ 6¼″
,, length, each	7′ 6″	7′ 7″	7′ 7″	8′ 1⅜″
,, pressure. lbs. per sq. in.	160	140	—	160
Tubes, number	109	102	94	124
,, diameter	1½″	1½″	1⅝″	1½″
,, length	7′ 10½″	7′ 10¼″	7′ 10½″	8′ 4¾″
Firebox, inside width	2′ 7″	2′ 1″	2′ 1¾″	—
,, inside length	2′ 5¾″	2′ 8½″	3′ 0″	—
,, depth	3′ 6″	3′ 2½″	4′ 5″–3′ 8″	—
,, outside width	3′	2′ 7¾″	2′ 7¾″	2′ 7¾″
,, outside length	6′	6′ 4″	3′ 6″	6′ 8″
Heating surface, firebox sq. ft.	60	84	29·5	69·9
,, ,, tubes ,,	670	629	313	817·2
,, ,, total ,,	730	713	342·5	887·1
Grate area ,,	11	11·2	6·3	12·1
Wheels, diameter	2′ 4″	2′ 8″	2′ 8″–1′ 7″	2′ 9¼″
Wheelbase, rigid	5′	4′ 6″	4′ 6″	4′ 8″
,, total	19′ 1″	18′ 8	13′ 11″	20′ 0″
Distance pivots	14′ 1″	—	—	—
Water tanks. galls.	680	720	430	667
Coal bunkers t.-cwt.	0–15	—	1–5	1–5
Weight in service ,,	19–10	20–1	17–0	28–6

0-4 + 4-0 Fairlie Locomotives of the Saxon State Rys.—Gauge 0m.75 (2 ft. 5½ ins.).

This railway system has a number of feeder lines running into mountainous districts on which most types of articulated or of semi-articulated locomotives have been tried.

In pursuance of this policy, the Saxon State Rys. ordered a *Fairlie* locomotive which was designed by the Fairlie Engine and Rolling Stock Co., and built locally.* (Principal dimensions, see Table 13).

Subsequently, some *Fairlie* compounds have been provided.

The Stratford on-Avon Ry.—Standard gauge.

This railway ordered *Fairlies* in 1876 from the Yorkshire Engine Co. They had cylinders 16 ins. by 20 ins. (0·41 m., 0·51 m.), drivers 3 ft. 6 ins. (1·067 m.) and 8 ft. (2·44 m.) wheelbase.

Heating surfaces: firebox 151 sq. ft.; tubes, 1,578; total, 1,729. Grate area, 29 sq. ft. (160·5 and 2·7 sq. m.).

With 2,000 gallons of water (9 cub. m.) they weighed 57 tons.

The Transcaucasian Ry. ordered no fewer than forty-five *Fairlies*, built both in England and in Austria, between the years 1872 and 1886.

The Chemins de fer de la Vendée.—Standard gauge.

In spite of strenuous efforts, this was, we believe, the only French line where *Fairlie* locomotives were ever used.

Queensland Rys.—3 ft. 6 ins. gauge.

The original section of this system is the line from Ipswich to Toowomba, where 64-ton train loads were to be dealt with. Some *Fairlie* locomotives were sent out and reached there in 1876.

The first of them, called "The Governor Cairns," actually hauled 139 tons at 15 miles an hour (24 km.) on its trial trip. It weighed 34 tons 9 cwt. (35·150 kg.).

* Messrs. Hawthorn, Leslie & Co. supplied further locomotives whose dimensions were as under:—

Cylinders	$8\frac{1}{2}$ ins. by 14 ins.
Steam pressure	140 lbs. per sq. in.
Boiler centre line	4 ft. 9 ins.
Heating surface, firebox	70·4 sq. ft.
,, tubes	622·2 sq. ft.
,, total	692·6 sq. ft.
Grate area	13·5 sq. ft.
Wheels, diameter	2 ft. 8 ins.
Wheelbase, rigid	4 ft. 6 ins.
Water capacity	630 galls.
Fuel	40 cub. ft.
Height	9 ft. 10 ins.
Length without buffers	27 ft. 10 ins.

The boiler was supported at four points on the main engine frame, at each end of the frame and from cross stays placed near the two throat plates on the fireboxes. The end supports had circular bearings with a projection to locate the bogie frames. Steam and exhaust pipes fitted with spherical and sliding joints were provided.

The New Zealand Rys.—Old Standard gauge.

The first railway in New Zealand, from Dunedin to Port Chalmers, was laid to standard gauge. Two *Fairlies*, named the "Rose" and the "Josephine," were sent out for construction work in 1872, and others followed in 1874 and 1875.

On 1-in-56 gradients, combined with 8½-chain curves, the first of these locomotives hauled as many as twenty-six wagons.

The 1874 *Fairlies* had Walschaert valve gear.

The principal dimensions are as under :—

Type	**0-4 + 4-0**	**0-4 + 4-0**	**0-4 + 4-0**
Builder	Vulcan.	Avonside.	Avonside.
Date	1872.	1874.	1875.
Cylinders, diameter	10″	9″	10″
,, stroke	18″	16″	18″
Wheels, diameter	3′ 9″	3′ 3″	3′ 3¾″
Water tanks	800 galls.	—	—
Weight in service	26 tons. *	32 tons.	37 tons.

Fairlie Locomotive of the Denver and Rio Grande R.R.—3 ft. gauge.

In 1873, the Duke of Sutherland presented a *Fairlie* locomotive to the Denver and Rio Grande R.R., a 3 ft. gauge line,† situated in Utah and Colorado (U.S.A.).

It gave satisfaction and shortly afterwards *Mason* introduced a modified type which had a certain vogue. We deal with this type below.

Fairlie Locomotive of the Nilgiri Ry.—Metre gauge.

This line, one of those which lead from the plains of India to hill stations, is 16¾ miles long (26 km.). It runs from Mettapollum to Coonoor, which is at an altitude of 5,613 ft. (1,711 m.). The Ghaut is climbed by a rack-rail section,‡ but

* Heating surface, 829 sq. ft.

† This locomotive, named "The Mountaineer," was used on the southern branch, the profile of which is very irregular, with gradients of 4 per cent. up the Veta Pass. It was withdrawn in 1883.

‡ The rack-rail section from Kullar to Coonoor is 12 miles (19 km.) long, with gradients of 8 per cent. The summit of the line at Ferryhill (12th mile of the railway) is 7,275 ft. (2,218 m.) above sea level.

The first of the two *Fairlies* which had been acquired was subsequently sold to the New South Wales Rys. In 1876 the Nilgiri Ry. put a "simple *Fairlie*" into service.

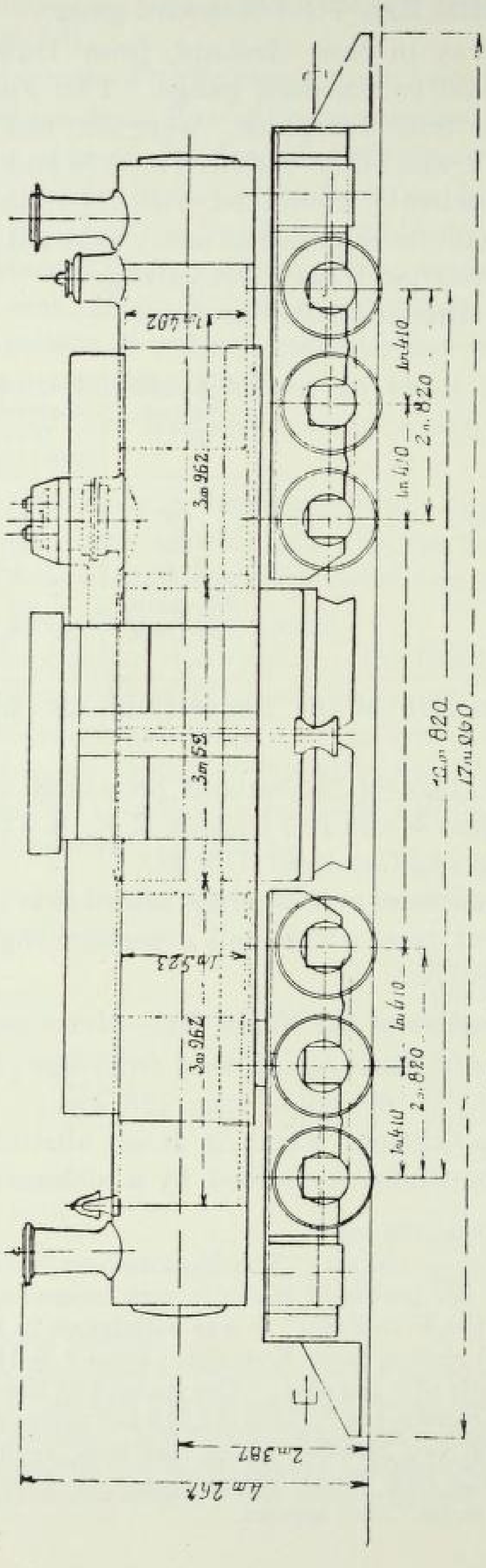

FIG. 49.—0-6 + 6-0 Fairlie Locomotive, Mexican Ry. (Standard Gauge.)

the portion of the line on the Nilgiri plateau has itself gradients of 4 per cent., necessitating the use of special locomotives. Some *Fairlies* have been in use here since 1880.

Class B.—0-6 + 6-0 Fairlies

0-6 + 6-0 Fairlie Locomotives of the Mexican Ry.—Standard gauge (Figs. 49 and 50).

With these locomotives we leave the historic treatment of the subject in order to deal with locomotives which are of special interest, because they have been in use for more than half a century on one of the most difficult lines in the world.*

This is the only system of steam locomotive which was used here, though the power of the units was increased as new orders were placed.† The 1911 type hauled 300-ton trains over gradients of 1 in 25 and reverse curves of 330 ft.; it had a weight of 20 tons per axle.

These locomotives remained in service until recently, when the line was electrified.

Other railways in Mexico have features of similar difficulty, and articulated locomotives have been frequently used on them.‡

* The main line of the Mexican Ry. runs from Vera Cruz to Mexico City, passing to the south of the Orizaba mountain range. There is a continuous ascent from Cordova (altitude 827 m.; 2,713 ft.). The rise continues even more steeply up to the summit of the line at Bocca del Monte (altitude 2,415 m.; 7,923 ft.). From this point the line runs along an elevated plateau to Mexico City (altitude 2,240 m.; 7,350 ft.). The length of the railway is 425 km. (264 miles). Nearly all of the gradients exceed 2 per cent., and are even as steep as 4 per cent., notably on a continuous section of 21 km. (13 miles) in length.

The radius of the curves is as small as 97·5 m. (320 ft.), and in many cases there is no straight alignment between reverse curves.

The *Fairlie* locomotives worked on the section from Cordova to Bocca del Monte, 174 km. (108 miles) long. A curious incident happened here some thirty years ago. One of these locomotives was standing at the top of a long incline, when, owing to its brakes being improperly secured, it started down the grade and ran for no less than 48 km. (30 miles) without derailing, which is very remarkable.

† The first of these locomotives described in Table 22 had a firebox 1·54 m. × 1·05 m. (5 ft. $0\frac{3}{4}$ in. × 3 ft. 5 ins.) × 1·62 m. (5 ft. $3\frac{3}{4}$ ins.) in height. The latest ones have fireboxes 1·63 m. × 1·26 m. (5 ft. 4 ins. × 4 ft. $1\frac{1}{2}$ ins.) and 1·77 m. (5 ft. 10 ins.) in height.

‡ The Mexican International Ry. also has a line from Vera Cruz to Mexico City, but this line passes to the north of the Orizaba range, instead of to the south, as does the other. It crosses the Mexican Ry.

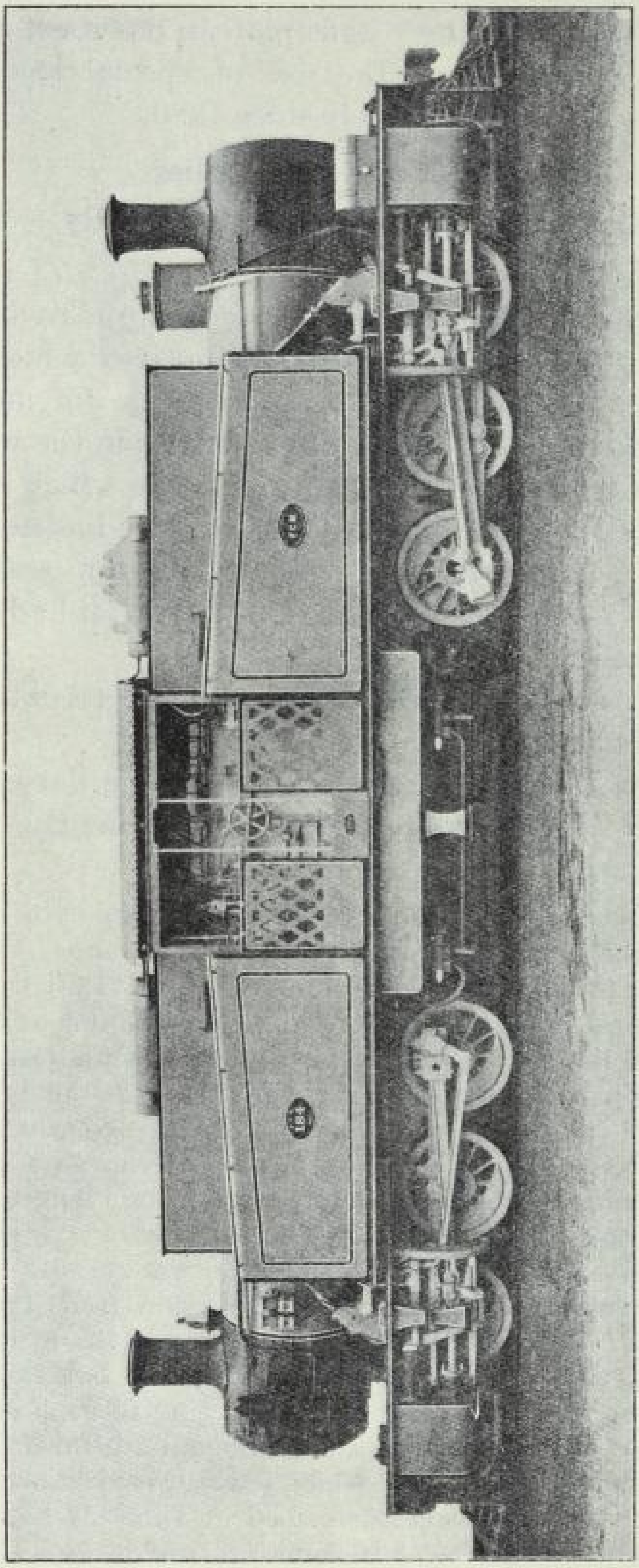

FIG. 50.—0-6 + 6-0 Fairlie Locomotive, Mexican Ry.
(Standard Gauge.)
Built by the Vulcan Locomotive Works. Others by the North British Locomotive Co.

at San Marco, passes to the south of Puebla, and recrosses the same line at Irold. Its length is nearly 32 km. (20 miles) less than that of the Mexican Ry. *Mallet* engines are used.

TABLE 22.—PRINCIPAL DIMENSIONS OF SIMPLE AND COMPOUND FAIRLIE LOCOMOTIVES

Railway		Mexican Ry.			Anglo-Chilian Nitrate Ry.	Nitrate Rys.	Military Lines.	Military Lines.	Saxon State Rys.
Gauge		Standard.			3′ 6″	1·435	0·60	0·60	1·00
Builder		N. British.	N. British.	Vulcan.	Yorkshire.	Yorkshire.	Cail-Denain.	Baldwin.	Chemnitz.
Date		1889.	1912.	1910.	1891.	—	1889.	1915.	1890.
Type		**0-6 + 6-0**	**0-6 + 6-0**	**0-6 + 6-0**	**0-6 + 6-0**	**2-6 + 6-2**	**0-4 + 4-0** Péchot-Bourdon.	**0-4 + 4-0** Péchot-Bourdon.	**0-4 + 4-0** Compound.
Cylinders, diameter	m.	0·41	0·43	0·48	0·36	0·43	0·18	0·18	0·28—43
,, stroke	m.	0·56	0·64	0·63	0·51	0·56	0·24	0·24	0·38
Boiler, centre line	m.	2·01	2·20	2·38	—	2·00	1·03	—	1·90
,, inside diameter	m.	Wagon top.	Wagon top.	0·77—1·27	1·07	·23 ext.	0·70	0·63	1
,, length	m.	10·26	11·20	9·55	30·5	13·45	—	—	—
,, pressure	kg. sq. cm.	11·6	14·1	13	11·3	11·3	12	12	14
Tubes, number		268	338	432	117	330	96	—	270
,, diameter	mm.	48	48	48	44	48	45 ext.	45 ext.	35·40
,, length	m.	3·56	3·94	3·94	3·20	3·45	1·70	—	2·40
Heating surface, firebox	sq. m.	16·7	21·8	22·8	11·3	17·9	3·6	3·8	7·8
,, ,, tubes	,,	142·4	199	254·4	104·4	175·1	22·1	23·2	71·3
,, ,, total	,,	159·1	220·8	277·2	115·8	192·9	25·6	27	79·1
,, ,, superheater	,,	None.	None.	None.	None.	None.	None.	None.	None.
Wheels, diameter	m.	3·1	4·1	4·41	2·0	3·3	0·5	0·5	1·9
,, ,,	m.	None.	None.	None.	None.	0·84	None.	—	None.
Wheelbase, rigid	m.	1·07	1·22	1·22	0·91	1·14	0·65	0·50	0·76
,, driving	m.	2·52	2·82	2·82	2·08	2·59	0·85	0·90	1·10
,, total	m.	9·88	10·82	10·82	7·87	9·72	3·80	2·30	7·60
Weight, adhesive	t.	98·5	121·9	140	55·7	86·5	12·3	12·7	40·7
,, empty	t.	—	101·3	—	43·5	56·3	10·0	—	33·2
,, in service	t.	98·5	121·9	140	55·7	86·5	12·3	12·7	40·7
Water tanks	cub. m.	12·9	15·9	—	5·0	11·8	1·7	1·5	3·2
Coal bunkers	t.	8·5	8·9	—	1·3	2·3	0·6	0·7	1·2
Tractive force	t.	15·1 (75%)	20·4 (75%)	23·7 (75%)	11·8	17·4	1·8 (65%)	—	6·5 (75%)

The heating surfaces are always computed externally, save for the Péchot-Bourdon and the Saxony State locomotives.

TABLE 22A.—PRINCIPAL DIMENSIONS OF FAIRLIE LOCOMOTIVES

Railway	Mexican Ry.				Anglo-Chilian Nitrate Ry.	Nitrate Rys.
Gauge	Standard.				3ft. 6ins.	Standard.
Builder	Yorkshire.	North British.	North British.	Vulcan.	Yorkshire	Yorkshire
Date	1883.	1902.	1912.	1910.	1891.	—
Type	**0-6 + 6-0**	**0-6 + 6-0**	**0-6 + 6-0**	**0-6 + 6-0**	**0-6 + 6-0**	**2-6 + 6-2**
Cylinders, diameter	16″	16″	17″	19″	14″	17″
,, stroke	20″	22″	25″	25″	20″	22″
Boiler, centre line	—	6′ $7\frac{1}{4}$″	7′ 3″	7′ 10″	—	6′ $6\frac{3}{4}$″
,, diameter	—	3′ $9\frac{7}{8}$″	4′ $0\frac{1}{4}$″	4′ $10\frac{3}{4}$″	3′ 6″	4′ $0\frac{1}{4}$″
,, length	—	11′ 3″	12′ 6″	37′ 4″	10′ 0″	11′ 4″
,, pressure	—	165	200	185	160	160
Tubes, number	—	134	338	432	117	330
,, diameter	—	2″	$1\frac{7}{8}$″	$1\frac{7}{8}$″	$1\frac{3}{4}$″	$1\frac{7}{8}$″
,, length	—	11′ $7\frac{3}{16}$″	12′ 11″	12′ 11″	10′ 6″	11′ $7\frac{1}{2}$″
Heating surface :—						
Firebox sq. ft.	159	180	23·4	245	120	192·5
Tubes ,,	1,501	1,532	2,142	2,739	1,100	1,885
Total ,,	1,660	1,712	2,376	2,984	1,220	2,075·5
Superheater ,,	None.	None.	None.	None.	None.	None.
Grate area ,,	—	33·0	43·5	47·7	21	35·5
Wheels, diameter	None.	None.	None.	None.	None.	2′ 8″
,, diameter	3′ 9″	3′ 6″	4′	4′	3′	2′ 9″
Wheelbase, rigid	8′ 3″	8′ 3″	9′ 3″	9′ 3″	6′ 10″	3′ 9″
,, driving	30′ $3\frac{1}{8}$″	32′ $5\frac{1}{8}$″	35′ 6″	35′ 6″	25′ 10″	—
,, total	30′ $3\frac{1}{8}$″	32′ $5\frac{1}{8}$″ ‡	35′ 6″	35′ 6″	25′ 10″	44′ 9″
Weight, adhesive§	163,000	99–8	120–2	138	55	85
,, empty§	—	—	99–19	—	43–5	—
,, in service§	163,000	99–8	20–21	138	55	85
Water galls.	2,350	2,850	3,500	—	1,100	2,660
Coal t.-cwt.	1–10	300 cf.	315 cf.	—	1–6	2–5
Tractive force lbs.	—	33·188	45·166 (75%)	52·176 (75%) †	26·123 (75%)	38·420 *

Class C.—2-6 + 6-2 Fairlie Locomotives

2-6 + 6-2 Fairlie Locomotives of the Nitrate Rys. (Chile).—Standard gauge (Fig. 51).

These differ from all other *Fairlie* locomotives in the fact

* Firebox, 10 ft. 4 ins. long, overall dimensions ; height, 13 ft. 6 ins. ; width, 10 ft. ; length, 52 ft.

† Maximum height, 14 ft. ; length, 56 ft. $1\frac{3}{4}$ ins.

‡ Distance between pivots, 22 ft. 8 ins.

§ Lbs. or tons and cwt.

that all their weight is not available for adhesion. Although this is a standard gauge line, the radius of some curves is as small as 91·5 m. (300 ft.) and gradients exceed 4½ per cent.

These locomotives had a bissel truck at each end, thus avoiding the overhang of the cylinders.

Nevertheless, the use of these bissel trucks was discontinued in subsequent locomotives and the 0-6 + 6-0 type was reverted to. *Meyer* locomotives are also used on this line and *Garratt* locomotives have now been introduced with marked success.

Class D.—Fairlie Double-boiler Express Locomotives

The extreme flexibility of this locomotive would seem to render it unsuitable for high speeds. In spite of this, as we have seen, it is contended that *Fairlie* locomotives have actually attained (accidentally, it is true) very high speeds in Mexico, and designs have certainly been prepared for locomotives for express passenger service.

Whether they were ever executed is an open question, and, in any case, even if some of them were ever built, they could not have been successful, since so little has ever been heard of them.

In 1881, 2-4 + 4-2 *Fairlies* with 5 ft. 6 ins. (1m.67) drivers seem to have been supplied to a Russian railway.

Fairlie also prepared designs of several classes of locomotives for French railways, but we believe they were not adopted. In one of them each unit had two coupled axles, with 5 ft. 9 ins. drivers.

Type 2.—The Mason-Fairlie Double-boiler Locomotives

Owing to the *Fairlie* boom, an American, William Mason, built a locomotive which incorporated most of the features of the *Fairlie* design, but he was unsuccessful. He tried to dispose of it to a Boston line, then to the Western Massachusetts and, finally, he managed to sell it to the Lehigh Valley R.R.

Thereafter, he built *Mason-Fairlie* single-boiler locomotives.

Type 3.—The Péchot-Bourdon Locomotives

These locomotives (Fig. 52), differ but little from the *Fairlie* engines. They were patented on June 3rd, 1887, as far as the following modifications are concerned :—

" A central position for the steam dome ensuring that the steam shall always be taken at a constant height above the water level of the boiler.

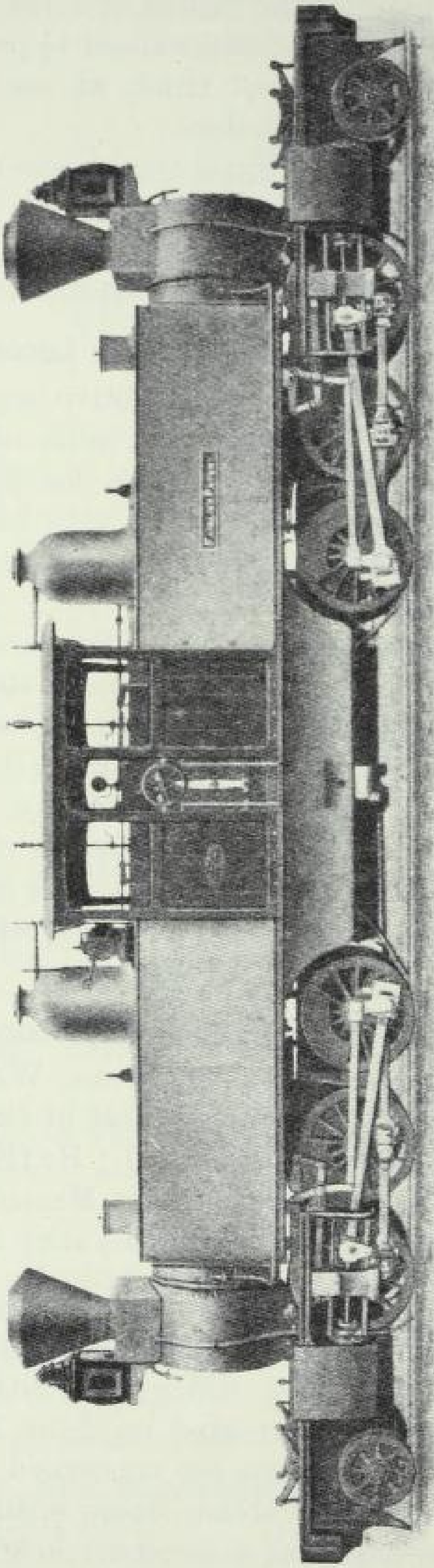

Fig. 51.—2-6 + 2-6 Double Fairlie Locomotive, Nitrate Rys. (Chile).
(Standard Gauge.)
Built by the Yorkshire Locomotive Works.

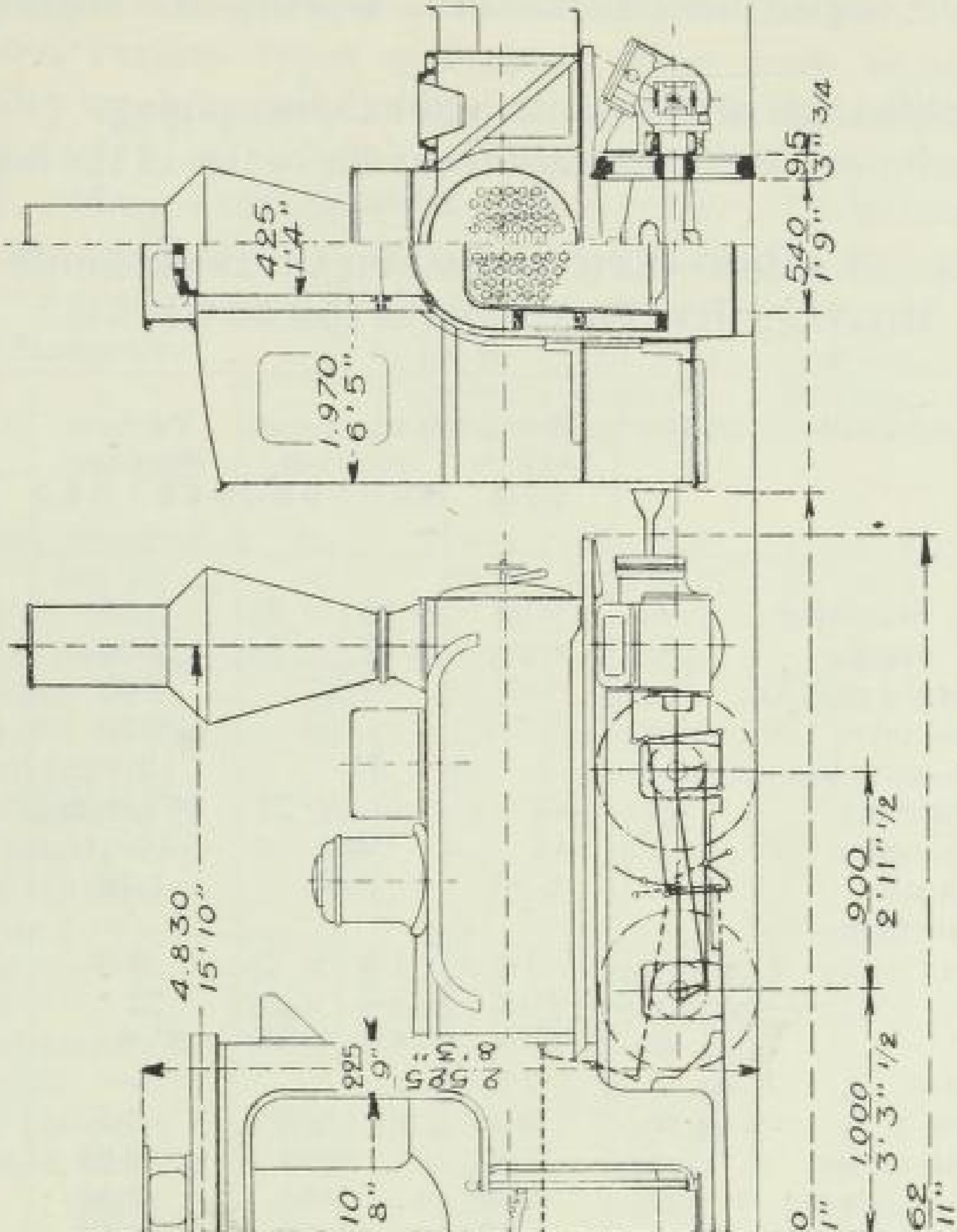

Fig. 52.—Péchot-Bourdon Locomotive.
(0m.60 (1 ft. 11⅝ ins.) Gauge.)

"The use of spring compensation between the boiler and the rear of the bogies, in order better to equalise the loads on the axles.

"Simplification of the steam and exhaust piping.

"Attachment of the drawgear near the centre of the bogies."

TABLE 23.—COMPARATIVE PRINCIPAL DIMENSIONS OF MILITARY RY. LOCOMOTIVES (0M.60 GAUGE)

Type of locomotive . . Axles	Klien-Lindner. **0-8-0**	Twin Locomotives. **0-6-0+0-6-0**	Péchot-Bourdon. **0-4-0+0-4-0**	Geared. **0-10-0**
Cylinders, diameter . m.	0·24	0·18 (× 2)	0·18	0·27
,, stroke . m.	0·24	0·24 (× 2)	0·24	0·30
Boiler, height of C.L. m.	1·20	1·17	1·03	—
,, diameter . m.	0·70	0·70	0·70	0·82
,, pressure kg. per cm.²	15	15	12	14
Tubes, number .	43	43 (× 2)	96 (× 2)	76
,, diameter . mm.	44	44	45	44·5
,, length . . m.	2·80	2·80	1·70	2·40
Heating surface :—				
Firebox . . sq. m.	1·5	1·5 (× 2)	3·6	2·9
Tubes . . . sq. m.	16·6	18·1 (× 2)	22	25·5
Total . . . sq. m.	25·4	18·1 (× 2)	25·6	28·4
Superheater . . sq. m.	7·3	—	—	—
Grate area . . sq. m.	0·5	0·4 (× 2)	0·5	0·7
Wheels, diameter . m.	0·59	0·59	0·65	0·60
Wheelbase, driving . m.	2·26	5·30	3·80	2·99
,, rigid . m.	0·79	1·30	0·85	1·60
,, total . m.	2·26	5·30	3·80	2·99
Water tanks . . m.³	1·1	0·9 (× 2)	1·7	1·2
Coal bunkers . . t.	0·3	0·3 (× 2)	0·6	0·4
Weight, empty . t.	9·6	6·3 (× 2)	10·00	12·5
,, in service . t.	12·0	7·5 (× 2)	12·3	15·0
Overall dimensions :—				
Length . . m.	5·98	8·24	5·76	—
Width . . m.	1·80	1·60	1·37	—
Height . . m.	2·90	1·60	3·00	—

These engines were first employed on the strategic railways of the *Toûl* fortified zone, and subsequently on a large scale during the Great War.*

* Large orders for these locomotives were placed by the French Government in England and in America. Thus, on April 24th, 1915, the Baldwin Co. despatched 100 of them which had been ordered to metric measurements on February 1st, 1915.

Unfortunately, owing to the fact that their smoke disclosed their presence, they could not be used near the front, and so in this area various types of tractors were used, though their flexibility was generally inferior to the *Péchot-Bourdon's.*

TABLE 23A.—COMPARATIVE PRINCIPAL DIMENSIONS OF MILITARY RAILWAY LOCOMOTIVES (1 FT. 11½ INS. GAUGE)

Type of locomotive	Klien-Lindner.	Twin Locomotives.	Péchot-Bourdon.	Geared.
Axles	**0-8-0**	**0-6-0 + 0-6-0**	**0-4-0 + 0-4-0**	**0-10-0**
Cylinders, diameter . ins.	9½	7⅛ (× 2)	7⅛ (× 2)	10⅝
,, stroke . ins.	9½	9½ (× 2)	9½ (× 2)	11¾
Boiler :—				
Height, centre line ft.-ins.	3–11¼	3–10¼	3–4½	—
Diameter . ft.-ins.	2–3⅝	2–3⅝	2–3⅝	2–8¼
Pressure . lbs./sq. ins.	213	213	171	199
Tubes, number . .	43	43 (× 2)	96 (× 2)	76
,, diameter . ins.	1$\frac{1}{16}$	1$\frac{1}{16}$	1¾	1$\frac{23}{32}$
,, length . ft.-ins.	9–2	9–2	5–7	7–10½
Heating surface :—				
Firebox . . sq. ft.	16·1	16·1 (× 2)	38·7	31
Tubes . . ,,	178·4	194·5 (× 2)	236·5	274
Total . . ,,	194·5	210·6 (× 2)	275·2	305
Superheater . . ,,	78·5	—	—	—
Grate area . . ,,	5·4	4·3 (× 2)	5·4	7·5
Wheels, diameter ft.-ins.	1–11¼	1–11¼	2–1⅝	1–11⅝
Wheelbase, driving ft.-ins.	7–5	17–4½	12–6	9–9¾
,, rigid ,,	2–7¼	4–3¼	2–9½	5–3
,, total ,,	7–5	17–4½	12–6	9–9¾
Water tanks . cub. ft.	39	32 (× 2)	60	42
Coal bunkers . tons-cwt.	0–6	0–6 (× 2)	0–12	08
Weight, empty ,,	9–9	6–4 (× 2)	9–17	12–6
,, in service ,,	11–16	7–8 (× 2)	12–2	14–15
Overall dimensions :—				
Height . ft.-ins.	19–7	27–0	18–11	—
Width . ,,	5–10	5–3	4–6	—
Length . ,,	9–6	5–3	9–10	—

These locomotives have the same defects as the *Fairlie* engines, *e.g.*, the risk of the engine crew being crushed or burnt if the engine overturned, and the high consumption of coal and lubricating oil.

It is interesting to compare them with the other locomotives for military service, such as the German and Japanese used, and with the *Klien-Lindner* locomotives, all built for a gauge of 1 ft. 11½ ins. (0·60 m.).

The only attempt to employ the *Péchot-Bourdon* engines for other than military service was at the Paris Exhibition of 1889, when one locomotive was run experimentally.

Type 4.—Compound Fairlie Double-boiler Locomotives

As far back as 1877, Anatole Mallet suggested that compounding should be applied to *Fairlie* locomotives; hence the name of *Mallet-Fairlie* or *Lindner-Fairlie* by which compound *Fairlies* of this group are sometimes designated.

There are, however, but few instances where this was put into practice.

0-4 + 4-0 Compound Fairlie Locomotives of the Saxon State Rys.—0m.75 (2 ft. $5\frac{1}{2}$ ins.) gauge.

Out of a batch of seven *Fairlie* locomotives built between the years 1890 and 1892, three were compound narrow gauge *Fairlies.**

In order to shorten the steam passage between H.P. and L.P. cylinders, all the cylinders were located at the centre of the locomotive.

In contradistinction to the *Mallet* locomotives, in which compounding is an essential feature, *Fairlies* do not seem to be well adapted for compounding and no material benefit seems to be derived therefrom. At any rate these locomotives remain the solitary examples of *compound Fairlies.*

SUB-GROUP II. C.—FAIRLIE LOCOMOTIVES WITH TWO SEPARATE BOILERS

Johnstone was the first to consider the advantages of two separate boilers instead of a double boiler as in the usual *Fairlie* locomotives, and he applied it to specially designed locomotives, which differed in many essentials from the *Fairlie* proper (1888).

In 1902, the Vulcan Foundry substituted two boilers to the *Fairlie's* double-boiler, thus also creating a new type of two-boiler locomotive.

* These locomotives were required to run through curves of 40 m. (131 ft.) radius.

The same railway administration used, concurrently with the *Fairlies*, *Meyer* locomotives, both simple and compound, and also *Mallets.*

Whereas the former was unsuccessful, the latter came up to expectations.

Type 1.—The Johnstone Locomotives

These American locomotives, derived from the *Fairlie* engine, were introduced by the Rhode Island Locomotive Works of Providence, Rhode Island (now absorbed by the American Locomotive Co.), in the year 1885 (Fig. 53).

Like the *Fairlie*, they had two boilers and two fireboxes, but they differed from them in two principles: the cylinders were attached to the frame and not to the bogies, the motion being transmitted by a very complicated system.

Also they were compounds; it did not matter in this case, as the steam, whether H.P. or L.P., did not flow through a

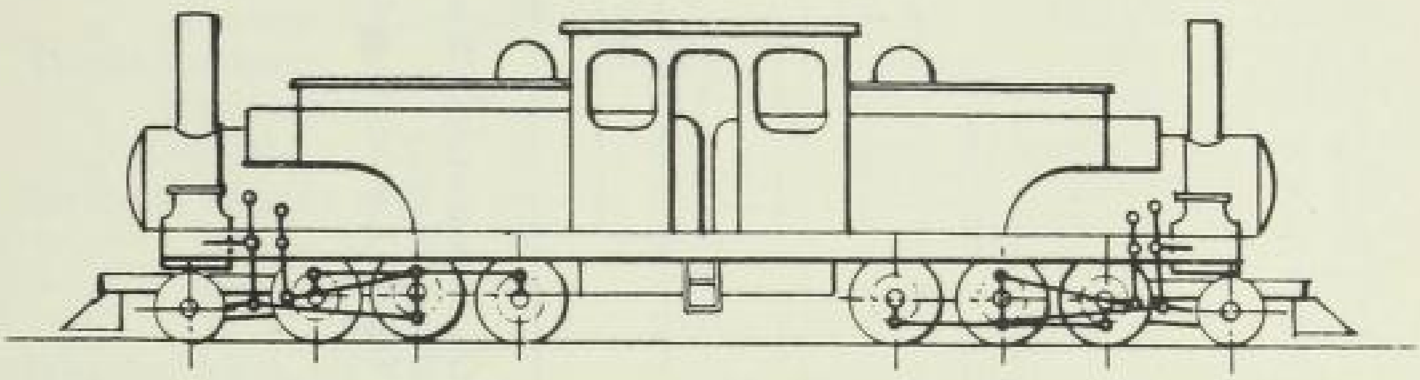

FIG. 53.—Johnstone Double-boiler Articulated Locomotive.

single articulated joint. Practice has proved, however, that this advantage is more than outweighed by the great inconvenience resulting from the complication of the valve gear, etc.

Instead of using spherical bearings in the valve gearing, which enable the bogies to radiate, an articulated device based on the use of a beam was adopted: this beam was vertical in its normal position, and was situated behind the cylinders which transmitted their motion to it. This beam was so connected that it always remained parallel to its original position, though in the curves it took an inclined position in a vertical plane. The other elements are clearly shown on the drawings.*

2-6+6-2 Johnstone Locomotives of the Mexican Central Ry.—Standard gauge (Fig. 54).

These locomotives weighed 113 tonnes (250,000 lbs.) of which 95 tonnes (210,000 lbs.) were available for adhesion. At the

* See also *Bulletin de la Société des Ingénieurs Civils de France*, 1893, p. 453; *Engineering News*, March 26th, 1892, p. 203.

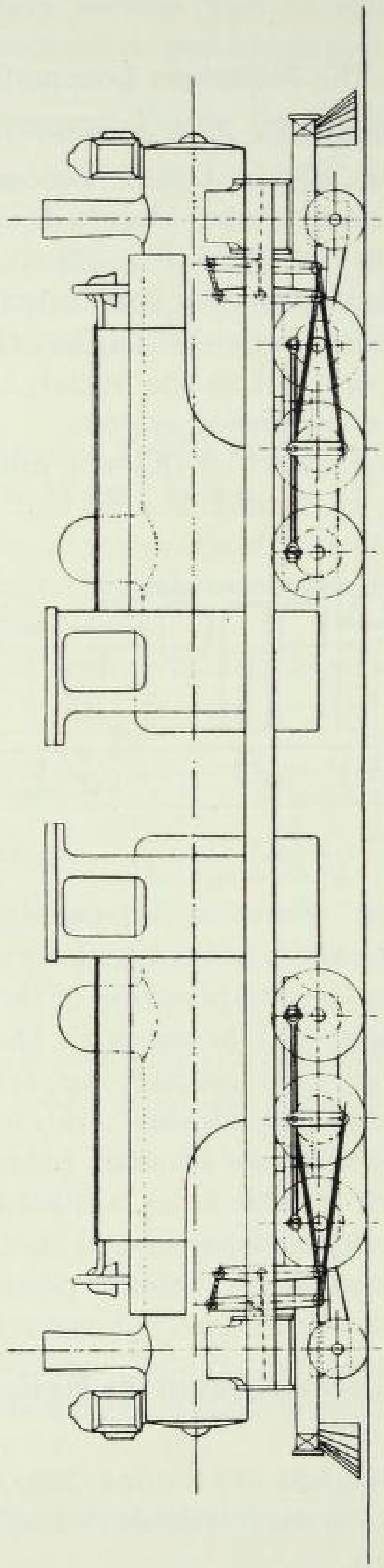

Fig. 54.—Johnstone Articulated Locomotive, Mexican Central Ry.
(Standard Gauge.)
Built by the Rhode Island Locomotive Works.

TABLES 24 & 24A.—PRINCIPAL DIMENSIONS OF FAIRLIE TWO-BOILER LOCOMOTIVES

Railway	Burma Rys.	Junin Ry. (Chile).	Burma Rys.	Junin Ry. (Chile).
Gauge	Metre.	0m.76.	Metre.	2 ft. 6 ins.
Builder	Vulcan.	Yorkshire.	Vulcan.	Yorkshire
Date	1907.	1906.	1907.	1906.
Type	**0-6 + 6-0**	**0-6 + 6-0**	**0-6 + 6-0**	**0-6 + 6-0**
Number of Boilers	2	2	2	2
Cylinders, diameter m.	0·36	0·32	14″	12½″
,, stroke m.	0·51	0·41	20″	16″
Boiler, centre line m.	1·87	1·49	6′ 1⅝″	4′ 10½″
,, diameter m.	1·08 out.	1·07 out.	3′ 6½″	3′ 6″
,, length m.	2·57	2·84	8′ 5″	9′ 3¾″
,, pressure kg./sq. cm.	12·7	11·3	180 lbs.	160 lbs.
Tubes, number	304	212	304	212
,, diameter mm.	41	41	1′ 0⅝″	1′ 0⅝″
,, length m.	2·67	2·92	8′ 9″	9′ 6 15/16″
Firebox, length, int. m.	1·35	1·09	4′ 0½″	3′ 6 13/16″
,, width, ,, m.	0·90	0·94	3′ 3″	3′ 1¼″
,, height, front m.	1·98	1·24	6′ 6″	4′ 0⅞″
,, ,, back m.	1·80	1·24	5′ 6½″	4′ 0⅞″
Heating surface:—				
Firebox sq. m.	12·8	10·9	138	117
Tubes ,,	104·2	86·4	1,132	930
Superheater ,,	129·9*	97·3	1,398*	1,047
Total ,,	None.	None.	None.	None.
Grate area ,,	2·4	2·0	26·0	21·7
Wheels, diameter m.	None.	None.	None.	None.
,, diameter m.	0·99	0·76	3′ 3″	2′ 6″
Wheelbase, rigid m.	2·31	1·83	7′ 7″	6′
,, driving 1 group m.	2·31	1·83	7′ 7″	6′
,, total m.	10·86	8·95	35′ 7½″	29′ 4½″ †
Overall height m.	—	3·23	11′ 0″	10′ 7″
,, width m.	—	2·51	8′ 6″	8′ 2¾″
,, length m.	—	12·34	52′ 2″	40′ 6″
Weight, adhesive t.	61·4	52·9	60–10	52–2
,, empty t.	51·3	41·8	50–12	41–4
,, in service t.	61·4	52·9	60–10	52–2
Water tanks cub. m.	2·3	6·8	500 galls.	1,500galls.
Coal bunkers t.	2·6	2·0	2–10	2–0
Tractive force t.	14·8 (90%)	10·3	32·566 (90%)	22·665

* Heating surface of water tubes included (128 sq. ft. 11·9 sq. m.).
† Distance pivot centres, 21 ft. 10½ ins. (6·67 m.).

time of their construction they were the largest in the world.* Their total wheelbase was 10·03 m. (32 ft. 11 ins.).

They were compound engines, and this complication made the maintenance charges too high. After a few years they were replaced by *Mallets*.

Type 2.—Modified Fairlie Locomotives with Two Separate Boilers

In 1902 the Vulcan Foundry built a modified form of *Fairlie* locomotive with separate boilers. It proved successful in practice and for a number of years this system became the accepted standard for all new *Fairlies*.

The two independent boilers are carried on a single deep girder frame. One advantage of this type is that the variation in water level on grades is reduced ; also there is no danger of the engine crew being crushed if the locomotive is overturned in a derailment.

The water tanks are interconnected and the water capacity is often augmented by a tank under the cab.

The disadvantage of the double-boiler type—if it is one—is that the overall length of the locomotive is increased by an amount equal to the distance between the two fireboxes.

The front ends of the boilers rest on castings fixed to the extreme ends of the frames. The under sides of these castings form pivots for the bogies, the pivots being 8 ins. behind the bogie centres instead of coinciding with them as previously.

Between the bogie frames is a corresponding casting in which a recess forms a socket for the pivot. A radial slide is provided at the inner end of each bogie ; this slide is fitted with springs which reduce the tendency to rock. The arrangement of the reversing shaft at the top of the tank obviates the difficulty arising from the fact that the ends of the swing link are attached to a fixed element (the carrier frame) and to a moving element (the bogie).

The arrangement of the steam piping has been simplified with the object of reducing the number of articulated connections. The ball of the movable joint has been placed

* When they were on their way to Mexico it was found that they could not pass through the tunnel of the Raton Pass, as they exceeded the loading gauge. They had therefore to be dismantled.

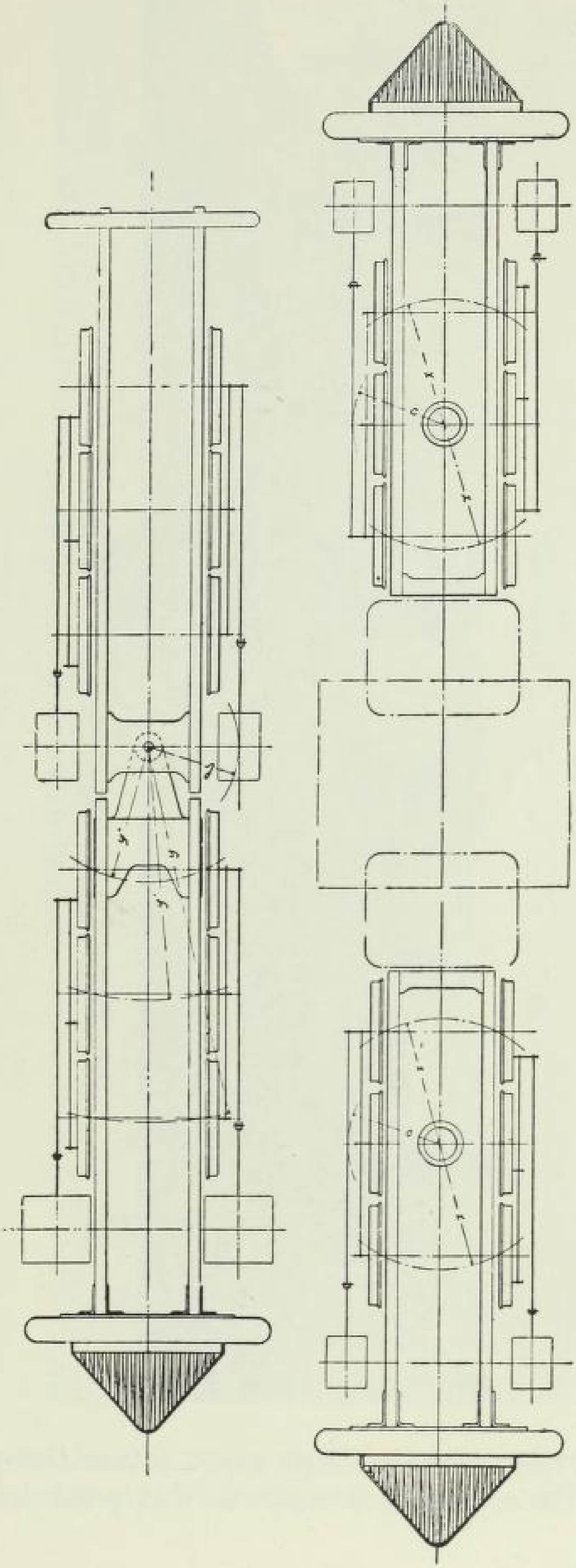

FIG. 55.—Comparison of Longitudinal Section of Mallet and Modified Two-boiler Fairlie Locomotive.

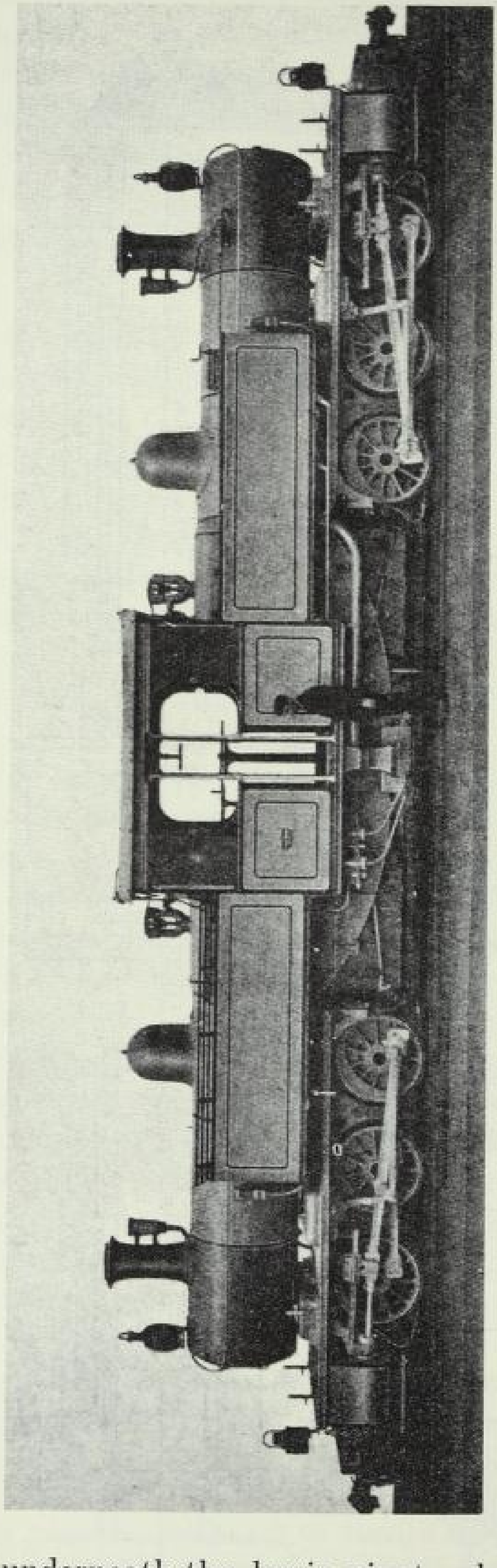

Fig. 56.—0·6 + 6·0 Modified Fairlie Locomotive, Burma Rys.
(Metre Gauge.)
Built by the Vulcan Locomotive Works.

immediately underneath the bogie pivot, where there is least movement. The steam is brought to this point by a pipe

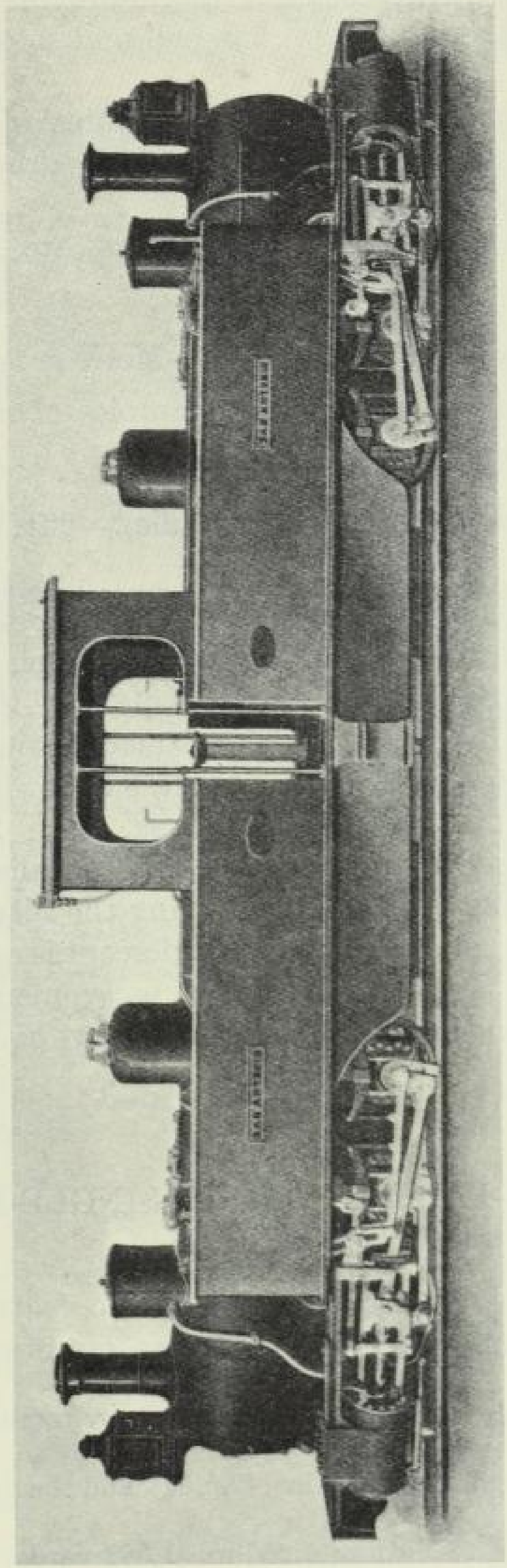

Fig. 57.—0-6 + 6-0 Two-boiler Fairlie Locomotive, Junin Ry. (Chile).
(2 ft. 6 ins. Gauge.)
Built by the Yorkshire Locomotive Works.

leading from the side of the boiler, and the ball fits into the socket of another pipe which leads the steam to the cylinders.

The exhaust pipes, which connect the intercylinder breeches pipe with the smokebox bottom, has ball and socket joints at each end.

As compared with former types, the number of articulated steam joints is reduced. Flexible piping is used in connection with the sand boxes.

In this new shape, *Fairlie* locomotives are still rather extensively used.

0-6 + 6-0 Fairlies of the Burma Rys.—Metre gauge (Fig. 56).

These 60-ton *Fairlies* are typical examples of metre gauge practice for this class of locomotive.*

0-6 + 6-0 Fairlies, F. C. de Junin (Chile).—2 ft. 6 ins. gauge (Fig. 57).

These locomotives are exceptionally large for so narrow a gauge and weigh 52 tons in working order. Their length also is considerable (40 ft. 6 ins.; 12m.34), especially if their short rigid wheelbase (6 ft.; 1m.83), is taken into account in connection with the distance between the bogies (17 ft. 3 ins.; 5m.30).†

The middle pair of wheels are flangeless.

These engines were adopted owing to the peculiar situation of this line, which, like all the lines serving the nitrate area of Chile, ascends the coastal plateau. The descent is so steep that the railway begins at the top of the escarpment (altitude 634 m.; 2,080 ft.), and is connected with the port of Junin by an aerial transporter.‡

GROUP II. D.—FAIRLIE GROUP SINGLE-BOILER LOCOMOTIVES

Though the double boiler was one of the features of the original *Fairlie* locomotives, it was not an essential one, and

* The Burma Rys. also use *Mallets*, and have more recently put some *Garratts* into service.

† The maximum breadth is 8 ft. 2 ins. (2m.51), and the overall height is 10 ft. 7 ins. (3m.23).

‡ This aerial line has a length of 1,250 m. (1,382 yards) for a rise of 534 m. (1,752 ft.), which it surmounts at a maximum slope of 53 per cent. Owing to this provision, the gradients of the railway itself do not exceed 3 per cent., and the radii of the curves do not fall below

Fairlie himself built some single-boiler tank locomotives, the cab, water tanks and coal bunker being carried on the trailing bogie.

We have previously referred to those locomotives, wherein the trailing bogie was undriven, and though this type met with little success, it was tried on several railways. Besides this the following should be noted :—

(1) *Fairlie* also built some single-boiler locomotives with two driven bogies. Since his time there have been further manifestations of the arrangements he introduced or improved.

(2) *Johnstone* also used the single boiler in some of his designs, whilst maintaining the special features of his own system.

(3) As recently as 1927 the Ravenglass and Eskdale Ry. reconstructed one of its locomotives on principles which bring it within this group.

(4) But a more radical departure was that realised by the North British Locomotive Co. in its so-called "modified *Fairlies*," which have some of the advantages of their competitors, the *Garratts*, and have the same widely spread wheelbase, though retaining the other features which characterise the *Fairlie* design.

(5) On the other hand, the *Golwé* design (the latest of this group so far) reverts to a shorter wheelbase.

100 m. (328 ft.). The profile of the line can be estimated from the following figures :—

	Distance.		Altitude.	
	km.	miles.	m.	ft.
Alto de Junin . .	0	0	634	2,080
Casa Puente . .	11·0	6·8	945	3,100
Cumbre . . .	20·5	12·7	1,216	3,990
Los Pozos . .	31·3	19·3	1,122	3,681
Santa Carolina . .	42·0	26·0	1,119	3,670
Reducto . .	51·1	31·8	1,140	3,740

The rails weigh 36 lbs. per yard, and the axle load does not exceed 8 tons 10 cwt.

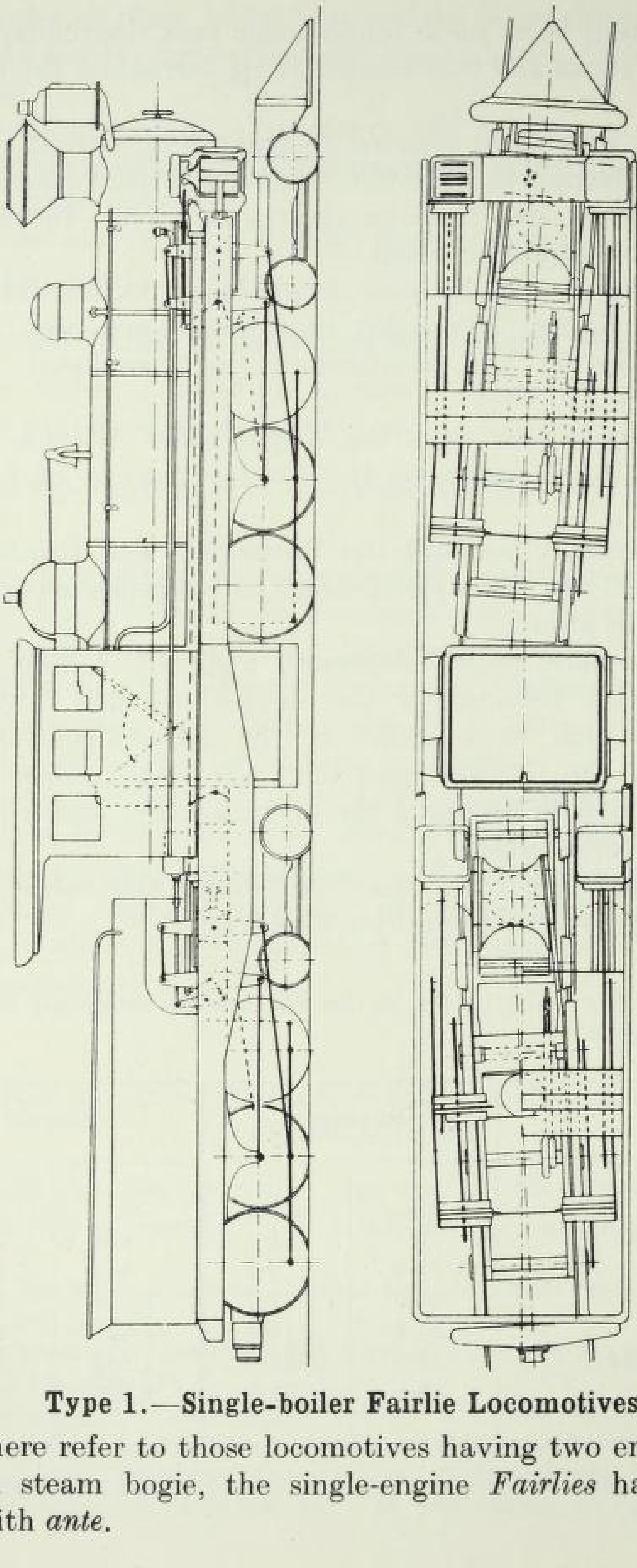

Fig. 58.—Johnstone Single-boiler Locomotive.

Type 1.—Single-boiler Fairlie Locomotives

We here refer to those locomotives having two engines, one to each steam bogie, the single-engine *Fairlies* having been dealt with *ante*.

Under their original form, they never met with any great success, and approached too much the *Meyer* design, which already held the field.

Type 2.—Single-boiler Modified Johnstone Locomotives

Johnstone, like *Fairlie* before him, endeavoured to simplify his locomotive, and, with this object in view, he provided it with a single instead of a double boiler.

In its new shape (1886), the locomotive had a tender of the usual design, both locomotive and tender being carried on a single continuous main frame. There were two identical 4-6-0 steam-driven bogies, one under the boiler and the other under the pseudo-tender (Fig. 58). The bogies were each driven by a pair of cylinders located above the leading four-wheel trucks. The centre pin of these latter, instead of being attached to a rigid frame, was attached to the driving-wheel truck frame, which was itself pivoted at a centre bearing.

The cylinders were attached to the main frames, the group of wheels to swivelling frames. To allow for the angle between the plane of motion of the crank pin and the longitudinal axis of the piston rod, the strap ends of the main connecting tension rods were pivotically connected to the brasses. A similar arrangement was applied to the eccentric rods.* Other details of this gearing have been given when dealing with the double-boiler *Johnstone* locomotives, and a further description of the single-boiler type is unnecessary, since it never got beyond the stage of projected designs prepared for the Mexican Central Ry.

Another type was designed with continuous main frames as in the former, but with two four-wheel trucks under the tender portion instead of the driven bogie quoted above.

Type 3

4-6-0 + 0-6-4 Locomotive, Ravenglass and Eskdale Ry.—Gauge 15 ins. (0m.38).

This remarkable little railway was originally laid to a broader gauge, but, owing to various causes, failed to pay its way and was finally closed down. After a time, the present

* See *Bulletin de la Société des Ingénieurs Civils de France*, March, 1893, p. 453 ; also *Engineering News*, March 26th, 1892, p. 302 ; and *Engineering*, January, 1887, p. 81.

Company purchased and reopened it as a 15-ins. gauge railway, with the hope that the curiosity awakened by so narrow a railway would bring tourists into the district.

The locomotives were replicas, to scale, of various types of main-line engines, and the Company succeeded beyond expectation, and deals with traffic of all descriptions. Indeed, this grew so rapidly that by 1928 it became necessary to overhaul the locomotive stock in view of increasing its steaming capacity, so as to deal with heavier trains.

Two of the units, the " River Esk " and the " River Mite," enter the scope of our studies, as their tenders have been provided with steam cylinders and engines. The former has been turned into a 2-8-2 + (0-8-0) steam tender applying the Poultney system (which will be described hereafter), and the latter into a 4-6-0 + 0-6-4 locomotive after the general lines of the single *Fairlie* locomotives.

Originally a 4-6-2 locomotive, the frames were cut off in front of the firebox, and side frames uniting the front engine (locomotive) to the back one (tender) bolted on either side to the central pivots provided on each of the carriages. Pivot castings are carried under the new and larger boiler and under the tender section, which latter has been considerably elevated so as to give clearance to the tender's driving wheels.

The Belpaire firebox is deep and large, and is situated back of the locomotive's drivers.

Suitable flexible joints (Dorman's Flextel type) are provided.

The front engine's exhaust is turned into the chimney ; the back engine's into a Weir feed-water heater, situated at the back of the tender, above the tender's cylinders, and is fed into the boiler by means of a Weir feed pump.

The running is steady and a speed of 38 miles per hour was reached during the trials.

This reconstruction was effectuated by Mr. E. H. Wright in the Company's own shops.

Type 4.—Modified Fairlie Locomotives

Modified Fairlie Locomotives of the South African Rys.— 3 ft. 6 ins. gauge (Fig. 59).

The recent success of the *Garratt* locomotives has stimulated the builders of *Fairlie* engines to endeavour to obtain some of

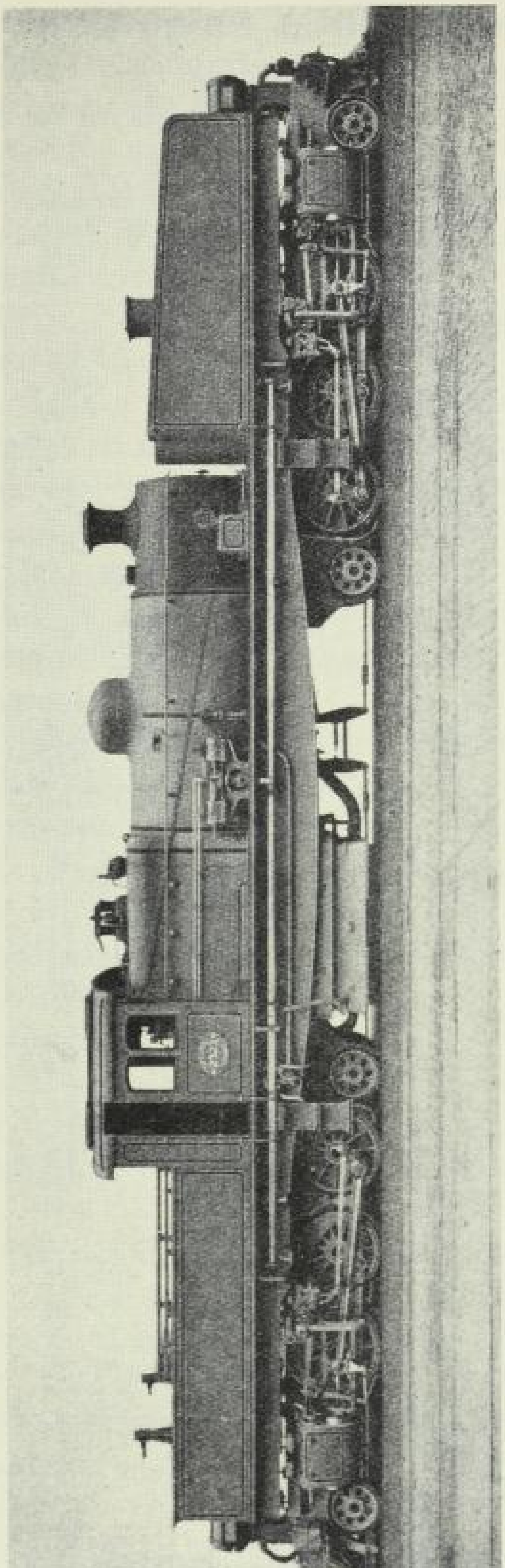

FIG. 59.—Modified Fairlie Locomotive.
(3 ft. 6 ins. Gauge.)
Built by the North British Locomotive Works for the South African Rys.

the advantages of these competitors. Thus the North British Locomotive Co. supplied some experimental engines to the

TABLE 25.—MODIFIED FAIRLIE SINGLE-BOILER LOCOMOTIVES

Railway Gauge	South African Rys. 3′ 6″		
Type, Double Builder Date	Prairie. N. British. 1925.	Prairie. N. British. 1925.	Mikado. Henschel. 1927.
Cylinders, diameter	14″	15″	18″
,, stroke	23″	24″	24″
Boiler, centre line	7′ 3″	7′ 6″	7′ 11″
,, diameter	5′ 1¾″	6′ 2⅜″	—
,, length	10′ 11″	10′ 2½″	15′
,, pressure lbs. sq. in.	180	180	180
Firebox, length	7′ 3″	7′ 6″	—
Tubes, number	24–143	24–190	—
,, diameter	2″	2″	—
,, superheater	11′ 3⅜″	10′ 8″	—
Heating surface :—			
Firebox sq. ft.	155	190	—
Tubes ,,	1,232	1,555	—
Total ,,	1,387	1,745	2,062
Superheater ,,	280	362 int.	725
Grate area ,,	34	40·8	53
Wheels, diameter	2′ 4½″	2′ 4½″	2′ 4½″
,, ,,	3′ 6¾″	3′ 9½″	3′ 9½″
,, ,,	2′ 4½″	2′ 4½″	2′ 4½″
Wheelbase, 1 group	—	18′ 4½″	22′ 10½″
,, rigid	8′ 0″	6′ 6″	12′ 9″
,, total	56′ 8″	58′ 7″	69′ 10″
Pivot centres	—	36′ 6″	42′ 1″
Overall height	12′ 3″	12′ 9″	12′ 11½″
,, width	9′ 1″	9′ 1″	—
,, length	65′ 9¼″	67′ 8¼″	77′ 6¾″
Tractive force (75%) lbs.	28,460	32,040	46,140
Water tanks galls.	3,000	3,800	3,600
Coal bunkers	5 t.(225 cub. ft.)	5 t. (225 cub. ft.)	9 t. (406 cub. ft.)
Weight, max. 1 axle t.-cwt.	10–5	12–7	13–6
,, adhesive ,,	62–16	72–17	104–18
,, in service ,,	99–12	113–0	152–12

South African Rys., where the *Garratt* engines are in great favour.

These locomotives retain the characteristic of the single *Fairlies*. The pivots are located at the centre of the rigid wheelbase of each truck. This lessens the wear between wheel flanges and rails.

The distribution of the loads on the axles, as the fuel and water are expended, has been improved.

On the other hand, the distance between the bogies has been increased to the same as that of the *Garratt* locomotives. This allows room for a better firebox with a satisfactory ash pit, resulting in a more efficient boiler, and also distributes the weight of the engine over a greater space.

The original "modified *Fairlie* locomotive" was a double-Mogul, supplied to the South African Rys. in 1924. Some improved and slightly more powerful locomotives of a similar type were supplied to the same railway in the following year. These having proved successful, a much more powerful engine was designed, and ten double-Mikados were built to this design by Henschel & Co., and delivered in 1927.

The boiler and the water tanks can be bodily removed from the continuous girder frame without interfering with other parts of the engine.

The leading bogie carries a pivot which works in a socket fixed to the lower portion of the boiler barrel. The back end of the firebox rests on either side of the frames of the rear bogie by means of spherical seated bearings and sliding plates, which are carried by brackets fixed to the frames

A large pipe, situated on the right side of the boiler, connects the two water tanks.

The steam pipes have universal joints.

The exhaust from all the cylinders is taken to the blast pipe in the smokebox, that from the cylinders of the trailing bogie being led by a pipe fixed to the left side of the main frame.

There are several features in these locomotives which, although they are not peculiar to the articulated system, are, nevertheless, worthy of note. Thus, there are four arch tubes which support the brick arch in the firebox. The truck frames are of the bar type. The radial displacement of the trucks is limited and spiral springs restrain their lateral movements.

The outside carrying axles are of the bissel type ; all carrying axles have $\frac{3}{4}$ in. side play.

The cylinders have piston valves with inside admission. The *Heusinger* valve gear is used with steam admission up to 80 per cent.

Type 5.—The Golwé Articulated Locomotive

The *Golwé* locomotive (Fig. 60) has a main frame and two driven bogies.

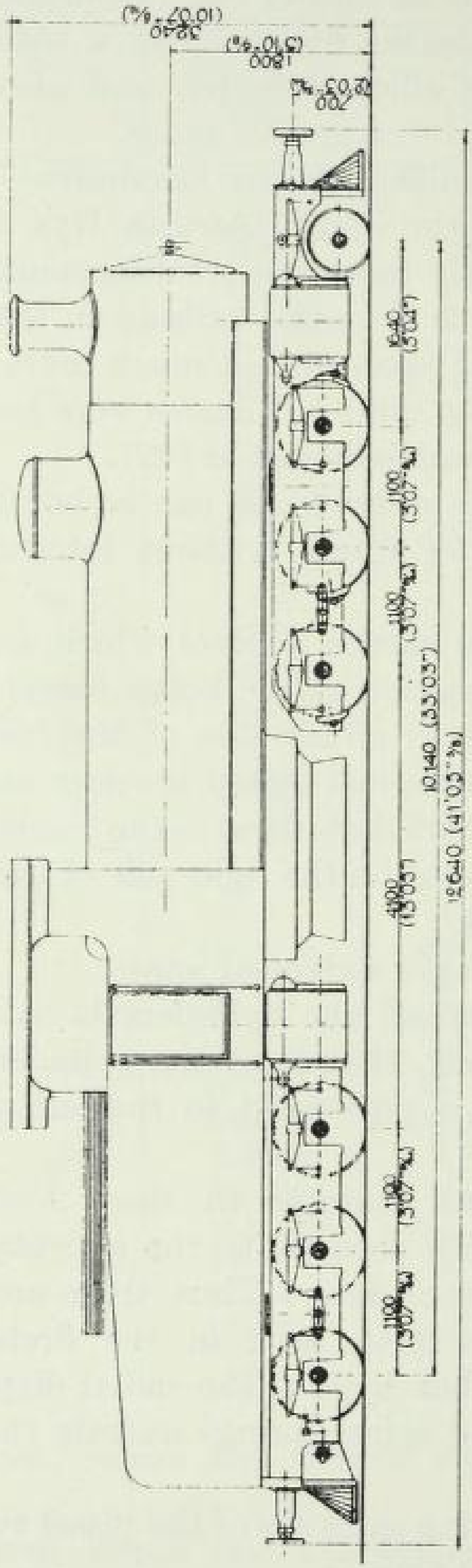

Fig. 60.—Schematical Outline of Golwé Locomotive.

Frame.—The girder frame carries the boiler, with its firebox and ash pan, the cab and the rear water tank and coal bunker.

Bogies.—The frame rests on the bogies by two hemispherical seated pivots, which engage with footstep bearings on the bogies. Spring boxes, on either side of the pivots, reduce the swing between the upper and lower part when rounding curves.

In order to reduce the distance between the bogies, the pivots are midway between the outermost axles of each bogie, while in the *Garratts* they are located at the inner ends of the bogies.

Firebox.—The distance between the bogies allows the fire-box to descend below them, which allows very free design without having to place the boiler centre line too high.

Pipe Work.—The main steam pipe from the dome divides into two branches in the smokebox. The left-hand branch feeds the front truck cylinders, and the right-hand branch the rear truck cylinders, and seamless pipes convey the steam to spherical steam joints fitted to the left front cylinder and to the rear right one.

The seamless pipes are joined by spherical joints acting as hinges and placed near the truck pivots, in order to minimise their motion. This brings the total number of joints in the live steam pipe work up to four.

The exhaust pipes are similar. Those from each truck pass into a single pipe located on the centre line. These two exhaust pipes are connected by spherical joints, also placed near the truck pivot, to a single exhaust main carried outside the locomotive and along the main frame which supports the boiler.

All the piping is thus easily accessible throughout.

Regulation of the Output of the Rear Cylinders.—This is a self-regulating device introduced to avoid one of the trucks skidding when the tanks or bunkers are almost empty, and which automatically reduces the cut-off on the rear cylinders and keeps it proportional to the adhesive weight.

This is obtained by the use of a steam distributing valve worked by a float placed in the water tank. This valve regulates the steam inlet on the small cylinder of a servo-motor set on the reversing lever. The piston displaces the leverage point of the rear-truck reversing shaft link, and this varies the cut-off of the rear cylinders.

Fuel and Water.—The water tank is U shaped. The legs of the U extend on either side of the rear end of the main frame.

In order to give the driver a clear view when running in reverse, the top of the water tank is sloped off to the rear.

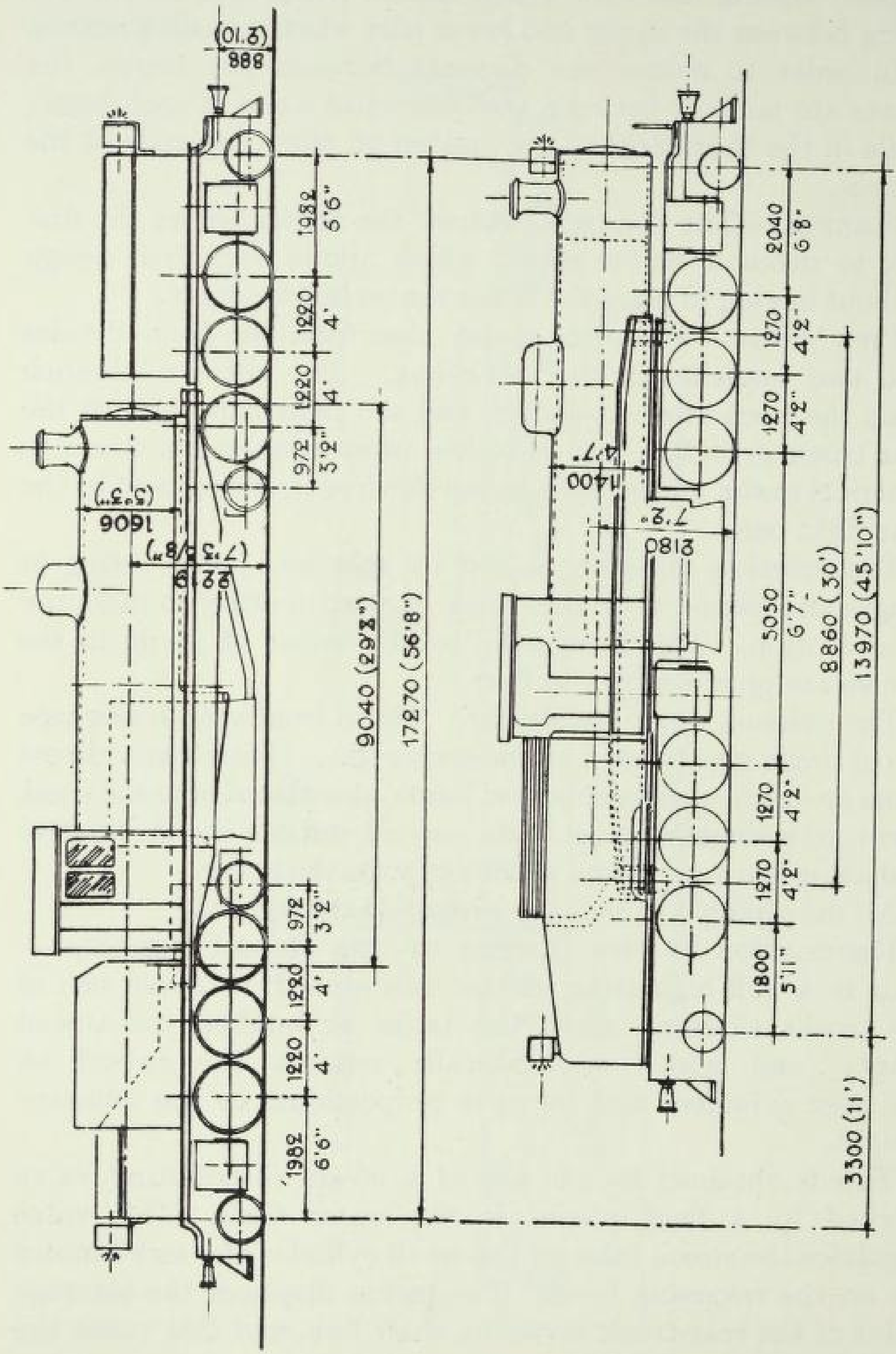

FIG. 61.—Comparison of Garratt and Golwé Locomotives of Same Power.

This water tank is fixed to the frame of the trailing bogie. while the coal bunker is carried on the main frame.

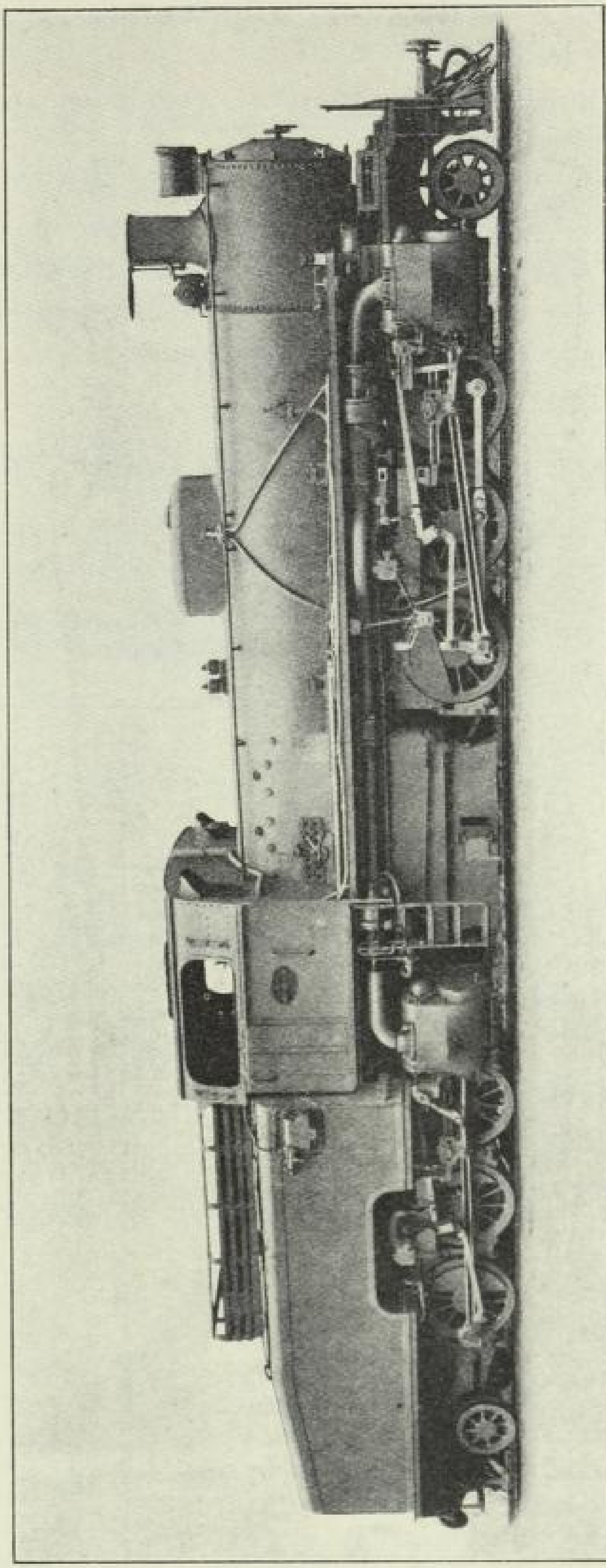

Fig. 62.—Golwé Locomotive, Ch. de Fer de la Côte d'Ivoire. (Metre Gauge.)

Comparison with other Articulated Locomotives.—In the *Golwé* the facilities for a good design of firebox are the same as in the *Garratt*. However, the space available for the boiler itself is more restricted, since the leading bogie is beneath the front of the boiler.

Both the overall length and total wheelbase are less than those of the *Garratt* (Fig. 61).

In comparison with other systems, the *Garratt* boiler has the advantage of being short, but it has the corresponding disadvantage—if it is one—that it cannot be greatly lengthened without involving an excessive distance between the bogies. This limitation does not obtain in the *Golwé*.

Table 26.—Principal Dimensions of Golwé Locomotives

Railway	Chemin de Fer de la Côte d'Ivoire.	
Gauge	Metre.	
Builder	Haine-Saint-Pierre.	
Date	1928.	
Cylinders, diameter	0m.40	1′ $3\frac{3}{4}$″
,, stroke	0m.56	1′ $10\frac{1}{16}$″
Boiler height of C.L.	2m.18	7′ $1\frac{25}{32}$″
,, diameter	1m.40	4′ $7\frac{5}{32}$″
,, pressure	12 kg. per sq. cm.	170 lbs. per sq. in.
Tubes, diameter	40/45 mm.	$1\frac{37}{64}$″/$1\frac{49}{64}$″
,, length	4m.30	14′ $1\frac{3}{8}$″
Heating surface, firebox	13·6 sq. m.	147·8 sq. ft.
,, ,, tubes	150 ,,	1,630·4 ,,
,, ,, total	163·6 ,,	1778·2 ,,
Grate area	2·75 ,,	29·89 ,,
Wheels, diameter, bissel	0m.71	2′ $3\frac{15}{16}$″
,, ,, driving	1m.10	3′ $9\frac{5}{16}$″
,, ,, coupled	1m.10	3′ $9\frac{5}{16}$″
Wheelbase, 1 group, front	4m.58	15′ $0\frac{11}{32}$″
,, ,, back	4m.34	14′ $2\frac{29}{32}$″
,, rigid	2m.54	8′ 4″
,, driving, 1 group	2m.54	8′ 4″
,, total	13m.97	45′ $10\frac{1}{16}$″
Centres of pivots	8m.86	29′ $0\frac{7}{8}$″
Overall, height	3m.70	12′ $1\frac{11}{16}$″
,, width	2m.60	8′ $6\frac{3}{8}$″
,, length	16m.53	54′ $2\frac{7}{8}$″
Weight, max., 1 axle	12·0 metric tons	11 tons 16 cwt.
,, total adhesive	72·0 ,,	70 tons 17 cwt.
,, ,, in service	90·0 ,,	86 tons 12 cwt.
Tractive force	14,000 kg.	30,870 lbs.
Coefficient of adhesion	5·12	5·19
Water	12·5 cub. m.	442 cub. ft.
Wood fuel	8 ,,	282 ,,

For equal power, the latter weighs less than the *Garratt*, because less metal is used in its construction.

Utilisation of Golwé Locomotives, Ch. de Fer de la Côte d'Ivoire.—Gauge, 1 metre.

Four locomotives of this type were supplied in 1928 to the Ivory Coast Ry. (Fig. 62). The leading dimensions are given in Table 26.

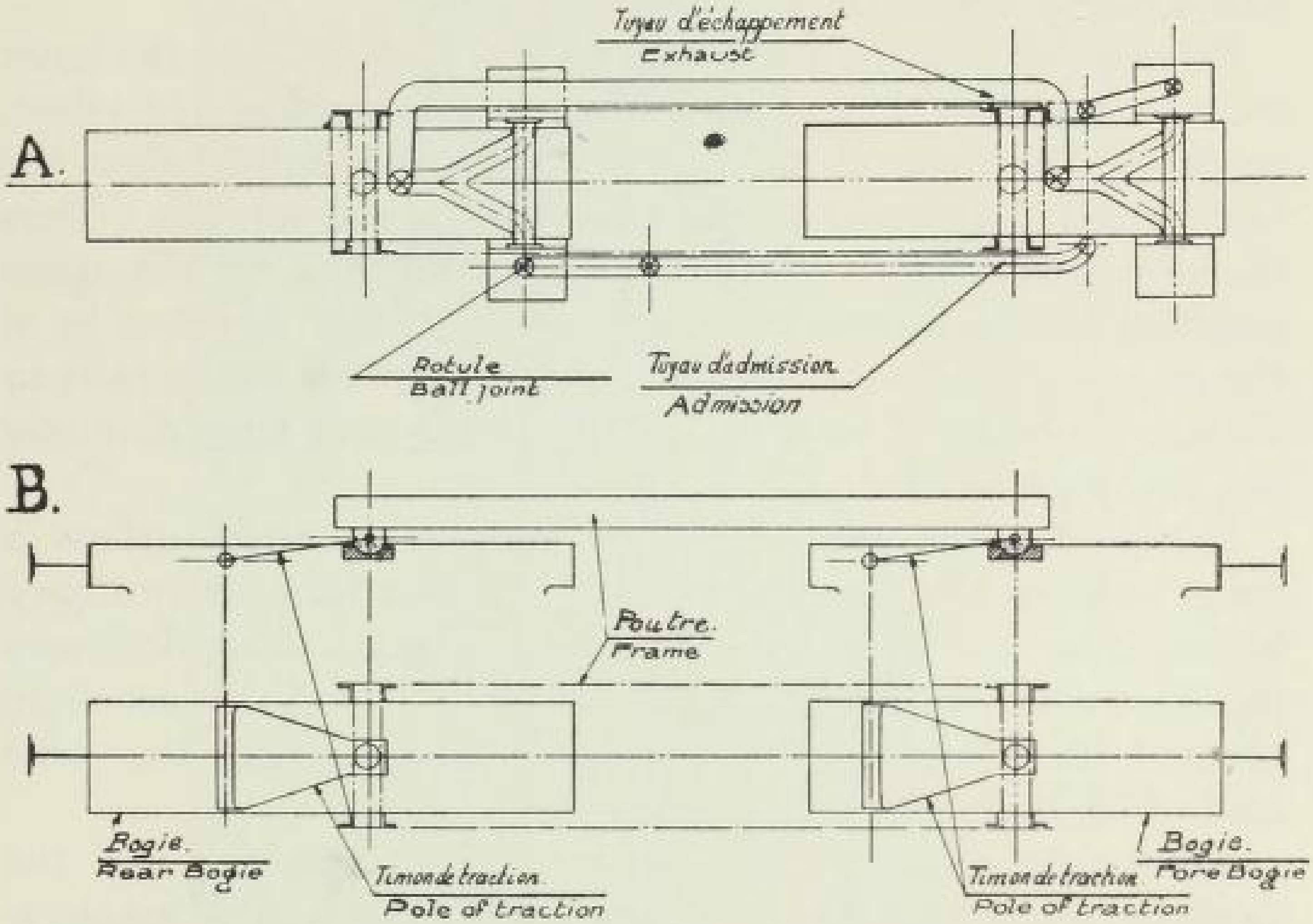

FIG. 63.—Plans of Golwé Locomotive.

GROUP III.—THE GARRATT GROUP OF LOCOMOTIVES *

General Characteristics

As in the case of the *Fairlie* type, the boiler and firebox of the *Garratt* are carried by a main frame to which the buffing and drawgear are attached. This frame rests on the inner ends of two motor bogies, which are spaced a considerable distance apart. The fuel and water are carried in tanks and bunkers immediately above these bogies.

Boiler.—The girders which carry the boiler rest on the inner ends of the two bogies. The boiler is therefore, in effect, suspended between them, and there are no axles below the boiler itself. This arrangement has several advantages. Thus the dimensions of the boiler are not restricted by the space required for the frames and the wheels. It can therefore be of the maximum diameter which the loading gauge of the railway allows. A boiler of relatively short length and large diameter can therefore be used.

Hence, for the same area of indirect heating surface a boiler such as the *Garratt's* is more efficient than an ordinary boiler, since the evaporative power of boiler tubes decreases rapidly with their length, and a number of short tubes are more efficient than fewer tubes of greater length giving the same area of heating surface (Fig. 65).

All necessary steam is therefore easily provided, and the steaming qualities of the *Garratt* boiler permits a rapid acceleration.

The reduced length of the boiler has an additional advantage on lines with very steep gradients, for the extreme variations on the water level thus produced do not cause either the crown of the firebox or the front ends of the tubes to become uncovered,

* Some of the information which follows has been taken from the Author's work "Les Locomotives Garratt" (Béranger, Paris and Liège) to which the reader is referred.

Other information which has enabled us to complete the information on this subject has been kindly furnished by the Garratt locomotive builders, Messrs. Beyer, Peacock and Co., of Manchester, Messrs. Sir W. G. Armstrong Whitworth, of Newcastle, Messrs. Maffei, of Munich, Henschel of Cassel, and Les Ateliers St. Léonard, of Liège; also by Mr. Whitelegg and Mr. Cyril Williams, to whom we tender our best thanks.

Some information has been gleaned from technical periodicals, notably the *Railway Gazette*, the *Locomotive* and *Engineering*. The remainder has been furnished by various railway companies.

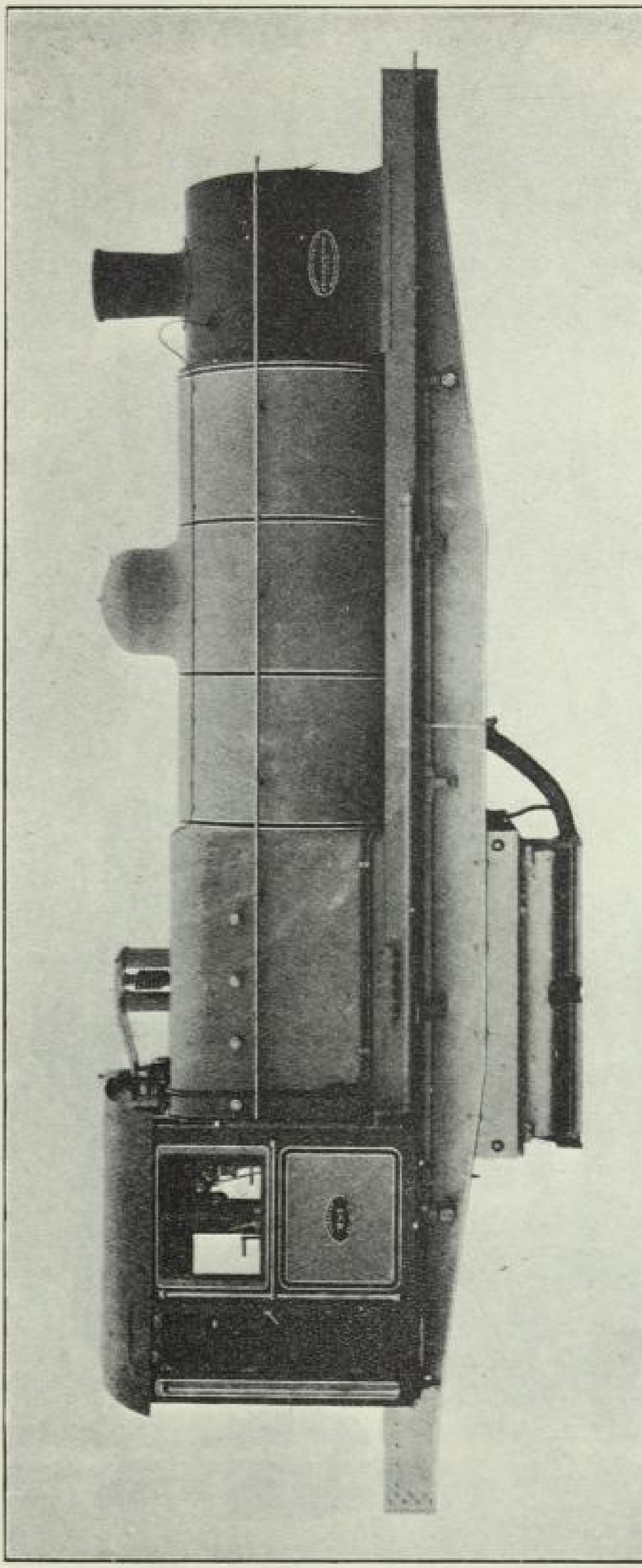

Fig. 64.—Main Frame with Boiler and Cab, Garratt Locomotive.
Built by Messrs. Beyer, Peacock and Co. for the South African Rys.

as may happen in the case of locomotives with very long boilers. Thus, for this reason, the large *Mallets* of the South African Rys. cannot be used on certain sections in Natal,

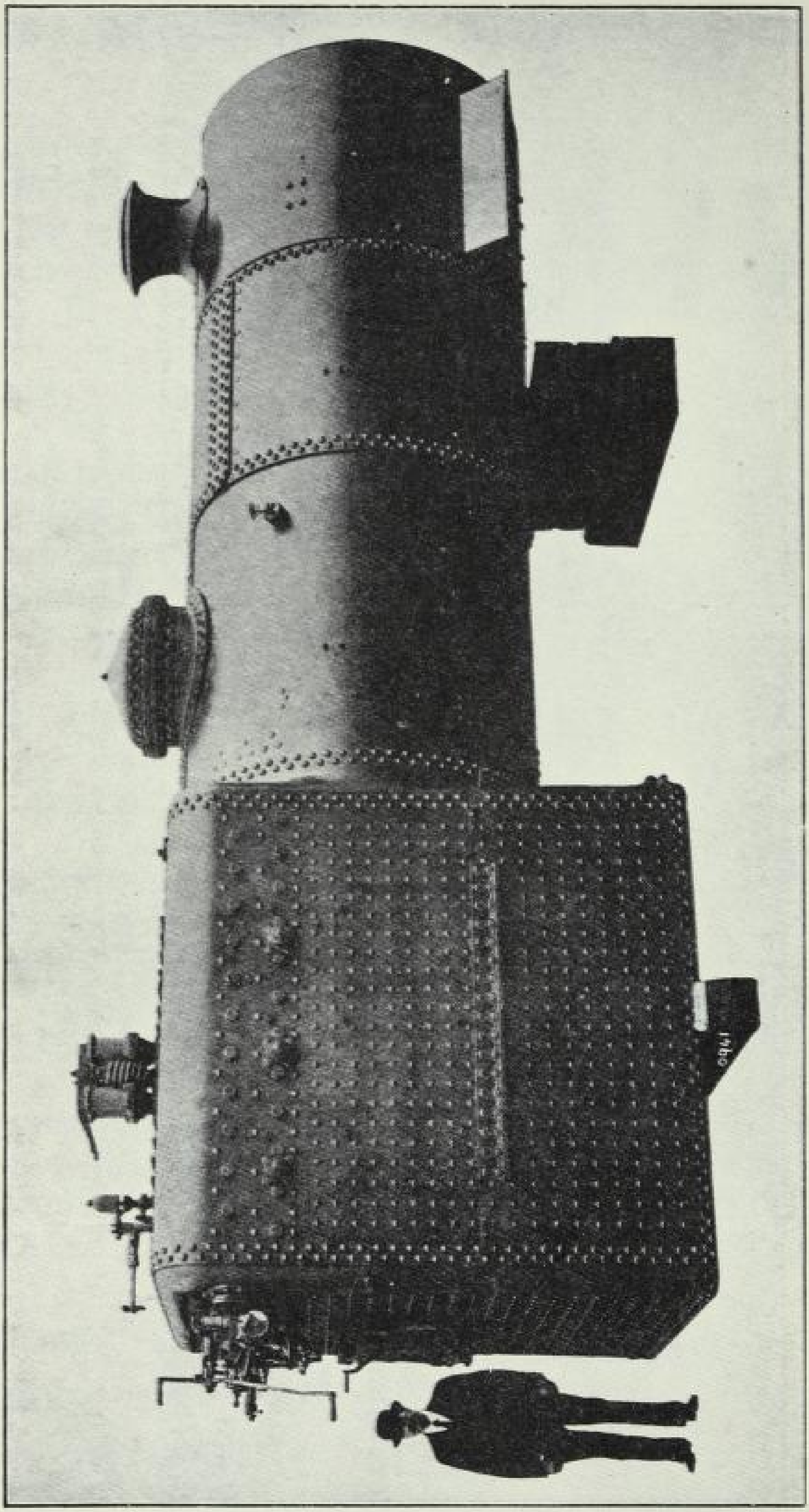

Fig. 65.—Boiler and Firebox of Garratt Locomotive, South African Rys. (3 ft. 6 ins. Gauge.)

although *Garratts* of the same power give excellent service on these sections.

The space available allows the centre line of the boiler to be kept at a reasonable height, while at the same time a sufficiently deep firebox can be provided. This is a material advantage, especially on narrow gauge lines.

FIREBOX.—The *Garratt* design allows of very satisfactory arrangements for the firebox. The wheels do not impede access to its angles. It is entirely free and can be made large and deep. The ashpit allows a uniform admission of air to all parts of the grate.

BOILER TUBES.—These are short. Rapid evaporation is therefore attained without an excessive draught in the firebox, which is only obtainable by a corresponding back pressure in the cylinders with a resultant loss in efficiency.

SUPPORTS OF THE MAIN FRAME.—The points of support of the main frame which carry the boiler are arranged in such a way as to maintain a regular distribution of the load whether the tanks and bunkers are full or almost empty, and, though the points of supports of the boiler are close to the end of the bogies, a proper adjustment of weight is obtained by placing the cylinders at the other ends and by proper distribution of the fuel bunker and of the tanks.

CYLINDERS.—These are usually four in number, two for each bogie. They are located at the further ends of the two bogies,* and are usually supported by a bissel which guides the locomotive when entering curves. The earlier *Garratts* worked with saturated steam, but nearly all the recent types have superheaters of the Schmidt, Robinson or Marine and Locomotive Superheater Co. types.

An experimental *Garratt* locomotive with eight cylinders has been used on the Tasmanian Railways for express service.

Still more recently six-cylinder, high-pressure engines have been built.

Only two classes of compound *Garratts* have been put into service.

EXHAUST STEAM.—The exhaust steam from both pairs of cylinders is led to two concentric exhaust pipes of the same sectional area.

STEAM PIPING.—The live steam pipes have a swivelling joint, the centre of which is coincident with the pivot of each

* With the exception of the first *Garratt* ever built (for Tasmania), in which all cylinders were situated at the inner ends of the bogies.

bogie. The exhaust steam passes through similar joints before entering the smokebox. The rear joint is prolonged by a sliding tube.

After some preliminary experiments, the design and construction of these joints has been satisfactorily achieved and no trouble has been experienced, although they carry high pressure steam.

Operating Levers.—The levers operating the link motion and reversing gear have universal joints.

Crank Axle.—This is generally the axle furthest from the cylinders.

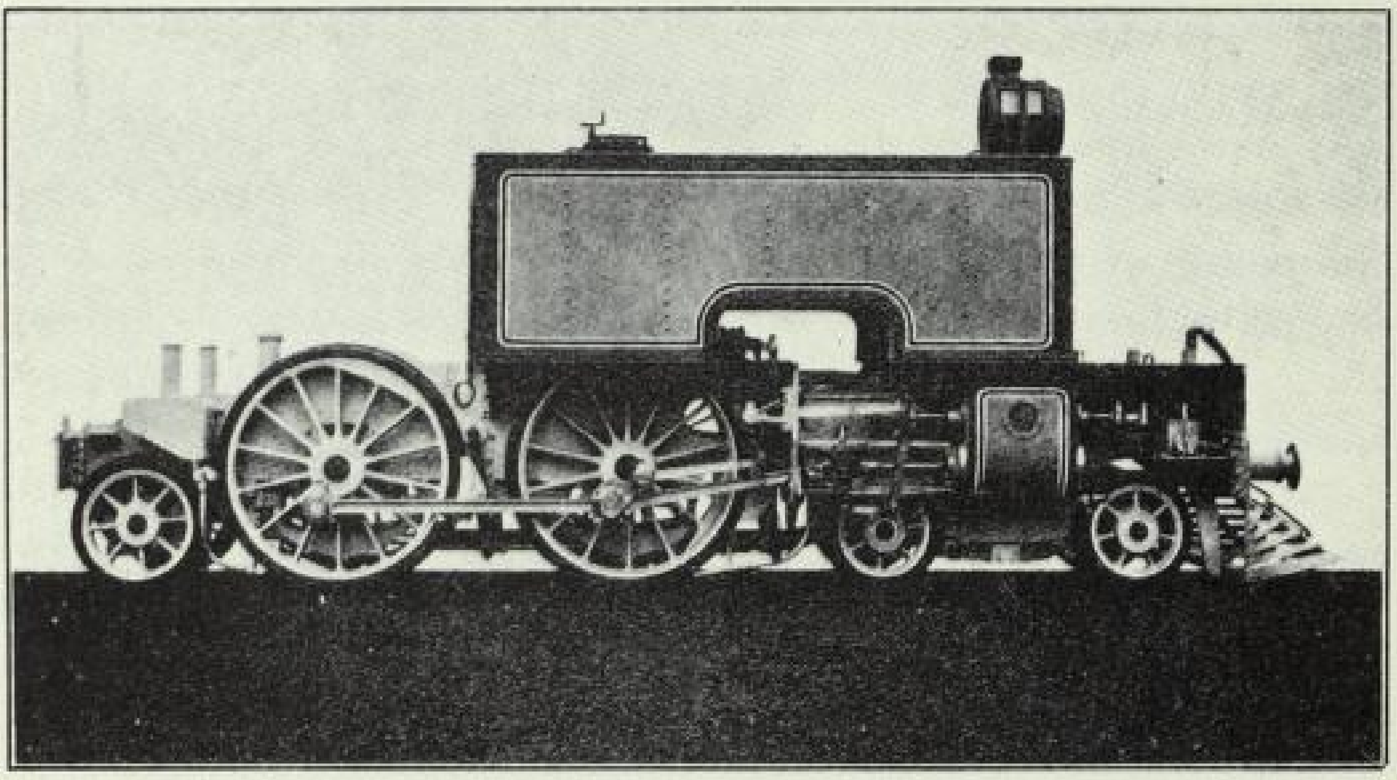

Fig. 66.—Front Bogie, Garratt Locomotive, Tasmanian Rys. (3 ft. 6 ins. Gauge.)

Wheelbase.—The play of the bogies in reference to one another and to the main frame of the locomotive is unrestricted.

The overall wheelbase is great, but as the *Garratts* are double-enders, turntables are not needed.

Owing to the considerable space between the two sets of wheels, the load per yard run of line is less than for other types of locomotives.*

Fuel and Water.—The water tanks and coal supplies are carried by the bogies.

As in the case of all locomotives without separate tenders, the adhesive weight diminishes as the consumption of fuel and water proceeds, but this is not a feature of much importance.

For footnote (*) see page 173.

The calculations of the adhesive weight are made on the basis of empty tanks and coal bunkers, a condition which never actually occurs in practice.

The reduction in the adhesive weight varies from 20 to 23 per cent. for completely empty tanks and bunkers, although under ordinary working conditions this reduction seldom exceeds 10 or 11 per cent.

It is necessary that the locomotive be so designed that the diminution of the adhesive weight shall be properly distributed over all the axles.

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* The following table quotes some examples :—

TABLE 27

Railway.	Type of Locomotive.	Gauge.	Weight. Tons per Metre.	Weight. Tons per foot run.
London & North Western Ry. . .	4-4-0	Standard	7·62	2·4
London, Brighton & S. Coast Ry. . .	4-4-2-T	,,	7·49	2·37
Metropolitan Ry. .	0-6-4-T	,,	8·12	2·34
Great Western Ry. .	2-6-0	,,	8·32	2·6
Eastern Bengal State Rys. . . .	2-6-4-T	5 ft. 6 in.	7·24	2·28
Great Western Ry. .	4-6-0	Standard	8·81	2·77
Chemin de fer du Midi	6-4-2	,,	8·35	2·66
Great Western Ry. .	4-6-2	,,	8·87	2·8
Great Central Ry. .	0-8-4-T	,,	10·98	3·15
Mexican Ry. (*Fairlie*) . . .	0-6-0+0-6-0	Standard	12·41	3·9
Southern Pacific Ry. (États-Unis) (*Mallet*) . . .	2-8-0+0-8-2	,,	10·96	3·45
Tasmanian Government Rys. (*Garratt*) . . .	4-4-2+2-4-4	3 ft. 6 ins.	4·77	1·5
San Paulo Ry. (Brazil) (*Garratt*) .	2-4-0+0-4-2	5 ft. 3 ins.	5·24	1·68
San Paulo Ry. (Brazil) (*Garratt*) .	2-6-0+0-6-2	Metre	5·21	1·64

In the case of locomotives for high speeds which have a relatively large number of axles which are not driven, it can be so arranged that these are chiefly affected by the reduction in weight due to the expenditure of fuel and water, so that the variation in the weight available for adhesion is relatively unimportant.

Steadiness in Running.—Like other articulated locomotives, the *Garratt* is superior both to ordinary rigid locomotives and to those of the *Mallet* type. This is due to the fact that the boiler is not rigidly connected to the frames which

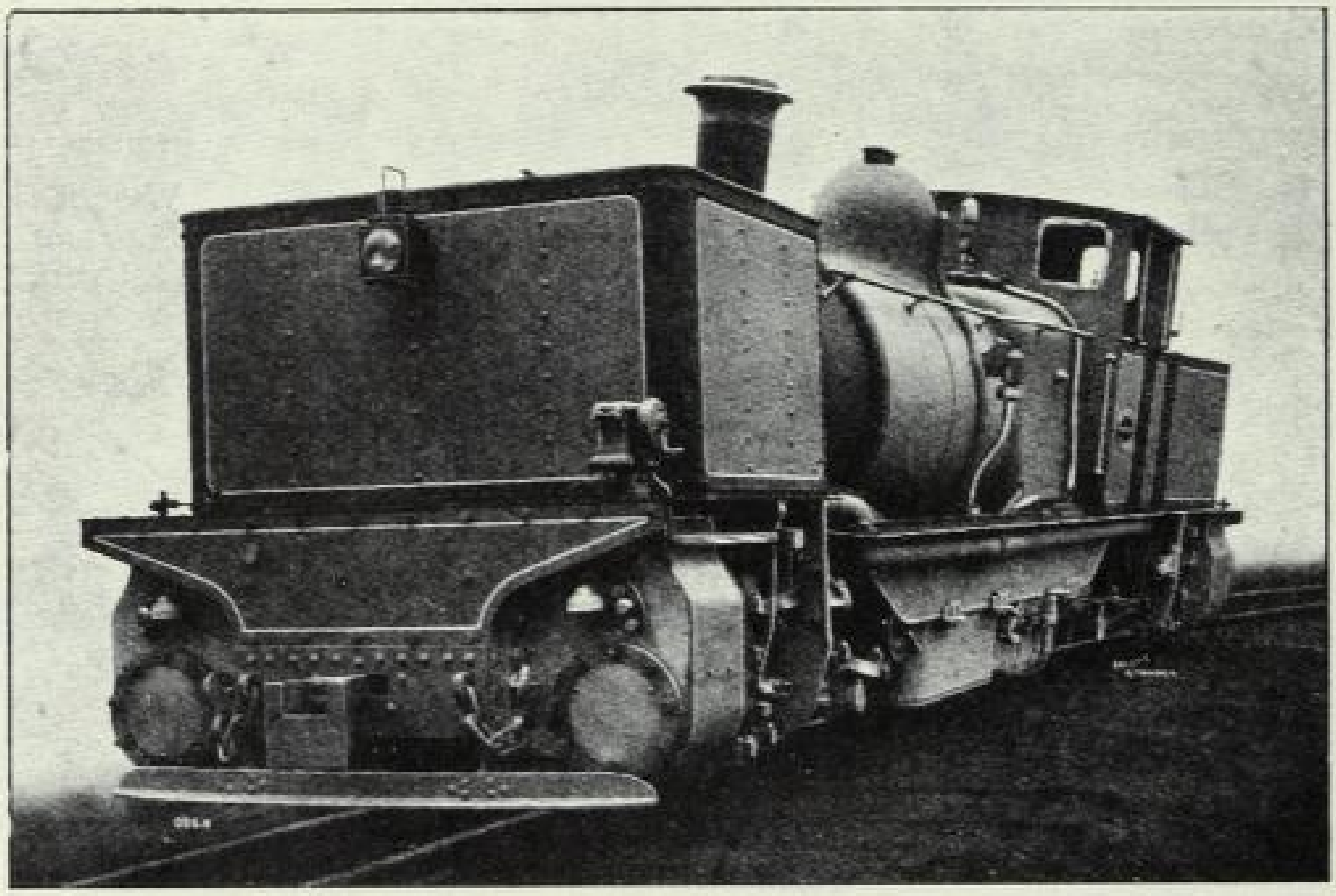


Fig. 67.—Darjeeling-Himalayan Ry. Garratt Locomotive on a Sharp Curve. (2 ft. Gauge.)

carry the wheels. It is not, therefore, directly subjected to any shocks due to inequalities in the road bed. It is this feature that allows speeds of 55 miles per hour to be reached on the 3 ft. 6 ins. gauge Tasmanian Rys., and speeds of 60 miles per hour on the South African Rys., while *Mallet* locomotives are unsafe at speeds of 50 km. (30 miles) per hour.

Running on Curves (Figs. 67 and 68).—When a *Garratt* locomotive is running through a curve, the centre line of the boiler lies in a chord of the arc of the curves and is therefore displaced towards the centre of the curve.

In the case of the *Mallet* locomotive, on the contrary, as the

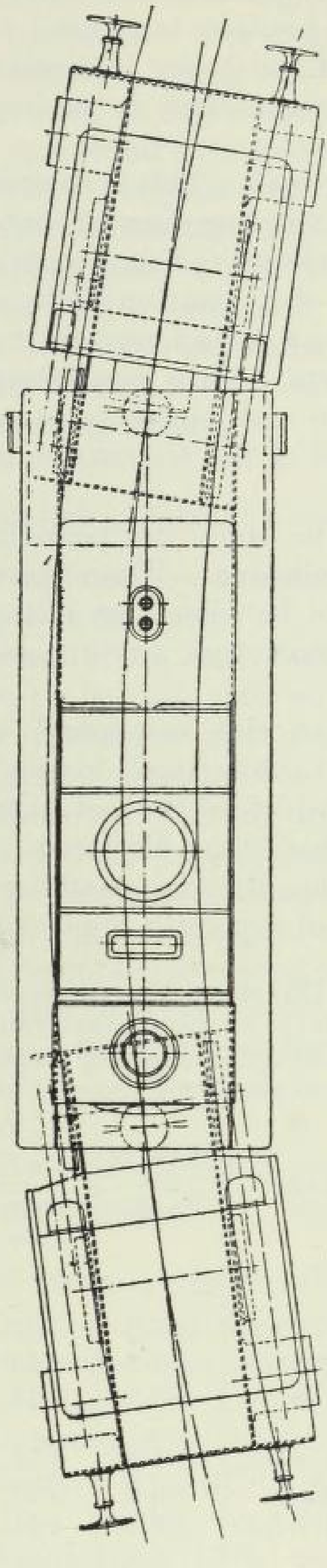


FIG. 68.—Standard Gauge Garratt Locomotive on 100 ft. Radius (30 m.) Curve, Hafod Copper Works.

boiler is integral with the main frame and the rear truck, its centre line takes up a position tangential to the curve, hence the leading portion of the boiler is displaced outwards, and also its centre of gravity. This is an important matter on lines with many curves.

Buffing and Drawgear.—This is so arranged as to permit vehicles easily to be coupled up even on curves.

Coefficient of Adhesion.—This is quite satisfactory.*

Latest Garratts.—Information kindly supplied whilst this book was in the press will be found in the Addenda, note 3.

Compound Garratts.—With two exceptions, all *Garratt* locomotives are simple and, curiously enough, the exceptions consist in the very first of the *Garratts* built and in one of the latest.

It was a mistake to apply compounding to the original *Garratt* sent out to Tasmania. When there are necessarily a number of problems to be solved, as is the case in any new type of articulated locomotive, any unnecessary complication should be avoided.

Between 1909, when this compound was supplied, and 1927, all *Garratts* were built as simple locomotives. Indeed, the builders have made a feature of the fact, in comparison with the *Mallet* locomotives which they displaced. We may therefore conclude that, at the time, the compound *Garratt* was premature.

Superheating was subsequently applied to all newer types

* The following table (28) shows the variations in the ratio of the tractive force (constant 0·75) to the weight available for adhesion for tanks and bunkers full, half full, and empty respectively.

Railway.	Gauge.	Axles of one Bogie.	Tanks and Bunkers.		
			Full. 1 to	Half Full. 1 to	Empty. 1 to
San Paulo Ry. .	5 ft. 3 ins	2-4-0	5·07	4·90	4·71
Tasmanian Govt. .	3 ft. 6 ins.	4-4-2	4·66	4·30	3·94
Arakan Flotilla Co.	2 ft.	0-6-0	5·42	5·02	4·65
Western Australian Govt. . . .	3 ft. 6 ins.	2-6-0	5·75	5·39	5·00
Mogyana Co. .	Metre.	4-6-0	5·63	5·32	4·85
Tasmanian Govt. .	3 ft. 6 ins.	2-6-2	4·51	4·11	3·62

and was most successful. And high-pressure steam joints ceased to give any trouble at a very early stage.

It was thought that even a long receiver pipe would not be very objectionable owing to superheating, hence the principal drawbacks of the compound principle disappeared.

On the other hand compounding possesses advantages, principally in superior thermal efficiency and in the elastic coupling of the two motor units, which reduces the tendency to slipping. The Burma Rys. recognised this in 1927, and their example may find followers, particularly on roads where the labour is sufficiently skilled to deal with the extra complications introduced by compounding.

Utilisation of Garratt Locomotives

The first *Garratt* locomotive was built in the year 1909 for a Tasmanian railway of 2 ft. gauge.

Since then, the use of *Garratt* locomotives has increased rapidly. They are to be met with on many railways of all gauges, where they are doing work of a most varied nature.

Europe.—These locomotives are in use on the Central Aragon and on the Catalan Rys. (Spain) and on several English standard gauge lines : the London and North-Eastern, the London, Midland and Scottish Ry. and also on the private line of the Hafod Copper Works in Wales.

Africa.—*Garratt* locomotives are used on the 2 ft. and 3 ft. 6ins. lines of the South African Rys., also on the Natal and Trans-Zambezian systems, on the Rhodesia Rys., on the Benguela Ry.

On the Kenya and Uganda Ry. and also on the Madagascar Ry. and in Algeria.

On the Congo Ry. and on the Mayumbé Ry., besides the Sierra Leone Government Rys. and the Mauritius Ry. (standard gauge).

South America.—These engines are used in Brazil on the 0·60 m. (2 ft. app.) and metre gauge lines of the San Paulo Ry. and on the metre gauge lines of the Mogyana Co. of the Western Ry. of Brazil and the Leopoldina.

Also on the standard gauge lines of the Entrerios and the Argentine North-Eastern Ry., on the Argentine Southern, the Cordoba Central Ry., besides the Chilian Nitrate Rys., the Bolivia Ry., the Antofagasta (Chile) and Bolivia Ry.

Finally on the Guayaquil and Quito Ry. (Ecuador) and on the Colombian National Ry.

Asia.—In Turkey, on the Smyrna-Aïdin Ottoman Ry.

On the metre gauge lines of the Burma Rys. and on the 2 ft. 6 ins. line of the Arakan Flotilla Co.

In British India, on the North-Western, the Eastern Bengal and the Bengal-Nagpur Rys. (5 ft. 6 ins. gauge). Also on the Assam-Bengal Ry. (metre gauge) and the Darjeeling-Himalayan Ry. (2 ft. gauge).

In Ceylon, on the Government Rys. (5 ft. 6 ins. gauge).

Oceana.—Western Australian Rys. and the Dundee Coal Co.'s Ry. (3 ft. 6 ins. gauge), Victorian State Rys. (2 ft. 6 ins. gauge).

Tasmanian Rys. (2 ft. and 3 ft. 6 ins. gauges).

New Zealand Government Rys.

Garratt Locomotives for Various Gauges

Since their first appearance on the 2 ft. gauge lines of the Tasmanian Rys., *Garratt* locomotives have been used on lines of all gauges, including, finally, standard gauge lines.

Some lines of 0·60 m., or 2 ft., gauge are very crooked.* Reverse curves succeed each other without intermediate tangents, and similarly up grades follow down grades without any level portions between them. When used on such lines the bogies of the *Garratt* locomotives must be able to move in every direction relatively to the boiler; there is always sufficient flexibility in the horizontal plane, but special care in design is needed to assure sufficient vertical flexibility.

There are but few large railways systems of 75 cm. or of 2 ft. 6 ins. gauge. However, *Garratt* locomotives are to be found on the Congo Ry.† There are many more *Garratt* locomotives on metric gauge lines,‡ the most powerful being the Burmese and the Kenya and Uganda Rys.

But there can be no doubt that the most interesting examples

* The following lines of 0·60 m., or 2 ft., gauges use *Garratt* locomotives: the Mayumbé Ry. (Belgian Congo), the South African Rys., the Darjeeling-Himalayan Ry. and the Tasmanian Government Rys.

† The following lines of 75 cm., or 2ft. 6 ins., gauges use them: the Zaccar Mines Ry., Congo Ry., Arakan Flotilla Co.'s Ry., Victorian Government Rys. and Sierra Leone Government Rys.

On 3 ft. gauge lines, *Garratts* are to be found in Colombia only.

‡ *Garratt* locomotives are used on the following metre gauge lines: On the Catalan Rys., on the Madagascar Ry., and on the Kenya and Uganda Ry., on the San Paulo Ry., the Mogyana, the Great Western

of *Garratt* locomotives are to be found on the 3 ft. 6 ins. gauge lines. Thus they are used for all services in South Africa, where they give the same service as the most powerful European locomotives. In Tasmania and New Zealand they run express trains.*

Garratts have been built to the following types: "double-Atlantic," "double-Prairie," "double-Mogul," "double-Consolidation" and even "double-Mountain"; also "double-Ten-wheels" and "double-Pacifics."

As the *Garratt* locomotive is pre-eminently suitable for lines with sharp curves, or with light road beds, it has generally been considered from this point of view, and its other advantage—namely, the means of providing a powerful boiler on a restricted loading gauge—is often overlooked. It is for this reason that standard and broad gauge lines have been so slow in considering the application of these locomotives.

Nevertheless, some *Garratt* locomotives with four axles, besides others of the "double-Mogul" and "double-Consolidation" types, are now to be found on standard gauge lines.†

In regard to *Garratt* locomotives for broad gauge lines, their use is justified, in certain cases, by the need of providing a long space between the outermost axles of the locomotive or by the difficulty of obtaining otherwise a locomotive of equal economy and power. The types hitherto used are the 2-4 + 4-2, 2-6 + 6-2 and 2-8 + 8-2,‡ whilst those under construction comprise the 4-6-2 + 2-6-4 and the 4-8-2 + 2-8-4.

of Brazil, the Leopoldina Ry; the Cordoba Central Ry., the Bolivia Ry. and the Antofagasta (Chile) and Bolivia Ry.; on the Burma Rys.

* *Garratts* are to be found on the following 3 ft. 6 ins. gauge lines: South African Rys., Trans-Zambezian Ry., Rhodesia Rys., former New Cape Central Ry., Benguela Ry.; also on the Guayaquil and Quito Ry., on the Tasmanian Government Rys., on the Western Australia Government Rys., on the Dundee Coal Co.'s Ry. and on the New Zealand Government Rys.

† *Garratts* are to be found on the following standard gauge lines: London, Midland and Scottish Ry., London and North-Eastern Ry., Argentine North-East Ry., Entrerios Ry., Nitrate Rys. (Chile), and the line of the Hafod Copper Works (Wales). Also on the Mauritius Ry. and on the Smyrna-Aïdin Ottoman Ry.

‡ *Garratt* locomotives are used on the San Paulo Ry. (5 ft. 3 ins.; 1·60 m. gauge), and on the North-Western, the Bengal-Nagpur and the Eastern Bengal Rys. of India (5 ft. 6 in. gauge), and also on the Ceylon Government Rys. and others are on order for the Central Aragon Ry. (Spain).

SUB-GROUP III. A.—THE GARRATT LOCOMOTIVES

Type 1.—Garratt Locomotives with Four Simple Admission Cylinders

These locomotives are used for passenger, mixed and goods traffic. We shall classify them according to the arrangement of their axles and, in each class, we shall examine those of various gauges, beginning with the narrowest and ending with the widest.

We have thought it desirable to quote numerous examples, both to exhibit the important place which these locomotives have attained during the last few years and also to demonstrate how well they are adapted to widely varying conditions.

Classification.—The following formations have been applied :—

Four driven axles	(A)	0-4 + 4-0.
	(B)	2-4 + 4-2.
Six driven axles	(C)	0-6 + 6-0.
	(D)	2-6 + 6-2 (double-Mogul).
	(E)	4-6 + 6-4 (double-Ten-wheels).
	(F)	2-6-2 + 2-6-2 (double-Prairie).
	(G)	4-6-2 + 2-6-4 (double-Pacific).
Eight driven axles	(H)	2-8 + 8-2 (double-Consolidation).
	(I)	2-8-2 + 2-8-2 (double-Mikado).
	(J)	4-8-2 + 2-8-4 (double-Mountain).

Modified Garratt Locomotives.—The standard simple admission *Garratt* is a locomotive with four cylinders and with or without a superheater. The standard type has, however, been modified in various details, not affecting its main principles.

The locomotives of the Congo Ry., which have a boiler with return flues, will be dealt with separately.

We shall afterwards consider those engines in which the number and arrangement of the cylinders differs from the standard type, namely :—

(1) Compound locomotives ;

(2) Locomotives with six or eight cylinders ; and

(3) We shall give a brief description of some proposed *Garratt* engines with three motor bogies.

TABLE 29.—PRINCIPAL DIMENSIONS OF **0-4 + 4-0** GARRATT LOCOMOTIVES

<table>
<tr><td>Gauge
Railway

Date
Builder</td><td>2′
Tasmanian.
Rys.
1909.
Beyer, Peacock.</td><td>2′
Darjeeling-
Himalayan Ry.
1911.
Beyer, Peacock.</td><td colspan="2">1′ 11⅝″
Mayumbé.</td><td>2′ 5½″
Zaccar
Mines Ry.
1912.
S. Léonard.</td><td>Metre.
P° Feliz
(Brazil).
1927.
S. Léonard.</td><td>Normal.
V. and S.
(Wales).
1923.
Beyer, Peacock.</td></tr>
<tr><td></td><td></td><td></td><td>1911.
S. Léonard.</td><td>1926–27.
S. Léonard.</td><td></td><td></td><td></td></tr>
<tr><td>Cylinder, diameter</td><td>11″ 17″</td><td>11″</td><td colspan="2">7⅞″</td><td>9¾″</td><td>9″</td><td>13½″</td></tr>
<tr><td>,, stroke</td><td>16″</td><td>14″</td><td colspan="2">11 13/16″</td><td>13¾″</td><td>13¾″</td><td>20″</td></tr>
<tr><td>Boiler, centre line</td><td>5′</td><td>5′ 6″</td><td>4′4¾″</td><td>5′ 2½″</td><td>5′ 5″</td><td>5′ 2½″</td><td>7′</td></tr>
<tr><td>,, diameter</td><td>3′ 11⅛″</td><td>3′ 10⅞″</td><td colspan="2">3′ 3″</td><td>3′ 9 5/16″</td><td>3′ 7″</td><td>7′</td></tr>
<tr><td>,, length</td><td>7′</td><td>7′</td><td colspan="2">6′ 6¾″</td><td>7′ 2⅝″</td><td>11′ 4⅞″</td><td>9′ 6″</td></tr>
<tr><td>,, pressure lbs. per sq. in.</td><td>195</td><td>160</td><td>171</td><td>185</td><td>177</td><td>185</td><td>180</td></tr>
<tr><td>Firebox, length</td><td>3′ 5 1/16″</td><td>4′ 1⅛″</td><td>2′ 5½″</td><td>2′ 9½″</td><td>3′ 10 1/16″</td><td>2′ 9½″</td><td>5′ 6″</td></tr>
<tr><td>Tubes, number</td><td>170</td><td>195</td><td>133</td><td>174</td><td>190</td><td>174</td><td>288</td></tr>
<tr><td>,, diameter</td><td>1¾″</td><td>1⅝″</td><td colspan="2">1⅝″</td><td>1⅝″</td><td>1⅝″</td><td>1¾″</td></tr>
<tr><td>Heating surface, firebox .sq. ft.</td><td>60</td><td>64</td><td>36·2</td><td>47·9</td><td>66</td><td>47·9</td><td>107</td></tr>
<tr><td>,, ,, tubes ,,</td><td>568</td><td>603</td><td>369</td><td>458·3</td><td>580</td><td>458·3</td><td>1,299</td></tr>
<tr><td>,, ,, total ,,</td><td>628</td><td>667</td><td>405·2</td><td>506·2</td><td>640</td><td>506·3</td><td>1,406</td></tr>
<tr><td>,, ,, superheater ,,</td><td>None.</td><td>None.</td><td>None.</td><td>None.</td><td>None.</td><td>None.</td><td>None.</td></tr>
<tr><td>Grate area ,,</td><td>14·8</td><td>17·5</td><td>8·6</td><td>9·7</td><td>15·3</td><td>9·7</td><td>22·7</td></tr>
<tr><td>Wheels, diameter</td><td>2′ 7½″</td><td>2′ 2″</td><td colspan="2">1′ 11⅝″</td><td>2′ 2⅜″</td><td>2′ 3½″</td><td>3′ 4″</td></tr>
<tr><td>Wheelbase, 1 group</td><td>4′</td><td>4′ 3″</td><td colspan="2">4′ 5 3/16″</td><td>4′ 7¼″</td><td>4′ 5 3/16″</td><td>5′ 6″</td></tr>
<tr><td>,, rigid</td><td>4′</td><td>4′ 3″</td><td colspan="2">4′ 5 3/16″</td><td>4′ 7¼″</td><td>4′ 5 3/16″</td><td>5′ 6″</td></tr>
<tr><td>,, total</td><td>26′ 9″</td><td>24′ 6″</td><td colspan="2">22′ 1⅜″</td><td>25′ 9 7/16″</td><td>22′ 1⅜″</td><td>32′ 2″</td></tr>
<tr><td>Distance Pivot centres</td><td>22′ 9″</td><td>17′ 3″</td><td colspan="2">15′ 0 5/16″</td><td>17′ 3⅞″</td><td>15′ 0¼″</td><td>22′ 6″</td></tr>
<tr><td>Maximum height</td><td>10′ 9″</td><td>8′ 6″</td><td>9′ 4 3/16″</td><td>10′</td><td>11′ 4⅝″</td><td>10′ 1⅝″</td><td>11′ 9″</td></tr>
<tr><td>,, width</td><td>7</td><td>6′ 5″</td><td colspan="2">6′ 0⅞″</td><td>6′ 7⅜″</td><td>6′ 4¾″</td><td>8′</td></tr>
<tr><td>,, length</td><td>34′</td><td>33′ 1⅛″</td><td colspan="2">28′</td><td>33′ 10 7/16″</td><td>30′ 0¾″</td><td>47′ 2″</td></tr>
<tr><td>Water . galls.</td><td>840</td><td>600</td><td>440</td><td>736</td><td>770</td><td>737</td><td>1,500</td></tr>
<tr><td>Fuel t.-cwt.</td><td>1</td><td>1</td><td>None.</td><td>None.</td><td>1</td><td>None.</td><td>1–10</td></tr>
<tr><td>Oil . galls.</td><td>None.</td><td>None.</td><td>172 g.</td><td>265 g.</td><td>None.</td><td>550 wood.</td><td>None.</td></tr>
<tr><td>Tractive force, 65% . lbs.</td><td>12,460</td><td>15,620</td><td>7,961</td><td>8,596</td><td>10.500</td><td>10,500</td><td>24,600</td></tr>
<tr><td>,, ,, 75%</td><td>14,280</td><td>13,530</td><td>6,900</td><td>9,900</td><td>9,900</td><td>9,096</td><td>21,320</td></tr>
<tr><td>Weight, maximum, 1 axle t.-cwt.</td><td>8–13</td><td>7–8</td><td>6–8</td><td>6–5</td><td>8–8</td><td>6–10</td><td>16–10</td></tr>
<tr><td>,, adhesive, empty ,,</td><td>26–13</td><td>21–4</td><td>19–4</td><td>19–19</td><td>27–1</td><td>19–19</td><td>49–12</td></tr>
<tr><td>,, adhesive, in service ,,</td><td>33–10</td><td>28–0</td><td>23–3</td><td>25–8</td><td>33–5</td><td>26–0</td><td>61–9</td></tr>
<tr><td>,, empty ,,</td><td>26–13</td><td>21–4</td><td>19–4</td><td>19–1</td><td>27–1</td><td>19–19</td><td>49–12</td></tr>
<tr><td>,, in service ,,</td><td>33–10</td><td>28–0</td><td>23–3</td><td>25–8</td><td>33–5</td><td>26–0</td><td>61–9</td></tr>
</table>

Class A.—Garratt Locomotives with 2 + 2 Coupled Axles (Table 29)

This is more especially a narrow gauge type. It is curious to note that the same arrangement of axles was adopted on the first locomotive built for a standard gauge railway.

0-4 + 4-0 Locomotives of the Darjeeling-Himalayan Ry.—Gauge, 2 ft.

This line runs from Siliguri (on the Eastern Bengal Ry.) to Darjeeling and is particularly difficult,* having severe gradients combined with curves of 21 m. (70 ft.) radius.

The contract specified that the locomotive should be able to negotiate curves and reverse curves of 60 ft. (19 m.) radius, separated by a 20 ft. (6 m.) straight alignment, of which 6 ft. (1·82 m.) only were on a level.

In accordance with the usual practice on this railway, water tanks were fitted under the boiler in order to lower the centre of gravity.

0-4 + 4-0 Locomotives of the Mayumbé Ry.—0·60 m. gauge.

On this line, *Garratt* locomotives succeeded the twin locomotives which were first employed. In the latest engines, the fuel and water capacity has been augmented by adding side tanks on each side of the boiler. These locomotives are designed to burn both coal and wood.

0-4 + 4-0 Garratt Locomotive of the Porto Feliz Sugar Co.—Metre gauge.

Not only is this Company's track of the lightest nature, but, owing to the spacing of the sleepers, the weight it will bear per lineal foot is also small.

The *Garratt* locomotives meet both requirements. Those furnished to the Sugar Co. are identical (except for such differences as are the outcome of the difference of gauge) with those supplied in the last instance to the Mayumbé Ry. (Congo), 0·60 m. (1 ft. 11⅝ ins. gauge).

* The line is 82 km. (51 miles) long. Siliguri is at an altitude of 121 m. (397 ft.). The initial section is fairly easy, but after that, until summit level at Ghoom, 76 km. (47¼ miles), altitude 2,257 m. (7,405 ft.), there is a continuous ascent with a 3·3 per cent. maximum grade. From Ghoom, there is a down grade to Darjeeling, 2,076 m. (6,812 ft.) altitude.

Table 29a.—Principal Dimensions of 0-4 + 4-0 Garratt Locomotives

Gauge	0·61.	0·61.	0·61.		0·75.	Metre.	Stand'd.
Railway	Tasmanian Govt. Rys.	Darjeeling-Himalayan.	Mayumbé (Congo)		Zaccar Mines.	Porto Feliz (Brazil).	V. & S. (Hafod Copper Works)
Date	1909.	1911.	1911.		1912.	1927.	1923.
Builder	Beyer, Peacock.	Beyer, Peacock.	St. Léonard. (Liége)		St. Léonard.	St. Léonard.	Beyer, Peacock.
Cylinders :—							
Diameter . m.	0·28-43	0·28	0·20		0·23	0·23	0·34
Stroke . . m.	0·41	0·36	0·30		0·35	0·35	0·51
Boiler :—							
Centre line . m.	1·52	1·37	1·34	1·59	1·65	1·59	2·13
Diameter . m.	1·20	1·19	0·99		1·15	1·90	1·52
Length . m.	2·13	2·13	2·00		2·20	3·48	2·89
Pressure kg./sq. cm.	13·7	11·3	12	13	12·5	13	12·7
Firebox :—							
Length, inside m.	1·04	1·25	0·75	0·85	1·18	0·85	1·67
Tubes :—							
Number . .	170	195	133	174	100	174	288
Ext. diameter mm.	44	41	41	41	41	41	44
Heating surface :—							
Firebox sq. m.	5·6	5·9	3·4	4·4	5·6	4·5	10
Tubes . . ,,	52·8	56·0	34·3	42·6	53·8	42·6	120·7
Total . ,,	58·4	61·9	37·6	47·0	59·4	47·0	130·6
Superheater ,,	None	None	None	None	None	None	None
Grate area ,,	1·4	1·6	0·8	0·9	1·4	0·9	2·1
Wheels, diameter m.	0·80	0·66	0·60		0·67	0·70	1·01
Wheelbase :—							
One group . m.	1·22	1·30	1·35		1·40	1·35	1·67
Rigid . . m.	1·22	1·30	1·35		1·40	1·35	1·67
Total . . m.	8·15	7·47	6·74		7·86	6·74	9·80
Dist. pivots . m.	6·93	5·26	4·58		5·28	4·58	6·86
Water tanks cub. m.	3·8	3·9	2	3·4	3·5	3·4	6·8
Coal bunkers . t.	1	1	None	None	1	2,500 litres	1·5
Oil tanks . m.	None	None	0·8	1·2	None	None	None
Overall height . m.	3·28	2·59	2·85	3·05	3·47	3·09	3·58
,, width . m.	2·18	1·91	1·85	1·85	2·02	1·95	2·44
,, length . m.	10·59	10·11	8·53	8·53	10·32	9·16	14·38
Tractive force :—							
At 65% . t.	5·6	6·1	3·1	3·4	4·2	4·1	9·7
At 75% . t.	6·5	7·1	3·6	3·9	5·2	4·8	11·2
Weight :—							
Max. 1 axle . t.	8·9	7·5	6·5	6·7	8·5	6·6	16·1
Adhesive, empty t.	27·1	21·5	19·5	20	27·5	—	50·3
,, in service t.	34·0	28·5	23·5	25·5	5·34	26·5	62·4
Empty . . t.	27·1	21·5	19·5	20	27·5	20·3	50·3
In service . . t.	34·0	28·5	23·5	25·5	5·34	26·5	62·4

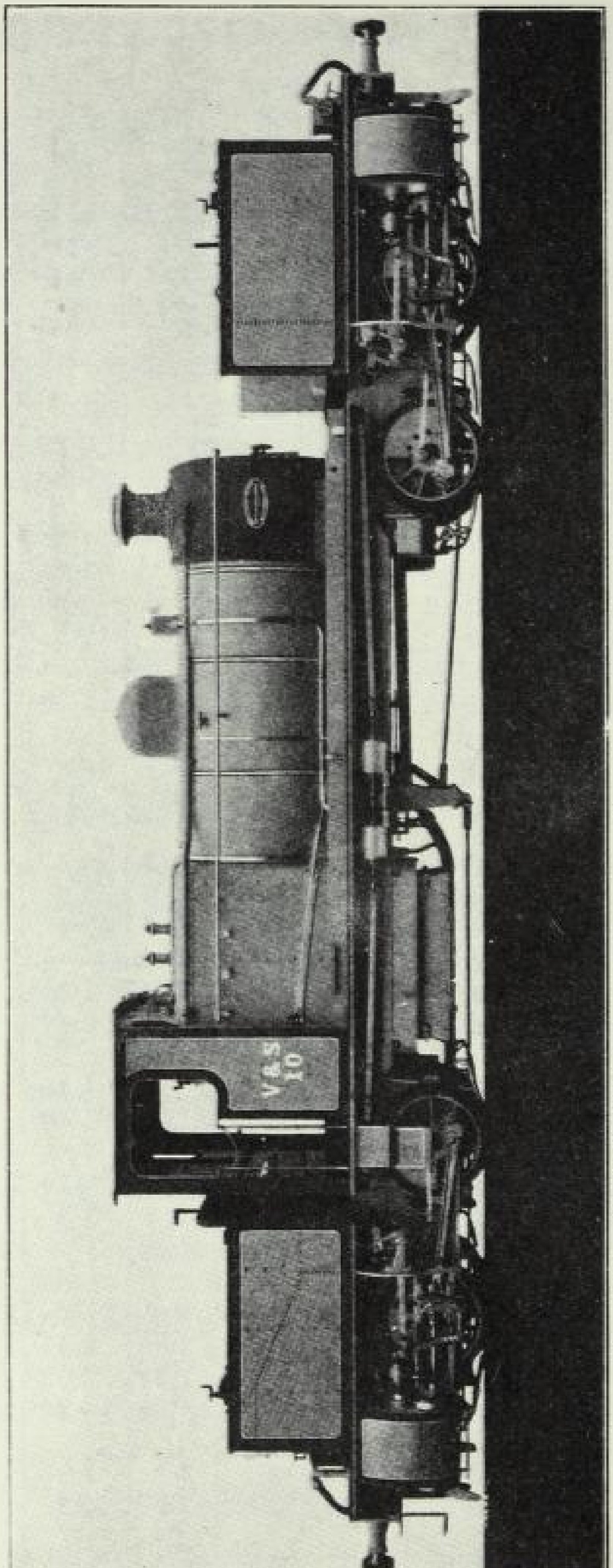


Fig. 69.—First British Garratt Locomotive, 0-4 + 4-0, Hafod Copper Works Railway (Standard Gauge.)
Built by Beyer, Peacock & Co.

It is also interesting to compare these locomotives with those supplied to other factory or industrial lines, as they show how even articulated locomotives can be employed there with efficiency.

We have noted that *Garratt*, geared *Klien-Lindner* and *Mallet* locomotives are used for this service.

0-4 + 4-0 Locomotives of the Hafod Copper Works* (Swansea, Wales).—Standard gauge (Fig. 69).

These were the first *Garratts* built for standard gauge.

The running conditions are exceptionally severe. The line in question is a private railway which connects the works in the valley of the River Tawe with the Great Western Ry. and with the canal, both of which are at a higher level. This section has gradients of 5 per cent. and curves of 100 ft. (30 m.) radius. As some of these curves are crossed on the level by other lines, it was not possible to improve them. The locomotives were therefore designed to run through curves of 90 ft. (27·50 m.) radius, which is an absurdly small radius for a standard gauge line.

The *Garratt* locomotive has replaced two locomotives with three coupled axles and draws loads of 150 tons.

Class B.—Garratt Locomotives with 2 + 2 Coupled Axles and Additional Undriven Axles

2-4 + 4-2 Locomotives of the San Paulo Ry.—Gauge 1·60 m. (5 ft. 3 ins.) (Fig. 68).

The San Paulo Ry.† connects the port of Santos with the capital of the state and with the town of Jundiahy. The line consists of two comparatively easy sections at either end,‡ connected by a series of remarkable inclined planes by which the Serra do Mar is scaled.§

* Messrs. Vivian & Sons, Ltd.

† Although the name of the state and its capital are written "Saõ Paulo," the railway uses the Spanish spelling, "San Paulo."

‡ Raiz do Serra, km. 22 (mile 13½), at the base of the mountain, is 20 m. (65·6 ft.) above sea level. Alto do Serra, km. 30·3 (mile 18¾), is 796·6 m. (2,615 ft.) high. Saõ Paulo, km. 78 (mile 48½) is 737 m. (2,421 ft.) high. Jundiahy, km. 139 (mile 86½), is 707 m. (2,323 ft.) high.

This line connects, at Saõ Paulo, with the main line of the Brazil Central Ry. and at Jundiahy with the Paulista Ry., both of the same gauge. The other State lines, as also the branch of the San Paulo Ry., are metre gauge.

§ A detailed description with plans will be found in the author's work, "Les Chemins de fer du Brésil."

Tables 30 & 31.—Principal Dimensions of Garratt Locomotives with 2 + 2 Driven and 1 + 1 Undriven Axles

Gauge	1·067	1·435	1·600
Railway	Tasmanian Govt. Rys.	Entrerios Ry.	San Paulo Ry.
Date	1912.	1927.	1915.
Builder	Beyer, Peacock	Beyer, Peacock	Beyer, Peacock
Type	**4-4-2 + 2-4-4**	**4-4-2 + 2-4-4**	**2-4-0 + 0-4-2**
Cylinders, diameter . m.	0·31 (8)	0·38	0·41
,, stroke . m.	0·51	0·56	0·61
Boiler, centre line . m.	2·28	2·59	2·59
,, diameter . m.	1·61	1·60	1·65
,, length . . m.	3·33	3·33	3·05
,, pressure— kg. per sq. cm.	11·3	13·4	11·3
Firebox, length inside m.	2·00	2·28	1·72
Tubes, number .	225–24	172–24	183–24
,, diameter outside mm.	133–44–38	133–48–35	133–54–38
Heating surface :—			
Firebox . sq. m.	14·4	14·1	13·5
Tubes . . ,,	142·2	122·1 & 1·9 arch tubes	129·7
Total . . ,,	156·5	138·1	143·2
Superheater surface ,,	30·9	25·1	28·2
Grate area . ,,	3·2	3·2	2·8
Wheels, diameter . m.	0·72	0·76	0·91
,, ,, . m.	1·52	1·42	1·52
,, ,, . m.	0·83	1	0·91
Wheelbase, 1 group . m.	6·33	6·86	4·22
,, rigid . m.	1·83	1·98	1·83
,, total . m.	18·85	19·81	14·58
Distance pivots . m.	9·30	10·31	9·00
Water tanks . cub. m.	13·6	15·9	6·8
Coal bunkers . . t.	4·1	5·1	2·5
Overall height . . m.	3·76	4·24	4·11
,, width . . m.	2·62	3·08	2·90
,, length . . m.	21·95	—	17·93
Tractive force, 65% . t.	9·1	9·9	9·7
Weight, max. 1 axle . t.	12·2	12·2	14·1
,, adhesive, empty t.	38·9	—	48·8
,, in service t.	48·7	48·7	56·5
empty . t.	73·4	—	67·1
,, in service . t.	96·0	106·7	81·7

In order to cope with the congestion of the traffic, the railway administration have been obliged continually to increase the power of their locomotives. But the presence of

Tables 30a & 31a.—Principal Dimensions of Garratt Locomotives with 2 + 2 Driven and 1 + 1 Undriven Axles

Gauge	3 ft. 6 ins.	4 ft. 8½ ins.	5 ft.
Railway	Tasmanian Govt. Rys.	Entrerios Ry.	San Paulo Ry.
Date	1912.	1927.	1915.
Builder	Beyer, Peacock	Beyer, Peacock	Beyer, Peacock
Type	**4-4-2 + 2-4-4**	**4-4-2 + 2-4-4**	**2-4-0 + 0-4-2**
Cylinders, diameter	12″ (8)	15″	16″
,, stroke	20″	22″	24″
Boiler, centre line	7′ 6″	8′ 6″	8′ 6″
,, diameter	5′ 4½″	5′ 3″	5′4⅞″ ext.
,, length	10′ 11″	10′ 11″	10′
,, pressure lbs. per sq. in.	160	190	160
Firebox length	7′ 5″	7′ 6″ ext.	5′ 7$\frac{13}{16}$″
Tubes, number	24–225	14–172	24–183
,, diameter	5¼″–1¾″	5¼″–1⅞″	5¼″–2⅛″
,, ,,	1½″	1⅜″	1½″
Heating surface, firebox sq. ft.	155·5	152 + 20 arch	145
,, ,, tubes ,,	1,531	1,315	1,396
,, ,, total ,,	1686·0	1,487	1,541
,, ,, super-heater ,,	333·0	270	304
Grate area	33·9	30·0	34·4
Wheels, diameter	2′ 4½″	2′ 6″	3′ 0″
,, ,,	5′ 0″	4′ 8″	5′ 0″
,, ,,	2′ 8½″	3′ 3½″	None.
Wheelbase, one group	20′ 9″	22′ 6″	13′ 10″
,, rigid	6′ 0″	6′ 6″	6′ 0″
,, total	61′ 10″	65′ 0″	47′ 10″
Distance of pivots	30′ 6″	33′ 10″	29′ 6″
Water tanks gall.	3,000	3,500	1,500
Coal bunkers t.-cwt.	4	5	2–10
Overall height	12′ 4″	13′ 11″	13′ 6″
,, width	8′ 7¼″	10′ 1″	9′ 0″
,, length	68′ 6″	75′ 0″	58′ 10″
Tractive force, 65% lbs.	23–040	25–190	24–580
,, ,, 75% ,,	19–968	21–830	21–303
Weight :—			
Max., 1 axle t.-cwt.	12	12	13–18
Adhesive, empty ,,	38–5	—	48–3
,, in service ,,	48	48	55–5
,, empty ,,	72–6	79–10	66–3
,, in service ,,	94–11	105–2	80–9

a weak point in the line (a bridge) prohibited an increase in the load per unit length of track. This peculiar reason has led to the introduction of *Garratt* locomotives.

They are for mixed service. On the level they can draw

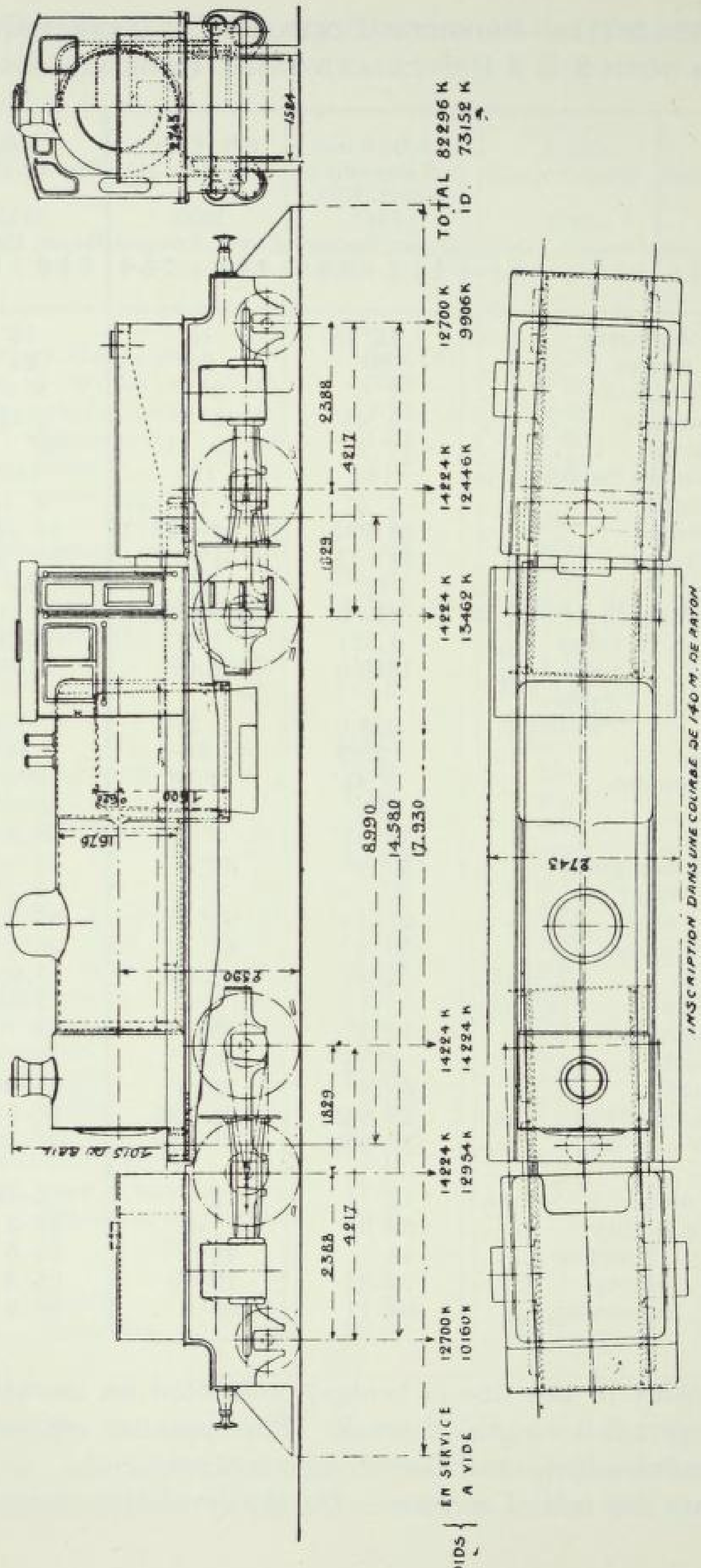


FIG. 70.—2-4 + 4-2 Garratt Locomotive, San Paulo Ry. (Brazil), (1m.60 (5 ft.) Gauge.)
Built by Beyer, Peacock and Co.

passenger trains of 350 tons at a speed of 75 km. (46½ miles) per hour. The weight per axle is restricted to 14 tons. Recently other *Garratts* have been introduced for express passenger service as well.

Class C.—Total Adhesion Garratt Locomotives with 3 + 3 Coupled Axles (Table 32)

This arrangement of axles is not much used and is only found on a few narrow gauge lines. In most cases it is considered desirable also to provide a bissel at each end of the locomotive.

0-6 + 6-0 Garratt Locomotives of the Congo Ry.—Gauge 0·75 m. (29½ ins.).

This line, in the Lower Congo, is 400 km. (248·6 miles) in length. It runs from Matadi to Leopoldville, forming a byepass to a series of rapids which obstruct the free navigation of the Congo River between these two points. This railway was built in the early days of the colonisation of this vast region of Central Africa. It had to be constructed cheaply, in spite of the fact that the country traversed was difficult and mountainous. The reduced gauge of 0·75 m. was therefore adopted, leaving the question of widening the line to be considered if and when the development of the traffic rendered it necessary.*

The traffic on this line has increased so rapidly that its conversion to the 3 ft. 6 ins. gauge can be foreseen. But, pending this change, more powerful locomotives have become essential.

Garratt locomotives for liquid fuel were decided upon. A commencement was made—mistakenly in the author's opinion —with an experimental locomotive with a novel boiler (Fig. 71). This caused many difficulties.

In this first locomotive, oil fuel was contained in one of the tanks carried on the leading bogie.

Two flues run longitudinally from one end of the boiler to

* The gauge of the track is actually 0·76 (2 ft. 6 ins.) without any spreading in curves. On the other hand, the gauge of the rolling stock is but 0·75 m. (2 ft. 5½ ins.). This device was adopted so as to enable the track layers to use metallic sleepers punched to one size only. It was claimed that were sleepers punched according to the gradual spread of the rails in the curves, the black labour might be unable to place them in the proper order.

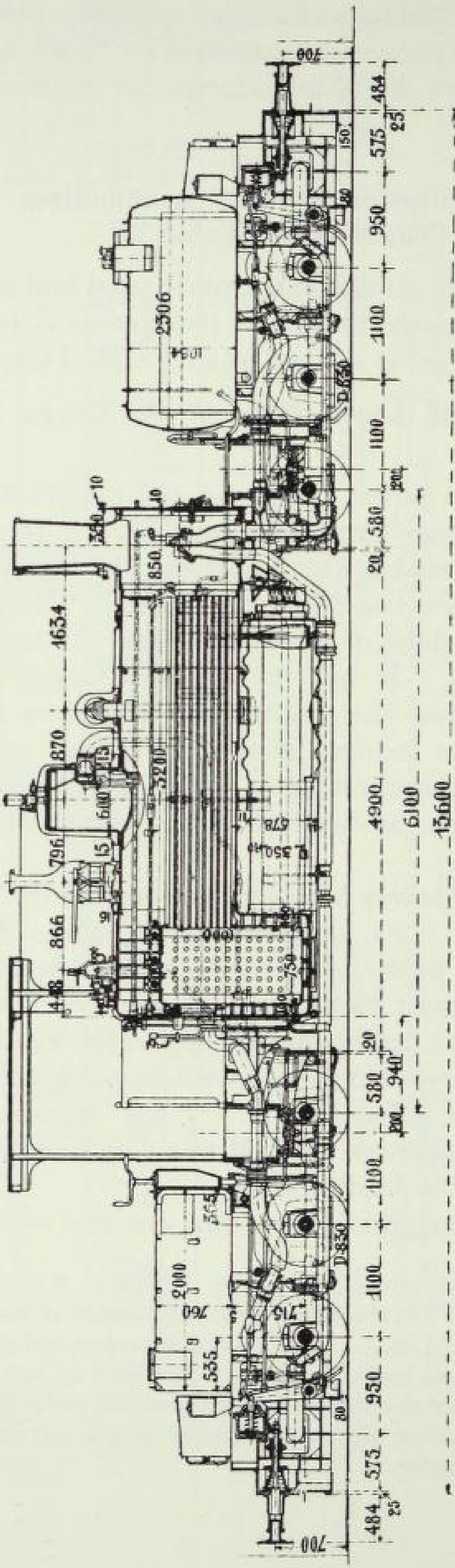


Fig. 71.—0-6 + 6-0 Experimental Oil-burning Garratt, Congo Ry. (0m. 75 Gauge)
Built by the Ateliers de Saint-Léonard (Liège).

TABLE 32.—PRINCIPAL DIMENSIONS OF **0-6 + 6-0** NARROW GAUGE GARRATT LOCOMOTIVES

Gauge	0·76	0m.75.			
Railway	Arakan Flotilla Co.	Congo Ry.			
Builder	Beyer, Peacock.	St. Léonard.	Type Do.	Do. & Cockerill.	St. Léonard.
Date	1913.	1913.	Altered	1919-1924	1925.
Cylinders :—					
Diameter . m.	0·22	0·31	0·31	0·34	—
Stroke . . m.	0·31	0·35	0·35	0·35	—
Boiler :—					
Centre line . m.	1·49	1·68	1·77	1·77	1·90
Diameter . m.	1·12	1·18	1·35	1·35	—
Length . .	2·13	3·20	2·55	2·80	—
Pressure— kg. per sq. cm.	12·7	14	14	14	—
Firebox :—					
Length inside m.	0·86	0·75	1·40	1·60	—
Tubes :—					
Number . .	141	119	119–16	156–24	—
Diameter outside mm.	44	55	41–110	41–110	—
Heating surface :—					
Firebox sq. m.	4·6	11·5	7·5	8	—
Tubes . . ,,	43·9	101·6	70·6	79·1	—
Total . ,,	48·5	113·1	78·1	87·1	—
Superheater surf. ,,	None	None	10·8	18·6	—
Grate area ,,	1·1	—	1·8	2·1	—
Wheels, diameter m.	0·61	0·83			
Wheelbase :					
One group . m.	1·47	2·20			
Rigid 1 group m.	1·47	2·30			
Total . . m.	7·37	10·50		10·90	10·78
Distance pivots m.	5·03	6·50		6·70	6·70
Water tanks cub. m.	2·5	4·6		3	4
Coal bunkers . t.	0·8	None		3	None
Oil tanks . cub. m.	None	1·8		None	1·4
Overall height . m.	3·05	3·30		3·50	3·60
,, width . m.	2·31	2·30		2·40	2·40
,, length . m.	10·24	13·60		14·65	14·53
Tractive force :—					
65% . . t.	3·8	7·4		8·9	8·9
75% . . t.	4·4	8·5		10·2	10·2
Weight :—					
Max. 1 axle . t.	4·1	—		9·7	9·9
Adhesive, empty t.	18·3	46·3		44·7	50·5
,, in service t.	23·9	56		54·2	59·5
Empty . . t.	18·3	46·3		44·7	50·5
In service . t.	23·9	56		54·2	59·5

TABLE 32A.—PRINCIPAL DIMENSIONS OF NARROW GAUGE 0-6 + 6-0 GARRATT LOCOMOTIVES

Gauge	2 ft. 6 ins.	0m.75			
Railway . . .	Arakan Flotilla.	Congo Ry.			
Builder. . . .	Beyer, Peacock.	St. Léonard.	St. Léonard.	St. Léonard. & Cockerill	St. Léonard.
Date	1913.	1913.	Altered Type.	1919–1924.	1925 .
Cylinders, diameter .	$8\frac{1}{2}''$	$12\frac{3}{16}''$	$12\frac{3}{16}''$	$13\frac{3}{8}''$	—
,, stroke .	$12''$	$13\frac{3}{4}''$	$13\frac{3}{4}''$	$13\frac{3}{4}''$	—
Boiler centre line .	$4'\ 10\frac{1}{2}''$	$5'\ 9\frac{11}{16}''$	$5'\ 9\frac{11}{16}''$	$5'\ 9\frac{11}{16}''$	$4'\ 9\frac{3}{8}''$
,, diameter .	$3'\ 8''$	$4'\ 5\frac{1}{8}''$	$4'\ 5\frac{1}{8}''$	$4'\ 5\frac{5}{16}''$	—
,, length . .	$7'\ 0''$	$8'\ 4\frac{3}{8}''$	$8'\ 4\frac{3}{8}''$	$9'\ 2\frac{1}{4}''$	—
,, pressure— lbs./sq. in.	180	199	199	199	—
Firebox, length. .	$2'\ 10''$	$2'\ 5\frac{1}{2}''$	—	$4'\ 11''$	—
Tubes, number . .	141	119	16–119	24–156	—
,, diameter .	$1\frac{3}{4}''$	—	$4\frac{5}{16}''$–$1\frac{5}{8}''$	$4\frac{5}{16}''$–$1\frac{5}{8}''$	—
,, ,, .	None.	None	$1\frac{1}{4}''$	$1\frac{1}{4}''$	—
Heating surface :—					
Firebox sq. ft.	50	124	81	86	—
Tubes . ,,	472	1,094	760	853	—
Total . ,,	532	1,218	841	939	—
Superheater ,,	None.	None.	116	200	—
Grate area ,,	12	—	19·2	22·3	—
Wheels, diameter .	$2'\ 0''$	$3'\ 8\frac{11}{16}''$			
Wheelbase, rigid .	$4'\ 10''$	$7'\ 3\frac{5}{8}''$			
,, one group	$4'\ 10''$	$7'\ 2\frac{5}{8}''$			
,, Total .	$24'\ 2''$	$34'\ 5\frac{3}{8}''$		$35'\ 9\frac{3}{16}''$	$35'\ 4\frac{3}{8}''$
Distance pivots .	$16'\ 6''$	$21'\ 3\frac{7}{8}''$		$21'\ 11\frac{13}{16}''$	$21'\ 11\frac{13}{16}''$
Overall height . .	$10'\ 0''$	$10'\ 10''$		$11'\ 5''$	$11'\ 9\frac{3}{4}''$
,, width . .	$7'\ 6\frac{5}{8}''$	—		$7'\ 10\frac{1}{2}''$	$7'\ 10\frac{1}{2}''$
,, length . .	$32''$	$44'\ 7\frac{7}{16}''$		$48'\ 0\frac{13}{16}''$	$47'\ 8''$
Water . . gall.	550	107		660	880
Coal . t.-cwt.	0–15	None.		3	None.
Oil . . gall.	None.	396		None.	297
Tractive force :—					
75% . . lbs.	9,754	18,760		22,558	22,558
65% . . . ,,	8,453	16,259		19,550	19,550
Weight, 1 axle t.-cwt.	3–19	—		9–8	9–15
,, empty ,,	18–10	45–11		44–2	49–14
,, in service ,,	23–11	54–4		53–18	58–11

the other, along its lower portion. At their rear ends, these flues communicate with the tube-plate of the combustion chamber, which replaces the ordinary firebox, and at the front with the upper part of the boiler, by means of a pipe of large diameter.

The oil burners were placed at the front ends of the flues. Oil fuel was injected and atomised by a steam jet. The products of combustion first traversed the longitudinal flues, then passed through the combustion chamber and returned by the Serve tubes with which the boiler was provided. It was hoped that the life of the firebox would be prolonged. Also, that a better evaporation would be obtained, owing to the increased length of the path traversed by the products of combustion, thereby enabling more heat to be extracted from the gases than in an ordinary boiler.

But these expectations were not realised. It was found that the mass of the refractory materials was insufficient to maintain satisfactory combustion at all speeds.

This experimental locomotive was therefore altered, the boiler wisely being replaced by one of ordinary type with moderate superheat.

The next *Garratts* were provided with Robinson superheaters.

In working, these locomotives have developed defects which have been taken into account in the construction of the present ones. They burn coal or oil and have no special features, except that longitudinal and transverse spring compensators are fitted to the two outer axles of each bogie. These compensators are so arranged as to allow these outer axles to take up the inclined positions which the magnitude of the slopes on the reverse curves demand.

Class D.—Double-Mogul (2-6 + 6-2) Garratt Locomotives (Table 33)

This is the most usual arrangement of axles. It provides sufficient adhesion for most requirements, while the bissels afford good guiding in the curves.

Double-Mogul Garratts of the Victorian Government Rys.—2 ft. 6 ins. gauge (0·76 m.).

These locomotives operate on branch lines which penetrate into the hilly districts of the colony. They abound in curves

TABLE 33.—PRINCIPAL DIMENSIONS OF DOUBLE-MOGUL (2-6 + 6-2) GARRATT LOCOMOTIVES

Gauge	2′ 6″	Metre.	Metre.		Metre.	3′ 6″	Standard.		Standard.
Railway	Victorian Govt. Rys.	Madagascar Ry.	Catalan Rys. (Spain).		San Paulo Ry. (Brazil).	Western Australian Govt. Rys.	Argentine North Eastern Ry. †		London, Midland and Scottish Ry.
Builder	B. Peacock.	S. Léonard.	S. Léonard.		B. Peacock.	B. Peacock.	B. Peacock.		B. Peacock.
Date	1926.	1926.	1922–1926.		1913.	1913.	1925–1927.		1927.
Type	**2-6 + 6-2**	**2-6 + 6-2**	**2-6 + 6-2**		**2-6 + 6-2**	**2-6 + 6-2**	**2-6 + 6-2**		**2-6 + 6-2**
Cylinder, diameter	13¼″	14 3/16″	14 3/16″		14″	13¼″	15″		18½″
,, stroke	18″	19 11/16″	19 11/16″		20″	20″	22″		26″
Boiler centre line	6′	7′ 2⅝″	6′ 10½″		7′	6′ 9″	7′ 9″		9′ 3″
,, diameter	5′ ext.	5′ 0¼″	5′ 0⅝″		5′ 4 11/16″	5′	5′ 3″		6′ 10″
,, length	9′	9′ 2¼″	11′ 3¼″		10′	9′	10′ 11″		12′ 3″
,, pressure lbs. per sq. in.	180	170	170		200	160	180		190
Tubes, number	21 + 160	24 + 191	24 + 191		339	21 + 162	24 + 172		44 + 258
,, diameter	4¾″–1¾″	4¾″–1¾″	4¾″–1¾″		1⅞″	5¼″–1¾″	5¼″–1⅞″		5¼″–2″
,, diameter, superheater	1⅜″	1⅜″	1⅜″		None.	1½″	1⅜″		1⅜″
Firebox, length	4′ 9 13/16″	5′ 3″	6′ 4⅜″		6′ 4″	5′ 6″	10′ 11″ ext.		9′ 6″
Heating surface, firebox . sq. ft.	99	114·5	114·5		139	107	152	152 + 20	183
,, ,, tubes ,,	950	1,088·6	1,323		1,726	960	1,328	1,315	1,954
,, ,, total ,,	1,049	1,203·1	1,427		1,865	1,067	1,480	1,487	2,137
,, ,, superheater ,,	219	248·0	296		None.	246	300	270	500
Grate area ,,	22·6	22·4	29·7		29·8	22·6	34·4	34·4	44·5
Wheels, diameter	2′ 0¾″	2′ 3½″	2′ 5″ (2′ 1⅜″)		2′ 3½″	2′ 6″	2′ 6″		3′ 3½″
,, diameter	3′	3′ 3¾″	3′ 3⅜″		3′ 6″	3′ 3″	3′ 9½″		5′ 3″
Wheelbase, 1 group	12′ 3″	14′ 8¾″	15′ 11⅛″		14′ 3″	13′ 9″	20′ 10½″	20′ 10½″	25′ 9″
,, rigid	6′ 9″	7′ 10½″	7′ 10½″		8′	7′ 6″	12′ 10½″	12′ 10½″	16′ 6″
,, total	44′ 6″	48′ 4¾″	52′ 8″		49′ 3″	47′	63′ 1½″	69′ 1½″	79′ 0″
Distance between pivots	24′ 9″	24′ 7¼″	27′ 10 11/16″		26′ 3″	25′	33′ 3″	33′ 3″	40′ 6″
Water . galls.	1,680	1,100	1,540		3000	2,000	3,000	3,000	4,500
Fuel capacity	3 to 10 cwt.	353 cub. ft.	3 to 10 cwt.		9 t.	4 t.	4 t.	3 t.	7 t.
Overall dimensions, height	10′ 8″	13′ 1½″	12′ 3⅜″		12′	12′	13′ 2″	13′ 2″	12′ 9″
,, ,, width	8′ 3″	8′ 8¾″	8′ 2½″		8′ 6″	—	10′ 1½″	10″ 1′	—
,, ,, length	51′ 8″	53′ 9¾″	56′ 7¼″		58′ 6″	53′ 7″	73′ 2″	—	87′ 11″
Tractive force, 75% . lbs.	23,690	25,450	25,788		28,000	21,600	29,700	27,700	40,250
,, ,, 65% . ,,	20,500	22,060	22,350		24,270	18,720 *	25,750	24,000	34,880
Weight, 1 axle . tons-cwt.	9–10	9–12	10–8	10–19	10–10	9–7	11–14	—	20–5
,, adhesive, empty ,,	—	—	—	—	47–12	44–8	—	—	—
,, adhesive, in service ,,	54–5	57–1	62–0	65–19	62–14	54–4	73–10	—	116
,, total, empty ,,	55–7	57–11	64–0	63–19	58–15	55–10	74–5	69–16	106–10
,, total, in service ,,	69–1	70–17	76–6	78–14	80–15	69–16	97–3	90–10	148–15

* Weights apply to the non-superheater locomotives.

† The Entrerios Ry. has similar locomotives. Their maximum weight per axle is 12 tons 9 cwt., and total weight in working order 96 tons. They carry 3,000 galls. of water and 4 tons of fuel.

of 2 or of 3 chains radius and gradients of 1 in 30. The weight of the rails is 60 lbs. per yard.*

* The Moe Hilhalla Ry. runs 26 miles from the main line into the mining district.

The Colac Crows Ry. runs 44 miles through heavily timbered country.

Double-Mogul Garratts of the Compagnie Generale de Chemins de fer Catalans (Spain).—Metre gauge.

In these locomotives the usual rectangular water tank on the leading bogie has been replaced by a cylindrical reservoir.

Double-Mogul Garratts of the South African Rys.—2 ft. and 3 ft. 6 ins. gauges.

Most of the railways in South Africa are controlled by the South African Rys. Administration, which operates a total length of 12,420 miles (19,988 km.), of which 11,509 miles (18,521 km.) are 3 ft. 6 ins. gauge, and the remainder 2 ft. gauge.* The lines of the neighbouring colonies are also laid to the 3 ft. 6 ins. gauge.

Apart from the gauge itself, these 3 ft. 6 ins. lines hardly differ from standard European railways. Thus the goods wagons have a capacity of 50 tons and more, while the passenger vehicles provide accommodation equal to that of the international rolling stock on European railways. High-powered locomotives are therefore necessary.

From our present point of view, this railway system is of special interest, because it has been the scene of systematic comparative trials of the various modern types of articulated locomotives.

When the demands of the traffic reached the limit with which rigid locomotives could cope, *Meyer* locomotives were tried. Some *Mallet* engines were next ordered in 1911, and experiments with these soon led to their being preferred to the *Meyer* type. This latter was therefore abandoned, and the use of the *Mallets* was so rapidly extended that there are now about eighty of them in service. Among this number are the most powerful *Mallets* ever built for a 3 ft. 6 ins. gauge.

The first *Garratt* locomotives were introduced in 1920. They were of three classes. The first was for the 2 ft. gauge lines, the second was a light and the third a heavy class for the 3 ft. 6 ins. lines.

After a series of trials which continued for nearly one year, further *Garratts* were ordered, and other classes have been added since ; the latest is to weigh 220 tons and to develop 72,000 lbs. tractive effort (at 75 per cent. boiler pressure).

Besides these, there are two other 2 ft. 6 ins. gauge lines where, so far it has not been necessary to introduce *Garratt* locomotives.

* Mileage operated at 31st March, 1928.

O 2

TABLE 34.—PRINCIPAL DIMENSIONS OF 3 FT. 6 INS. GAUGE GARRATT LOCOMOTIVES OF THE SOUTH AFRICAN RYS.

Gauge	3′ 6″	3′ 6″	3′ 6″	3′ 6″	3′ 6″	3′ 6″	3′ 6″	3′ 6″	3′ 6″
Type: Double	Mogul.	Prairie.	Prairie.	Prairie.	Mikado.	Mikado.	Pacific.	Prairie (Union).	Pacific (Union).
Builder	B. Peacock.	B. Peacock.	B. Peacock.	B. Peacock.	B. Peacock.	B. Peacock.	Hanomag.	Maffei.	Maffei.
Date	1920.	1924.	1925.	1924.	1925.	1925.	1928.	1927.	1928.
Cylinders, diameter	18″	12″	15″	14″	18″	18″	16″	18½″	19½″
,, stroke	26″	20″	24″	23″	26″	24″	26″	26″	26″
Boiler, centre line	7′ 9″	7′	7′ 9″	7′ 3⅜″	7′ 9″	7′ 9″	7′ 9″	8′ 0¾″	8′ 3″
,, diameter	6′ 9″	4′ 6″	6′ 1⅜″	5′ 3¼″	6′ 10½″	6′ 10½″	6′ 5½″	6′ 2½″	7′ 9½″
,, length	8′ 7″	10′	10′ 2½″	10′ 11″	11′ 3″	11′ 3″	11′ 3 3/16″	13′ 8½″	13′ 8½″
,, pressure . lbs. per sq. ft.	180	180	180	180	180	180	185	180	180
Tubes, number	40 + 279	21 + 119	32 + 184	24 + 149	36 + 288	36 + 288	36 + 234	30 + 170	43 + 195
,, diameter	5¼″–2″	5¼″–1⅞″	5½″–2″	5½″–2″	5½″–2″	5½″–2″	5½″–2″	5½″–2¼″	5½″–2½″
,, ,,	1½″	1⅜″	1½″	1½″	1½″	1½″	1½″	1½″	1½″
Firebox, length	8′ 9″	5′ 6″	7′ 6″ ext.	7′ 3″	8′ 9″	8′ 9″	8′ 1¼″	8′ 5⅜″	8′ 5⅜″
Heating surface, firebox . sq. ft.	211	102·6	167	156·8	210	199	—	223	241
,, ,, tubes ,,	2,343	913·4	1,510	1,266·2	2,366	2,366	—	2,326	2,157
,, ,, total ,,	2,554	1,016·0	1,677	1,413	2,576	2,565	2,158	2,649	2,398
,, ,, superheater ,,	526	None.	355	247	390	344	463	754	824
Grate area ,,	51·8	23·4	40	34	52	51·6	44·0	49·5	59·5
Wheels, diameter	2′ 6″	2′ 3″	2′ 4½″	2′ 4½″	2′ 6″	2′ 4½″	2′ 6″	2′ 6″	2′ 6″
,, ,,	4′	3′ 6½″	3′ 9½″	3′ 6¾″	4′ 9″	3′ 9½″	4′ 6″	4′ 0″	5′ 0″
,, ,,	None.	2′ 3″	2′ 4½″	2′ 4½″	2′ 6″	2′ 4½″	2′ 6″	2′ 6″	2′ 6″
Wheelbase, 1 group	16′ 2″	17′ 5″	18′ 9″	17′ 8¼″	21′ 4½″	22′ 10½″	23′ 5″	19′ 8″	25′ 2″
,, rigid	9′	8′	8′ 6″	8′	10′	9′ 2″	9′ 6″	9′ 0″	10′ 9″
,, total	58′ 7″	53′	58′ 4″	56′ 8″	67′ 4″	70′	69′ 9″	66′ 11″	76′ 7″
Pivot centres	33′ 3″	26′ 6″	30′ 6″	29′ 8″	35′ 4″	35′	33′ 2″	39′ 1″	39′ 6½″
Overall height	12′ 10″	12′ 3″	12′ 10″	12′ 3″	12′ 11 7/16″	12′ 11 7/16″	12′ 10″	12′ 11 7/16″	12′ 11½″
,, width	10′	7′ 6″	8′ 6″	9′ 0½″	10′	10′	—	9′ 11″	9′ 11¼″
,, length	65′ 5″	59′ 6″	58′ 4″	65′ 4″	76′ 10″	—	—	74′ 8″	85′ 0″
Water tanks . galls.	4,600	2,000	3,800	3,000	4,600	4,600	3,983	5,280	6,000
Coal bunkers . tons	9	4	5	5	10	9	10	14	13·5
Tractive force, 75% . lbs.	47,380	18,290	32,030	28,470	39,900	46,140	—	—	—
,, ,, 65% . lbs.	41,063	15,850	27,760	24,740	34,780	40,050	33,075	—	—
Max. weight, 1 axle . t.-cwt.	17–15	7–10	12–15	10–5	16–3	12–18	13–3	18–10	18–12
Weight, adhesive, empty ,,	81	—	—	—	—	—	—	—	—
,, ,, in service ,,	104–10	46–15	75–6	63–0	94–11	101–15	104–5	110–3	184–10
,, total, empty ,,	96–4	57–0	86–10	73–8	107–10	—	79–0	119–0	135–10
,, ,, in service ,,	133–15	75–0	114–0	96–16	147–13	144–11	140–7	164–0	180–10

TABLE 35.—PRINCIPAL DIMENSIONS OF 2 FT. GAUGE GARRATTS, SOUTH AFRICAN RYS.

Type : Double-		Mogul.		Prairie.
Builder		Beyer, Peacock & Co.		Hanomag.
Date		1920.	1925.	1927.
Cylinders, diameter		10½″		12″
,, stroke		16″		16″
Boiler centre, line		5′ 3″		5′ 5″
,, diameter		4′ 3″		—
,, length		9′ 0″		—
,, pressure	lbs. per sq. in.	180		180
Tubes, number		211	13–115	—
,, diameter		1¾″	5½″–1¾″	—
,, diameter (sup.)		None.	1½″	—
Firebox, length		4′ 9″	4′ 9″	—
Heating surface :—				
Firebox	sq. ft.	80	80·6	—
Tubes	,,	897	660·9	—
Total	,,	977	741·5	921
Superheater	,,	None.	141·5	141·5
Grate area	,,	19·4	19·5	19·5
Wheels, diameter		1′ 9″		1′ 9″
,, ,,		2′ 6″		2′ 6″
,, ,,		None.		1′ 9″
Wheelbase, 1 group		10′ 3″		—
,, rigid		5′ 9″		6′ 3″
,, total		39′ 9″		42′ 9″
Pivot centres		22′ 0″	22′ 9″	—
Overall dimensions, height		10′ 4″		10′ 4″
,, ,, width		7′ 0″		—
,, ,, length		46′ 0″		—
Water	galls.	1,350		1,880
Fuel	t-cwt.	2 10		4
Tractive force 75%	lbs.	15,880	15,870	—
,, ,, 65%	,,	13,763	13,760	—
Weight, 1 axle	tons-cwt.	6–0	6–11	—
,, adhesive, empty	,,	27–15	—	—
,, ,, in service	,,	36–3	38–12	41–8
,, total, empty	,,	33–7	—	45–8
,, ,, in service	,,	44–15	48–13	61–13

Finally, *modified Fairlie* and *Garratt-Union* locomotives—a type derived from that described above—have now been introduced.

Double-Mogul Garratts of the South African Rys.—2 ft. gauge lines.

As with other articulated locomotives, it was the flexibility of the *Garratt* design that first induced this railway administration to try it. Of the five locomotives ordered in 1920–21, three were for the 2 ft. lines of Natal, two of them having superheaters. They were put to work on the Stuartstown section, where the conditions are very severe.* They replaced 4-8-2 tender locomotives of 29 tons weight, which were dealing with loads of 90 (short) tons.

The 45-ton *Garratts* without superheaters handled loads of 150 (short) tons, this being an increase of 66 per cent. over the loads hauled by rigid locomotives. The superheater *Garratts* hauled 165 (short) tons.†

Similar locomotives, but of the 2-6-2 + 2-6-2 type, have been placed on other 2 ft. gauge lines of very light construction.

Double-Mogul Garratts, of the South African Rys.—3 ft. 6 ins. gauge lines.

On this system, numerous comparative tests have been carried out between *Mallet* and *Garratt* double-Mogul locomotives. The former weighed 180 tons 14 cwt. (183 metric tons) and the latter 135 tons 2 cwt. (136 metric tons). Both had driving wheels of 4 ft. diameter (1m.22), and carried 160 lbs. (12·66 kg.) boiler pressure. Their respective tractive force at 65 per cent. boiler pressure was 42,000 and 41,200 lbs. (19,015 and 18,670 kg.).‡

A comparison of the boilers of the two types shows (Fig. 72) that the firebox of the *Mallet* has a more complicated shape than that of the *Garratt* and requires more plates for its construction. The tubes in the *Garratt* are half the length of those in the *Mallet* (11 ft. and 22 ft. respectively; 3m.35 and 6m.70).

* The Stuartstown branch is 115 miles long and runs from Umzisto to Donnybrook. It rises from a level of 171 ft. (52 m.) to 4,617 ft. (1,407 m.). The ruling gradient is 3 per cent. compensated. The minimum radius of curvature is 150 ft. (45·7 m.). The rails weigh 20 lbs. per yard (9 kg. per metre).

† The tractive force of the 4-8-2 rigid locomotives was 8,180 lbs. (3,700 kg.); that of the new *Garratts*, 15,880 lbs. (6,844 kg.).

‡ This corresponds to 48,400 lbs. (21,940 kg.) and 47,500 lbs. (21,540 kg.) respectively, at 75 per cent. of the boiler pressure, and 50 per cent. for the L.P. cylinders of the *Mallet*.

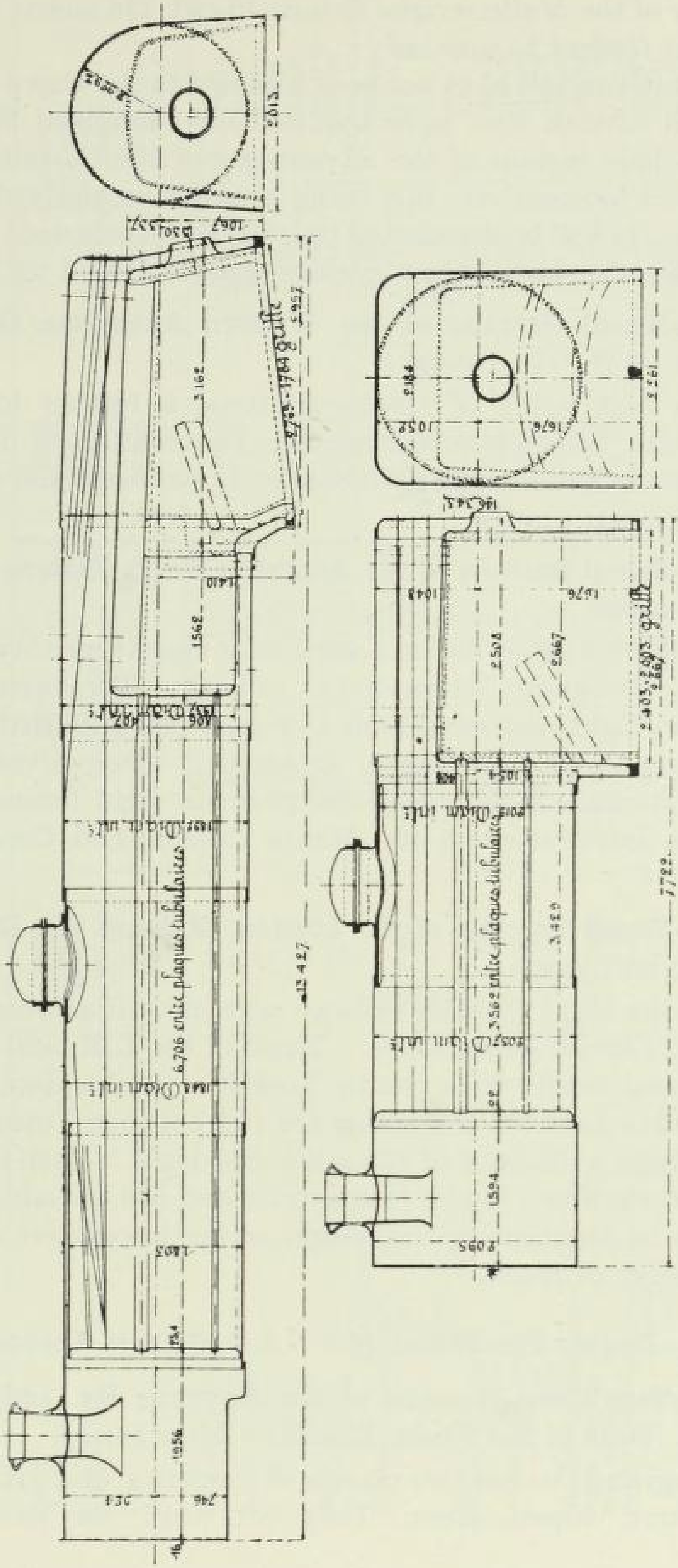


FIG. 72.—Boilers of Mallet and Garratt Locomotives compared, South African Rys. (3 ft. 6 ins. Gauge.)

The boiler of the *Mallet* weighs 35 tons 10 cwt. (36 metric tons); that of the *Garratt* 25 tons only.

Comparative trials have not been confined to the above types. The South African Rys. have acquired some modified *Fairlies* (which include certain of the advantages of the *Garratts*) and some *Union* locomotives, this being a new type derived from the latter. It will be interesting to learn the conclusions which the simultaneous use of these various types will lead to.

Double-Mogul Garratts of the Western Australian Government Rys.—3 ft. 6 ins. gauge.

After a first batch of six locomotives, a further lot was ordered with Schmidt superheaters. The conditions on this line are severe and include gradients of $4\frac{1}{2}$ per cent. and curves of 100 m. (328 ft.) radius.

Double-Mogul Garratts of the Argentine North Eastern Ry.—Standard gauge.

This railway's main line is a section of the Buenos Ayres to Asuncion (Paraguay) international railway. The permanent way is very light, the maximum axle-load being limited to 11 metric tons. For this reason, articulated locomotives with 50 per cent. more power than the previous rigid locomotives have been introduced on the Monte Caseros and Concordia section.

Double-Mogul Garratts of the London, Midland and Scottish Ry.—Standard gauge.

This is the third English railway administration which has introduced *Garratt* locomotives. Those of the L.M. and S. are used for coal traffic from South Yorkshire to London. One thousand five hundred ton trains are run between Totton and Brent Sidings, a distance of 126 miles (203 km.). Each *Garratt* does the work of two tender locomotives and has the additional advantage of distributing the weight of the locomotive over a greater length of track.

Class E.—Double-Ten-Wheel (4-6 + 6-4) Garratt Locomotives

Double-Ten-Wheel Garratts of the Mogyana Ry. and Navigation Co. (State of Saõ Paulo, Brazil).—Metre gauge.

The Mogyana Co. has two classes of *Garratts :* one with, and one without, superheaters. They are used for passenger

TABLES 36 AND 36A.—PRINCIPAL DIMENSIONS OF DOUBLE-TEN-WHEEL (**4-6 + 6-4**) GARRATT LOCOMOTIVES

Gauge / Railway / Builder / Date / Type	3′ Colombian National. Armstrong, Whitworth. 1928. **4-6 + 6-4**	Metre. Mogyana Rys. and Nav. Co. Beyer, Peacock. 1912. **4-6 + 6-4**	1914. **4-6 + 6-4**	0m.91 Colombian. National. Armstrong, Whitworth. 1928. **4-6 + 6-4**	Metre. Mogyana. Rys. and Nav. Co. Beyer, Peacock. 1912. **4-6 + 6-4**	1914. **4-6 + 6-4**
Cylinders, diameter	16″	13″	14″	0m.41	0m.33	0m.36
,, stroke	22″	20″	20″	0m.59	0m.51	0m.51
Boiler, centre line	—	6′ 10″	7′ 0″	—	2m.10	2m.13
,, diameter	—	4′ 10⅞″	4′ 10⅞″	—	1m.50	1m.68
,, length	11′ 8″	10′ 0″	10′ 0″	3m.55	3m.05	3m.05
,, pressure lb./sq. in	—	180	160	—	11·7 atm.	11·3 atm.
Tubes number	226–27	280	167 + 21	226–27	280	167–21
,, diameter	2″	1⅞″	1⅞″–5¼″	51 mm.–133 mm.	48 mm.	44 mm.–133 mm.
,, ,, superheater	—	None	1⅜″	—	None	38 mm.
Heating surface, firebox	156 sq. ft.	125·2 sq. ft.	126 sq. ft.	14·5 sq. m.	11·7 sq. m.	11·7 sq. m.
,, tubes	1,381 + 433 ,,	1,422 ,,	1,142 ,,	128·3 + 40·2 ,,	132·1 ,,	106·1 ,,
,, total	1,970 ,,	1,547·5 ,,	1,268 ,,	183·0 ,,	143·8 ,,	117·8 ,,
,, superheater	300 ,,	None	268 ,,	27·9 ,,	None	14·9 ,,
Grate area	34·8 ,,	27·3 ,,	27·3 ,,	3·2 ,,	2·6 ,,	2·6 ,,
Wheels, diameter	2′ 4½″	2′ 0¾″	2′ 0¾″	0m.72	0m.70	0m.70
,, diameter	3′ 4″	3′ 9″	3′ 9″	1m.01	1m.14	1m.14
Wheelbase, 1 group	—	17′ 8″	17′ 8″	—	5m.39	5m.39
,, rigid	7′ 10″	8′ 6″	8′ 6″	2m.39	2m.59	2m.59
,, total	58′ 0″	46′ 0″	55′ 4″	17m.67	16m.86	17m.07
Distance between pivots	—	28′ 2″	27′ 6″	—	8m.38	8m.38
Water capacity	2,650 galls.	2,000 galls.	2,000 galls.	12,047 litres	9,000 litres	9,000 litres
Fuel capacity	7 tons	4 tons	4 tons	7·1 tonnes	4 tonnes	5 tonnes
Overall dimensions, height	—	12′	12′ 1½″	—	3m.66	3m.66
,, ,, width	—	8′ 8″	8′ 10″	—	2m.64	2m.64
,, ,, length	—	65′	65′ 7″	—	19m.81	20m.01
75%, Tractive force lbs.	—	20,280	20,900	—	9,200 kg.	9,500 kg.
Weight, adhesive t.-cwt.	63–9	51–0	58–14	—	52·3 tons	53·9 tons
,, in service ,,	96–0	74–1	75–14	97·6 tons	74·9 ,,	76·1 ,,
,, empty ,,	—	57–2	53–6	64·5 ,,	58·1 ,,	64·0 ,,

service, hauling 175-ton trains at a maximum speed of 40 km. (25 m.) per hour. The length of the run is 250 km. (155·25 m.), which include some 3 per cent. gradients and curves of 100 m. (328 ft.) radius. Wood fuel is used.

The piston valves have interior admission. Contrary to the usual practice, the second coupled axle is driven instead of the third, which reduces the length of the connecting rods.

Since 1911 this company has also used 2-6 + 6-2 *Mallets* on its goods service.

4-6 + 6-4 Double-Ten-Wheel Garratt Locomotives, Colombian National Rys.—3 ft. gauge.

We have previously noticed this railway, which is rapidly modernising its locomotive stock. The latest additions are *Garratt* locomotives supplied by Messrs. Armstrong, Whitworth in 1928–1929.

They call for no special comment, save that they are of remarkable power and efficiency for so narrow a gauge.

Class F.—Double-Prairie Garratt Locomotives (2-6-2 + 2-6-2)

In order to improve the guidance of the locomotive and also to reduce the load on the inner driven axle of each of the sets of wheels, a bissel is often added at the inner ends of each bogie thus constituting the type under notice (Table 37).

Double-Prairie Garretts of the Sierra Leone Government Ry.—2 ft. 6 ins. gauge.

These locomotives haul train loads up to 190 tons gross on a section of line having a ruling gradient of 2 per cent. and curves of 5 chains radius.

Double-Prairie Garratts of the South African Rys.—2 ft. gauge.

These locomotives formed part of an order for forty *Garratts* placed with German builders in 1926. Three of them are for service on the narrow gauge section in Natal.

To enable them to negotiate curves of 165 ft. radius, the outer axles are bissels and the inner axles are of the Gölsdorf system. Bar frames are used.

Double-Prairie Garratts of the Rhodesia Rys.—3 ft. 6 ins. gauge.

These locomotives work from Villa Machado (altitude180 ft.;

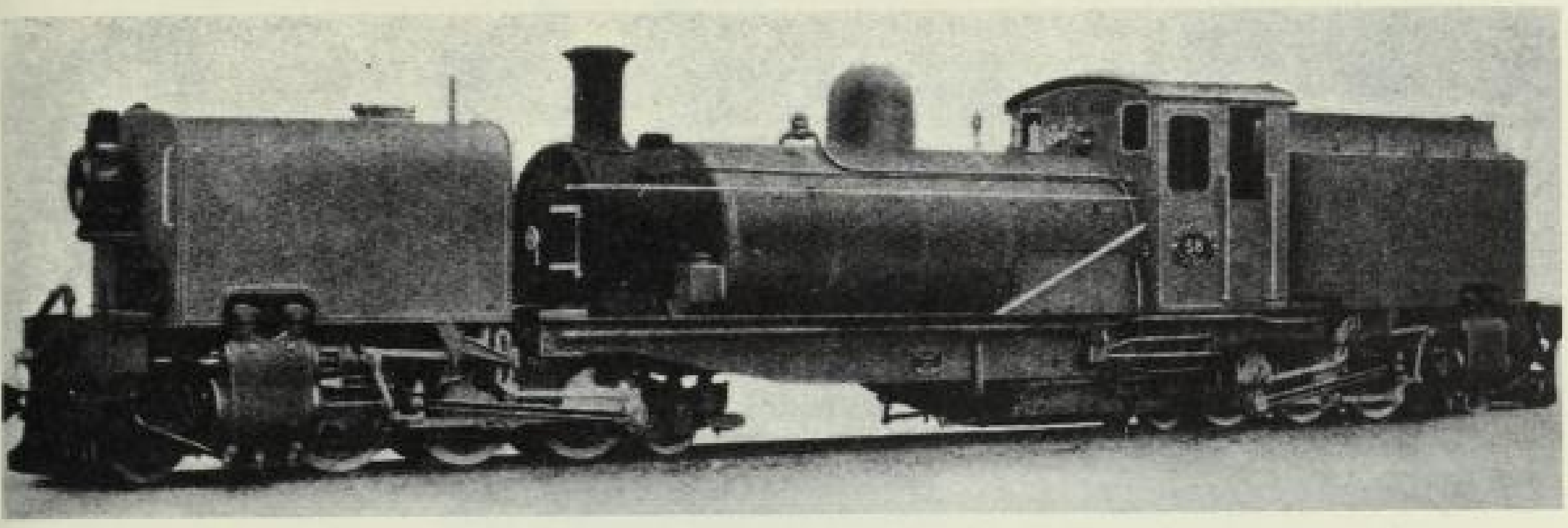


FIG. 73.—2-6-2 + 2-6-2 Garratt Locomotive, South African Rys. (2 ft. Gauge.)

55 m.) to Umtali, altitude 3,572 ft. (1,144 m.), a distance of 144 miles (232 km.). The ruling gradient is 2 per cent.

Double-Prairie Garratts of the Tasmanian Government Rys.—3 ft. 6 ins. gauge.

In the year 1912 and in consequence of the success of its first *Garratt* locomotives, this administration ordered for use on its 3 ft. 6 ins. gauge lines the two passenger locomotives already referred to, and two goods locomotives, all of which were fitted with superheaters. The boilers and fireboxes were the same in both types. The overhang of the cylinders was eliminated by providing the goods engines with pony trucks and the passenger locomotives with bogies. Piston valves were used in all these locomotives.

The ruling gradient of this line is 2½ per cent. and the minimum radius of curvature 100 m. (328 ft.).

Double-Prairie Garratt of the Dundee Coal Co. (Western Australia).—3 ft. 6 ins. gauge.

This locomotive is used for short haulage and for shunting. It works on a branch line, 11 miles in length, having gradients of 1 in 79 and curves of 300 ft. radius—which is laid with 60-lbs. rails.

Double-Prairie Garratts of the ex-New Cape Central Ry.* and of the Trans-Zambezian Ry.—3 ft. 6 ins. gauge.

These locomotives closely resemble the Tasmanian Govern-

* The New Cape Central Ry. was the most important South African line in private ownership. Its main line from Ashton to Mossell Bay is 189 miles (301 km.) in length, and forms part of the trunk line connecting the Cape with Port Elizabeth. It has recently been purchased by the Union and incorporated in its system.

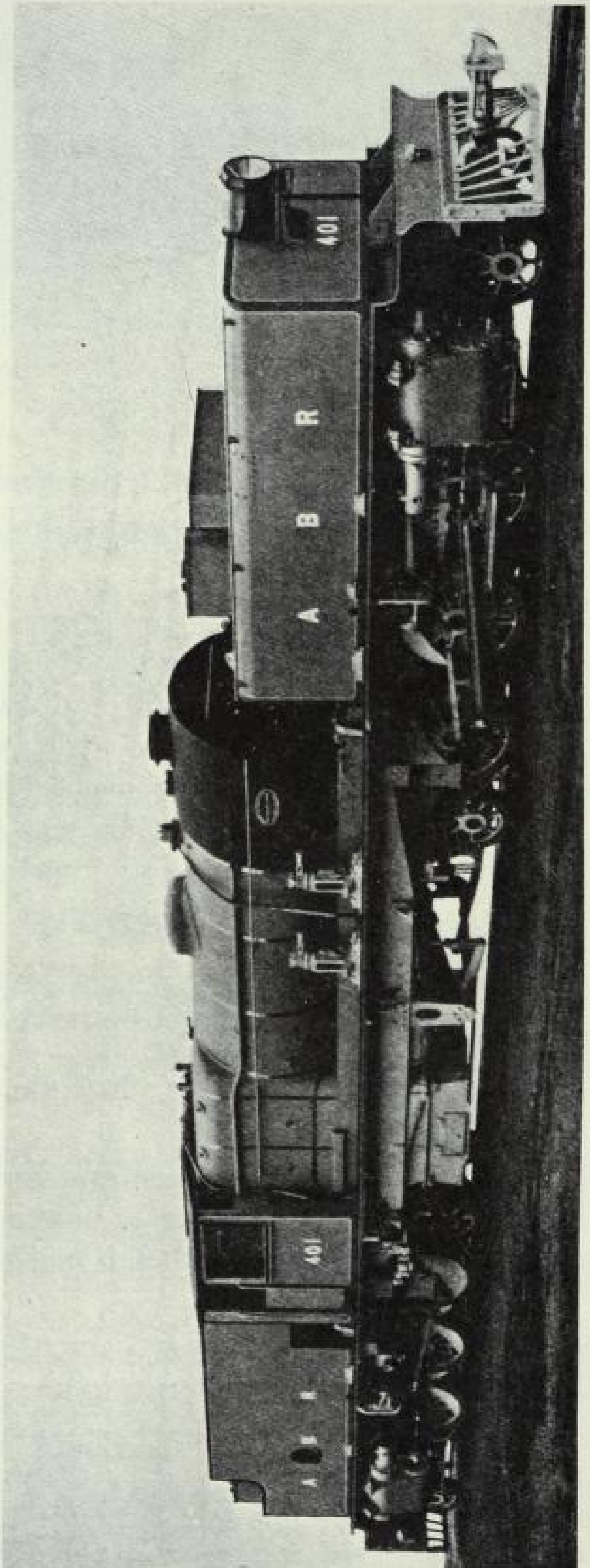


FIG. 74.—2-6-2 + 2-6-2. Garratt Locomotive, Assam-Bengal Ry. (Metre Gauge.)
Built by Beyer, Peacock & Co.

TABLE 37.—PRINCIPAL DIMENSIONS OF DOUBLE-PRAIRIE (2-6-2 + 2-6-2) GARRATT LOCOMOTIVES*

Gauge	2' 6"	3' 6"	3' 6"	3' 6"	3' 6"	3' 6"	3' 6"	Metre	3' 6"	5'	5' 6"
Railway	Sierra Leone Govt. Ry.	Tasmanian Govt. Rys.	South African Rys.	Trans-Zambezian Ry.	New Cape Central Ry.	Rhodesia Rys.	South African Rys.	Assam-Bengal Ry.	Trans-Zambezian Ry.	S. Paulo (Brazil) Ry.	North-Western (India).
Date	1926.	1912.	1921.	1924.	1923.	1926.	1927.	1927.	1928.	1928.	1925.
Cylinders, diameter	10"	12" (8)	12"	15"	15"	16"	Union. 18½"	14"	15"	20"	18½"
,, stroke	16"	20"	20"	22"	24"	24"	26"	24"	22"	26"	26"
Boiler, centre line	5' 4"	7' 3"	7'	7' 3"	7' 3⅜"	7' 9'	8' 0¾"	7' 6"	7' 3⅜"	9' 6"	9' 3"
,, diameter	4" 4"	5' 4½"	4' 6 15/16"	5' 4½"	6' 1¾"	6' 1¾"	6' 2½"	5' 4½"	5' 4½"	6' 9"	6' 10"
,, length	8' 7"	10' 11"	10'	10' 11"		12'	12' 0¾"	—	10' 1"	—	12' 3"
,, pressure lbs. per sq. in.	175	160	180	180		180	180	180	180	200	180
Tubes, number	15 + 124	24 + 225	21 + 128	24 + 225		32 + 184	30 + 170	26 − 186	24 − 225	50 − 230	44 + 258
,, diameter	5¼"–1⅞"	5¼"–1¾"	5¼"–1⅞"	5¼"–1¾"		5¼"–2"	5½"–2¼"	5¼"–1¾"	5¼"–1¾"	5¼"–2¼"	5½"–2"
,, diameter	—	1½"	1¾"	1⅜"		1⅜"	—	1⅜"	1⅜"	1⅜"	1⅜"
Firebox, length	4' 6"	7' 3"	5' 6"	7' 3"		6' 5¾"	—	6' 6"	7' 3"	8' 5"	9' 6"
Heating surface, firebox sq. ft.	76·5	157	105	157		164	223	132	157	205	236 (235)
,, ,, tubes ,,	647·5	1,530	944	1,530		1,676	2,326	1,298	1,530	2,749	2,544 (2,469)
,, ,, total ,,	724	1,687	1,049	1,687		1,840	2,649	1,430	1,687	2,954	2,780 (2,704)
,, ,, superheater ,,	120	333	174	293		380 int.	754	268	293	668	565 (550)
Grate area ,,	18·2	33·9	23·3	33·9		38·8	59·5	30	33·9	49·2	56·5
Wheels, diameter	1' 6"	2' 3"	2' 3"	2' 4½"		2' 4½"	2' 6"	2' 4"	2' 4½"	3' 3"	3' 0"
,, diameter	2' 4"	3' 6"	3' 6¼"	3' 6¾"		4'	4'	4' 0"	3' 6¾"	5' 6"	4' 3"
,, diameter	1' 6"	2' 3"	2' 3"	2' 4½"		2' 4½"	2' 6"	2' 0"	2' 4½"	3' 3"	3' 0"
Wheelbase, 1 group	13' 9"	17' 8"	17· 5"	17' 8"		19' 3"	19' 8"	19' 4"	17' 8"	25' 7"	23' 0"
,, rigid	6'	8'	8'	8'		8' 9"	9' 0"	8' 11"	8' 0"	12'	11' 0"
,, total	43' 4"	56' 8"	53'	56' 8"		61'	66' 11"	59'	56' 8"	73'	72'
Pivot centres	22' 9"	29' 8"	26' 6"	29' 8"		31' 3"	39' 1"	30' 2"	29' 8"	39' 10"	36'
Overall, height	10' 9¾"	12' 1"	12' 3"	12' 3"	12' 5"	13'	12' 11 7/16"	11' 3"	12' 3"	14'	13' 6"
,, width	7' 6"	8' 6"	5' 6"	9' 0½"	9' 0½"	—	9' 11"	8' 6"	9' 0¼"	10'	10'
,, length	49' 6"	63' 4"	59' 6"	63' 3"	65' 3"	70' 7½"	74' 8"	—	—	—	—
Water tanks galls.	1,200	3,000	2,000	3,000	3,000	4,350	5,280	2,400	3,500	3,100	6,500
Coal bunkers tons	3	4	4	9	4	7	14	6	4	5	11
Tractive force, 75 % lbs.	15,000	28,280	18,290	31,250		34,560	—	26,460	31,270	47,270	47,100
,, ,, 65% lbs.	13,000	24,510	15,851	27,083		29,950	—	—	—	—	40,820
Weight, maximum axle t.-cwt.	5–0	9–10	7–10	10–10	10–10	13–0	18–10	9–10	11–0	—	19–6
Weight, adhesive, empty ,,	—	43–4	34–17	49–6	53	58–11	—	—	—	—	—
,, ,, in service ,,	30–1	57	44–18	62–19	63	77–11	110–3	57	65–15	111	115–8
,, total, empty ,,	34–10	67–17	53–19	72–19	72–11	90–10	119–0	—	—	—	130–15
,, ,, in service ,,	46–13	89–19	70–10	95–5	94–17	122–3	164–0	90–4	99–13	158–4	178–8

* Builder: Messrs. Beyer, Peacock & Co.

ment's goods engines and differ from them in details only. The passenger trains consist of seven bogie coaches and weigh about 270 tons. As the line has some 30 miles (approx. 50 km.) of 2·5 per cent. gradients, trains were formerly double-headed, but a single *Garratt* deals with them now.

In these locomotives, the wheels of the second coupled axle of each group have thinner flanges than the others.*

The Trans-Zambezian uses *Garratts* for mixed service on the 174-mile section (280 km.) which unites the Biera Rys. at Dondo with the Central Africa Ry. at Chindio.† The 4-8-0 rigid locomotives formerly used, dealt with 270-ton trains, while the *Garratts* handle loads up to 620 tons, although the maximum axle-load per locomotive axle is only 10 tons 7 cwt.

Identical *Garratts* are used by the Natal Navigation and Collieries Co.

We have grouped these locomotives together, because they differ in minor details only.‡

* They have a different type of superheater, the boiler pressure is higher, the diameter of the carrying wheels is slightly greater, and the fuel capacity of one of them has been increased.

† This line was opened in 1922.

The summit level is at an altitude of 1,017 ft. (310 m.), and is reached by gradients of 1¼ per cent., but the curves are not sharp. The rails weigh 60 lbs. per yard.

‡ The New Cape Central Ry.'s *Garratts* have the boiler centre line ⅜ in. higher than the Trans-Zambezian Ry.'s. Their maximum height is 12 ft. 5 ins.

They carry only 4 tons of fuel, hence the weights are as follows :—

Total, empty	72 tons 11 cwt.
,, in service	94 ,, 17 ,,
Adhesive, empty	53 ,, 0 ,,
,, in service . . .	63 ,, 0 ,,

The 1927 *Garratts* of the Trans-Zambezian Ry. differ from the former ones in a number of details. The boiler centre line is 7 ft. 3⅜ ins. above rail level, and fuel and water quantities have been altered to 3,500 galls. and 4 tons, hence different weights :—

Weight, maximum 1 axle . .	11 tons.
,, adhesive	65 ,, 15 cwt.
,, in service	99 ,, 13 ,,

The cylinders have Hendrie by-pass valves.

The brake cylinders, shaft, etc., of the combined steam and hand-screw brake gear are attached to the boiler frame. The tractive effort per M.E.P. in cylinders works out at 231·6 lbs., and the factor of adhesion in service at 417.

Double-Prairie Garratt Locomotives, Great Western Ry. of Brazil.—Metre gauge.

The Great Western Ry. operates an important system in north-eastern Brazil. This is a hilly country which calls for the use of powerful and supple locomotives. Hence the *Garratts* supplied in 1928.

TABLE 38.—PRINCIPAL DIMENSIONS OF THE LATEST DOUBLE-PRAIRIE GARRATTS

Railway	Great Western of Brazil.	Guayaquil and Quito.
Gauge	Metre.	3′ 6″
Builder	Armstrong, Whitworth.	Beyer, Peacock & Co.
Date	1928.	1929.
Cylinders, diameter	14½″	15½″
,, stroke	20	20″
Boiler, centre line	7′ 3″	—
,, diameter	5′ 8½″	5′ 10½″
,, pressure . lbs./sq. in.	200	200
Tubes, number	32–168	32–191–32
,, diameter	5¼–1⅞″–1⅜″	5¼″–2″–1¾″
,, length	9′ 0″	121
Firebox, width	—	6′ 9″
,, length	6′ 0″	7′ 6″
Combustion chamber, length	9′ 0″	—
Heating surface, firebox . sq. ft.	121	171
,, tubes . ,,	1196	1,784
,, total . ,,	1317	1,955
,, superheater ,,	285	383
Grate area . ,,	28·1	40·4
Wheels, diameter	2′ 7″	2′ 4½″
,, diameter	3′ 6″	3′ 2″
Wheelbase, rigid	7′ 10″	7′ 3″
,, 1 group	17′ 6″	17′ 1″
,, total	53′ 0″	57′ 5″
Pivot centres	26′ 6″	—
Overall height	12′ 3″	—
,, width	8′ 10″	—
Fuel	4 tons	2,500 galls.
Water . galls.	2,180 + 1,380	2,500
75% Tractive force * . lbs.	30,000 (75%)	37,930
Weight, in service . tons-cwt.	89–0	120–7
,, adhesive . ,,	60–16	81–0

* Ratio of adhesion, Guayaquil and Quito locomotive, 4·54.

Double-Prairie Garratt, Guayaquil and Quito Ry. (Ecuador).—3 ft. 6 ins. gauge.

All the railways of the western coast of South America are situated on the western slope of the Cordilleras. Gradients are steep and curves frequent. They all therefore, sooner or later, call upon articulated locomotives to work their traffic; and one of the latest converts to the *Garratt* principle is the line under notice.

This American-built railway, which was completed in 1908, starts from Doiran, opposite the port of Guayaquil and, after crossing 54 miles of delta lands, scales the sierra between Bucay (km. 87, altitude 297 m.—mile 54, altitude 974 ft.) and Palmira (km. 166, altitude 3,239 m.—mile 103, 10,627 ft.). The summit is situated at Umbina (km. 275, 3,604 m.—mile 171, 11,840 ft.) and the line undulates beyond until Quito, the capital, is reached at the 464th km. (mile 288) and at an altitude of 2,852 m. (9,375 ft.) above sea level.

Steepest gradients are 1 in 18; shortest radius of curves is 3 chains only, which corresponds to 5·5 per cent. compensated. There are forty-two 29-degree curves (200 ft. radius), and 222 of 16-degrees (368 ft.). Rails weigh 55 lbs. per yard; heavier 70-lb. rails are being laid on certain sections.

Garratt 2-6-2 + 2-6-2 oil-burning locomotives were supplied in 1929 for dealing with the traffic under these difficult conditions.

Double-Prairie Garratts of the South African Rys.—Gauges 3 ft. 6 ins. and 2 ft.

After having put 2-6 + 6-2 *Garratts* into service, this railway ordered two new types of *Garratt* locomotives in which were embodied certain improvements which practical experience had indicated, chief of which was the addition of a bissel at the inner end of each bogie. These new designs include a light type for use on the Eastern and Central divisions and a heavier type for the coast lines in Natal. In both cases the axle-load is low, being 7 tons 10 cwt. and 10 tons 5 cwt. respectively. More recently, in 1925, a third type has been put into service having an axle-load of 16 tons 3 cwt.*

* There are fifteen of these *Garratts* in service, known as the " G.D.3 " class. They deal with the traffic on the lines which run from sea-ports to the interior, namely :—

(*a*) From Capetown to Caledon, *viâ* the Lowrie Pass. On this

Double-Prairie Garratts of the North Western Ry. of India.—Gauge 5 ft. 6 ins.

The Mushkaf-Bolan section of this railway has a length of 176½ miles (284 km.) with gradients of 4 per cent. At first these were worked with racks, but these have long been discontinued.

On these gradients, Consolidation locomotives * to the number of three, or even four, were needed to deal with each 160-ton train. They were replaced by Mikados, and subsequently it was decided to use articulated locomotives. Some *Mallet* and *Garratt* locomotives of similar capacities were therefore obtained, and it was found that they could deal with loads

section there is a 10-mile (16 km.) continuous incline of 2½ per cent. gradient with curves of 330 ft. (100 m.) radius. The load dealt with is 380 short tons (345 metric tons).

(*b*) From Durban to the north coast—124 miles (200 km.) including 1 in 30 gradients and non-compensated curves of 300 ft. (91 m.) radius.

(*c*) From Pietermaritzburg to Franklin—140 miles (225 km.) which include a continuous incline of 2½ per cent. on 37 miles (60 km.) with curves of 300 ft. (91 m.) radius. The summit level of the line is at 2,944 ft. (897 m.) altitude.

It may be of interest to recall that though the greater number of South African *Garratts* were built by Messrs. Beyer, Peacock & Co., of Manchester, a certain number have recently been delivered from Germany. They comprise the following (up to March, 1928) :—

For the 2 ft. gauge, the Hanomag built three 2-6-2 + 2-6-2 *Garratts*, with cylinders 12 ins. × 16 ins. (305 × 406 mm.).

For the 3 ft. 6 in. gauge, the following were provided :—

By the Hanomag, thirty-seven double-Pacifics, cylinders 16 ins. × 26 ins. (406 × 660 mm.).

By Henschel, ten double-Mikados, cylinders 18 ins. × 24 ins. (457 × 610 mm.).

By Maffei ten double-Prairies, cylinders 19½ ins. × 26 ins. (470 × 660 mm.).

By Maffei, two double-Pacifics, cylinders 19½ ins. × 26 ins. (495 × 660 mm.).

By Krupp, twenty-six double-Prairies, cylinders 14 ins. × 22 ins. (356 × 584 mm.).

The prices of the orders placed at the commencement of 1928 were for Henschel's locomotives, £6,935 each. For Krupp's batch of twenty-six, £5,770 each. For the Linke-Hofmann Works locomotives (double-Prairies), £6,000 each.

* These locomotives had cylinders 23½ ins. × 26 ins. (0m.599 × 0m.660). At 90 per cent. of the boiler pressure the tractive force was 32,080 lbs. (14,550 k.).

75 per cent. greater than those previously drawn by the Mikados.

The *Garratts* are designed to burn oil fuel if required.*

Double-Prairie Garratts, San Paulo Ry. (Brazil).—5 ft. 3 ins. gauge (1m.60) (Figs. 75 and 76).

Since 1914, this railway has used *Garratt* locomotives for passenger express service between Alto de Serra and Jundiahy. As elsewhere, the weight of the trains has increased and fre-

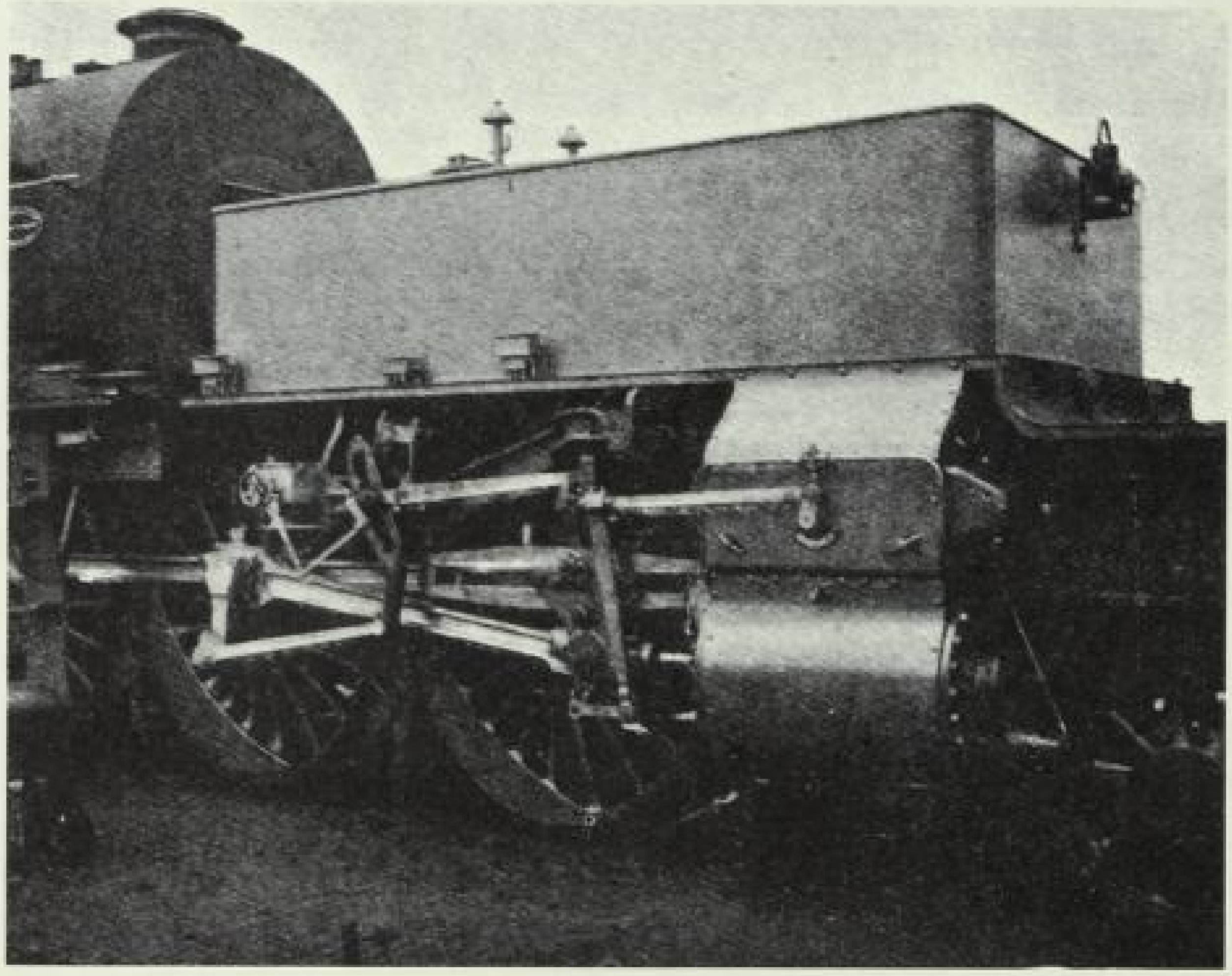


Fig. 75.—Garratt Locomotive with Lentz Poppet Valves, San Paulo Ry. (Brazil).

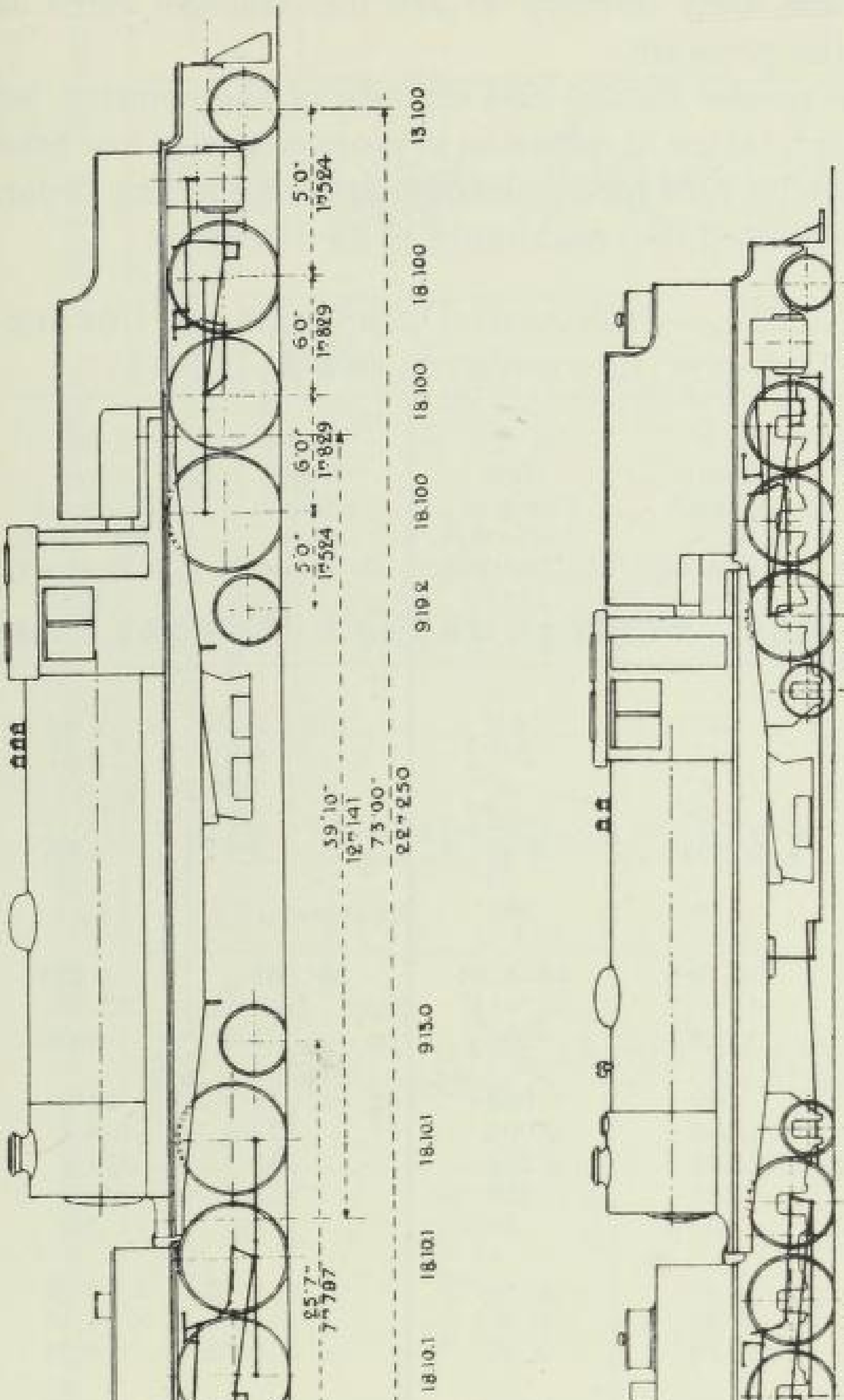
quently reaches 400 tons, which must be moved at speeds ranging up to 36 miles an hour. A new type of *Garratt* locomo-

* The *Garratts* work between Sibi and Kolpur, a distance of 62 miles (100 km.). The gradients and the loads drawn are as follows: Sibi to Abigum, 39 miles (63 km.), 1 in 50 grade. The *Garratt* hauls 640 tons unassisted. Then for the next 7½ miles (12 km.) a pilot is added over the 1 in 33 grade.

The next 15¾ miles (25 km.) have 1 in 25 gradients and two pilot engines are added. These pilots weigh 117 tons in working order (tender included). On this section there are two reverses, and the minimum radius of curvature is 800 ft. (244 m.).

On the fourth and last section, the *Garratt* without assistance hauls 354 tons where the 117-ton rigid locomotives drew only 160 tons.

tive has therefore been designed which is notable in many respects.



FIGS. 76 and 77.—2-6-2 + 2-6-2 Garratt Locomotives, San Paulo Ry. (5 ft. 3 ins. Gauge) and Assam-Bengal Ry. (Metre Gauge).

With the exception of the passenger *Mallets* of the Atchison, Topeka and Santa Fe R.R., these locomotives have the largest driving wheels employed in articulated locomotives, viz., 5 ft. 6 ins., whereas the former ones of the same railway were 5 ft. only.

In spite of this, they develop 47,270 lbs. tractive force at 75 per cent. boiler pressure.

Owing to the special nature and climate of the country, an exceptionally high factor of adhesion is necessary, and has been provided ; it reaches 5·26 for the locomotives in working order.

The cut-off is limited to a maximum of 66·6 per cent.

Tables 39 and 39a.—Principal Dimensions of Double-Pacific Garratt Locomotives (**4-6-2 + 2-6-4**).

Gauge	3′ 6″	3′ 6″	1·067	1·067
Railway	South African Rys.	New Zealand Govt. Rys.	South African Rys.	New Zealand Govt. Rys.
Builder	B. Peacock.	B. Peacock.	B. Peacock.	B. Peacock.
Date	—	1928.	—	1928.
Type	**4-6-2 + 2-6-4**	**4-6-2 + 2-6-4**	**4-6-2 + 2-6-4**	**4-6-2 + 2-6-4**
Cylinders :—				
Diameter	18″	16½″	m. 0·46	0·42
Stroke	24″	24″	,, 0·61	0·61
Boiler :—	7′ 9″	—	,, 2·36	—
Centre line	7′ 9″	—	,, 2·36	—
Diameter	6′ 10½″	6′ 6″	,, 2·10	1·98
Pressure lbs./sq. in.	180	200	kg./sq.cm. 12·7	14·1
Tubes :—				
Number	36–288	43 – 224	36–288	43–234
Diameter	5½″–2″	5¼″–1¾″	mm. 140–51	133–44
Length	11′ 3″	12′	m. 3·43	3·66
Heating :—				
Firebox . sq. ft.	199	266	sq. m. 18·5	24·8
Tubes ,,	2,366	2,008	,, 219·8	186·5
Total ,,	2,565	2,274	,, 238·3	211·3
Superheater ,,	344	520	,, 32·0	48·3
Grate area ,,	51·6	58·3	,, 4·8	5·4
Wheels :—				
Diameter	2′ 4½″	2′ 6½″	m. 0·72	0·77
Diameter	3′ 9½″	4′ 9″	,, 1·15	1·45
Diameter	2′ 4½″	2′ 9″	,, 0·72	0·84
Wheelbase :—				
1 group	22′ 10½″	25′ 5″	,, 6·98	7·75
Total	70′ 0″	76′ 7½″	,, 21·33	23·45
Overall width	10′	—	,, 3·05	—
Water capacity galls.	4,600	4,000	cub. m. 20·9	18·2
Coal capacity t.-cwt.	9–0	6–0	t. 9·1	6·1
Tractive force, 75% . lbs.	46·140	51·580	,, 20·9	23·3
Factor of adhesion	—	3·8	—	3·8
Weight :—				—
Adhesive t-cwt.	101–15		,, 103·3	
In service ,,	144–11	145–14	,, 146·8	147·9

TABLE 40.—PRINCIPAL DIMENSIONS OF 2-8 + 8-2 (DOUBLE-CONSOLIDATION) GARRATT LOCOMOTIVES

Gauge		Metre.	Metre.	Standard.	Standard.	Standard.	5' 6"
Railway		Burma Rys.	Burma Rys.	Mauritius Rys.	London and N. Eastern Ry.	Smyrna-Aïdin-Ottoman Ry.	Bengal-Nagpur Ry.
Builder		Beyer, Peacock.	Beyer, Peacock.	Beyer, Peacock.	Beyer, Peacock.	Beyer, Peacock.	Beyer, Peacock
Date		1923.	1927.	1927.	1925.	1927.	1925.
Cylinders, diameter		15½"	17½"–26½"	19"	18½" (6)	17½"	20"
,, stroke		20"	20"	24"	26"	26"	26"
Boiler, centre line		7' 3"	7' 3"	9' 0"	8' 6"	8' 3"	8' 3"
,, diameter		5' 6" ext.	5' 6"	6' 4⅝"	7' ext.	6' 1⅝"	7' 1 9/16"
,, length		11'	11 9"	12' 5"	13'	12' 6"	13' 3"
,, pressure	lbs. per sq. in.	180	200	200	180	180	180
Tubes, number		27–232	28–206	42–227	45–275	368	48–289
,, diameter		5¼"–1¾"	5¼"–1¾"	5¼"–2"	5¼"–2"	2"	5¼"–2"
,, diameter		1⅜"	1⅜"	1⅜"	1⅜"	None.	1⅜"
,, length		11' 9"	11' 9"	12' 10¼"	13' 15"	12' 11"	13' 8"
Firebox, length		9'	9'	9' 6" ext.	9' 4"	8' 9" ext.	10' ext.
Heating surface, firebox	sq. ft.	183·5	183·5	213·5	237	202	263
,, ,, tubes	,,	1,551·5	1,551·5	2,266	2,757	2,489	2,954
,, ,, total	,,	1,735	1,735	2,479·5	2,994	2,691	3,217
,, ,, superheater	,,	319	319	522·5	646	None.	642
Grate area	,,	43·9	43·9	53·9	56·5	48·5	67·3
Wheels, diameter		2' 4½"	2' 4½"	2' 9"	2' 8"	4' 2½"	3'
,, diameter		3' 3"	3' 3"	3' 10½"	4' 8"	—	4' 8"
Wheelbase, 1 group		16' 9"	17' 4½"	23' 1"	26' 6½"	23' 3"	24' 2"
,, rigid		10' 6"	11'	15' 9"	17' 10½"	15' 9"	16' 0"
,, total		58' 6"	59' 7"	71' 8"	79' 1"	72'	76' 6"
Pivot centres		32' 9"	33'	38' 4"	40' 8"	36' 0"	40' 1½"
Overall, height		11' 3"	11' 3"	14' 8"	12' 10"	13' 3"	13' 6"
,, width		8' 6"	8' 6"	9' 9½"	9'	9' 5"	10' 6"
,, length		70' 9"	70'	80'	87' 8"	81' 2"	86' 9"
Water tanks	galls.	2,000	1,780	5,000	5,000	5,000	5,000
Coal bunkers	tons	5	4	6	7	8	8
Tractive force	lbs.	33,260	34,550	55,890	64,370	42,560	50,140
Weight, max. 1 axle	tons-cwt.	10–1	10–13	16–3	18–6	14–10	18–15
,, adhesive	,,	79–0	84–9	127–9	143–18	115–4	148–10
,, empty	,,	81–10	85–0	117–0	139–0	—	141–5
,, in service	,,	97–10	103–7	154–15	178–0	140–4	180–10

One of the batch of six locomotives built in 1927 has Lentz poppet valves (Fig. 75). They should prove successful as their low inertia and almost frictionless operation are particularly suitable for express locomotives.

Other features do not call for comment; they embody modern details of approved types.

Class G.—Double-Pacific Garratt Locomotives (4-6-2 + 2-6-4)

These locomotives (Table 39) hardly form a class by themselves. They are but the logical development of the double-Mikados as applied to fast passenger service.

So far, the only instances are those quoted hereunder and others on order for the Central Aragon Ry. (Spain)* built in Germany in 1927–28 for the South African Rys., but there is every likelihood of the type proving acceptable in service and of further specimens being built for these or other railways.

Double-Pacific Garratts of the South African Rys.—3 ft. 6 ins. gauge.

These locomotives follow recent practice. They have plate frames for the boiler and bar frames for the bogies. These are of the swing bolster type and the trailers have parallel lateral displacement.

Double-Pacific Garratt Locomotives, New Zealand Government Rys.—3 ft. 6 ins. gauge.

These are large six-cylinder locomotives and are referred to further on, in the chapter which deals with these locomotives.

Class H.—Double-Consolidation Garratt Locomotives (2-8 + 8-2)

This type is the logical development of the high-powered *Garratt*. It is already to be found on lines of metre, 3 ft. 6 ins., standard, and 5 ft. 6 ins. gauges.

Double-Consolidation Locomotives of the Burma Rys.—Metre gauge (Fig. 78).

Almost at its inception, this railway administration was obliged to use articulated locomotives. First came *Fairlies*, subsequently *Mallets* and, lately, some *Garratt* locomotives were acquired in order to carry out comparative trials with the other types.

These *Garratts* were the most powerful built so far for the metre gauge. They are capable of drawing loads of 200 tons

* See under Addenda, note 1.

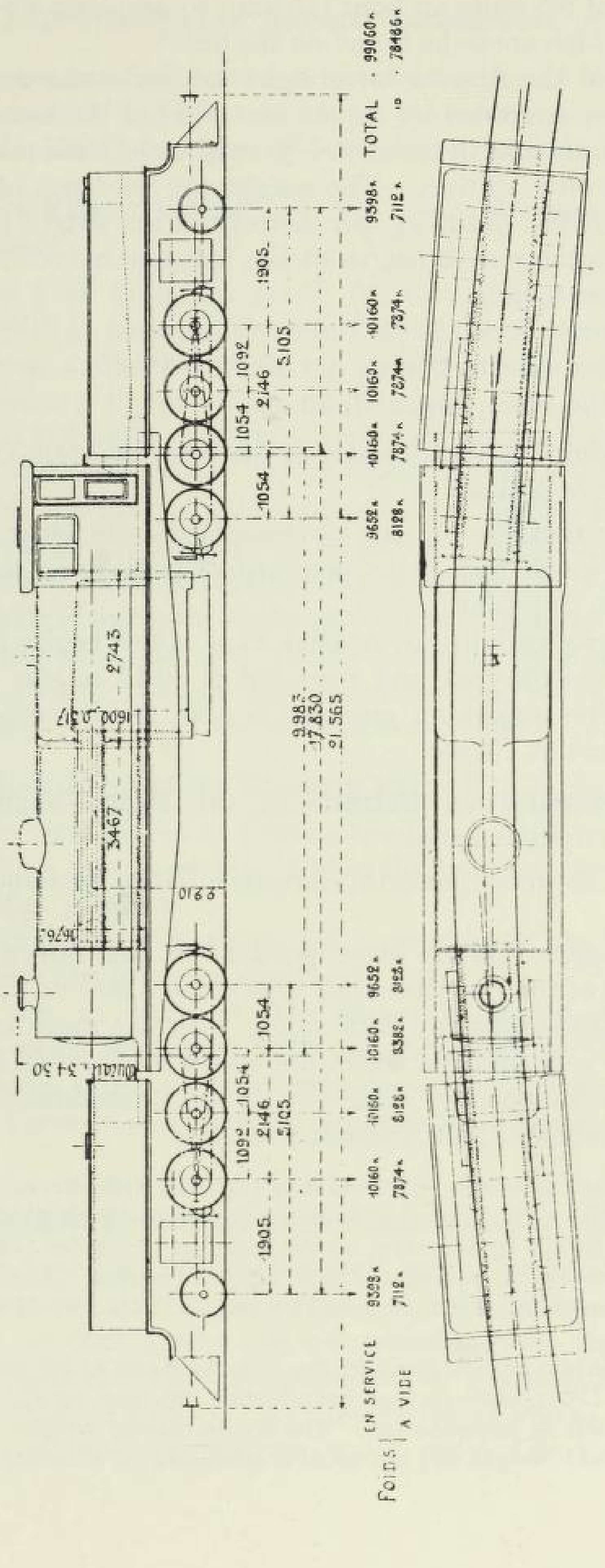


FIG. 78.—2-8 + 8-2 Garratt Locomotive, Burma Rys.
(Metre Gauge.)

at a speed of 9·5 miles an hour (15 km.) up the long 4 per cent. gradients which are to be found on the line.*

They were the first to have eight coupled axles and their tractive force exceeded by 40 per cent. that of the locomotives previously used on this railway. Nevertheless, their maximum axle-load is only 10 tons. The weight per yard run of wheel-base is 11,370 lbs. (5,540 kg. per metre) and the weight per yard run of the total overall length of the locomotives is 4,300 lbs. (2,133 kg. per metre).

The Burma Rys. have recently acquired a compound *Garratt* with a view to finding out whether it offers any advantages over the non-compounds in use.

Double-Consolidation Garratts of the Smyrna-Aïdin-Ottoman Ry.—Standard gauge.

These locomotives present no peculiarities in their design. As the rails weigh only 60 lbs. per yard, the maximum axle load is limited to 14½ tons.

The *Garratts* work up the Azazieh Pass, which begins 38 miles (61 km.) from Smyrna and rises 705 ft. (217 m.) in 6 miles (9 km.). The maximum gradient is 1 in 36 uncompensated for 818 ft. radius curves.

Double-Consolidation Garratts of the Bengal-Nagpur Ry. (India).—5 ft. 6 ins. gauge.

These are the most powerful *Garratts* hitherto introduced into India.

On the approximately level portions of this railway, rigid locomotives of the Consolidation type draw 1,500- to 1,600-ton trains. The *Garratts* can deal singly with the same loads up to the 1 per cent. grades, which are met with between Chakardapur and Sharsuguda,† while two of the Consolidations were previously required ‡ for the same service.

* One of these grades is 16¾ miles long (27 km.) with curves of 330 ft. (100 m.) radii. The trials between the two types took place on the section from Sedaw to Maymyo, which includes 11·2 miles (18 km.) of 4 per cent. grades and curves of 330 ft. (100 m.) radius. At the top of the bank, there is another incline of 11·8 miles (19 km.) at 2½ per cent. grade.

† The line is laid with 85½ and 90 lbs. rails (42·5 and 45 kg. per metre).

‡ The two Consolidations together weighed 228 tons, of which 55 per cent. was available for adhesion. The single *Garratt* weighs 180 tons 10 cwt., of which weight 82½ per cent. is available for adhesion.

Class I.—Double-Mikado Garratt Locomotives (2-8-2 + 2-8-2)

The reasons which have led to the adoption of this type as a development of the 2-8 + 8-2 type, are the same as in the case of the double-Prairie type (2-6-2 + 2-6-2) already referred to.

Double-Mikado Garratts of the South African Rys.—3 ft. 6 ins. gauge.

In the year 1925, the South African Rys. put into service their "G.E." type of *Garratt* locomotives, six in number. They were allocated to mixed traffic on the section from Johannesburg to Mafeking, *viâ* Zeerust. The length of this section is 200 miles (319 km.), and there are gradients of 2½ per cent. in both directions. As the weight of rails is only 60 lbs. per yard, the maximum load per axle is limited to 12¾ tons, which entails distributing the weight over eight coupled axles. To facilitate running through sharp curves, the wheels of the driven axle of each group (the second) have flangeless tyres.

In the year 1926, ten similar locomotives were put into service. They work on the Natal section, where the ruling gradient is 1 in 30 and there are curves of 300 ft. radius.

Double-Mikados of the Rhodesia Rys.—3 ft. 6 ins. gauge.

Orders were placed in 1928 by the Rhodesia Rys. for *Garratts* of this class able to develop 48,735 lbs. tractive force at 75 per cent. boiler pressure.

The total weight is about 152 tons, despite the 60-lbs. rails with which the lines are equipped.

They are to work on the Bulawayo-Wankie-Livingstone section, which contains 1 in 50 uncompensated gradients.

The same railways previously owned a number of Double-Mikado *Garratts* (two batches comprising twelve and sixteen units).

Double-Mikado Garratts of the Nitrate Rys.—Standard gauge.

In the year 1925 this railway put some *Garratts* into service on the Iquique and Carpas section, 20 miles (32 km.) in length. It has 4 per cent. grades non-compensated, with curves 200 ft. (66 m.) radius, which is equivalent to a straight incline of 4·62 per cent. or 1 in 21. At a speed of 7½ miles (12 km.) per hour, 4-8-4 tank locomotives could draw 180 tons approx.

Tables 41 and 42.—Principal Dimensions of 2-8-2 + 2-8-2 and 4-8-2 + 2-8-4 Garratt Locomotives

Railway	South African Rys.	Nitrate Rys. (Chile)	Kenya and Uganda Ry.	Bolivia Ry.	Buenos Ayres Gt. Southern Ry.	Benguela Ry.
Date	1925.	1926.	1927.	1929.	1928.	1927.
Gauge	3′ 6″	Standard.	Metre.	Metre.	5′ 6″	3′ 6″
Type . . . Double-	Mikado.	Mikado.	Mountain.	Mountain.	Mountain.	Mountain.
Cylinder, diameter	18″	22″	16½″	18″	17½″	18½″
,, stroke	24″	20″	22″	26″	25″	24″
Boiler, height of centre	7′ 9″	9′	7′ 6″	7′ 9″	—	8′ 3″
,, diameter	6′ 10½″	7′ 3⅜″	5′ 10 11/16″	6′ 10½″	6′ 1½″	6′ 10½″
,, length	14′	13′	12′	13′	12′ 2¾″	12′
,, pressure . . . lbs. per sq. in.	180	200	170	185	200	180
Tubes, number	36–288	50–299	32–218	45–275	36–223	40–267
,, diameter	5½″–2″	5⅜″–2″	5¼″–1⅞″	5¼″–1⅞″	5¼″–1⅞″	5½″–2″
,, diameter (superheater tubes)	1½″	1½″	1⅜″	1⅜″	—	1¾″
Firebox, length	8′ 9″ (ext.)	9′ 1⅛″ (int.)	7′ 6″ (ext.)	9′ 3″	8′ 0″	8′ 9″
Heating surface, firebox . . . sq. ft.	210	276	174	217	204	229
,, ,, tubes . . . ,,	2,366	3,070	1,863	2,647	2,003	2,327
,, ,, total . . . ,,	2,576	3,346	2,037	2,864	2,207	2,556
,, ,, superheater . . . ,,	390	744	380	598	442	458
Grate area . . . ,,	52	68·8	43·6	54·9	44·2	51·5
Wheels, diameter	2′ 4½″	2′ 2″	2′ 4½″	2′ 4″	2′ 9¼″	2′ 4½″
,, diameter	3′ 9½″	3′ 6″	3′ 7″	4′ 0″	4′ 7½″	4′
,, diameter	2′ 4½″	2′ 2″	2′ 4½″	2′ 9″	3′ 2″	2′ 10″
Wheelbase, 1 group	22′ 10½″	22′ 6″	24′ 8″	28′ 10½″	30′ 6″	27′ 2″
,, rigid	12′ 9″	12′ 0″	12′ 3″	10′ 0″	10′ 3″	13′ 6″
,, total	70′	71′ 9″	72′	81′ 10″	83′ 7½″	78′ 2″
Pivot, centres	35′	38′ 3″	34′ 10″	—	—	36′
Overall dimensions, height	12′ 11 7/16″	14′	12′ 6″	—	—	13′ 2½″
,, ,, width	10′	10′ 4″	9′ 6″	—	—	9′ 11½″
,, ,, length	—	—	82′ 1″	—	—	85′ 6″
Capacity, water . . . galls.	4,600	5,500	4,250	5,000	4,600	500
,, coal . . . tons	9	6	6	—	8	540 cub. ft. (6 t.)
,, oil . . . galls.	None.	1,410	—	1,670	—	None
Tractive force (at 75 per cent.) . . . lbs.	46,140	30,150	35,520	48,700	43040	46.200
Weight, 1 axle . . . tons-cwt.	12–15	18–0	10–10	13–2	12–7	12–15
,, adhesive . . . ,,	100–15	140–10	79–7	104–3	101–6	100–14
,, empty . . . ,,	—	—	—	—	—	120–10
,, in service . . . ,,	145–11	187–3	125–7	169–13	165–2	158–1

At the same speed, the *Garratts* dealt with a load of 360 tons.*

Class J.—Double-Mountain Garratt Locomotives (4-8-2 + 2-8-4) (Table 42)

This is the most recent class of *Garratt* locomotives. It is, in effect, a double-Mikado modified by the substitution of four-wheeled bogies for the bissels at the outer ends of the trucks, and is likely to be further developed.†

Double-Mountain Garratts for the Kenya and Uganda Ry.—Metre gauge.

The main line from Nairobi to Nakuru, 122 miles (197 km.) in length, has a heavy section as far as Uplands, with 32 miles (51 km.) of continuous 2 per cent. grades. As the track is laid with 40 lb. rails, the maximum axle load is 10 tons. The locomotives deal with 400-ton trains.‡

Double-Mountain Garratts for the Cordoba Central Ry. (metre gauge) are on order.

Double-Mountain Garratts of the Benguela Ry.—3 ft. 6 ins. gauge.

This railway, which runs from Lobito Bay to the Katanga frontier, has several long banks of 2½ per cent. grade, up which

* Following American practice, these locomotives have bar frames and steel fireboxes with round tops. The inner carrying axles have radial boxes.

The following comparative data for the two types are of interest :—

	4-8-4-T.	Garratt.
Tractive force . . . . . . lbs.	31,110	69,150
Weight in working order . . tons-cwt.	112	287–4
Weight of train hauled . . . . ,,	180	360
Ratio, weight of train to locomotive weight .	1·48	2·14
Tractive force . . . . lbs. per ton	277·7	370

† For the Central Aragon Ry.'s *Garratts* now on order, see Addenda, note 1.

‡ Four of these locomotives are now at work, and twelve more are on order. These latter will have additional water space of 1,000 gallons. The axle load will be increased to 10½ tons, and the total weight of the locomotive, in working order, will be 130 tons.

the *Garratts* haul 450-ton trains. These locomotives have been designed with greater flexibility than those of the South African Rys. For this purpose, four-wheeled bogies have been fitted ; the wheels of the outer coupled axles have no flanges and the rigid wheelbase of each group has been reduced from 12 ft. 9 ins. to 9ft. These modifications allow the 300 ft. radius curves of the San Pedro (mile 33½ ; km. 54) and Cubal and Huambo section (mile 327 ; km. 426) to be easily negotiated.

The maximum speed is 45 miles per hour.

The water capacity of the locomotives has been increased. The fireboxes are copper with arch tubes, and are designed for burning wood.

The Lentz patent poppet valve gear is provided with by-pass arrangements. The steam chests are cast separately from the cylinders. The copper firebox is provided with arch tubes.

Double-Mountain Garratt Locomotives, Bolivia Ry.—Metre gauge.

It will be remembered that this railway's main line lies on the Bolivian plateau, which is scaled by the Antofagasta (Chile) and Bolivia Ry. The Bolivia Ry. carries this line on to Guaqui ; it lies at an altitude some 12,000 ft. above sea level. From Guaqui, there is a sharp fall at a rate of 3 per cent. for 17 km. (10½ miles) down to La Paz, which is situated at 4,803 m. (13,394 ft.) above sea level. The *Garratts* supplied in 1929 are to work here and also on branches provided with lighter rails. This is why the weight per axle has been limited to 13 tons.

These *Garratts* are the most powerful metre gauge locomotives in existence. They have bar frames, steel fireboxes and adjustable pivot centres. They are provided with M.L.C. superheaters and Weir feed-water heaters. The size of the firebox is noteworthy, the grate being no less than 9 ft. 6 ins. long by 6 ft. 6 ins. wide, and the firebox 9 ft. 3 ins. by 7 ft. 4½ ins. outside, truly remarkable dimensions for metre gauge locomotives.

Double-Mountain Garratts, Buenos Ayres Great Southern Ry.—5 ft. 6 ins. gauge (1m.67).

These locomotives were the first *Garratts* delivered to railways having 5 ft. 6 ins. gauge lines in the Argentine. Weight had to be kept as low as possible—hence the adoption of the double-Mountain instead of the double-Pacific type. As for curvature, the first and third pairs of coupled wheels are flangeless.

The bogies are of the swing link type ; the coupled wheels spring rigging is compensated in two groups, the rear one including the trailers.

These locomotives are oil burners.

They will operate from Bahia Blanca (Ingenio White) to Zapala, a distance of 465 miles (652 km.), more than half of which are easy, but beyond the line rises 1,371 ft. (418 m.) in 40 miles (64 km.) with maximum gradients of 1 in 80.

GARRATT LOCOMOTIVES WITH SPECIAL ARRANGEMENTS OF CYLINDERS

In addition to the usual arrangement of four simple admission cylinders, *Garratt* locomotives have been built with three other cylinder arrangements, namely :—

(1) Six simple admission cylinders.

(2) Eight simple admission cylinders.

(3) Four-cylinder compound locomotives.

The first compound *Garratt* was put into service on the Tasmanian Rys., on which system the only eight cylinders simple *Garratt* hitherto constructed, are also in use.

Type 2.—Six-Cylinder Simple Garratt Locomotives

Double-Consolidation Garratts (2-8 + 8-2) of the London and North-Eastern Ry.—Standard gauge.

These were the first six-cylinder *Garratts* to be built. It would seem likely that their use will be extended, since the three-cylinder arrangement is found satisfactory in the case of rigid locomotives.

Although these *Garratts* have a maximum axle load considerably below the limit on this railway, their power is 50 per cent. greater than that of the rigid locomotives which they have displaced. They are intended for use as banking locomotives between Wath and Penistone on the Worsborough branch.*

* The length of the section is 7 miles (11 km.) of which nearly 2 miles consist of a 2½ per cent. gradient. Hitherto 1,000-ton trains were hauled up the bank by two locomotives in front and two or even three pushers. A single *Garratt* does the work of the latter. The dimensions of these locomotives are given in Table 40.

Double-Pacifics of the New Zealand Government Rys.—3 ft. 6 ins. gauge.

These locomotives, three of which were supplied at the end of 1928 by Messrs. Beyer, Peacock and Co. to the New Zealand Government Rys., will run the main line express trains at a maximum speed of 50 miles an hour, and negotiate 1 in 40 gradients.

The restricted height available has hampered the designers, but, in spite of this, the locomotives represent a good example of what can be accomplished on the 3 ft. 6 ins. gauge. Indeed, the boiler has a diameter of 6 ft. 6 ins.

The cylinders are slightly inclined. The outside valves are actuated by Walschaert, and the inside ones by Gresley's valve gear, with 50 per cent. maximum cut off.

The firebox has two Nicholson thermic syphons and fuel is fed by a Duplex mechanical stoker. For this reason, the main frame is extended backwards, so that the bunker is attached to the back of the cabin, thus producing a transition type between the *Garratt* proper and the *Union-Garratt*.

Type 3.—Eight-Cylinder Simple Garratt Locomotives

Double-Atlantic Garratts (4-4-2 + 2-4-4) of the Tasmanian Government Rys.—3 ft. 6 ins. gauge.

These are the only eight-cylinder *Garratts* yet built. They are provided with Schmidt superheaters. It is because the *Garratt* design permits the use of a boiler of relatively high evaporative power that it is possible to use so many cylinders This is, however, not to be recommended.

There are two outside and two inside cylinders on each bogie. They drive the first of the coupled axles. In order to provide ample space for the motion work and valve gear of the inside cylinders, the usual lower parts of the water tanks had to be omitted.

These locomotives draw heavy express trains between Hobart and Launceston at a maximum speed of 50 miles per hour (80 km. per hour). This is a remarkable speed for so narrow a gauge and for articulated locomotives, which are popularly considered to be incapable of more than very moderate speeds.*

* Recently a speed of 60 miles per hour has been attained on the section between Launceston and Deloraine.

The leading dimensions of these locomotives are given in Table 30.

The service for which these locomotives were designed is a sufficient explanation of the provision of the four-wheeled bogies at the outer ends of each truck and the bissels at the inner ends.

Type 4.—Compound Garratt Locomotives

0-4 + 4-0 Compound Garratts of the Tasmanian Government Rys.—3 ft. 6 ins. gauge.

These locomotives, supplied by Messrs. Beyer, Peacock & Co., of Manchester, were the first *Garratts* ever built. They were specified to be compound locomotives by the purchasers.*

Unlike all the other *Garratts* since constructed, the cylinders are located at the inner ends of the bogies with the object of reducing the length of the steam pipes between them.

These locomotives were designed for use on the north-eastern section of the line from Dundas, which comprises some 4 per cent. gradients and curves of 100 ft. (33 m.) radius.

All the cylinders have piston valves. The H.P. cylinders drive the trailing bogie. The H.P. steam is led to these cylinders by a pipe which has a universal joint immediately above the centre of rotation of the rear bogie. The receiver piping between the H.P. and L.P. cylinders consists of a long tube, 4¾ ins. (0m.121) diameter, carried outside the locomotive at 7¾ ins. approx. above rail level. It has a universal joint at each end, and at the rear end a telescopic sleeve joint is also provided. In view of its exposed situation, the receiver piping is lagged with asbestos. The exhaust from the L.P. cylinders passed into a single pipe which has a universal joint at the bottom and a sliding joint at the top.

Compound Double-Consolidation (2-8 + 8-2) Garratt Locomotive of the Burma Rys.—Metre gauge (Fig. 78).

After a number of comparative tests between *Mallet* and *Garratt* locomotives, this railway decided in favour of the latter, though they recognised that compounding as applied in the *Mallet* had its good points.

It was therefore decided to try a compound *Garratt* † generally similar, in other respects, to the simple *Garratts* already in use,

* Leading dimensions are given in Table 29.

† The leading dimensions of these locomotives are given in Table 40

in the hope that economies in fuel and water consumption and, possibly, in maintenance charges might be realised.

In this compound locomotive the H.P. cylinders are at the cab end and the L.P. cylinders in front. Both have piston valves, those of the H.P. cylinders with inside admission and those of the L.P. cylinders with outside admission.

The calculated tractive force is 34,550 lbs. at 75 per cent. boiler pressure, or at 90 per cent. (which is now usually taken for locomotives with superheaters) the tractive force is 40,200 lbs. The respective factors of adhesion, in working order, are 5·47 and 4·7.

A number of detail improvements in design have been introduced with a view to rendering the engine mechanism and the pipe connections more readily accessible. Thus the bunkers and tanks have been raised so as to permit of easy access to the steam piping and its joints.

We believe this locomotive will compare advantageously with the simple *Garratts*. But will this outbalance the drawback of using a more complicated machine where available labour may not be all that could be desired ? Experience alone can answer this query.

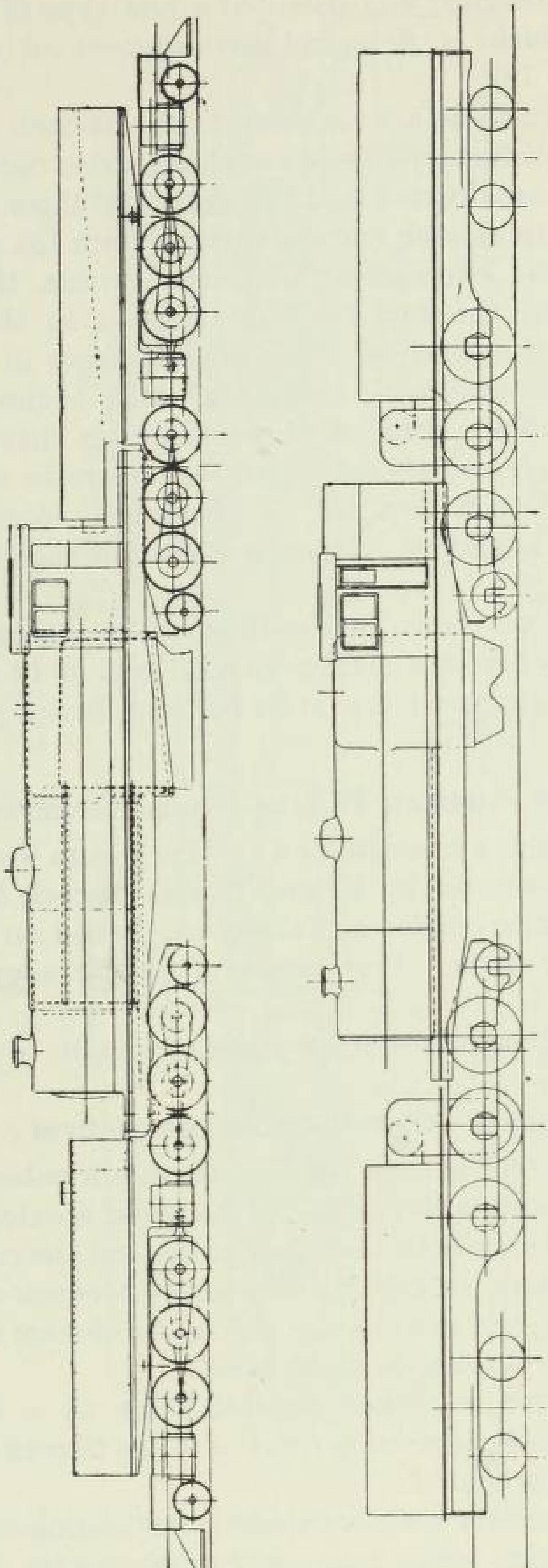
SUB-GROUP III. B.—LOCOMOTIVES DERIVED FROM THE GARRATT

The great success of the *Garratt* has stimulated designers both to adapt the *Garratt* to future demands for locomotives of greater power, as in the *Garratt-Mallet* and the *Garratt-Union* types, and also to incorporate in locomotives of other types, the successful features of the *Garratt*. Two cases in point are the modified *Fairlie*, built by the North British Locomotive Co., and the *Golwé* locomotives.

The latter have already been dealt with in the section dealing with the *Fairlie* engines. The former are considered hereafter.

Type 1.—Garratt-Mallet Locomotives

As in the case of other types of locomotives, it is necessary to make timely provision in designs for future demands for locomotives more powerful than any at present in service. To meet such contingencies Messrs. Beyer, Peacock & Co., Man-



FIGS. 79 and 80.—Projects of Mallet-Garratt and of Garratt Turbine Locomotives.

chester, have designed and patented a new type of articulated locomotive which is a logical development of the *Garratt* principle (Fig. 79).

In this design there are six driven axles at each end. As it would be unsatisfactory to have so many axles rigidly coupled together, they are divided into two groups of three each. The outermost group at each end are integral with the main frame as in the *Mallet* locomotives. In other words, the boiler is carried between the two running units as in the ordinary *Garratt* design, but each of these units consists in effect of a complete *Mallet* unit with two six-wheeled bogies, one fixed and one movable. Each of these bogies is driven by two cylinders. There are therefore four cylinders in all for each unit, two H.P. and two L.P. The whole locomotive has therefore eight cylinders. There is a bissel at each end of each unit.

The locomotive shown in the illustration is designed for a 3 ft. 6 ins. gauge with a maximum axle load of 12 tons 8 cwt. The calculated tractive force (at 90 per cent. boiler pressure) is 83,500 lbs.

Type 2.—Garratt Turbine-driven Locomotive

Fig. 80 represents a design for a turbine-driven *Garratt*, which has also been patented by Messrs. Beyer, Peacock & Co. The exhaust is led into condensers which are carried on the frames of the running units. Provision is made for supplementary sets of wheels.

No actual locomotives have yet been built to the above designs.

Type 3.—Garratt-Union Locomotives

These engines differ from the *Garratts* in a number of points.

The girder frame which supports the boiler is extended backwards so as to carry both the water tanks and the coal bunker. There is, therefore, no relative movement between the bunker and the firebox, and this enables automatic stokers to be used. In this case the Duplex stoker is fitted.

The locomotive is carried on the frame by a three-point suspension, namely, a pivot in front as in the *Garratt* design and two side brackets behind.

The fuel and water tanks carried on the leading bogie follow its angular motion when running through curves, but this is

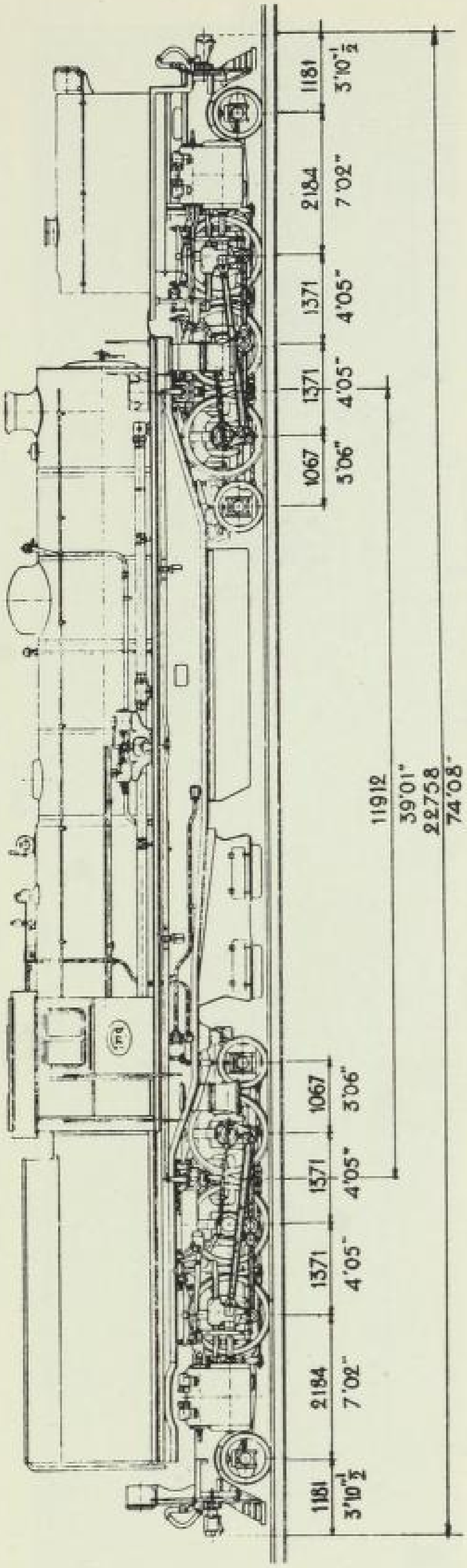


FIG. 81.—2-6-2 + 2-6-2 Union-Garratt Locomotive, South African Rys.
(3 ft. 6 ins. Gauge.)
Built by J. A. Maffei, of Munich.

not the case with those carried on the trailing bogie. These latter take up a position tangential to the curve, consequently

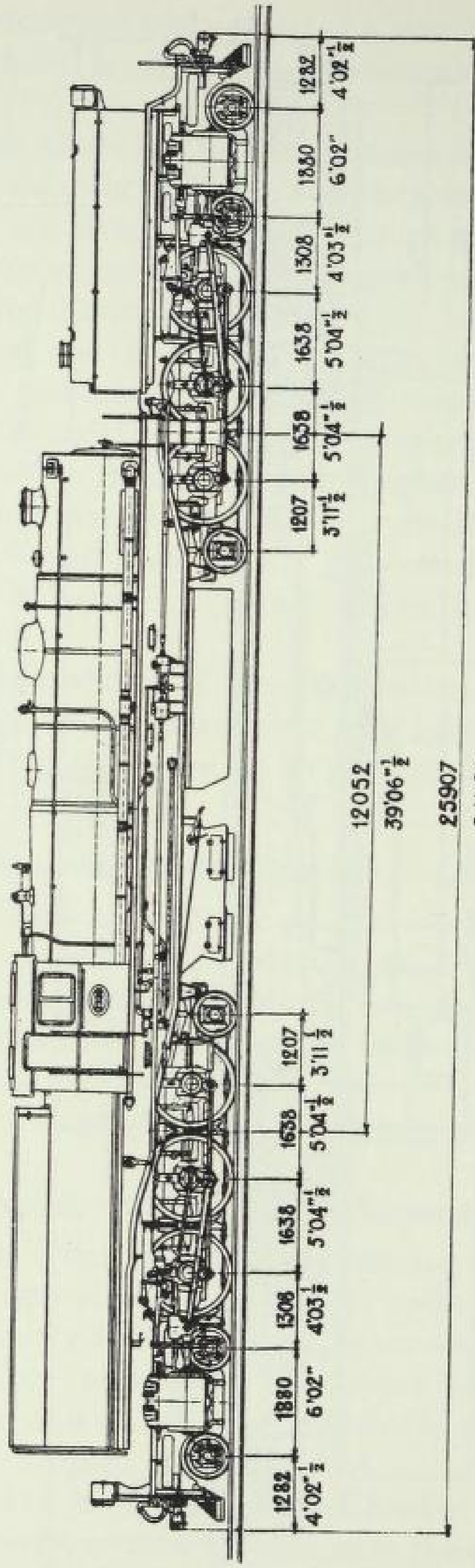


Fig. 82.—4-6-2 + 2-6-4 Union-Garratt Locomotive, South African Rys.
(3 ft. 6 ins. Gauge.)
Built by J. A. Maffei, Munich.

their weight is not symmetrically distributed on the trailing bogie.

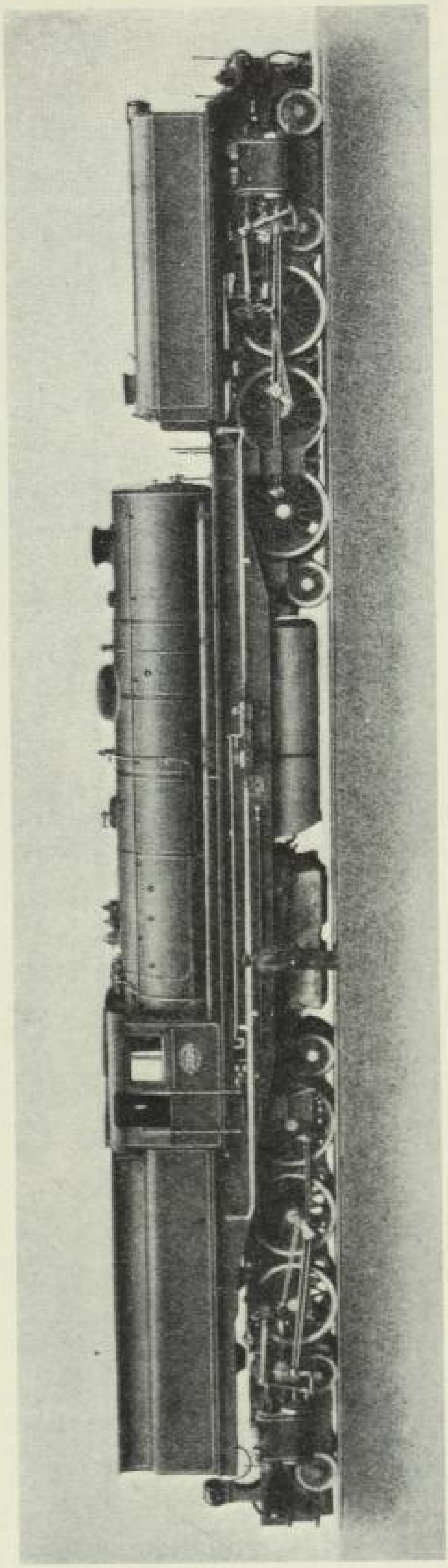


Fig. 83.—4-6-2 + 2-6-4 Union-Garratt Locomotive, South African Rys.
(3 ft. 6 in. Gauge)
Built by J. A. Maffei, Munich.

It has been thought desirable to lengthen the boiler and its tubes.

TABLES 43 and 43A.—PRINCIPAL DIMENSIONS OF GARRATT-UNION LOCOMOTIVES

Railway . .	South African Rys.			
Gauge . .	1m.067 (3 ft. 6 ins.)			
Builder . .	Maffei, of Munich (1927).			
	Metric Dimensions.		English Dimensions.	
Type . . .	**2-6-2+2-6-2**	**4-6-2+2-6-4**	**2-6-2+2-6-2**	**4-6-2+2-6-4**
Cylinders :—				
Diameter . .	0m.47	0m.50	18½″	19½″
Stroke . .	0m.66	0m.66	26″	26″
Boiler :—				
Height of centre line . .	2m.53	2m.52	8′ 0¾″	8′ 3″
Length . .	9.m.72	9m.03	32′ 0¾″	29′ 7⅜″
Diameter . .	1m.89	2m.37	6′ 2¼″	7′ 9½″
Pressure . .	12·6 kg. per sq. cm.		180 lbs. per sq. in.	
Tubes :—				
Number . .	30–170	43–195	30–170	43–195
Diameter . .	140–57 mm.	140–63 mm.	5½″–2¼″	5½″–2½″
Length . .	5m.50	4m.16	18′ 0½″	13′ 8″
Firebox :—				
Width . .	2m.15		7′ 0⅝″	
Length . .	2m.58		8′ 5⅜″	
Heating surface :—				
Firebox . .	20·7 sq. m.	22·4 sq. m.	223 sq. ft.	241 sq. ft.
Tubes . .	216·1 ,,	200·4 ,,	2,326 ,,	2,157 ,,
Total . .	236·8 ,,	222·8 ,,	2,649 ,,	2,398 ,,
Superheater .	70·0 ,,	76·0 ,,	754 ,,	824 ,,
Grate area . .	5·5 sq. m.		59·5 sq. ft.	
Wheels diameter :—				
Pony . .	0m.76		2′ 6″	
Driving . .	1m.22	1m.52	4′ 0″	5′ 0″
Wheelbase :—				
Rigid . .	2m.74	3m.28	9′ 0″	10′ 9″
1 group . .	5m.99	6m.36	19′ 8″	25′ 2″
Total . .	20m.40	23m.34	66′ 11″	76′ 7″
Centres of pivots .	11m.91	12m.06	39′ 1″	39′ 6½″
Overall :—				
Height . .	3m.95		12′ 1 7/16″	
Width . .	3m.03		9′ 11″	
Length . .	22m.76	25m.91	74′ 8″	85′ 0″
Water tanks .	24 cub. m.	27·3 cub. m.	5,280 galls.	6,000 galls.
Fuel bunkers .	14·2 met. t.	13·5 met. t.	14 t. 0 cwt.	13 t. 5 cwt.
Tractive force (at 75 per cent.) .	15,000 kilo.	20,200 kilo.	33,070 lbs.	44,540 lbs.
Weight :—				
Max., one axle .	18·8 met. t.	18·9 met. t.	18 t. 10 cwt.	18 t. 12 cwt.
Adhesive . .	112·0 ,,	112·0 ,,	110 t. 3 cwt.	110 t. 3 cwt.
Total, empty .	122·9 ,,	137·7 ,,	119 t. 0 cwt.	135 t. 10 cwt.
Total, in service	169·8 ,,	187·5 ,,	164 t. 0 cwt.	184 t. 10 cwt.

In order to do this without unduly increasing the overall length of the locomotive, the leading water tank has been reduced in length and the balance of the water capacity made up by providing a well tank under the boiler. Also the main pivot, which in the standard *Garratt* design is located between the first and second axles, has been moved forward so that the leading bogie is brought further back underneath the boiler.

Simultaneous patent applications for these modifications were made by Beyer, Peacock and by Maffei by mutual arrangement for different countries.

Double-Prairie (2-6-2 + 2-6-2) (Fig. 81) and Double-Pacific (4-6-2 + 2-6-4) Garratt-Union Locomotives of the South African Rys.—3 ft. 6 in. gauge.

These locomotives were built by Maffei in 1927 and 1928. They are used concurrently with the standard *Garratts* and the *modified Fairlies* of this railway.

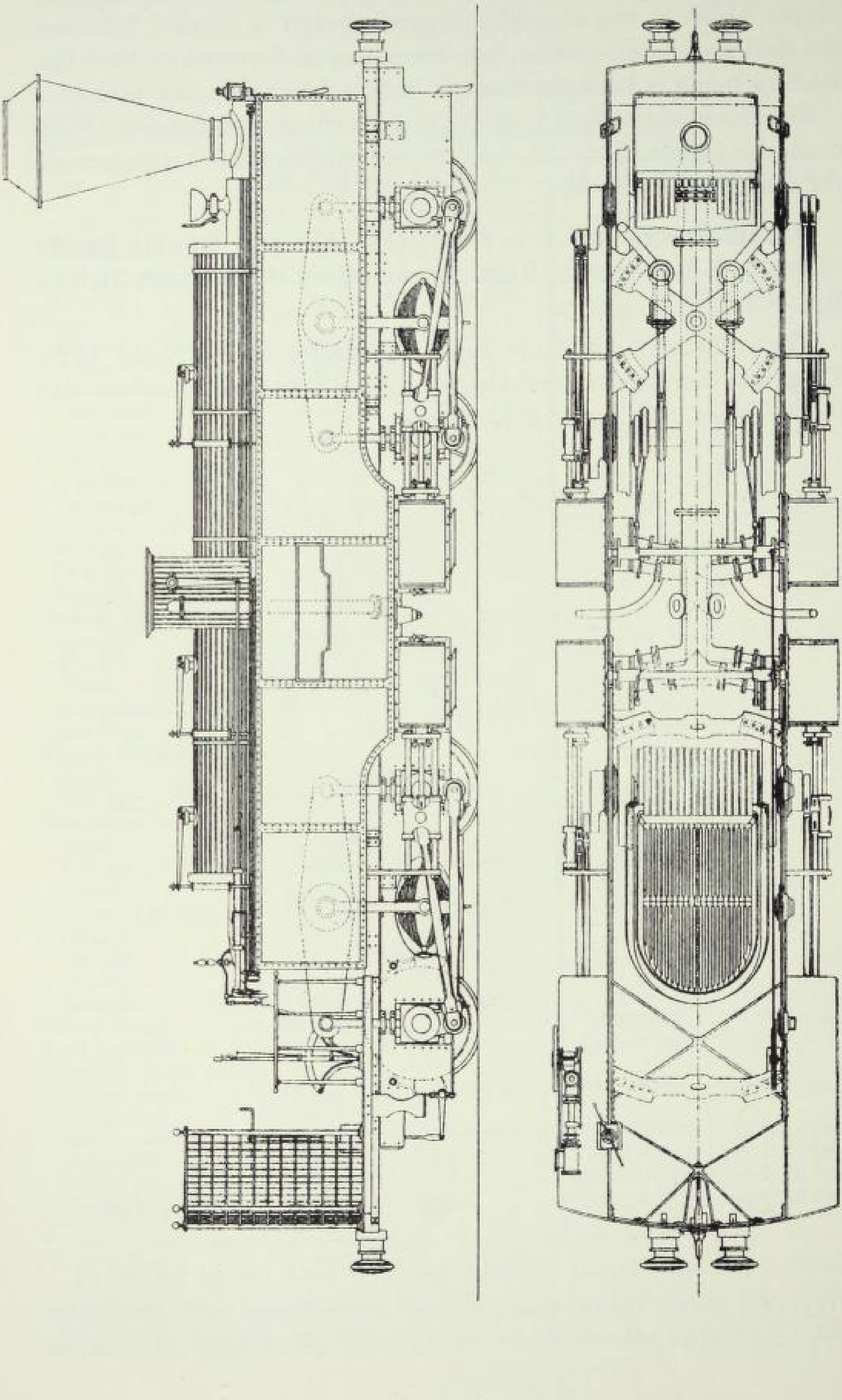


FIG. 84.—The "Wiener Neustadt" Locomotive (Semmering Contest).

GROUP IV.—THE DU BOUSQUET ARTICULATED LOCOMOTIVES

Earlier Types

Certain of the features found in these locomotives were also found in earlier ones. Nevertheless, there are many differences not only in the details but in essentials, between the *du Bousquet* locomotives and their predecessors.

Type 1.—The Wiener-Neustadt Locomotive

This tank locomotive (Fig. 84) was built for the Semmering Contest in 1851 ; certain of its interesting features have been repeated since. It had a single boiler and two sets of driving wheels, each with two-coupled axles and two cylinders. All cylinders were grouped at the centre of the locomotive.

The boiler was carried on an external main frame. The side members of this frame lay over the side members of the bogie frame in the normal position. The main frame was supported on the bogies by circular seatings. The leading bogie alone had also a central pivot ; this could not be provided on the trailing bogie owing to the presence of the firebox. The rear bogie could only move radially and had no transverse play.

The buffing and drawgear was attached to the main frame.

The steam pipes were concentric to the above seatings ; they had sliding joints with stuffing boxes. Fig. 84 shows the general arrangement of the pipe work.

The chief defect of this design was that the bogies could not move transversely in relation to the boiler. Some play between the moving parts was, indeed, provided, but this was inadequate.*

* The leading dimensions of this locomotive were as follows :—

TABLE 44

Cylinders, diameter	0·329 m.	13 ins.
,, stroke	0·632 m.	24⅞ ins.
Boiler pressure	8·8 k. per sq. cm.	111 lbs. per sq. in.
Tubes, length	6·380 m.	21 ft.
Heating surface	170 sq. m.	1,830 sq. ft.
Grate area	1·70 sq. m.	18·3 sq. ft.
Diameter of wheels	1·06 m.	3 ft. 5¾ ins.
Wheelbase of one bogie	2·205 m.	7 ft. 2½ ins.
Total wheelbase	8·120 m.	27 ft. 7½ ins.
Weight in working order	61 metric tons.	60 tons 5 cwt.
Average load per axle	15·25 ,,	15 tons 1 cwt.
Tractive force (constant 0·65)	6·40 ,,	14,110 lbs.

Type 2.—The du Bousquet Locomotives

Du Bousquet revived the original idea embodied in the *Wiener-Neustadt* locomotive. He designed a locomotive which, like the latter, had two driven bogies supporting a frame on which the boiler was carried. The buffing and drawgear were attached to this frame.

Cylinders.—The four compound cylinders are set opposite one another and located at the centre of the locomotive. The length of the steam piping is thereby reduced. To eliminate the overhang of the cylinders, a bearing axle is added to each group of driven axles, which are three in number, giving the arrangement 0-6-2 + 2-6-0.

The Frame and its Supports.—The frame consists of channel steel. While the *Wiener-Neustadt* engine was supported on its two trucks by circular seatings, the *du Bousquet* locomotive is supported on the rear bogie by a flat pivot and on the front bogie by a spherical pivot which works in a footstep bearing. This bogie can take up any position in relation to the boiler, while the rear bogie is only free to turn about a horizontal axis.

Steam-Piping.—The high pressure steam piping passes through the pivot of the rear bogie. As the movement at this point is limited, a simple joint suffices. The steam pipe between the high and low pressure cylinders has universal and telescopic joints. The flexible piping for the exhaust from the low pressure cylinders consists of armoured rubber hose.

Fuel and Water.—The fuel and water are carried on the locomotive. The water is carried inside tanks running the full length of the boiler, with the exception of its central portion, above the bissel axles. This break gives better access to the motion work and relieves the load on the pivots.

The coal is carried in bunkers behind the cab.

Utilisation of the du Bousquet Locomotives

The increase of power of rigid locomotives has ousted these from their sphere of usefulness, and, as there has been no call for further *du Bousquets* of increased power, no further locomotive of this type have been built recently, though a number of the original ones are still in service.

0-6-2 + 2-6-0 du Bousquet Locomotives of the Chemin de fer du Nord, France.—Standard gauge (Fig. 85).

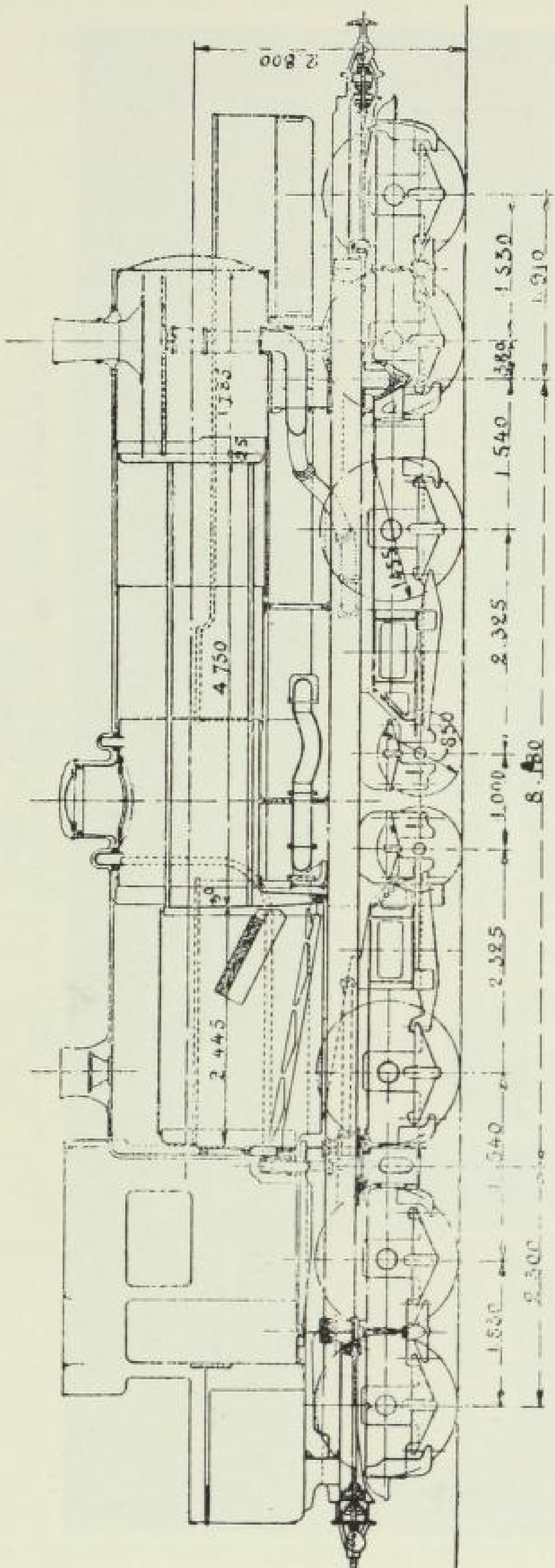


FIG. 85.—0-6-2 + 2-6-0 du Bousquet Locomotive, Chemin de fer du Nord (France). (Standard Gauge.) Built at the Co.'s shops.

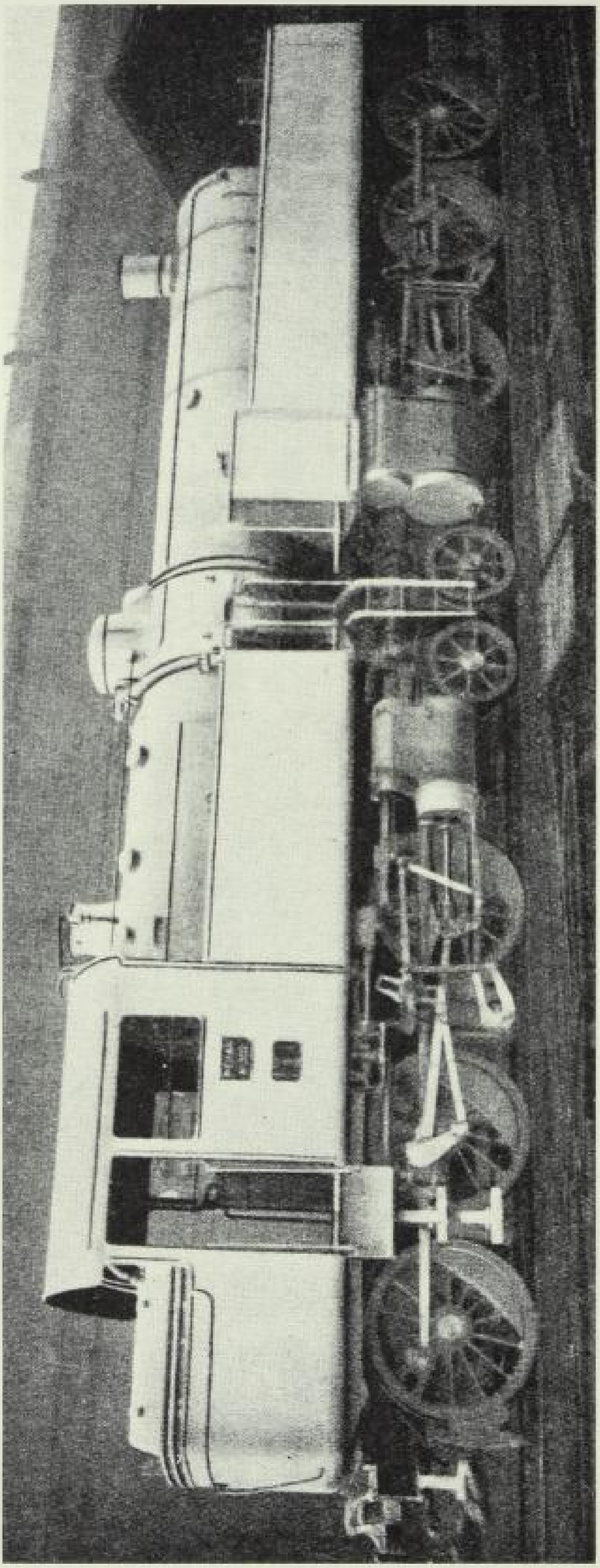


Fig. 86.—0-6.2 + 2-6-0 du Bousquet Locomotive, Pekin-Hankow Ry.
(Standard Gauge.)
Built at the Forges et Aciéries de Haine-St. Pierre (Belgium).

TABLE 45.—PRINCIPAL DIMENSIONS OF DU BOUSQUET LOCOMOTIVES (METRIC MEASURES)

Gauge	1·435.	1·435.	1·672.
Railway	(1) Nord; (2) Est; (3) Ceinture.	Pekin-Hankow	Andalusian (Spain).
Builder	(1 & 2) Co.'s shops; (3) Batignolles	Haine-Saint-Pierre	Métallurgique, Couillet.
Year	1905-1911.	1906.	1911.
Type	**0-6-2 + 2-6-0**	**0-6-2 + 2-6-0**	**0-6-2 +2 -6-0**
Cylinders, diameter H.P. m.	0·40	0·49	0·40
,, ,, L.P. m.	0·63	0·62	0·63
,, stroke m.	0·68	0·66	0·63
Boiler :—			
Height of centre line m.	2·80	2·75	2·75
Mean diameter m.	1·46 int.	1·46	1·50
Pressure kg. per cm.²	16	15	16
Tubes, number	130 Serve.	130 Serve.	256
,, diameter, int. mm.	70	70	45
,, length m.	4·75	4·75	4·75
Firebox, depth, front m.	1·48	1·48	1·75 ext.
,, ,, rear m.	1·14	1·14	1·39 ext.
Grate, length m.	2·54	2·54	2·52
,, width m.	1·19	1·19	1·39
Heating surface, firebox m.²	12	12	14
,, ,, tubes m.²	232·6	232·6	172
,, ,, total m.²	244·6	244·6	186
Grate area m.²	3	3	3·5
Wheels, diameter m.	0·85	0·85	0·85
,, ,, m.	1·46	1·35	1·35
Wheelbase, rigid m.	3·37	3·37	3·37
,, one bogie m.	5·80	5·80	5·80
,, total m.	12·59	12·59	12·59
Centres of pivots m.	8·18	8·18	8·18
Water cub. m.	12·8	12·8	9
Coal t.	5	5	4
Max. tract. force, compnd. t.	18·1	15·9	14·8
,, ,, simple t.	24·1	22·3	26·7
Maximum dimensions :—			
Height m.	4·22	4·17	4·63
Breadth m.	16·19	15·05	15·05
Length m.	2·85	2·94	3·26
Weight, adhesive, t.	72–90	72–90	68–78
,, ,, empty t.	78	86·5	80
,, in service t.	102 (106)	109·8	94

This type was designed to meet special traffic requirements.* A powerful locomotive was required capable of drawing trains

* Numbers 6,121 to 6,168 were built in the Company's shops.

TABLE 45A.—PRINCIPAL DIMENSIONS OF THE DU BOUSQUET LOCOMOTIVES (ENGLISH MEASURES)

Gauge	Standard	Standard	5 ft. 6 ins.
Railway	(1) Ch. de fer du Nord; (2) Est; (3) Ceinture.	Pekin-Hankow	Andalusian.
Builder	(1 & 2) the Co.'s Workshops; (3) Batignolles.	Haine-Saint-Pierre.	Metallurgique, Couillet.
Date	1905–1911.	1906.	1911.
Type	**0-6-2 + 2-6-0**	**0-6-2 + 2-6-0**	**0-6-2 + 2-6-0**
Cylinders, diameter H.P.	$15\frac{3}{4}''$	$19\frac{1}{4}''$	$15\frac{3}{4}''$
,, ,, L.P.	$24\frac{3}{4}''$	$24\frac{3}{8}''$	$24\frac{3}{4}''$
,, stroke	$26\frac{3}{4}''$	26″	$24\frac{3}{4}''$
Boiler, height of centre line	9′ 2″	9′ 0″	9′ 0″
,, mean diameter	$4'\ 9\frac{1}{2}''$	$4'\ 9\frac{1}{2}''$	4′ 11″
,, pressure lbs./sq. in.	227·5	213·3	227·5
Tubes, number	130	130	256
,, diameter, int.	$2\frac{3}{4}''$	$2\frac{3}{4}''$	$1\frac{13}{16}''$
,, length	15′ 7″	15′ 7″	15′ 7″
Firebox, depth, front	$4'\ 10\frac{1}{4}''$	$4'\ 10\frac{1}{4}''$	5′ 9″ ext.
,, ,, rear	3′ 9″	3′ 9″	$4'\ 6\frac{3}{4}''$ext.
Grate, length	8′ 4′	8′ 4″	$8'\ 3\frac{5}{8}''$
,, width	$3'\ 5\frac{1}{8}''$	$3'\ 5\frac{1}{8}''$	$4'\ 6\frac{3}{4}''$
Heating surface, firebox	129·1 sq. ft.	129·1 sq. ft.	150·5 sq. ft.
,, ,, tubes	2,495 ,,	2,495 ,,	1849·5 ,,
,, ,, total	2624·1 ,,	2624·1 ,,	2,000 ,,
Grate area	32·3 ,,	32·3 ,,	38·7 ,,
Wheels, diameter	$2'\ 9\frac{1}{4}''$	$2'\ 9\frac{1}{4}''$	$2'\ 9\frac{1}{4}''$
,, ,,	$4'\ 9\frac{1}{4}''$	4′ 5″	4′ 5″
Wheelbase, rigid	$11'\ 0\frac{1}{2}''$	$11'\ 0\frac{1}{2}''$	$11'\ 0\frac{1}{2}''$
,, 1 bogie	18′ 10″	18′ 10″	18′ 10″
,, total	41′ 5″	41′ 5″	41′ 5″
Centre of pivots	$26'\ 9\frac{1}{2}''$	$26'\ 9\frac{1}{2}''$	$26'\ 9\frac{1}{2}''$
Water capacity	452 cub. ft.	452 cub. ft.	318 cub. ft.
Coal bunkers	4 t. 18 cwt.	4 t. 18 cwt.	4 t. 18 cwt.
Overall, height	13′ 10″	13′ 8″	15′ 1″
,, width	9′ 4″	$9'\ 7\frac{3}{4}''$	10′ 8″
,, length	52′ 9″	$48'\ 11\frac{1}{4}''$	$48'\ 11\frac{1}{4}''$
Weight, adhesive	71 t. 0 cwt.–88 t. 16 cwt.	71 t. 0 cwt.–88 t. 16 cwt.	67 t.–77 t.
,, empty	77 t. 0 cwt.	85 t. 7 cwt.	78 t. 19 cwt.
,, in service	100 t. 13 cwt.–104 t. 12 cwt.	108 t. 7 cwt.	92 t. 15 cwt.
Tractive force compound	41,900 lbs.	45,050 lbs.	32,630 lbs.
,, ,, simple	43,140 ,,	49,170 ,,	58,870 ,,

of 950 tons at a speed of 50 to 60 km. (31 to 37 miles) per hour between Lens and Valenciennes or Busigny, where the gradients do not exceed 0·6 per cent., and also to deal with similar trains at a speed of 15 to 18 km. per hour on the section from Busigny to Hirson, where the gradients reach 1·2 per cent. These trains form part of the great volume of mineral traffic between the collieries of the North and the East of France. They are drawn as far as Lens by ordinary eight-coupled locomotives.

It was therefore necessary to adopt a diameter of about 1·50 m. (4 ft. 11 ins.) for the driving wheels and to have the adhesive weight carried by six driving axles.

These locomotives have worked satisfactorily ; an average of 21·6 kg. of coal and 71 gm. of lubricants were consumed per kilometre (79½ lbs. and 28 lbs. per mile). Maintenance costs were 22 centimes per kilometre (2·1 penny per mile), pre-war.

0-6-2 + 2-6-0 du Bousquet Locomotives of the Grande Ceinture Ry.—Standard gauge.

These locomotives are identical with the former.*

0-6-2 + 2-6-0 du Bousquet Locomotives of the Chemin de fer de l'Est.—Standard gauge.

These thirteen locomotives were built from plans supplied by the Nord ; they are therefore identical with the latter's.

0-6-2 + 2-6-0 du Bousquet Locomotives, Pekin-Hankow Ry.—Standard gauge (Fig. 86).

These locomotives differ from the former in details only.

0-6-2 + 2-5-0 du Bousquet Locomotives, Andalusian Rys.—5 ft. 6 in. gauge.

These, again, are similar to the former locomotives, save for such differences as are due to the larger gauge.

No other locomotives of this system have been built since.

* These locomotives were numbered 6,001 to 6,038. Thirty-two of them were built by the "Société des Batignolles," and six by the Cockerill Works in Seraing.

They burnt 26 to 28 kg. of coal, and used 180 litres of water per train-kilometre (92·99 lbs. and 63½ gallons per train-mile), which worked out at 52 gm. and 0·36 litre of water per tonne-kilometre.

In 1914, they used to average 515-tonne trains, with a maximum of 900.

Lubrication consumption : 60 grammes per train-kilometre (27 lbs. per train-mile).

BOOK II

SEMI-ARTICULATED LOCOMOTIVES

BOOK II

SEMI-ARTICULATED LOCOMOTIVES

THE term " semi-articulated " is herein used to describe all those locomotives with two sets of driven wheels, one of which is rigidly fixed to the main frames while the other is carried by a second truck capable of angular movement, as in the case of a fully articulated locomotive. The immediate reasons which led to the inception of the semi-articulated design were two in number. Firstly, it was considered that fully articulated locomotives were lacking in lateral stability, especially at high speeds. Secondly, it was found that there was difficulty in maintaining the joints of the flexible pipe system tight against high-pressure steam. These considerations were certainly of considerable weight in earlier days, but they have now lost much of their former importance.

Nevertheless, it is true that if a semi-articulated locomotive is designed—as, for example, the *Mallet*—for compound working, the H.P. cylinders driving the fixed set of wheels, then the flexible pipes leading to the driven bogie have only to be kept tight against the pressure at which the H.P. cylinders exhaust.

A number of types of semi-articulated locomotives have been evolved, the majority of which have given indifferent satisfaction. On the other hand, a single type, the *Mallet*, has had outstanding success, and among the thousands which have been built are some of the most powerful locomotives in the world.

PART I

SEMI-ARTICULATED LOCOMOTIVES WITH A SINGLE ENGINE AND TWO DRIVEN SETS OF WHEELS

In locomotives of this class, one or more of the coupled axles are rigid, while the others have arrangements by which they can take up angular positions in relation to the former.

It is convenient to group them in accordance with the methods by which motion is transmitted from the rigid to the moving units.

Section I. A.—Transmission by Chains.—The *Bavaria* system (the oldest) and the *Winterthur* one.

Section I. B.—Transmission by Gears.—The early *Baldwin*, *Engerth* and *Winterthur* systems ; later, the *Henschel* and *Orenstein and Koppel* systems.

Section I. C.—Transmission by Reciprocating Mechanism.—This is accomplished in five ways :—

(*a*) By rods located on the axis of the locomotive : *Maffei*, *Thouvenot*, *Weidknecht*, *Roy*, *Rarchaert* and *Dredge and Stein's* systems.

(*b*) By oscillating levers : *Rarchaert*, *Gouin and Larpent*, *Maffei*, and also *Hagans'* systems.

(*c*) By means of driven countershafts : *Weidknecht*, *Köchy*, *Gouin and Boutmy*, *Aliger*, *Kirchweger* and *Rarchaert's* systems.

(*d*) By means of coupling bars of varying lengths : *Fretel*, *Vogel*, *Neuhaus* systems ; also *Klose's*.

(*e*) By means of ball and socket joints : *Heywood*, and especially *Klien-Lindner's* systems.

Although some of these systems are still in use, most of them have not developed. We shall not, therefore, devote much space to them, with the exception of those of *Hagans*, of *Klose*, and of *Klien-Lindner*, the latter of which has had considerable practical success, and is not so well known as it deserves to be.

It should be noted that all the above methods of transmission have also been tried or used on locomotives with two motor units.

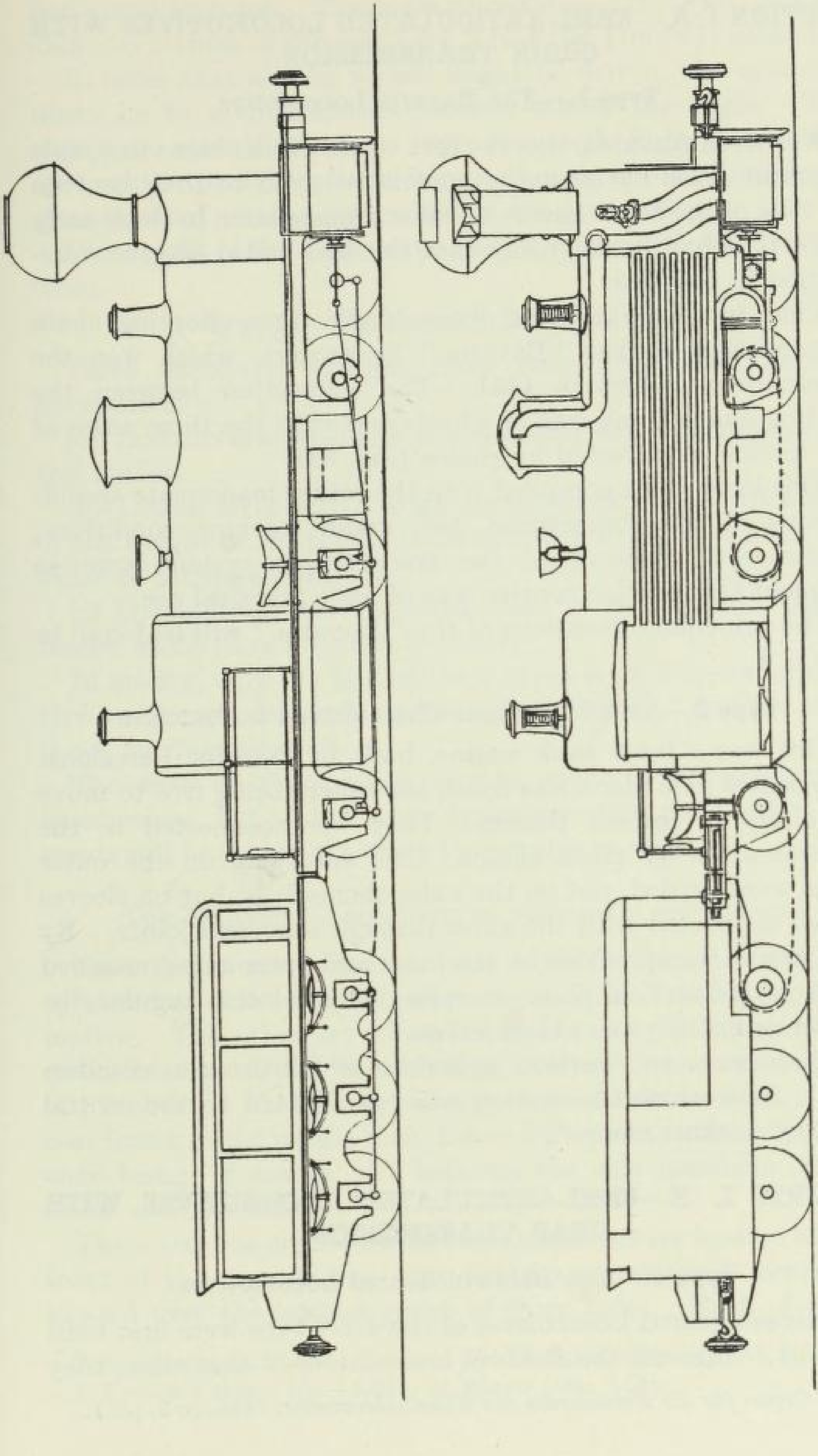


FIG. 87.—The "Bavaria" Chain Connected Locomotive, presented by Maffei at the Semmering Contest.

SECTION I. A.—SEMI-ARTICULATED LOCOMOTIVES WITH CHAIN TRANSMISSION

Type 1.—The Bavaria Locomotive

Norris, in America, was the first to use pitch chains to couple adjacent axles by means of sprockets keyed to their centres. In view of the crude nature of chain transmission in those early days, it is hardly surprising that the idea failed to give satisfaction in practice.

This, however, did not deter *Maffei* from adopting chain transmission in his " Bavaria " locomotive, which won the Semmering Contest in 1851. The connection between the leading and trailing sets of wheels and with the three axles of the tender was effected by chains (Fig. 87).

This locomotive complied with the rather inadequate specifications of the competition, but, under working conditions, repairs and renewals of the transmission system were so frequent that the locomotive was of little practical use.

The principal dimensions of the " Bavaria " will be found in Table 1.

Type 2.—The Winterthur Chain-driven Locomotive

This was a 0-6-0 tank engine, built in 1886 for Barcelona. The centre axle alone was fixed, the others being free to move angularly in respect thereto. They were connected to the central axles by pitch chains. The sprockets on the outer axles were carried, not on the axles themselves, but on sleeves which connected with the axles through universal joints. By this means the sprockets on the inner and outer axles remained in the same vertical plane, in spite of the relative angular displacement of the axles themselves.

There were two vertical cylinders, which drove a countershaft, from which the motion was transmitted to the central axle by another chain.*

SECTION I. B.—SEMI-ARTICULATED LOCOMOTIVES WITH GEAR TRANSMISSION

Type 1.—The Baldwin Geared Locomotives

Baldwin geared locomotives of the 4-2-0 type were first built in 1841. Like all the *Baldwin* locomotives of that time, they

* *Organ für die Fortschritte des Eisenbahnwesens*, 1886, p. 3, pl. 1.

had a leading bogie. The bogie wheels were 2 ft. 7½ ins. (0m.80) diameter ; those of the rear axle, 3 ft. 6 ins. (1m.067) diameter.

In order that all the wheels might be driven, the cylinders drove on to a countershaft located behind the bogie. The rear axle was driven from this countershaft by connecting rods, while the bogies were driven therefrom by a system of gears located on the centre line of the locomotive.*

The weight of the locomotive was 13 tons 6 cwt. (13·5 metric tons).

Type 2.—The Engerth Locomotives †

Three successive designs have been known as *Engerth* locomotives :

(*a*) Locomotives with two motor-trucks, one of which carries the tender.

(*b*) Locomotives with a single motor-truck but in which part of the weight of the tender is transmitted to the locomotive in order to increase adhesion.

(*c*) Locomotives with four coupled axles and a separate tender which have no special feature.

In reality, only the first of these types is an *Engerth* locomotive proper ; the second is a " modified *Engerth*," and the third is not an *Engerth* at all.

The first of these three groups alone is an articulated locomotives, but as the three types are often confused, a few words will be said of the other two groups as well.

The Engerth Locomotives properly so called

These locomotives had two sets of driven wheels. One set consisted of three coupled axles and was fixed under the locomotive. The other set consisted of two coupled axles which constituted a sort of bissel whose exterior frame surrounded the firebox so that the overhang thereof was avoided. The rear frame rested on the main frame by a pivot, sufficient clearance being, of course, left between the side members of the frame and the boiler.

There was one engine whose two cylinders were located at the front of the locomotive ; they drove a countershaft centrally located over the leading group of three axles. Each of these

* See description in the Baldwin illustrated catalogue, 1881, p. 19.

† French Patent, No. 18,619, of March 10th, 1854.

axles carried a spur wheel which meshed with a pinion on the countershaft. The latter was, in part, of square section, and the wheels could be disconnected from the countershaft by the simple expedient of sliding the pinion longitudinally along the squared portion of the shaft.

In order to afford flexibility in negotiating curves, the necessary play was provided in the frame which surrounded

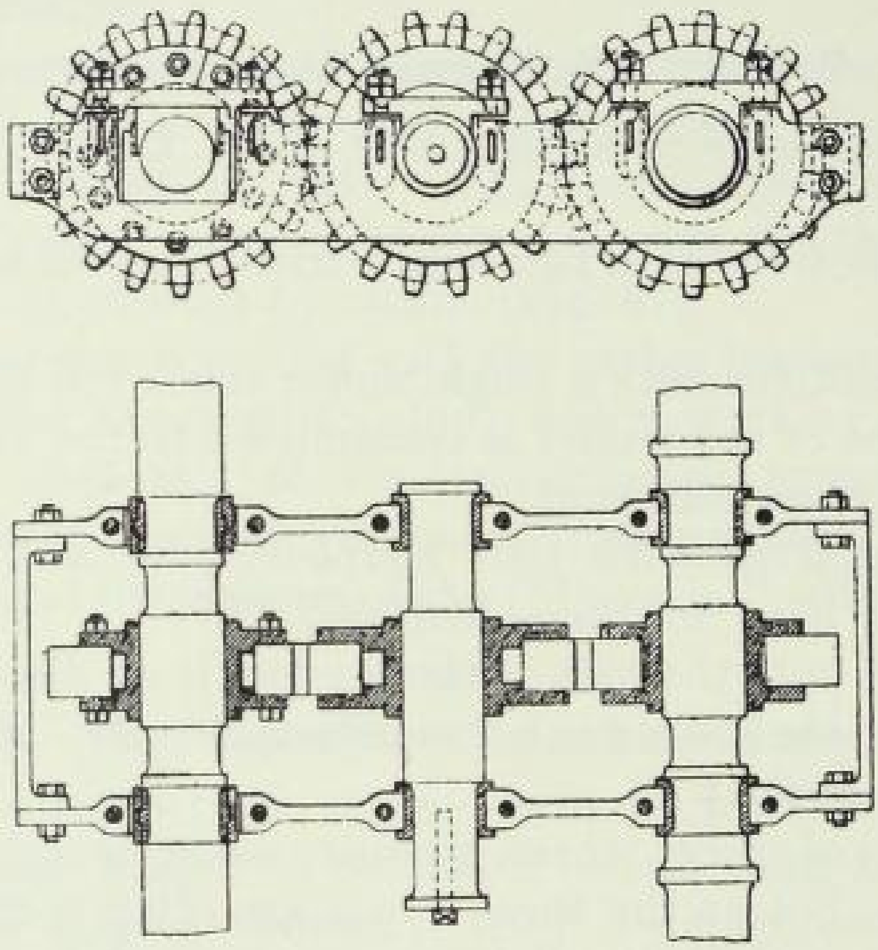


Fig. 88.—Gearing of Engerth Locomotive.

the third driven axle. The teeth of the gear wheels were also tapered off in both directions.

The side members of the truck carried the footplate and behind it the fuel bunkers and water tanks.

But the use of all this gearing, in those early days when accurate machine-cut gears were not to be obtained, gave much trouble in practice ; hence they were eventually suppressed altogether, and these locomotives were converted into ordinary locomotives with four-coupled axles and separate tenders.

The Engerth Locomotives of the Südbahn.—Standard gauge (Figs. 88 and 89).

In view of the ill success of the locomotives which competed at the Semmering Contest, they were replaced by locomotives on the new system designed by M. Engerth, the chief engineer

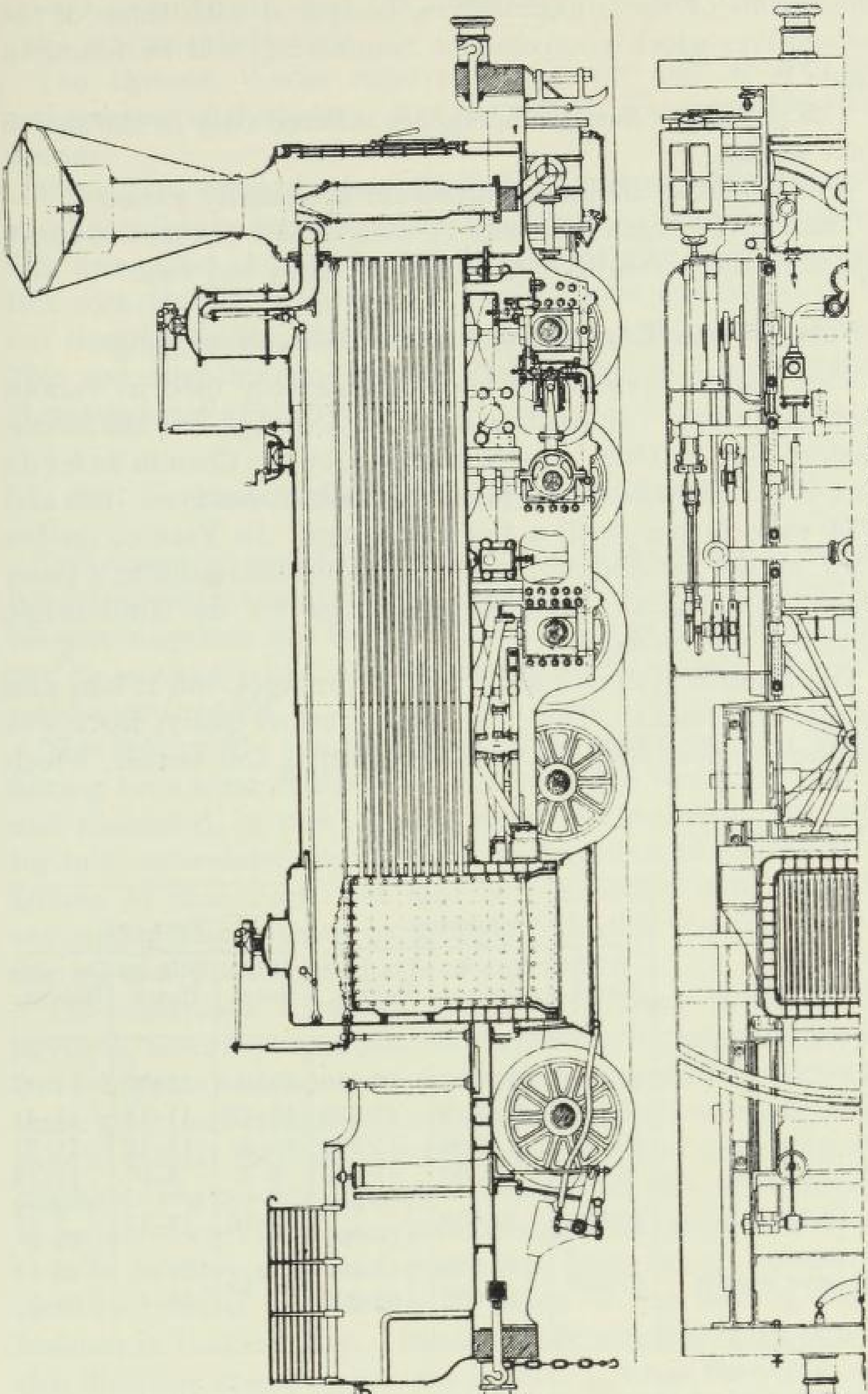


Fig. 89.—0·6 + (4) Engerth Locomotive of the Südbahn. (Standard Gauge.)

of this railway. Between 1851 and 1863 about a hundred of these locomotives were built and put in service. The leading dimensions of these locomotives, compared with those of the locomotives which competed at Semmering, will be found in Table 1.

The passenger and goods engines differed only in the size of their wheels.

The weight available for adhesion necessarily varied.

The heaviest axle load was 17 tons 15 cwt. (18 metric tons), although the locomotive itself did not carry any fuel.*

Various other Engerth Locomotives.—Standard gauge.

The *Engerth* system has been considerably used in various parts of Europe. In Austria, on the Cracow Ry. and the South-Eastern Ry., in 1856. In Switzerland, on the Chemin de fer du Jura-Neufchâtelois, where locomotives built between 1859 and 1874 were in use until a few years ago. In France, on the Nord, on the Est and on the Dauphiné systems; and to a lesser degree in Belgium, on the Chemin de fer du Nord-Belge. Germany was spared.

The *Engerth* system had certain advantages, but it had also serious drawbacks. Thus, the gears worked badly, there was insufficient flexibility between locomotive and tender, which

* Axle loads :—

Axle	Kilogrammes.			Tons-cwt.		
	With Gears.	Without Gears.	Do. plus Ballast.	With Gears.	Without Gears.	Do. plus Ballast.
1st . . .	15·250	13·700	12·000	15–0	13–10	11–17
2nd . . .	10·700	12·050	11·350	10–13	11–18	11–4
3rd . . .	15·650	11·750	11·300	15–8	11–12	11–3
4th . . .	6·250	3·500	11·750	6–3	3–9	11–12
5th and 6th .	19·800	18·000	9·000 10·600	19–10	17–15	8–18 10–9
Adhesive weight .	67·650	37·500 59·000	46·400 66·000	66–10	37–0 58–4	45–15 65–2

The weight of the geared locomotive is computed with 4·500 litres (4 tons 9 cwt.) of water. The adhesive weight, of course, diminished with its consumption. The weight of the ungeared locomotive is constant.

caused derailments, and the distribution of the load on the axles was unsatisfactory.

The Creusot Works removed the gears and altered the arrangement of the axles. But the remedy was worse than the disease.

From 1861 onwards the "Südbahn" followed the example of other railways and uncoupled the tender. A fourth coupled axle was added at the rear and the water tanks were removed. But with this arrangement the leading axle was found to be too heavily loaded with 13 tons 10 cwt. (13·7 metric tons). This was corrected by placing a ballast load of 2 tons 19 cwt. (3 metric tons) at the rear.

Modern Rod and Geared Locomotives

In locomotive practice in general, and in the design of articulated locomotives in particular, it is never safe to conclude that because a system has been tried and failed in the past, it may not be revived with modifications at a later date and give satisfactory results.

This is specially true in regard to the use of gearing, which, having been tried in the earliest days of the steam locomotive and discarded, is now being largely reintroduced, not only for fully articulated locomotives, as described in the previous section of this work, but also in connection with partially articulated locomotives, to provide a flexible medium for the driving of the outermost axles of a group.

The enormous advances which have been made in the strength, accuracy, durability and efficiency of gears during the last few years and the entirely satisfactory results obtained by those used in electric traction, in road vehicles and even, in the case of geared turbines, for the very high powers required in machine engineering, enable modern machine-cut gearing to be introduced into locomotive design with entire confidence.

It is in Germany that gearing is being most extensively used for partial articulation by some of the leading engine builders in that country. But the work which is being done in this direction seems to be little known. It has therefore been thought well to devote some little space to a description of German methods of partial articulation.

Type 3.—The Orenstein and Koppel System of Gear Transmission*

In this system (Fig. 92) the middle axles are coupled together in the usual way, allowing inside or outside framing, and the outer axles are connected to them by a member containing a train of gearing which remains in constant alignment and is contained in a dust-proof case. The first pinion is mounted on the extreme fixed axle by a universal joint around which the member swings.

The second pinion, which is mounted on the outside (and swinging) axle, remains always perpendicular to it, the whole member thus rotating about the universal joint as a centre. In between the pinions is a toothed wheel which runs on ball bearings and which has no angular motion. Its periphery is connected to the swinging axle by spiral springs, thus relieving the universal joint of most of the weight of the locomotive. From the construction point of view the axle coupled by gearing does not add to the weight of the lower elements of the locomotive.

The arrangement is as follows :—

As shown in Fig. 90, A, the axle *a* is arranged in the usual manner and actuated by the side rods. On the middle of this axle there is a spherical seating *b*, which serves as a support and a pivot for the cast steel gear box, *c*, of the neighbouring radial axle *d*, which may be considered as a bissel. Owing to this arrangement the axle *d* and the gear-box *c* can pivot laterally and radially on *b*. The axle *d* is driven from the neighbouring axle by means of three pinions, *e*, *f*, and *g*, which are enclosed in the dust-tight gear case *c*, which itself consists of two elements (Fig. 90, A and B). The pinions are held by their two extremities in the box, as is also the radial axle, the lateral supports outside the box being only used for guidance. Owing to the shape of the extremities *h* (Fig. 90, C and D) of its concave hub, the driving pinion *e* is retained in the axis of its hub, but it is capable of movement in the spherical seating *b*, on the fixed axle. The pinion *e*, together with the gear-box, can therefore pivot on *b*, while retaining its alignment with the

* The first locomotive of this type was supplied by this firm to the German engineers in 1917.

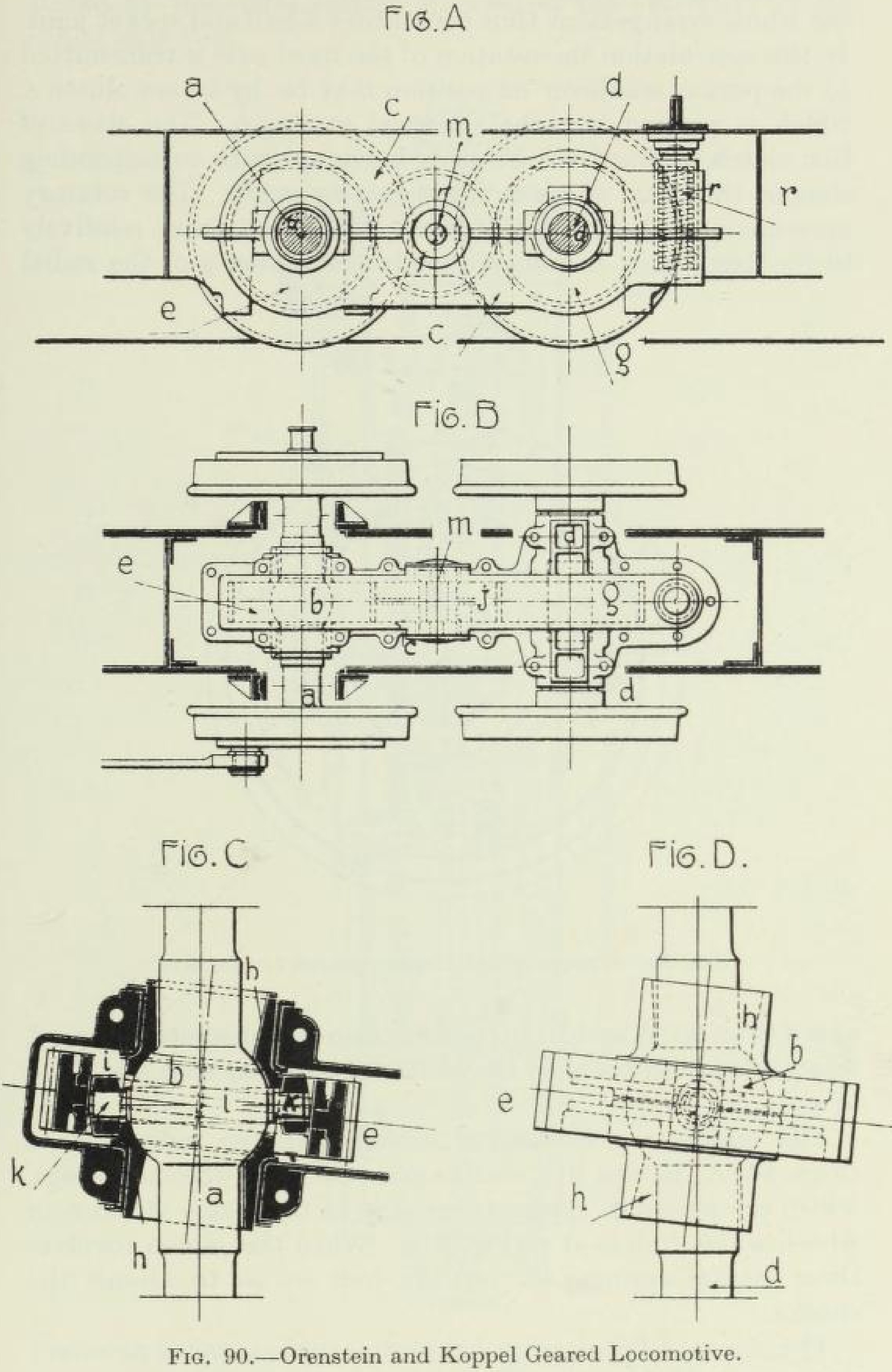


FIG. 90.—Orenstein and Koppel Geared Locomotive.

other pinions in the gear case, as shown in Fig. 90, C and D, and the whole arrangement thus constitutes a ball and socket joint. In this articulation the rotation of the fixed axle is transmitted to the pinion, whatever its position may be, by a claw clutch *i*, which is pressed into the spherical seating *b*. The claws of this clutch, *h*, fixed to the ends *k*, engage with corresponding slots in the gear, which is made in two parts. The rotatory movement of the driving pinion *e*, which can move relatively to the fixed axles, is transmitted to the pinion *g* of the radial

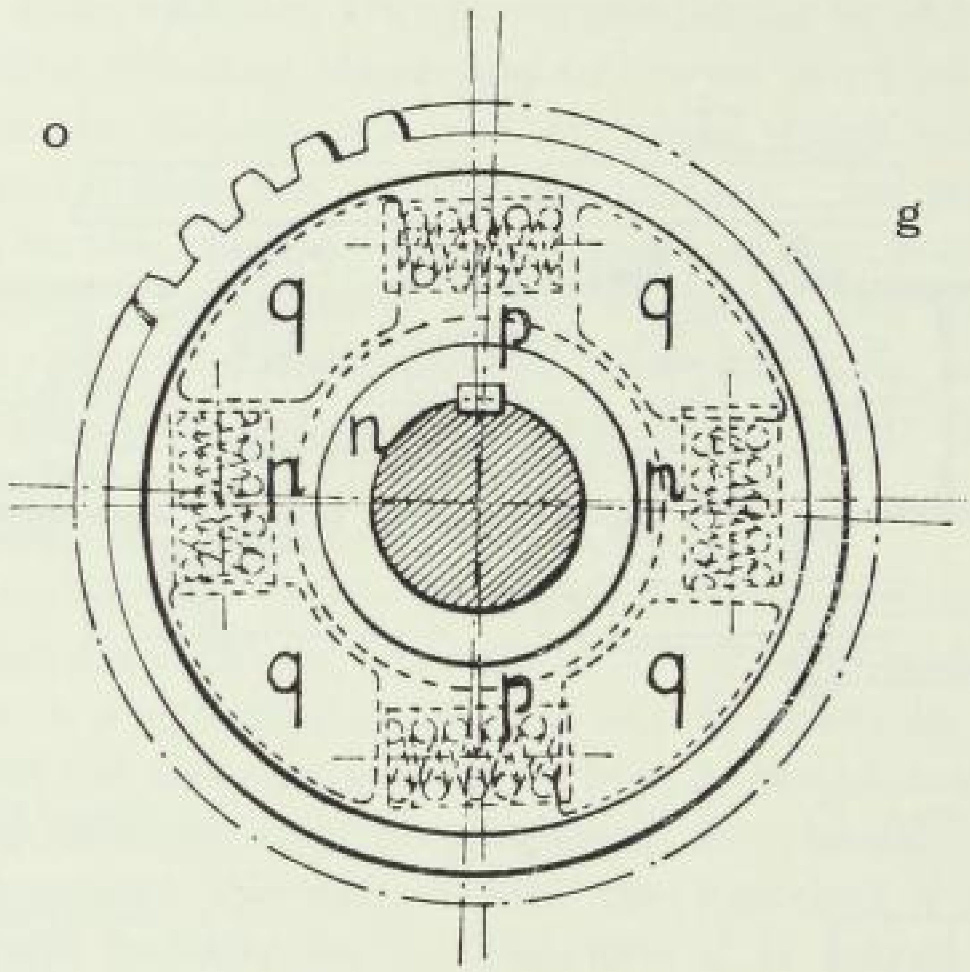


FIG. 91.—Orenstein and Koppel Geared Locomotive.

axle *d* (Fig. 90, A and B) by means of an intermediate pinion, *f*, located between them in the centre of the gear case and fixed at *m*.

The pinion *g* is carried on a sleeve on the radial axle *d* (Figs. 90, A, B, and 91), and is provided with special springs, which are placed in symmetrical slots in the disk *o* of the spur wheel, whose hub is at *n* (Fig. 91). When the pinion revolves these special springs act on the hub so as to absorb the shocks.

The object of this arrangement is to avoid excessive pressures due to rail shocks, etc. The pinion on the radial axle is protected by the spiral springs situated at the extremity of the radial axle box.

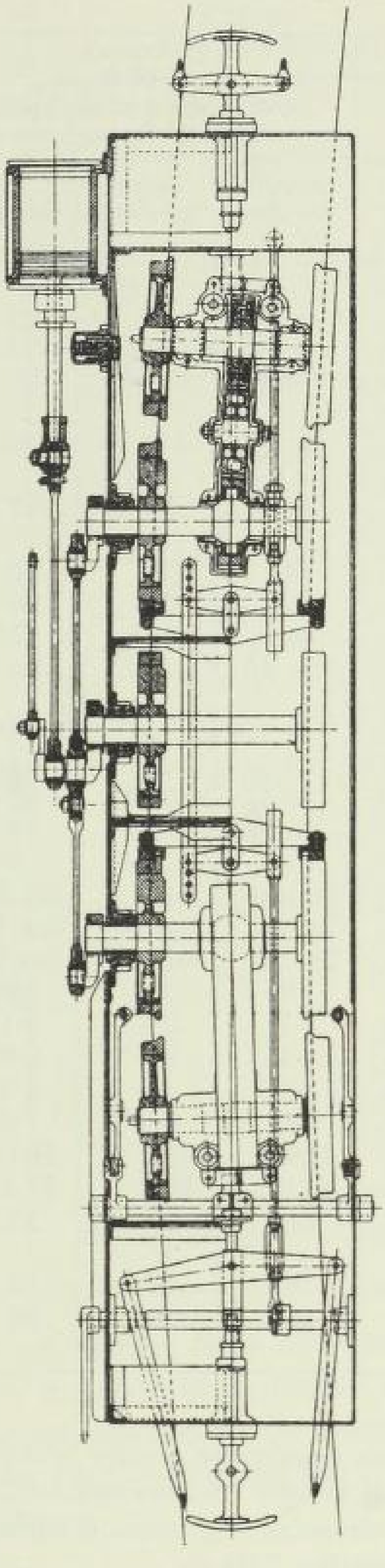


FIG. 92.—Orenstein and Koppel Locomotive with End-Geared Axles.

In Tables 46 and 46A will be found the principal dimensions of certain of these locomotives.

TABLE 46.—PRINCIPAL DIMENSIONS OF SINGLE GEARED-AXLE LOCOMOTIVES

Type	0-10-0			0-10-0	
Builders	Orenstein and Koppel.			Henschel.	
Railway	German Army.	Reichs-bahn.	—	Reichs-bahn.	Java.
Gauge	0m.60.	0m.785.	1m.00.	1m.435.	0m.70.
Cylinders :					
Diameter	0m.27	0m.45	0m.40	0m.60	0m.32
Stroke	0m.30	0m.45	0m.45	0m.55	0m.36
Boiler :					
Diameter	0m.82	1m.10	1m.05	1m.50	—
Pressure kg. per sq. cm.	14	13	12	14	12
Tubes :					
Number	76	68	65	26+110	—
Int. diameter . mm.	40	60	60	39·5–125	—
Ext. diameter ,,	44·5	65	65	44·5–135	—
Length	2m.40	3m.50	2m.80	4m.50	—
Heating surface :					
Firebox . sq. m.	2·9	5·5	4·6	10·0	—
Tubes ,,	25·5	48·6	34·0	107·2	—
Total ,,	28·4	54·1	38·6	117·2	40·2
Superheater ,,	None	19·1	16·0	47·0	None
Grate area ,,	0·7	1·4	1·0	2·4	1·2
Wheels, diameter	0m.60	0m.82	0m.85	1m.10	0m.72
Wheelbase, rigid	1m.60	2m.20	2m.10	3m.40	1m.80
,, total	2m.99	4m.14	4m.18	6m.20	3m.40
Normal h.p.	90	300	250	1,000	—
Tractive force . t.	3·1	8·6	6·1	15·0	3·1
Fuel . t.	0·4	1·5	2·0	3·2	—
Water . cub. m.	1·2	4·5	5·0	8·0	—
Weight, 1 axle . t.	3·0	8·0	7·6	17·0	4
,, empty t.	12·5	32·0	29·0	67·0	18
,, in service t.	15·0	40·0	37·8	85·0	19·6
Min. rad. of curves m.	20	30	35	100	35
Speed :					
Normal km./h.	8	10	10	17	—
Maximum ,,	20	30	30	45	— *

* This locomotive has a separate tender which, with 2·5 cub. m. of water and 3 tons of coal, weighs 7·6 tons against 2·7 empty.

Diameter of tender wheels is 0·55 m. and wheelbase, 1·20 m. ; wheelbase, locomotive and tender, 7·54 m.

Overall dimensions are : height, 3·10 m. ; width, 2·40 m. ; length, locomotive and tender, 10·60 m.

TABLE 46A.—PRINCIPAL DIMENSIONS OF SINGLE GEARED-AXLE LOCOMOTIVES.

Type	0-10-0			0-10-0	
Builders	Orenstein and Koppel.			Henschel.	
Railway	German Army.	Reichs-bahn.	—	Reichs-bahn.	Java.
Gauge	$1' 11\frac{1}{2}''$	$2' 6\frac{5}{8}''$	Metre.	Standard.	$2' 4''$
Cylinders, diameter	$10\frac{5}{8}''$	$17\frac{3}{4}''$	$15\frac{3}{4}''$	$23\frac{5}{8}''$	$12\frac{5}{8}''$
„ stroke	$11\frac{7}{8}''$	$17\frac{3}{4}''$	$17\frac{3}{4}''$	$21\frac{3}{4}''$	$14\frac{1}{4}''$
Boiler :					
Diameter	$2' 8\frac{1}{4}''$	$3' 7\frac{1}{4}''$	$3' 5\frac{3}{8}''$	$4' 11''$	—
Pressure lbs./sq. in.	199	185	171	199	171
Tubes :					
Number	76	68	65	26+110	—
Int. diameter	$1\frac{11}{16}''$	$2\frac{3}{8}''$	$2\frac{3}{8}''$	$1\frac{5}{8}''$–$5''$	—
Ext. diameter	$1\frac{3}{4}''$	$2\frac{9}{16}''$	$2\frac{9}{16}''$	$1\frac{3}{4}''$–$5\frac{3}{8}''$	—
Length	$7' 10''$	$11' 6''$	$8' 2''$	$14' 9''$	—
Heating surface :					
Firebox . sq. ft.	31·2	60·1	49·5	107·5	—
Tubes „	274·0	522·5	580·5	1152·5	—
Total „	305·2	582·6	630·0	126·0	432
Superheater	None.	205·4	172·0	505·4	None.
Grate area „	7·53	15	10·75	24·8	13
Wheels, diameter	$1' 11\frac{5}{8}''$	$2' 8\frac{1}{4}''$	$2' 9\frac{1}{2}''$	$3' 7\frac{3}{8}''$	$2' 4\frac{3}{8}''$
Wheelbase, rigid	$5' 3''$	$7' 3''$	$6' 10''$	$11' 2''$	$6' 3''$
„ total	$9' 9''$	$13' 7''$	$13' 9''$	$20' 4''$	$11' 2''$
Normal H.P.	90	300	250	1,000	—
Tractive force . lbs.	6,850	19,000	13,450	35,500	6,850
Fuel bunkers tons-cwt.	0–8	1–9	1–19	3–3	—
Water tanks . galls.	264	990	1100	1760	—
Weight :					
1 axle . tons-cwt.	2–19	7–18	7–10	16–15	3–18
Empty „	12–6	31–10	28–12	67–2	17–15
In service „	14–16	39–8	37–2	83–15	19–6
Min. rad. of curves	66′	98′	115′	328′	115′
Speed :					
Normal m.p.h.	5	$6\frac{1}{4}$	$6\frac{1}{4}$	$10\frac{1}{2}$	$6\frac{1}{4}$
Maximum „	$12\frac{1}{2}$	$18\frac{1}{2}$	$18\frac{1}{2}$	33	—

To show to what an extent they are already in use, we give hereunder a list of a number of railways where Orenstein and Koppel geared locomotives are to be found :

Deutsch Reichsbahn (26).—For 0m.785 (2 ft. $6\frac{5}{8}$ ins.) for metre and for standard gauges.

Narrow gauge lines :—

Steinhelle-Medebach.—0m.75 (2 ft. $5\frac{1}{2}$ ins.) gauge.

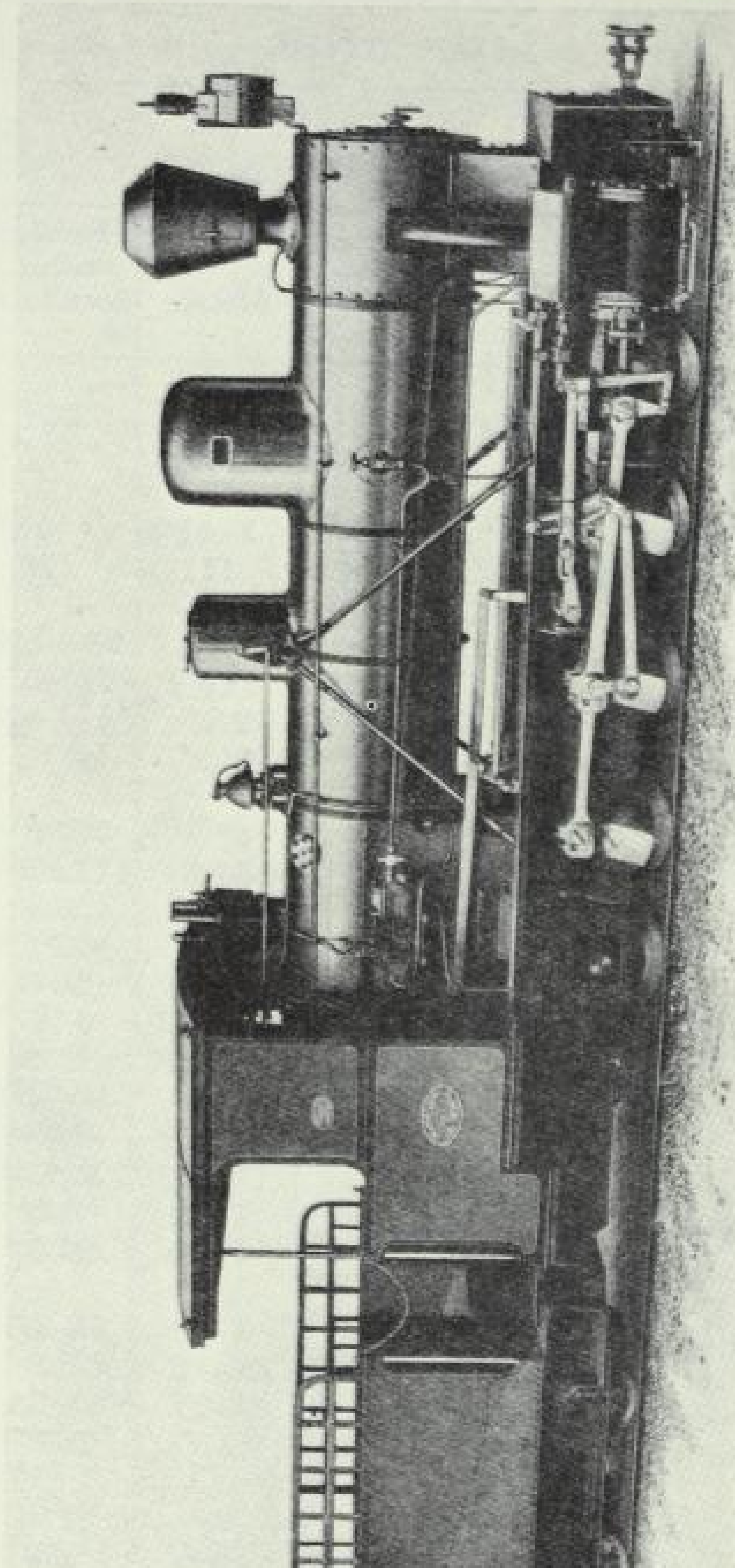


Fig. 93.—Henschel Locomotive with a Gear-Coupled Axle.

Bromberger Kreisbahn.—0m.60 (1 ft. $11\frac{1}{2}$ ins.) gauge.
Chemin de fer de la Côte d'Or (France).—Metre gauge.
Three companies in Brazil.—Metre gauge.

Bor Mines Ry. (Jugoslavia).—2 ft. 6 ins. gauge.

Suzumki & Co. (Japan) (31 locomotives).—0m.60 (1 ft. 11½ ins.) gauge.

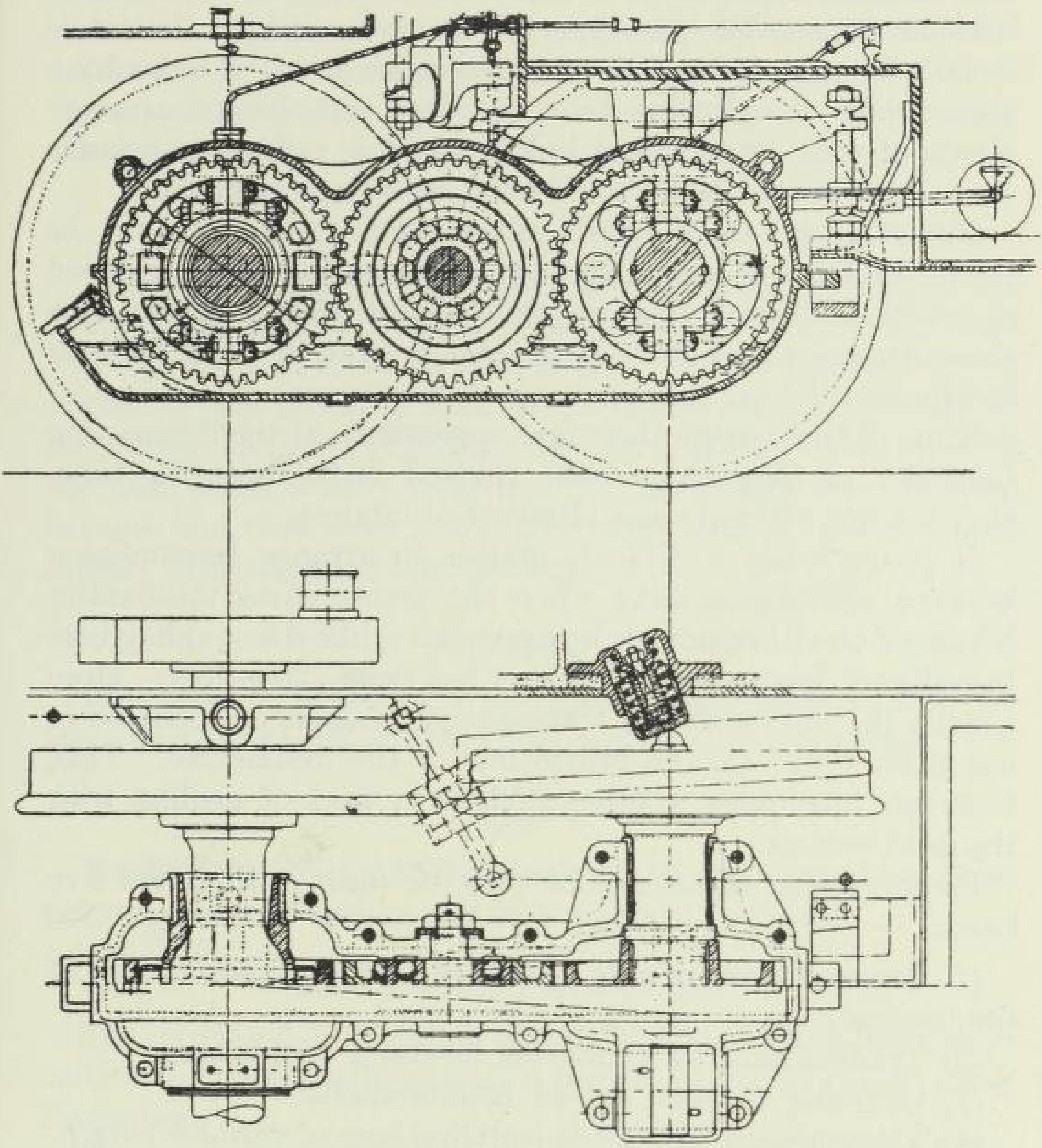


FIG. 94.—Henschel's Gear Coupling of Driving Axles.

German Army (34 locomotives).—0m.60 (1 ft. 11½ ins.) gauge.

Java (15 tender locomotives).—0m.70 (2 ft. 4 ins.) gauge.

Type 4.—The Henschel Type of Single Geared Axle

Messrs. Henschel & Co., of Cassel, have also built a number of geared locomotives (Fig. 93 and 94).

SECTION I. C.—SINGLE-ENGINE SEMI-ARTICULATED LOCOMOTIVES AND TRANSMISSION BY RECIPROCATING MECHANISM

A number of patents have been taken out for various transmission systems of this type. When we consider that it is usually far simpler to drive a convergent group of axles by a second pair of cylinders than to adopt complicated arrangements of rods, cranks, and link work, it is rather remarkable that so much attention should have been given to them.

Nevertheless, some reference to these designs should be made. Little will be said about those which have not succeeded in practical working, but we shall deal at greater length with those designs which have been used in practice with more or less (generally less) success.

Some of them made their first appearance at the Semmering Contest; as they have been revived from time to time, they are not without some elements of interest.

It is obviously a difficult matter to arrange transmission between convergent axles when the transmitting mechanism is located on either side of the locomotive, like the coupling bars in ordinary locomotives, but this has been attempted. More usually the mechanism of transmission is single and located in one place only—on the centre line of the locomotive. This, however, introduces another difficulty: that of dealing with the dead centres.

Reciprocating transmissions may be dealt with under five heads :—

(1) Transmission by rods located on the longitudinal axis of the locomotive.

(2) Transmission by oscillating levers or weigh bars.

(3) Coupling through driven countershafts.

(4) Transmission by outside coupling bars of variable length.

(5) Transmission by quills.

GROUP I.—TRANSMISSION BY RODS LOCATED ON THE AXIS OF THE LOCOMOTIVE

Many of these systems overcome the difficulty in regard to dead centres by the use of the bell crank.

If a bell crank placed on the centre line of the locomotive is connected to the centres of two adjacent axles A and B of two sets of wheels by a horizontal link, and if the centres of each of these axles is connected to a countershaft placed above and equidistant from them, the whole arrangement constitutes an isosceles triangle.

Each of the axles A and B is driven by two rods, so that when one of them is on a dead centre the other can act. The countershaft C normally drives one rod directly, but if it cannot do so owing to a dead centre, it drives it indirectly through the other axle and the two other rods.

Type 1*

Maffei employed the bell crank in a design presented at the Semmering Contest. The countershaft was driven in the usual way by two cranks set at 90 degrees. The motion was transmitted to the axles by a central rod and cranks. The third rod, which connected directly the two adjacent axles, enabled the dead centres to be overcome. This system was defective because the rods were not in the same vertical plane, which rapidly dislocated the mechanism.

Type 2

Thouvenot † curved the rods so as to bring them all into the same vertical plane, but this introduced serious weakness.

Type 3

Weidknecht (1878–1880) suppressed the portion of the axles between the two cranks and only retained half axles.

Type 4.—Roy's Locomotive

Roy proposed a solution of the problem which, although defective, was actually tested on the Ch. de fer du P.L.M., near Marseilles.

The locomotive in question had four axles. The centre pair were rigidly connected by the usual side rods. Each of the outer axles was cranked at its centre and connected to its neighbour by a plain coupling bar located on the centre line of the locomotive.

* *Vide* Couche and the portfolio of locomotives of the Semmering Contest.

† *Vide* Thouvenot's book, " Un Moyen de franchir les Alpes."

A rather extraordinary situation was thus produced. Although the centre pair of rigid axles had no dead centres, each of the two outer axles had two dead centres when the coupling bar was horizontal, and in this position the locomotive could not (theoretically) move at all. But in practice there was a certain amount of play in the joints of the mechanism, so the outer axle generally rotated, but it was quite uncertain whether it would revolve in the same or the opposite way as the rigidly coupled axles. In the latter case the locomotive could not move either forward or backward, and even if another locomotive was coupled to it, it could not be moved unless, by repeated shocks, the connecting rod was jarred off the deal centre in the right direction, which was a pure matter of chance.

The feelings of the crew who had to drive such a locomotive need no description. As to those who designed and constructed such a machine, the least said the better.

Type 5

Rarchaert, in one of his systems (Fig. 101), also used the centrally located bell crank.

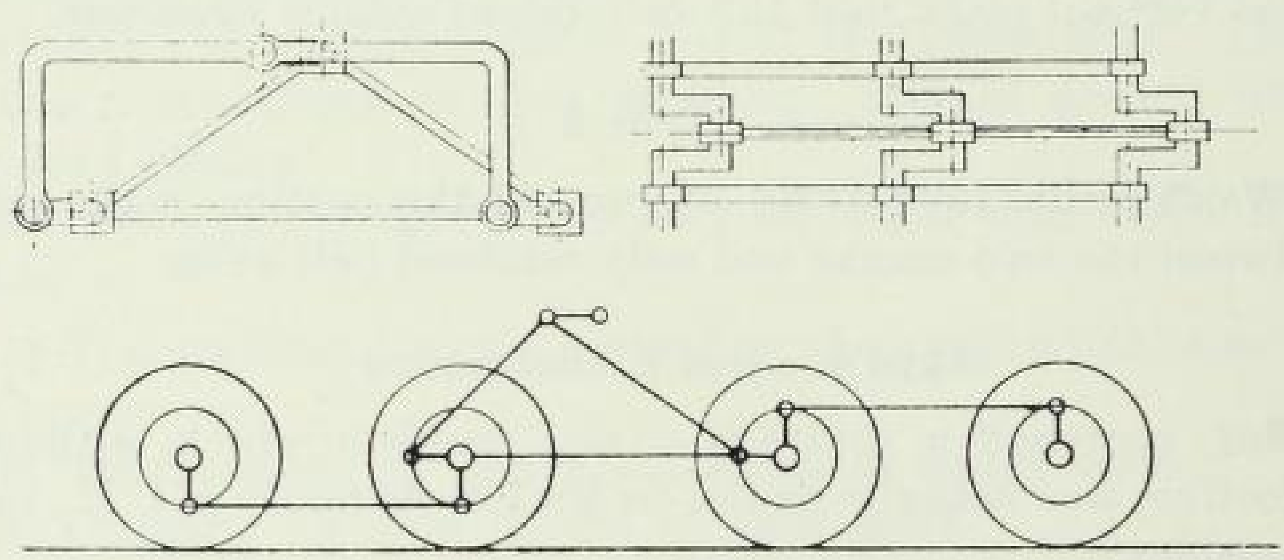


FIG. 95.—The Dredge and Stein Patent.

Type 6.—The Dredge and Andrew Stein System (Fig. 95)

In this system the motion is not transmitted directly to the countershaft, but to the rear axle of the first group, and is transmitted thence through the countershaft to the leading axle of the second group. This countershaft is simply an intermediary. But the central bell crank is retained.

The two adjacent axles were therefore united by a central coupling rod with spherical bearings.

The countershaft was carried in a double frame which rested on the axles on either side of the crank webs and as near to them as possible. By giving a little play to the bottom brasses of the double frame the convergent movement of the axles was not obstructed.

The countershaft was also connected by coupling bars to the heads of the central coupling bar, thus completing the usual bell-crank.

GROUP II.—METHODS OF COUPLING CONVERGENT AXLES BY MEANS OF OSCILLATING LEVERS

This method, unlike that previously described, has been in practical use. *Rarchaert's* system has been tried, and *Hagans'* was, at one period, extensively used.

Type 1

Lucien Rarchaert,* a fertile inventor, successively proposed a number of systems, all of which are of interest from the theoretical point of view.

Fig. 101 represents his three principal systems. It should be noted that these drawings give only the principles of the transmission, the practical realisation of these principles being a much more complicated matter. Thus, on the second of these designs, it was necessary to duplicate the mechanism and use two oscillating levers, each working on a crank pin ; these two crank pins were at right angles and a return crank was interposed. A detailed description is given in Mallet's report already referred to. We need not refer further to this very complicated system, as it has not been used in practice.

Type 2

Gouin and **Larpent** † both endeavoured to simplify *Rarchaert's* systems. In *Larpent's* system the oscillating lever is maintained at an equal distance from the axles by coupling rods acting on a control lever. The axis of the levers is maintained at the desired height by means of suspension rods.‡

* *Vide* Couche, "Annales des Mines," 1863.

† *Vide Bulletin de la Société des Ingénieurs civils de France,* 1860.

‡ *Vide* Mallet, *loc. cit.*

Type 3

One of **Maffei's** designs, submitted at the Semmering Contest, had an oscillating lever driving the convergent axles through vertical coupling bars, one on each side.*

Type 4.—The Hagans Locomotive

The *Hagans* locomotive † has two sets of wheels. The leading one consists of three coupled axles and is connected to the main frame of the locomotive. The trailing set consists of a truck with two coupled axles.

The cylinders which drive the leading set are at the front of the locomotive and drive the axles of this group of wheels in the usual manner. The drive is also transmitted to the axles of

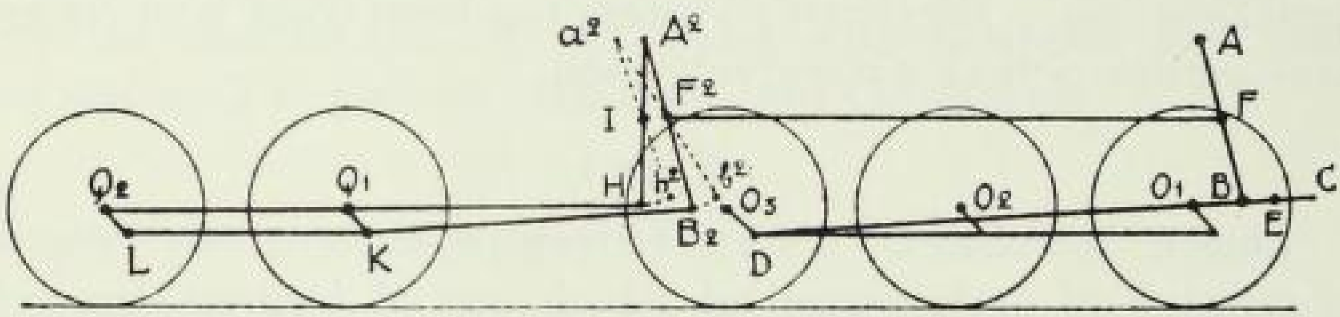


Fig. 96.—The Hagans System.

the trailing bogie by a system of rods and oscillating levers, which allow of the lateral displacement of the trailing bogie.

The principle of the system is ingenious (Fig. 96). The piston C drives the axles of the fixed leading group in the usual way by a connecting rod CD.

It also drives the axles of the movable rear set of wheels, but, as it is necessary for this group to be capable of convergent movement so that the distance between the fixed and moving axles varies on curves, this drive is transmitted by an interesting system based on the articulation of a vertical lever AB, which oscillates about its upper fixed extremity A, and is connected to the piston rod by a small link BE.

At the rear there is another lever, $A^2 B_2$. The two levers are connected at their centres by the rod $F F^2$. While the top end of the first lever is fixed, that of the second is not, but it is connected to a third lever, A^2 I H, which oscillates about its fixed centre I.

* *Vide* the "Atlas du Semmering," *loc. cit.*

† D.R.P. 58, 848; *Zeitschrift*, November 7th, 1891, 1276.

The lower end of the second lever drives the rear axles. The third lever is connected to the first convergent truck by a long bar.

The action on curves is as follows :—

When the axle Q_1 approaches the axle O_3, A^2 takes up the position a^2, and the displacement, H h^2, is approximately equal to the displacement B_2 b^2. The length of the rod, B_2L, remains constant, and the drive is readily transmitted on curves.

This system was first applied in 1894. It was much in evidence for some time in Germany, where the German Railway Union awarded a prize to its inventor. Its use extended so rapidly that, in 1905, there were 152 *Hagans* locomotives in service on the Prussian and Hessian State Rys. A few were also sent out to Tasmania. But their use declined with equal rapidity and soon after 1907 they had disappeared, it being found that the same results could be obtained with the much simpler *Gölsdorf* axles.

Hagans Locomotives on Various Railways.—In 1895 the Weidknecht Works (Paris) built a *Hagans* locomotive for the Volo Lechonia Ry. (Greece), 2 ft. gauge. Another was built for the Chemins de fer de la Drôme (metre gauge), but there were no repeat orders.

2-6 + 4-0 Hagans Locomotive for the Tasmanian Government Rys.—2 ft. gauge.

Both the Tasmanian and the South African railways have to deal with heavy traffic over difficult lines, and both have followed a forward policy in trying a number of new types of locomotives able to handle their traffic satisfactorily.

The North-East Dundas line abounds in sharp curves and heavy gradients. A locomotive able to negotiate curves of 1½ chains radius and gradients of 1 in 25 with loads up to 100 tons was required.

The ten coupled wheels were grouped into two portions worked by a single engine on the *Hagans* principle.

The wheels of the second pair of coupled axles are flangeless.

Hagans Locomotives, Prussian State Rys.—After a first trial in 1893, a locomotive of this type was exhibited at the Paris International Exhibition in 1900.

Further locomotives were built in 1902 to deal with the

TABLE 47.—PRINCIPAL DIMENSIONS OF HAGANS LOCOMOTIVES

Type	0-4+4-0	2-6+4-0	0-4+6-0			
Railway	Light Ry. (Germany).	Tasmanian Govt. Rys.	Prussian State Rys.			
Gauge	0m.90.	0m.61.	Standard.			
Builder	Hagans.	Erfurt Works.	Schichau.	Schichau.	Vulcan.	Henschel.
Date	1893.	1902.	1894.	1898.	1900.	1902.
Cylinders :						
Diameter . m.	—	—	0·48	—	—	—
,, . m.	0·33	0·39	0·68	0·45	0·50	0·52
Stroke . m.	0·36	0·39	0·63	0·63	0·55	0·60
Boiler :						
Centre line m.	—	—	—		—	2·35
Diameter . m.	—	—	1·40		—	1·60
Pressure kg./sq. m.	12	13	12		12	12
Tubes :						
Number . .	82	—	186		—	—
Diameter . m.	41	—	50		—	—
Length . m.	3·60	—	4·45		—	—
Heating surface :						
Firebox . sq. m.	—	—	—		—	8·4
Tubes . ,,	—	—	—		—	129·1
Total . ,,	51·0	—	116		120·3	137·5
Grate area . ,,	0·85	—	1·5		2·6	2·4
Wheels :						
Diameter . m.	None.	0·61	None.		None.	None.
,, . m.	0·75	0·84	1·65		1·10	1·20
Wheelbase :						
Rigid . m.	—	1·10–1·65	—		2·40	2·68
Total . m.	—	6·35	—		5·70	6·86
Overall—						
Height . m.	3·25	3·12	—		4·25	4·25
Width . m.	—	2·31	—		3·08	—
Length . m.	8·35	8·84	—		10·90	11·91
Tractive force t.	3·750	3·600	6·600		11·300	17·100
Water tanks cub. m.	3·4	0·5	—		8·0	6·0
Coal bunkers t.	0·4	—	—		2·0	1·5
Weight :						
Empty . t.	23	33	34·5		50·9	56·0
In service . t.	28	43	40·3		66·0	71·5
Adhesive, max. t.	28 †	38	40·3 *		66·0	71·5

* Maximum speed, 50 km. an hour (31 miles).

† Maximum gradients, 2·5 per cent., and minimum radius of curves, 40 m. Weight hauled, 144 tons.

TABLE 47A.—PRINCIPAL DIMENSIONS OF HAGANS LOCOMOTIVES

Gauge	0m.70.	2′	Standard.			
Railway	Light Ry. (Germany).	Tasmanian Govt. Rys.	Prussian State Rys.			
Builder	Hagans.	Erfurt Works.	Schichau.	Schichau.	Vulcan.	Henschel.
Date	1893.	1902.	1894.	1898.	1900.	1902.
Gauge	**0-4 + 4-0**	**2-6 + 4-0**	**0-6 + 4-0**	**0-6 + 4-0**	**0-6 + 4-0**	**0-6 + 4 0**
Cylinders, diameter	—	—	18 15/16″	—	—	—
,, diameter	13″	15 1/2″	26 3/4″	17 3/4″	19 11/16″	20 1/2″
,, stroke	14 3/16″	15 7/8″	24 13/16″	24 13/16″	21 11/16″	23 5/8″
Tubes, number	82	—	186		—	—
,, diameter	1 5/8″	—	2″		—	—
,, length	11′ 9 3/4″	—	14′ 7 1/4″		—	—
Boiler, diameter	—	—	—		—	5′3″ (int.) *
,, pressure . . . lbs. per sq. in.	171	185	171		171	171
Heating surface, firebox . . . sq. ft.	—	—	—		—	90
,, ,, tubes . . . ,,	—	—	—		—	1,388
,, ,, total . . . ,,	549·0	—	1,248·7		1,294	1,478
Grate area . . . ,,	9·1	—	16·1		28	25·8
Wheels, diameter	None.	2′ 0″	None.		None.	None.
,, diameter	2′ 2 1/2″	2′ 9″	5′ 4 11/16″		5′ 7 3/8″	3′ 11 1/4″
Wheelbase, rigid	—	3′ 7 3/16″–5′ 5″	—		7′ 10 1/2″	8′ 9 1/2″
,, total	—	20′ 10″	—		18′ 8″	22′ 6″
Overall height	10′ 7 15/16″	10′ 3″	—		14′ 0″	14′ 0″
,, width	—	7′ 7″	—		10′ 1″	—
,, length	27′ 4 3/4″	29′ 0″	—		25′ 9″	39′ 1
Tractive force . . . lbs.	8,278	7,900	14,500		24,920	27,700
Water tanks . . . gall.	748	110	—		1,760	1,320
Coal bunkers . . . lbs. or t.–cwt.	882	—	—		2–0	1–5
Weight, empty . . . ,,	50,700 lbs.	32–19	34–0		—	55–5
,, in service . . . ,,	61,700 lbs.	42–17	39–18		65–2	70–12
,, adhesive . . . ,,	61,700 lbs.	37–6	39–18		65–2	70–12

* Centre line 7′ 8″.

heavy goods traffic of the Stettin-Jasenitz section and a number of others followed down to 1907, when their construction seems to have ceased, other types having become available.

GROUP III.—SINGLE-ENGINE SEMI-ARTICULATED LOCOMOTIVES WITH CONVERGENT AXLES COUPLED THROUGH DRIVEN COUNTERSHAFTS

Once again we find the first applications of this method at the Semmering Contest.

Type 1

One of Maffei's designs had a bell crank and a countershaft.

Type 2

Weidknecht's designs had two countershafts coupled to a third placed above them by double links located as close as

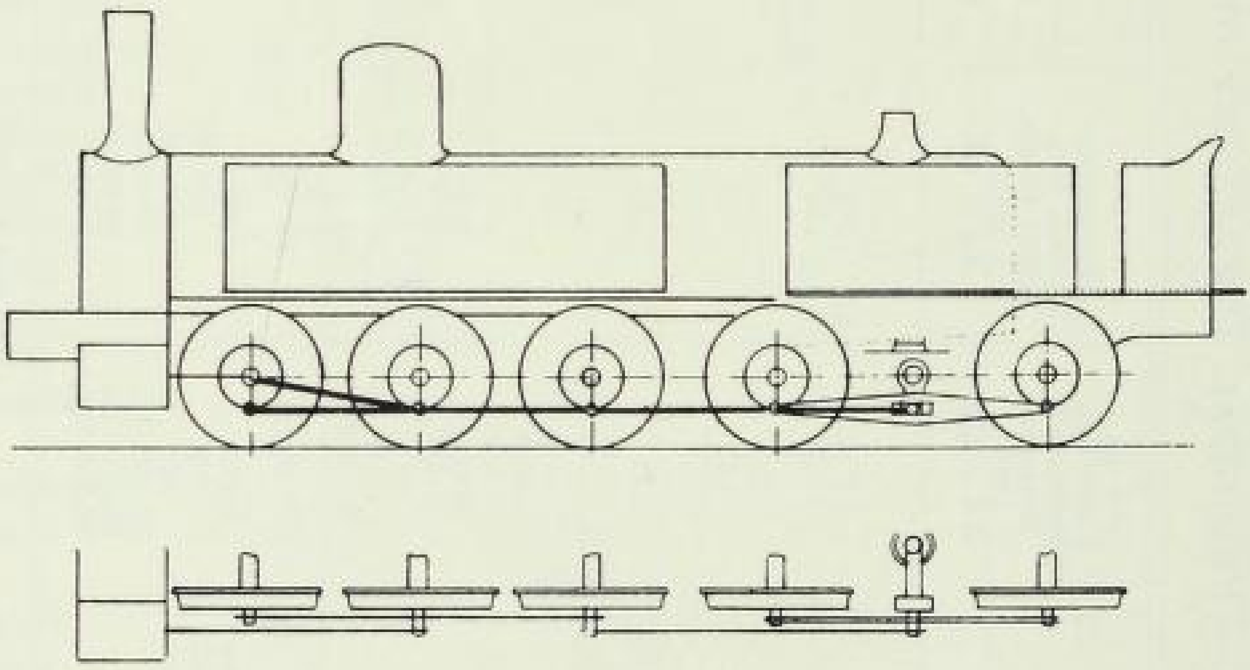


Fig. 97.—Gouin System.

possible to the longitudinal axis of the locomotive. The cylinders drove direct on to the upper countershaft.

Type 3.—Köchy's System *

The countershaft was combined with external coupling rods. Grooves were cut in these bars in which the coupling pins of the convergent wheels worked. On *à priori* grounds, all systems with slotted coupling bars would seem to be defective.

* D.R.P. 69,642, *vide Zeitschrift des Vereins*, August 26th, 1893.

Type 4

Gouin's system is similar to the above (Fig. 97). The coupling bar of the rear truck is slotted and engages with the crank pin of a countershaft, which is itself coupled to the leading (fixed) set of wheels.*

Type 5

In collaboration with **Boutmy, Gouin** adapted his system to a locomotive with six coupled axles, of which the centre pair only were fixed (Fig. 98).

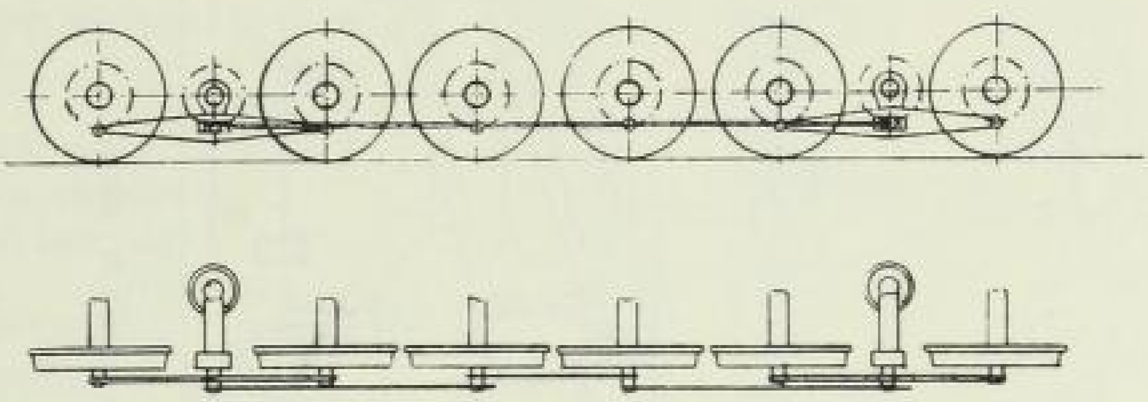


FIG. 98.—Gouin-Boutmy System.

Type 6.

Aliger employed a countershaft † in conjunction with a central coupling bar and two side rods, in order to eliminate dead centres.

Type 7.—Kirchweger's System ‡ (Fig. 99)

In this system there is a countershaft, which is maintained at an equal and constant distance from the adjacent axles by means of tie rods, but which can oscillate in a vertical plane. This is the converse of the *Fink* system, in which the countershaft oscillates horizontally.

Kirchweger's countershaft rises on one side of the interior arc and descends on the opposite side. Unfortunately, these inclinations had to be regulated by an angular mechanism,

* A model was exhibited at the Conservatoire des Arts et Métiers in Paris in 1865.

† See *La Revue Industrielle*, June 30th, 1875.

‡ See Couche, "Matériel de chemin de fer."

which proved defective in practical working, and led to the condemnation of the system.

In a subsequent design *Kirchweger* replaced the tie rods by

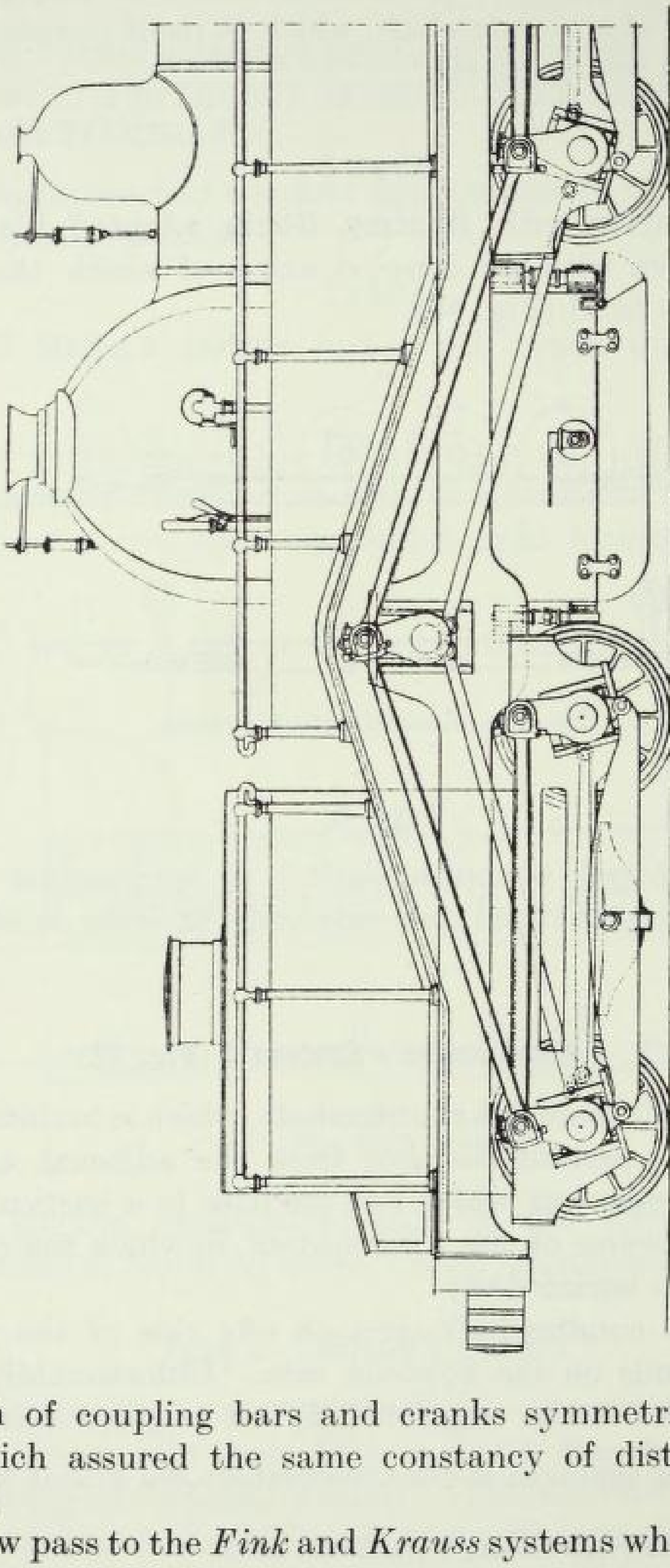


Fig. 99.—Kirchweger's System.

a system of coupling bars and cranks symmetrical with the first, which assured the same constancy of distances as the tie rods.

We now pass to the *Fink* and *Krauss* systems which have been effectively used in practice.

TABLE 48.—PRINCIPAL DIMENSIONS OF FINK LOCOMOTIVE

Gauge		Standard.	
Railway		Austrian State Rys.	
Builder		Austrian Ry. Co.'s Works.	
Date		1862.	
Type		**0-6 + 4-0**	
Name		Steierdorf.	
Cylinders, diameter	m.	0·46	$18\frac{1}{8}''$
,, cylinder	m.	0·63	$24\frac{15}{16}''$
Tubes, number		158	158
,, diameter	mm.	50	$1\frac{15}{16}''$
,, length	m.	4·35	$14'\ 3\frac{1}{4}''$
Boiler pressure	kg. per sq. cm.	7	99 lbs. per sq. in.
Heating surface, firebox	sq. m.	7·3	78·6
,, ,, tubes	,,	115·7	1,245
,, ,, total	,,	123·0	1,324·6
Grate area	,,	1·4	15·0
Wheels, diameter	m.	1·00	$3'\ 3\frac{3}{8}''$
Wheelbase, rigid	m.	2·21	$4'\ 0''$
,, driving	m.	5·87	$19'\ 3\frac{1}{8}''$
Water tanks	t.	5·0	1,100 galls.
Coal bunkers	t.	1·9	4,190 lbs.
Weight, max., 1 axle	t.	9·9	21,800 ,,
,, in service	t.	47·9	105,800 ,,

Type 8.—Fink's System (Fig. 100)

The *Fink* locomotive has two sets of wheels with outside frames, which are mutually articulated. The back of the firebox rests on a pseudo-tender by a cross member, which is supported by a roller.

The drive is transmitted from one set to the other through a countershaft connected by coupling rods with each of the groups. This countershaft always remains parallel to the axles of the leading group, but its position varies in reference to the axles of the trailing group, to which it is connected by struts which rest on the first axle of the rear group. These struts can oscillate around their lower ends.

When running on a straight line, these struts stand vertically. When running through curves, the struts incline in the opposite direction and the distance between the countershaft and the nearest axle of the rear group is increased if the inclination of the strut is forward, and decreased if it is backward. The pressure between the rails and the wheel flanges of the first axle

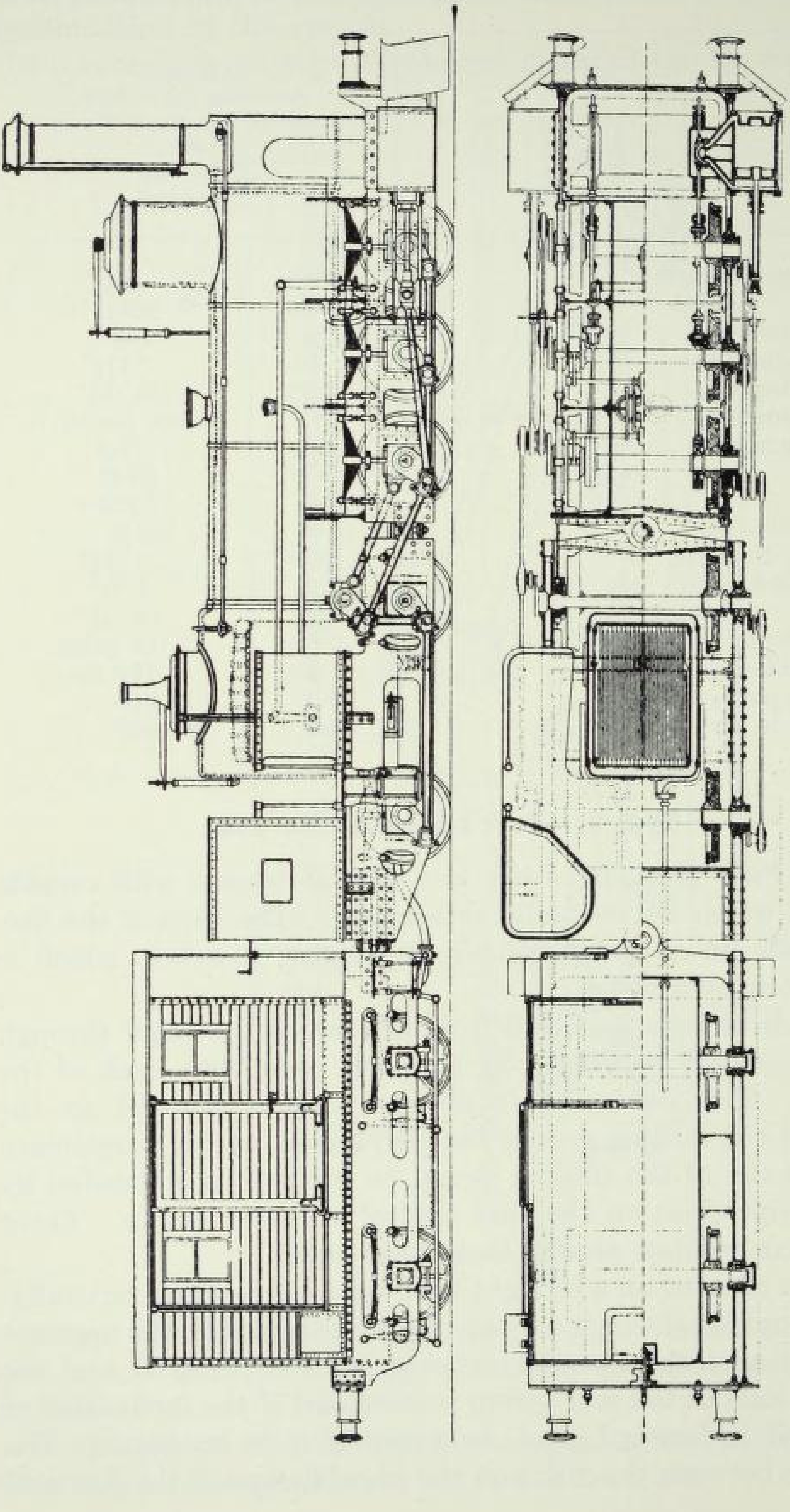


Fig. 100.—The Fink System. The "Steierdorf," of the Austrian State Rys. (Standard Gauge.)

of the rear group is sufficient to start these movements and to cause this axle to set itself at right angles to the curve.

The movement is transmitted from this axle to the neighbouring axle of the first group of wheels because, in spite of all these movements, the coupling pins of the two groups remain parallel.

The countershaft which is parallel to the first group of wheels descends in proportion to the sharpness of the curve and moves convergently in reference to the axles of the second group of wheels.

This design is ingenious, but it is not geometrically accurate, because the different pieces of the mechanism are not all in the same plane. *Fink* himself estimated that the error was about 1 mm. in certain elements. These cross stresses necessitated the components being made of large cross section.

0-6 + 4-0-T Locomotives of the Austrian State Rys.—Standard gauge.

The first locomotive of this type, named the "Steierdorf," was exhibited in London in 1862 and in Paris in 1867.

The two cylinders were in front and the two groups of wheels had outside frames and were mutually articulated. As it was found that the rear axle was overloaded, the water was transferred to a special tender of 5½ cub. m. (194 cub. ft.) capacity.*

Two other locomotives of this type were subsequently built, named the "Krassova" and the "Gerliste." They only differed from the first one in that the struts were carried outside the side members of the frame in order that the frame breadth might be the same for locomotives and tender. The other components of the mechanism were in the same vertical plane.

In spite of this, these locomotives did not give satisfaction.

* The distribution of the load on the axles was as follows :—

1st axle	9·200 kg.	...	9 tons 1 cwt.
2nd "	9·100 "	...	9 " 0 "
3rd "	8·750 "	...	8 " 12 "
4th "	6·250 "	...	6 " 4 "
5th "	9·100 "	...	9 " 0 "
Tender	15·200 "	...	15 " 0 "
Total	57·000 kg. (42·400 kg. adhesive).		56 tons 5 cwt. (41 tons 17 cwt. adhesive).

Type 9.—Rarchaert's System

In 1855 and subsequent years, *Rarchaert* patented several designs for transmission of motion between two convergent sets of wheels (*vide* Fig. 101).

Two of these systems were based on the use of oscillating levers; the third on the use of a central bell-crank. It was

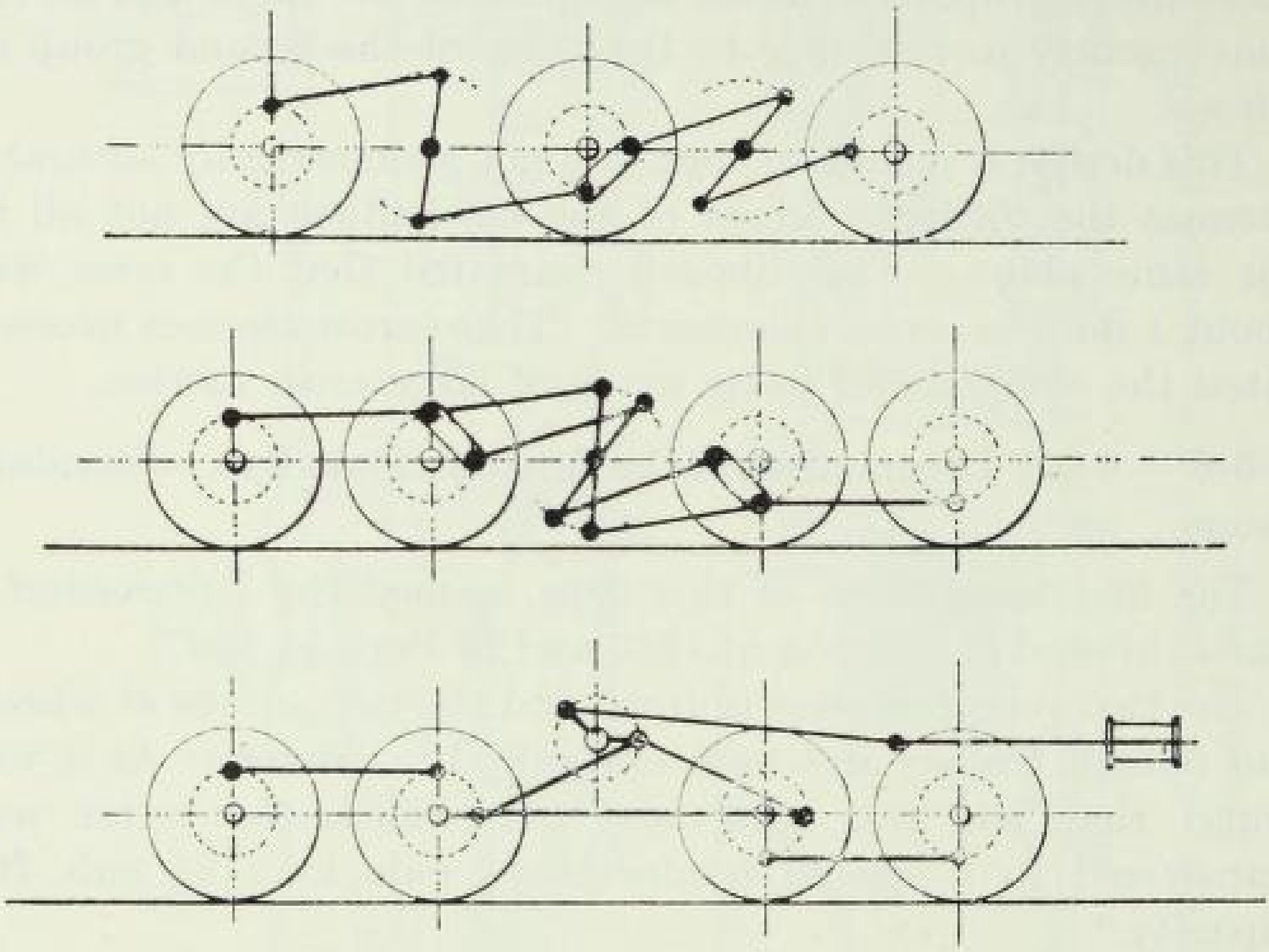


FIG. 101.—Rarchaert Systems, I., II. and III.

used on a locomotive supplied to the Chemin de fer de Vitré and on the Chemin de fer d'Orléans à Châlons.*

This locomotive had two four-wheeled bogies. The cylinders drove a countershaft situated between them, and the motion was transmitted thence to the adjacent axles by bell cranks.

GROUP IV.—SINGLE-ENGINE SEMI-ARTICULATED LOCOMOTIVES WITH CONVERGENT AXLES COUPLED BY MEANS OF COUPLING BARS OF VARIABLE LENGTH

There are two distinct ways in which this can be accomplished :—

(*a*) By the use of slotted coupling bars.

* *Annales des Mines*, Vol. IV., 1874, and Vol. X., 1876.

(*b*) By providing a suitable kinematic system which allows one side of adjacent axles to approach while the other moves further apart.

The first method is of little interest because it has never had a practical result.

Types 1 to 4

In 1843, *Norris* took out a patent for a coupling rod made in two parts which could slide upon one another, following a path which formed the arc of a circle having the convergent axle for its centre. Subsequently, several other designs have been proposed on these lines, such as that of *Fretel*.*

The second method has, however, received practical application, although it is very complicated.

We need only refer in passing to *R. Vogel* † and *E. Neuhaus's* systems, but we shall give a short description of the *Klose* system.

Type 5.—The Klose ‡ System

The object of the system is to permit the convergence of some of the coupled axles of a two-cylinder locomotive (Fig. 102).

The crank pin of the central driven axle carries a jointed

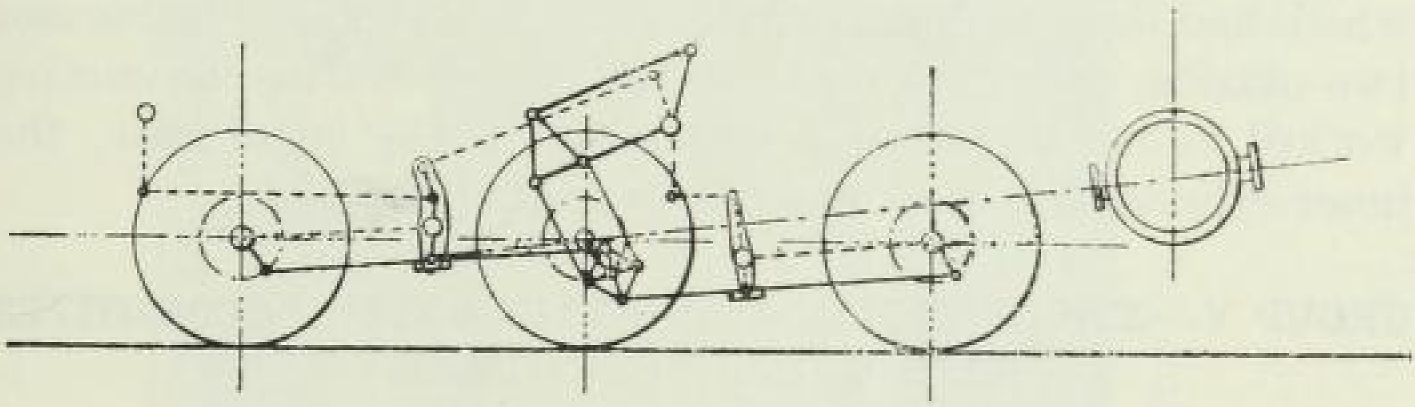


FIG. 102.—The Klose System.

lozenge, and the two points of the lozenges carry the rods coupling the other axles.

This lozenge piece can take up an inclined position, which allows the adjacent axles on either side to approach or recede from the central axle without interference with the transmission of the drive.

* *Engineer*, September 26th, 1884, p. 246.

† D.R.P. 73,183 ; *Zeitschrift des Vereines*, May 26th, 1894, p. 654.

‡ Klose was successively engineer of the Chemin de fer de l'Union Suisse and manager of the Wurtemburg Rys.

The convergent movement of the outer axles is regulated by an articulated system.

A number of *Klose* locomotives have been built. The first of them were used on the 2 ft. 6 ins. (0m.76) lines of Bosnia and others on railways in Saxony,* in Wurtemburg, in Switzerland, etc.

In 1892, the Wurtemburg Rys. had a Klose locomotive built

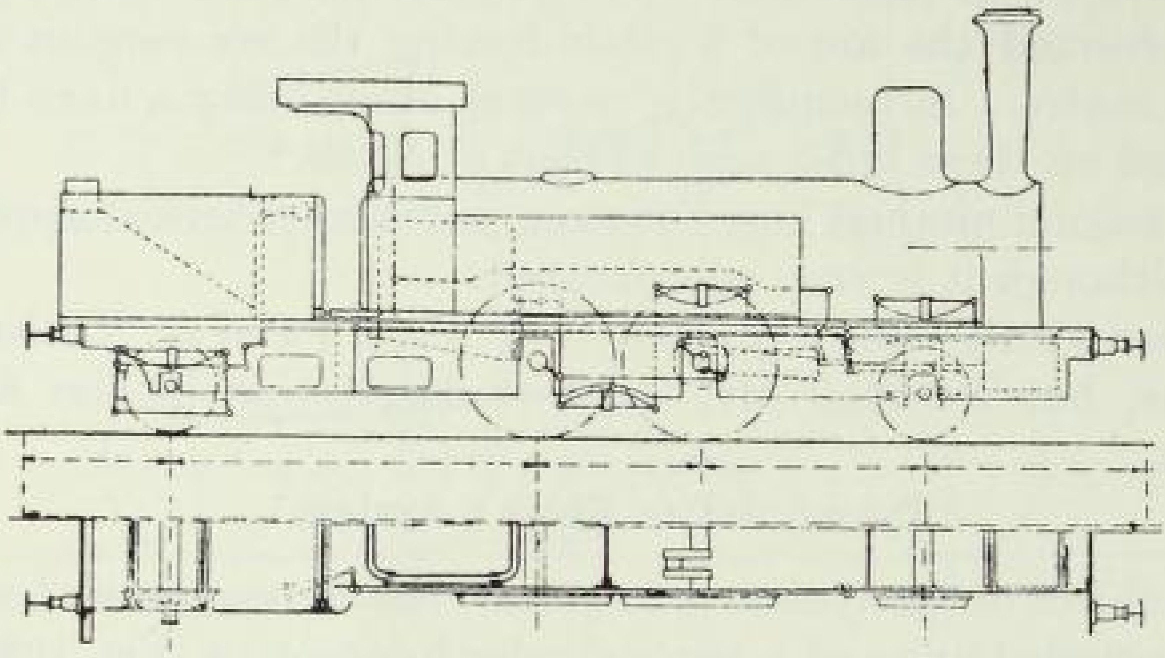


FIG. 103.—Klose Partially Articulated Locomotive, Swiss Union Ry. (Standard Gauge.)

which had three cylinders of the same diameter, one inside and two outside, with the cranks at 120 degrees. This locomotive worked either simple or compound. In the latter case, the inner cylinder was H.P. and the two others L.P.†

GROUP V.—SINGLE-ENGINE SEMI-ARTICULATED LOCOMOTIVES WITH QUILL TRANSMISSION

In this ingenious transmission, the axle of the pair of wheels which are required to move convergently in reference to the fixed axles of the locomotive is itself also fixed. It is, however, surrounded by a hollow sleeve which carries the wheels. The sleeve is connected with the axle at the centre by means of a ball and socket or universal joint. While, therefore, the axle itself remains parallel to the fixed axle of the locomotive the wheels, together with the sleeve to which they are fixed, can take up any position which the curves of the line may demand.

* The first of these was supplied in 1891. An improved class was tried in 1910.

† Eisenbahn, *Technik der Gegenwart.*

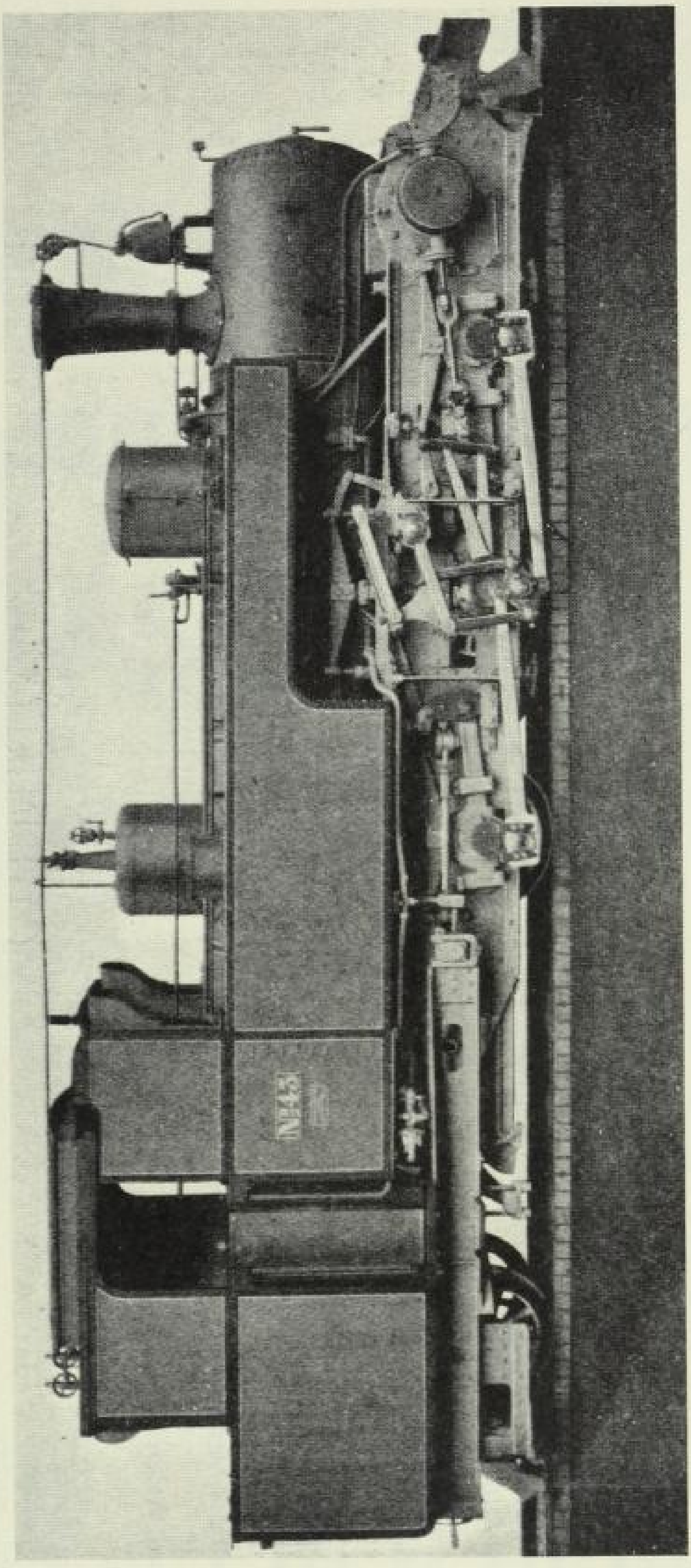


FIG. 104.—0-6-2 Klose Locomotive, Saxony State Rys.
(2 ft. 5½ ins. Gauge.)
Built by the Chemnitz Works.

TABLE 49.—PRINCIPAL DIMENSIONS OF KLOSE LOCOMOTIVES

		0·6·2	Rack and Adhesion.	0·6·2	0·4·4	2·4·2
Railway		Swiss Union Ry.	Appenzel Road Rys.	Saxon State Rys.	Wurtemburg State Rys.	
Gauge		Standard.	—	0m.75.	Standard.	Standard.
Builder		—	—	—	Esslingen.	Esslingen.
Date		1886.	1888–1890.	—	1892.	1892.
Cylinders, diameter	m.	0·41	—	0·32	0·34	0·42 (4)
,, stroke	m.	0·58	0·36 (4)	0·40	0·50	0·56
Boiler diameter		—	—	—	1·14	1·48
,, pressure	kg. per sq. cm.	—	12	10	12	12
Tubes, number		—	—	—	140	250
,, diameter	mm.	51	—	—	45	45
,, length	m.	—	—	—	3·71	4·30
Heating surface, firebox	sq. m.	6·9	6·0	3·6	—	—
,, ,, tubes	,,	122·4	82·0	42·7	—	—
,, ,, total	,,	130·2	88·0	46·2	71·0	148·0
Grate area	,,	1·4	1·4	0·9	1·0	2·0
Wheels, diameter	m.	—	0·86 rack	0·76	—	—
,, ,,	m.	—	0·82 adhesion	0·86	0·90	1·65
Wheelbase, rigid	m.	1·70	3·00	2·80	—	—
,, total	m.	7·83	6·00	5·75	—	—
Overall, height	m.	4·45	—	3·00	3·54	4·13
,, width	m.	—	—	2·00	—	—
,, length	m.	11·59	—	9·00	8·13	10·30
Water tanks	cub. m.	6·7	3·0	2·00	2·4	—
Coal bunkers	t.	2·2	1·0	1·2	2·5	2·5
Weight, empty	t.	—	26·0	20·0	22·0	47·7
,, in service	t.	49·5	33·0	25·6	29·9	54·2
,, adhesive	t.	29·0	—	19·0	15·04	27·6

TABLE 49A.—PRINCIPAL DIMENSIONS OF KLOSE LOCOMOTIVES

Type	0-6-2	Rack and Adhesion.	0-6-2 —	0-4-4	2-4-2
Railway	Swiss Union Ry.	Appenzel Road Rys.	Saxon State Rys.	Wurtemburg State Rys.	
Gauge	Standard.	—	2 ft. $5\frac{1}{2}$ ins.	Metre.	Standard.
Builder	—	—	—	Esslingen.	Esslingen.
Date	1886.	1888–1890.	—	1892.	1892.
Cylinders, diameter	$16\frac{3}{16}''$	—	$12\frac{5}{8}''$	$13\frac{3}{8}''$	$16\frac{1}{2}''$
,, stroke	$22\frac{7}{8}''$	$14\frac{3}{16}''$ (4)	$15\frac{3}{4}''$	$19\frac{5}{8}''$	$22''$
Boiler diameter	—	—	—	$3'\ 8\frac{7}{8}''$	$4'\ 6\frac{5}{16}''$
,, pressure . . . lbs. per sq. in.	—	171	142	171	171
Tubes, number	—	—	—	140	250
,, diameter	$2''$	—	—	$1\frac{7}{8}''$	$1\frac{7}{8}''$
,, length	—	—	—	$12'\ 2\frac{1}{8}''$	$14'\ 1\frac{1}{4}''$
Heating surface, firebox . . . sq. ft.	74·2	64·5	38·3	—	—
,, ,, tubes . . . ,,	1,316	881·5	459·6	—	—
,, ,, total . . . ,,	1,490·2	946·0	497·1	764·3	1,593·1
Grate area . . . ,,	15·0	15·0	9·7	10·8	21·5
Wheels, diameter	—	$2'\ 9\frac{7}{8}''$ rack	$2'\ 9\frac{7}{8}''$	—	—
,, ,,	—	$2'\ 8\frac{1}{4}''$ adhesion	$33\frac{7}{8}''$	$35\frac{3}{8}''$	$5'\ 4\frac{7}{8}''$
Wheelbase, rigid	$5'\ 4\frac{1}{2}''$	$9'\ 10''$	$9'\ 2\frac{1}{2}''$	—	—
,, total	$25'\ 8\frac{1}{2}''$	$19'\ 8''$	$18'\ 10\frac{3}{8}''$	—	—
Overall height	$14'\ 7''$	—	$9'\ 10\frac{1}{8}''$	$11'\ 7\frac{1}{4}''$	$13'\ 6\frac{1}{2}''$
,, width	—	—	$6'\ 6\frac{3}{4}''$	—	—
,, length	$38'\ 0''$	—	$29'\ 6\frac{3}{8}''$	$26'\ 8\frac{1}{16}''$	$33'\ 9\frac{1}{2}''$
Water tanks . . . galls.	14–70	790	440	530	—
Coal bunkers . . . tons–cwt.	2–4	0–19	1–19	2–10	—
Weight, empty . . . ,,	—	25–13/27–5	19–0	21–14	47–0
,, in service . . . ,,	48–17	32–11/34–3	21–13	29–12	53–0
,, adhesive . . . ,,	28–12	—	18–14	14–16	27–4

This arrangement was employed by *Heywood* and by *Cowles*, and also in the *Klien-Lindner* system, which takes its name from two German engineers who have given it extensive practical use.

Type 1.—The Heywood System

This system is alluded to because it is believed to be the first practical application of the above principle. It was used in or about the year 1880 for some 0-6-0 locomotives of the small Duffield Bank Ry., which had a gauge of 15 ins. (0m.38).

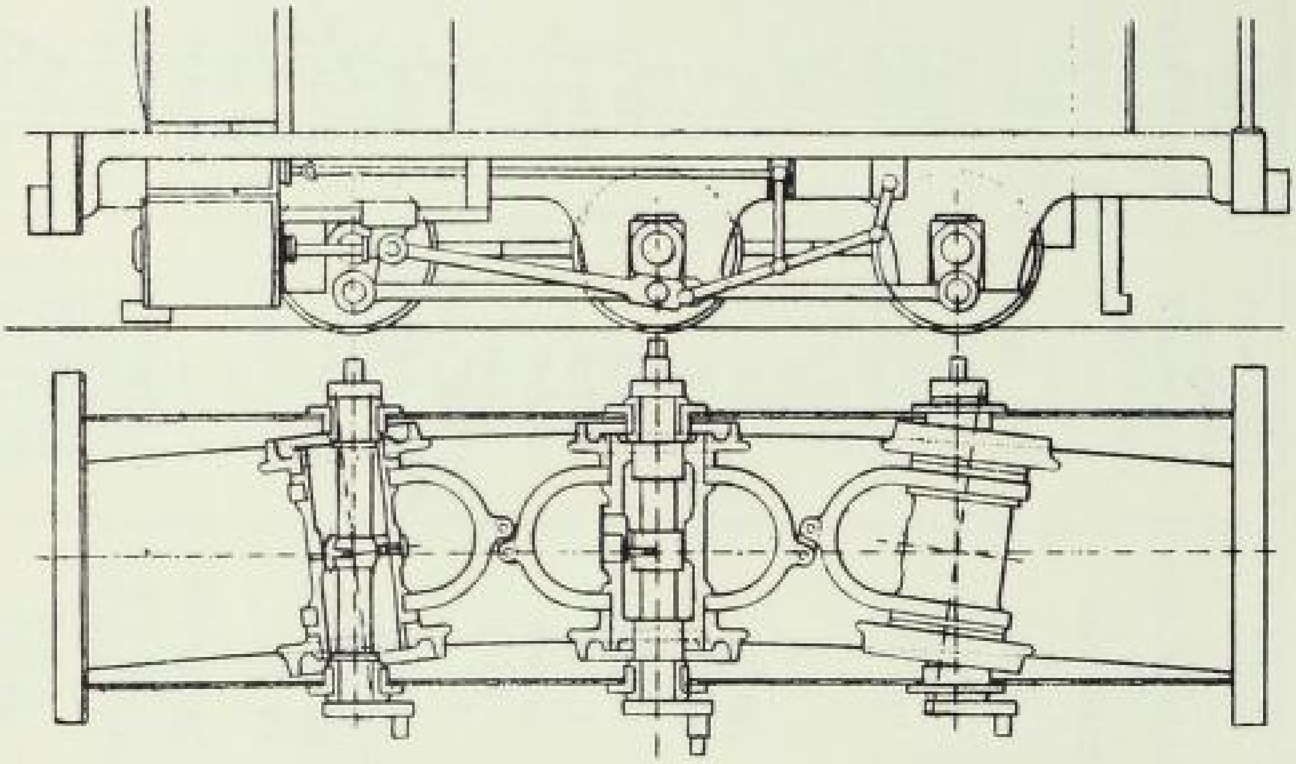


FIG. 105.—The Heywood System, Duffield Bank Ry.

The central axle could slide laterally within a sleeve. The two outer axles were capable of joint convergent movement. The central axle was driven and was connected to the two others by coupling bars with universal joints.

The locomotive could negotiate curves 16½ ft. (5 m.) radius.

Type 2.—The Klien-Lindner Locomotives

This system is certainly one of the most interesting of those which provide for the radial and lateral displacement of one of the coupled axles.*

It is remarkable that although the *Klien-Lindner* system is

* It was invented by the Saxon engineer Klien, of Dresden, about 1890, and Herr Lindner helped to work it out and to build the first locomotive of this type for the Saxon State Rys.

It was awarded German Patent No. 27,892, elaborated by Patent 68,932 of 1893.

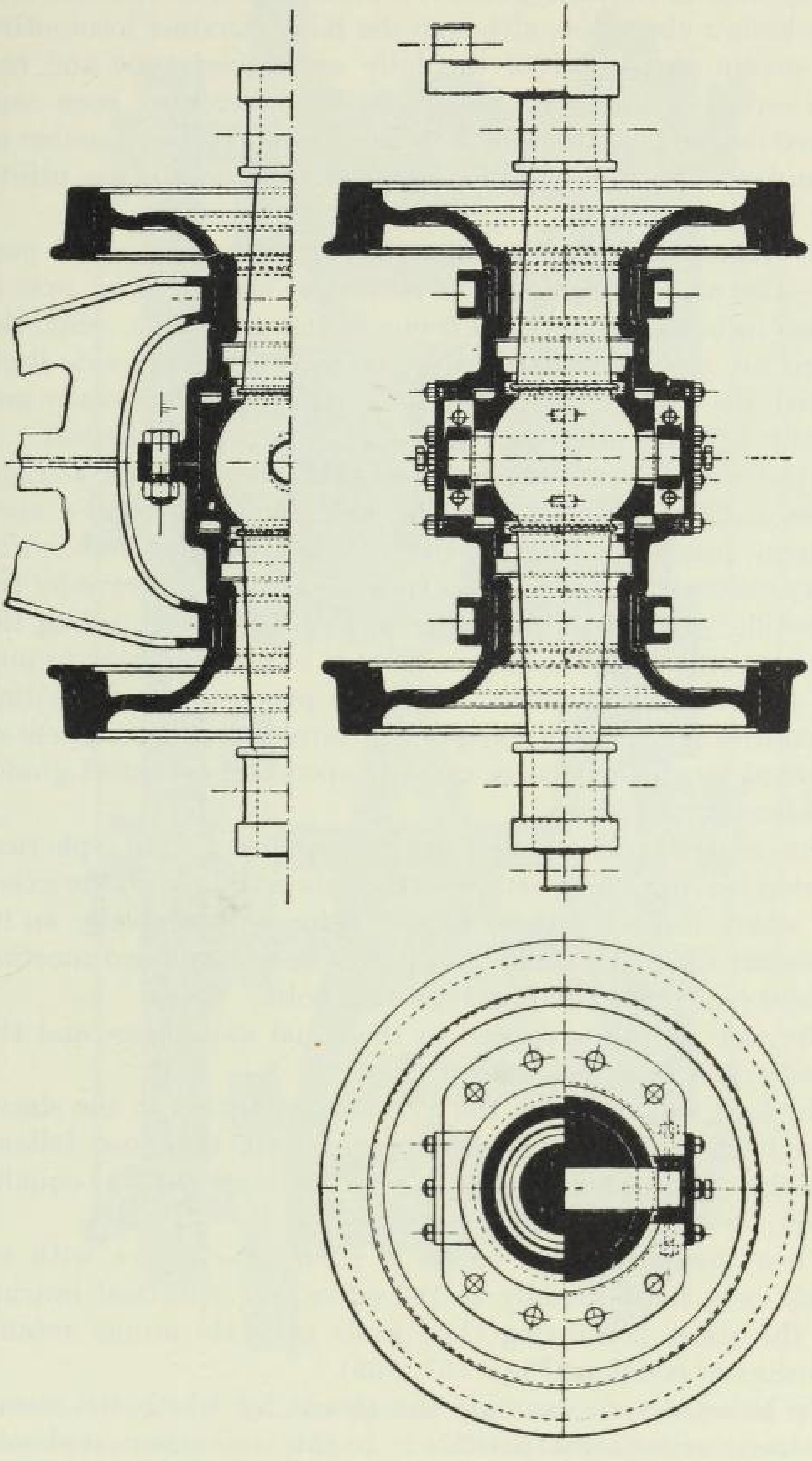


FIG. 106.—Klien-Lindner Axle Built by Orenstein and Koppel.

largely used in Germany, and to a lesser degree in Austria, it is little known elsewhere, although the Klien-Lindner locomotive is a severe competitor of the fully articulated type and has even replaced it in some cases. It has, therefore, been considered desirable to describe it in detail and to give a number of examples of its use in order that the wide field of its utility may be appreciated.

The Klien-Lindner axle (Fig. 106) consists of a central portion—the axle proper—and a cast steel sleeve. The axle is carried in boxes on the rigid frame in the usual way, while the wheels are secured to the sleeve. Hence, while the axle itself is fixed, the sleeve, with its wheels, can move both laterally and radially. The central part of the axle proper is spherical. A hole is drilled through the centre of this spherical boss, at right angles to the centre line of the axle, and a hardened steel gudgeon pin is forced into it by hydraulic pressure. The rotary movement of the axle is transmitted to the sleeve by the projecting portions of the gudgeon pin, without impeding the radial movement of the sleeve. But it is also necessary to provide for lateral movement. For this purpose, the projecting extremities of the gudgeon pin are furnished with slippers of hardened steel which work on corresponding cast-steel guides machined in the sleeve.

The central part of the sleeve contains a split spherical bisected bearing which embraces the spherical boss on the axles. The sleeve itself is in two halves, being split centrally on its transverse diameter. The two halves have machined meeting surfaces and are limited by lugs with bolts.

The axle proper is carried in the usual axle boxes and the forged crank pins are pressed on.

The load supported by the axle is transmitted to the sleeve through the central spherical bearing. It therefore follows that the two wheels are, approximately, always equally loaded.

When the locomotive enters a curve, the sleeve with its wheels sets itself radially to the curve, the spherical bearing and the slides permitting this, while the axle proper retains its ordinary position (Figs. 107, 108).

We have now to examine the means by which the sleeve is restored to its normal position. In this connection, it should be remembered that this system is most usually applied to

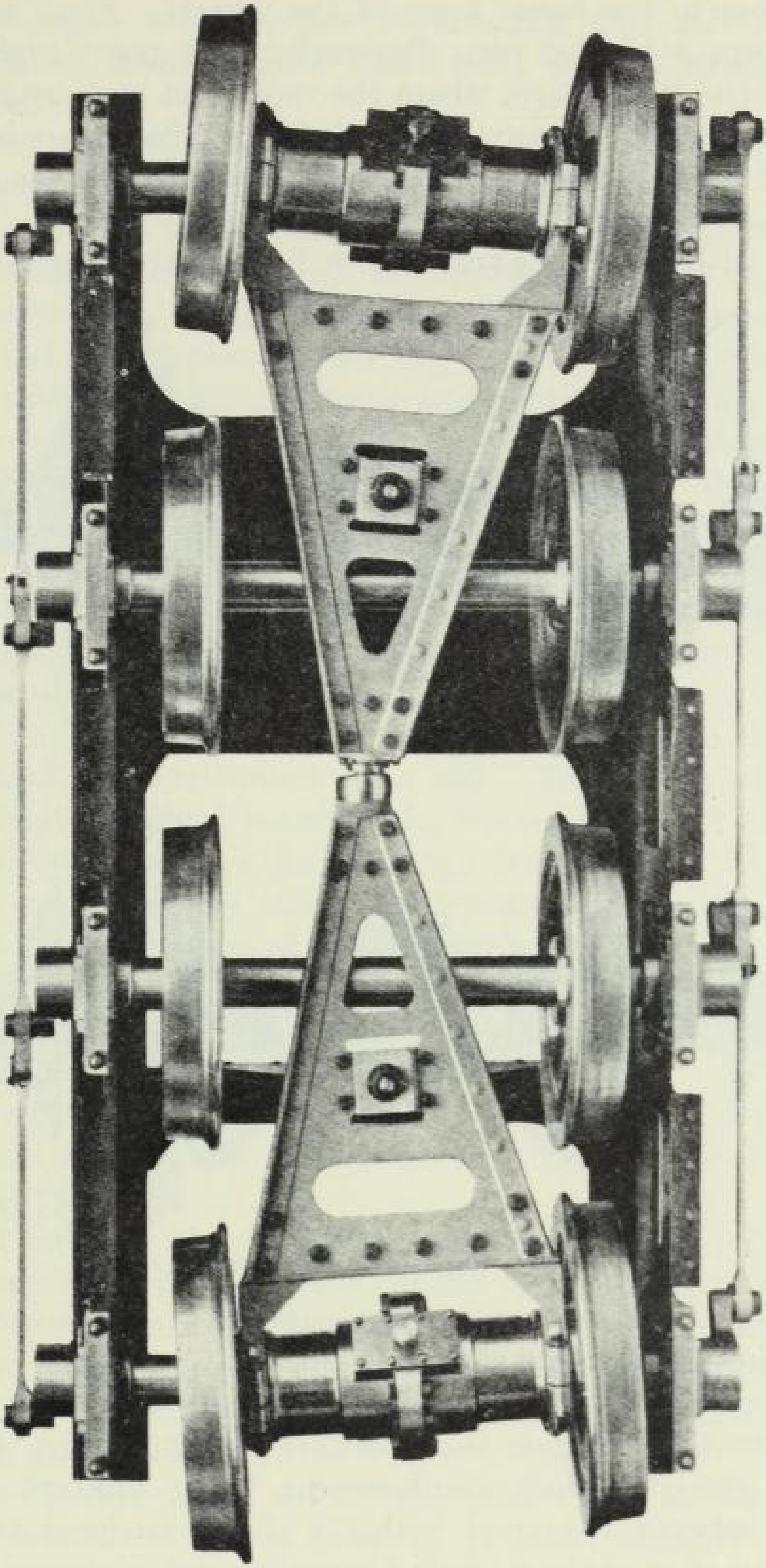


FIG. 107.—Locomotive Frame with Fore and Rear Klien-Lindner Maffei Axles.

locomotives with four or five coupled axles, and that it is only the outer axles which have the *Klien-Lindner* arrangement.

Two cast steel straps, lined with white metal, embrace the sleeve close to the inside faces of the wheels. From each of these straps a tie rod runs diagonally to a point under the centre of the locomotive, where the rods meet and are united. The sleeve of the other extreme axle has similar straps and tie rods, and the apices of the two triangles thus formed are united by a spherical joint.

Pivots with flat sliding surfaces are fixed to the frames on the

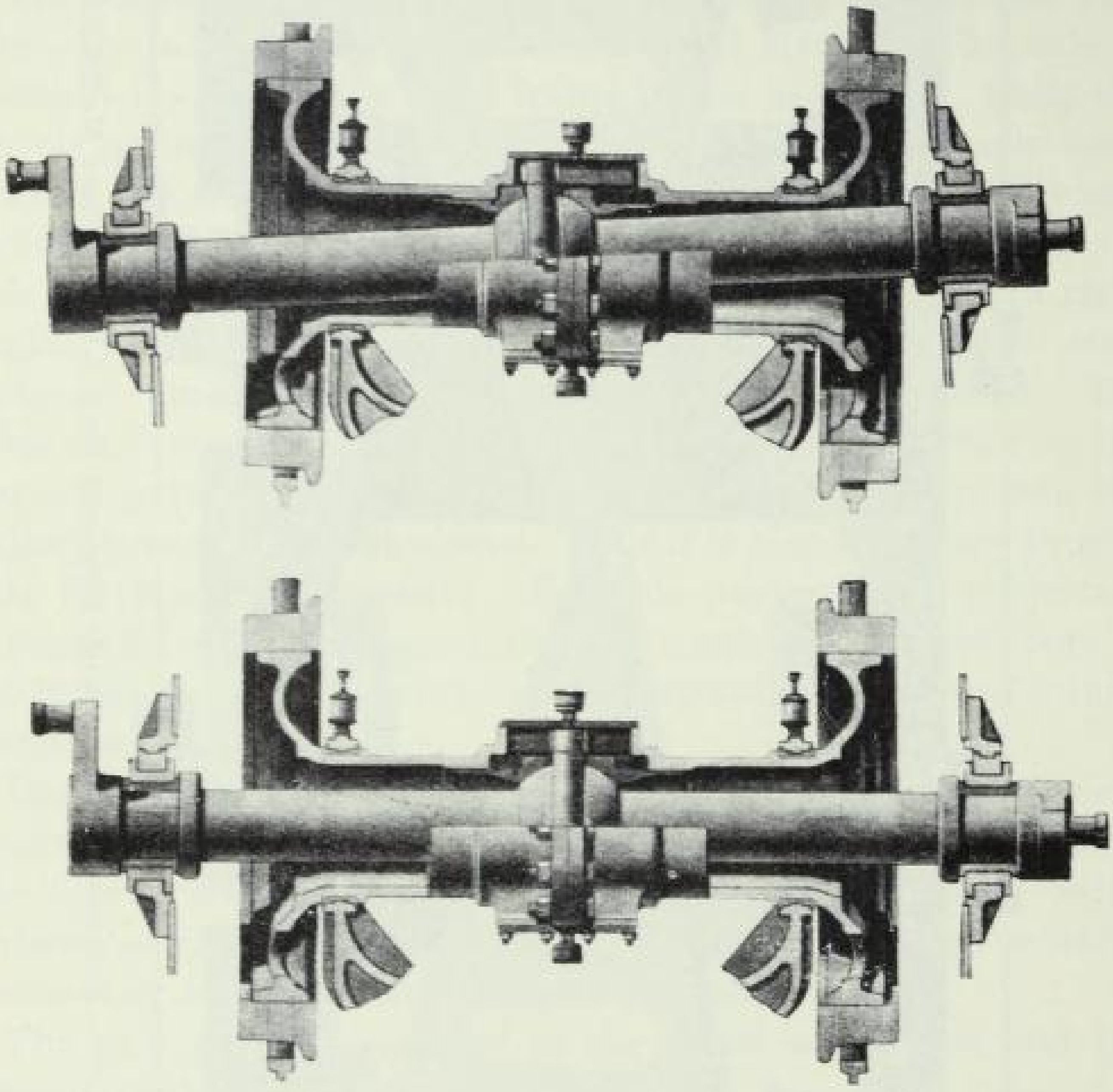


FIG. 108.—Maffei Klien-Lindner Axles.

centre line of the locomotive at points between the centre of the locomotive and the sleeves.

The sleeves of the two outer axles thus move over on curves and automatically regain their parallel positions when the line becomes straight, their displacement being uniform. The distance between the pivot with the sliding surfaces and the point of junction of the tie rods depends on the minimum radius of the curves which have to be negotiated. The intermediate axles follow the track of the extreme axles and, in effect, form bogies with them.

Pony axles are therefore superfluous, and *Klien-Lindner* locomotives usually have their total weight available for adhesion.

In other applications of this system, readjustment is effected by springs placed in the centre of the frame.

The objection to this arrangement is that the violence of the readjustment increases with the sharpness of the curve, and on all curves the friction and the resistance are increased.

The flat sliding pivot resists the displacement of the sleeves when running on straight track and avoids "hunting," which is quite perceptible in some types of articulated locomotives. The rigidity of the locomotive is a function of the distance between the two pivots.

THE KLIEN-LINDNER ORENSTEIN AND KOPPEL AND BORSIG SYSTEMS differ from the above in several particulars. The chief difference is that the tie rods from the straps on the sleeves do not extend to the centre of the locomotive, but are attached to a sleeve on the adjacent axle. These intermediate sleeves do not rotate and are united by a rod. The sliding pivots are consequently located between the sleeves of the extreme and those of the adjacent axles. The guided length of the locomotive in alignments is therefore increased. The tie rods are attached to the sleeves of the inner axles by spherical joints.

Fig. 109 shows a four-axle set of wheels negotiating a curve of 25 m. (82 ft.) radius, built on this principle by Messrs. Borsig, of Berlin.

The middle axles have radial displacements, the group of each two outer axles being similar to the Krauss-Helmholtz bogie (1888).

Until the outbreak of the War, the single firm of Orenstein and Koppel had built upwards of 300 locomotives of this type, mostly for German narrow gauge railways, and experimental standard gauge locomotives for the Prussian and for the Saxony State Rys. Others were supplied to Austria, to Hungary, to Sweden, and to Italy.

Klien-Lindner axles act in the same way as transversal weight equalisers, thus adding to the stability of the locomotives.

THE LUTTERMÖLLER SYSTEM.—On sharp curves, where the outer rail is relatively much higher than the inner one, the weight of the locomotive is so rapidly thrown inwards that the

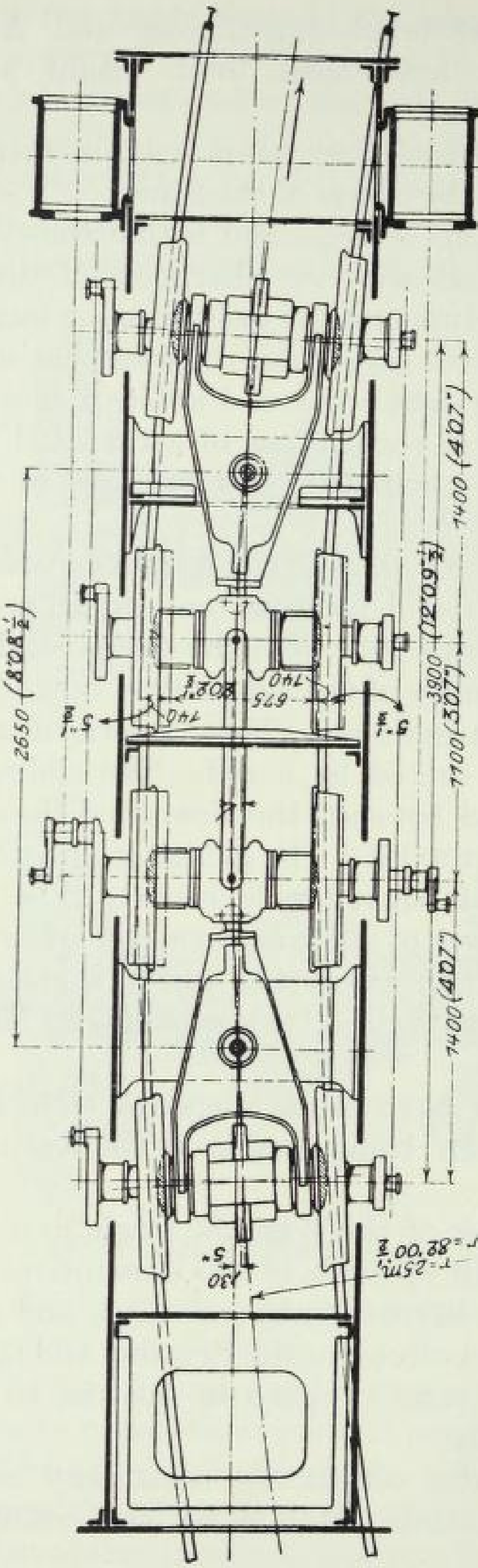


Fig. 109.—Locomotive with Two Klien-Lind er Axles. Disposition on a 25 m. (81 ft.) Radius Curve. Borsig (Berlin) System and Build.

outer wheel of the second axle has a tendency to rise, which is dangerous.

To obviate this drawback, Herr Luttermöller, chief engineer of Messrs. Orenstein and Koppel, brought the junction of the tie rods of the hollow axle still nearer to it at a point situated between the two outer axles, but nearer the inner one (Figs. 110 and 111).

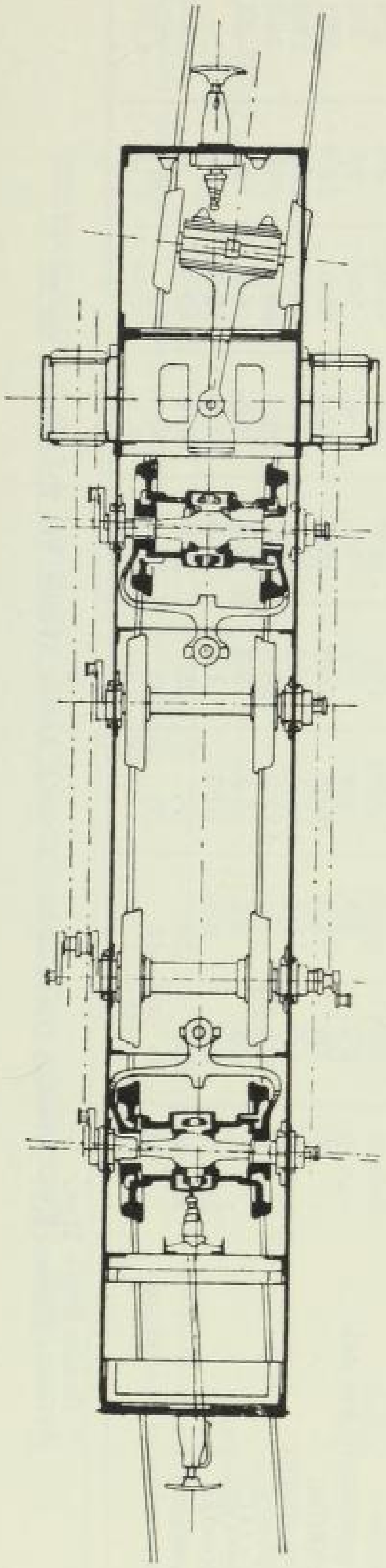


Fig. 110.—The Luttermöller System. Orenstein and Koppel Build.

The centre of rotation of the straps is the lower part of a pivot fixed under the framework.

As for the Klien-Lindner axle, the following modifications have been introduced: the central (solid) axle's right and left bronze bearings are only allowed to move horizontally in the steel sleeve. This latter has right and left bronze bearings, which are fixed to the wheels with which they rotate.

There is, of course, the usual ball and socket joint in the middle.

As the central axle's bearings are only allowed to move horizontally, it is clear that in negotiating a curve the central axle cannot rise more than an ordinary one and that the drawback stated above is thereby obviated.

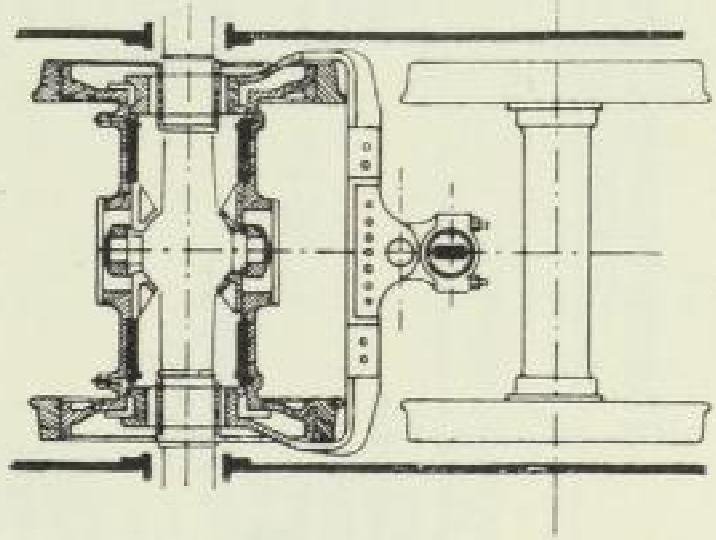


Fig. 111.—The Luttermöller System.

Table 50.—Principal Dimensions of Klien-Lindner 0-8-0-T Locomotives

Gauge / Builders	m.	0·60 to 0·875 m. Maffei.		0·70 to 0·914 m. Maffei.		0·75 m. Orenstein and Koppel.	0·785 m. Orenstein and Koppel.	1 m. Orenstein and Koppel.	0·75.* m. Henschel.	0·75.† m. Orenstein and Koppel.
Cylinders, diameter	m.	0·19	0·25	0·29	0·30	0·30	0·34	0·43	0·35	0·34 & 0·53
,, stroke	m.	0·30	0·35	0·35	0·35	0·40	0·40	0·50	0·40	0·43
Boiler pressure	kg. per sq. cm.	13	12	12	13	12	13	12	12	14
Tubes, number		44	90	60	115	110	132	140	—	—
Heating surface, firebox	sq. m.	1·9	3·3	3·6	4·7	4·2	5·0	7·0	—	4·2
,, ,, tubes	sq. m.	12·1	28·7	27·3	41·2	35·8	56·0	78·2	—	45·7
,, ,, total	sq. m.	14	32	30·9	45·9	40·0	61·0	85·2	55·0	50
Great area	sq. m.	0·4	0·7	0·8	1·0	0·8	1·0	1·3	1·0	0·96
Wheels, diameter	m.	0·60	0·65	0·65	0·70	0·75	0·81	0·95	0·81	0·86
Wheelbase, rigid	m.	0·75	0·80	0·86	0·90	1·00	1·10	1·35	1·00	1·50
,, total	cub. m.	2·25	2·40	2·95	3·10	3·40	3·90	4·35	3·00	3·90
Fuel, kind		Lignite.	Wood.	Oil, Wood, Bagasse, etc.			—	Coal.	—	—
Fuel	t.	0·5	1·2	1·2	1·0	1·0	1·3	2·0	1·0	0·96
Water tanks	cub. m.	0·8	1·3	1·4	2·5	2·0	2·5	4·0	3·0	2·4
Weight, maximum per axle	t.	2·6	3·8	4·4	5·2	—	—	—	7·5	7·2
,, empty	t.	7·9	11·9	13·6	16·0	17·2	22·0	36·0	23·0	22·1
,, in service	t.	9·9	14·8	17·1	20·7	21·5	27·5	44·0	28·8	27·8
Normal power	h.p.	45	—	125	150	150	200	300	—	—
Tractive force	t.	1·3	2·3	3·3	3·5	3·8	4·5	6·6	4·5	4·1
Speed, normal	km./h.	9·5	9·0	10·5	11·5	10·5	12·0	12·0	—	—
,, maximum	km./h.	25	28	28	35	27·0	30·0	40·0	—	—
Maximum radius of curvature	m.	10	15	20	25	25	30	40	30	—

* Saxon State Rys.
† Oberschlesien Ry.—Overall Dimensions: Height, 3m.05, Width, 2m.70, Length, 8m.22.

TABLE 50A.—PRINCIPAL DIMENSIONS OF KLIEN-LINDNER **0-8-0-T** LOCOMOTIVES

Gauge Builders		1′ 11⅝″ — 2′ 10½″ Maffei.		2′ $3\frac{9}{16}$″ — 3′ Maffei.		2′ 5½″ Orenstein and Koppel.	2′ 6″ Orenstein and Koppel.	Metre. Orenstein and Koppel.	2′ 5½″ * Henschel.	2′ 5½″ † Orenstein and Koppel.
Cylinders, diameter		7½″	9⅞″	$11\frac{7}{16}$″	$11\frac{13}{16}$″	$11\frac{13}{16}$″	13⅜″	$16\frac{15}{16}$″	$13\frac{13}{16}$″	13⅜″ & 20⅞″
,, stroke		$11\frac{13}{16}$″	$13\frac{13}{16}$″	$13\frac{13}{16}$″	$13\frac{13}{16}$″	15¾″	15¾″	19¾″	15¾″	$16\frac{15}{16}$″
Boiler, pressure	lb./sq. in.	185	171	171	185	171	185	171	171	199
Tubes, number		44	90	60	115	110	132	140	—	—
Heating surface, firebox	sq. ft.	20·4	35·5	38·7	50·5	45	53·7	75·3	—	45
,, ,, tubes	,,	130·1	308·5	293·5	443	385	602·2	840·7	—	491
,, ,, total	,,	150·5	346	332·2	493·5	430	656	916	—	536
Grate area	,,	4·3	7·5	8·6	10·75	8·6	10·75	14	10·75	10·3
Wheels, diameter		1′ 11⅝″	2′ 1⅝″	2′ 1⅝″	2′ $3\frac{9}{16}$″	2′ 5½″	2′ 7⅞″	3′ 1½″	2′ 7⅞″	2′ 9⅞″
Wheelbase, rigid		2′ 5½″	2′ 7½″	2′ 9⅞″	2′ 11½″	3′ 3⅜″	3′ 7⅝″	4′ 5¼″	3′ 3⅜″	4′ 11⅛″
,, total		7′ 4½″	7′ 10½″	9′ 8″	10′ 2″	11′ 2″	12′ 9½″	14′ 3½″	9′ 10″	11′ 2″
Fuel, description		Lignite.	Wood.	Oil, Wood, Bagasse, etc.			—	Coal.	—	—
,, weight	t.-cwt.	0–10	1–4	1–4	1–0	1–0	1–5	1–19	1–0	0–19
Water	cub. ft.	28·25	46	50	88	70·5	88	141	106	84·75
Weight, per axle, maximum	t.-cwt.	2–11	3–15	4–7	5–2	—	—	—	7–8	7–0
,, empty	,,	7–16	11–15	13–8	15–14	16–18	21–13	35–8	22–16	21–14
,, in service	,,	9–14	14–13	16–18	20–8	21–3	27–1	43–6	27–18	26–19
Normal power	h.p.	45	—	125	150	150	200	300	—	—
Tractive force	lbs.	2,867	5,070	7,280	7,720	8,380	9,925	14,550	9,925	9,040
Speed, normal	m.p.h.	6	5½	6½	7	6½	7½	7½	—	—
,, maximum	,,	15½	17½	17½	21¾	16¾	18½	25	—	—
Minimum radius of curvature		33′	50′	66′	82′	82′	98′	131′	98′	—

* Saxon State Rys.

† Oberschlesien Ry.—Overall Dimensions: Height, 10′ 0″, width, 8′ 10″, length, 27′ 0″.

But this still allowed the locomotive too much freedom to rotate vertically about the ball and socket joint, which, combined with the horizontal rotation about the pin under the frame, caused the latter or the straps to break frequently. This again has been remedied by the simple device of replacing this pin by a double articulation (Figs. 110 and 111).

A number of locomotives were built in compliance with these ideas, but in practice the simpler device was found to answer as well, and the more complicated construction has been abandoned.

The Sardinian Ry. Co. further improved conditions by adding a bissel, and uses locomotives of the 2-8-0 type.

Fuel and Water.—The water is carried partly in well tanks below the frame, and partly in side tanks. When this is insufficient, a tender is added.

Classification of the Klien-Lindner Locomotives.—Apart from the differences in details of construction which have already been referred to, these locomotives may be classified according to their axle formation. *Klien-Lindner* tank engines are built with three, four or five coupled axles, tender locomotives with four coupled axles only.

Since the successful use of gearing for driving fourth and fifth coupled axles, few *Klien-Lindner* locomotives with five coupled axles have been built, and manufacture has been confined to the four-axle type.

Utilisation of Klien-Lindner Locomotives

Although these locomotives have been most widely used on narrow gauge lines, they are also appearing on standard gauge systems.

The locomotives for gauges of 0·60 m. or 0·61 m. (1 ft. 11$\frac{5}{8}$ ins. or 2 ft.), 0·70 m. or 0·711 m. (2 ft. 3$\frac{5}{8}$ ins. or 2 ft. 4 ins.), 0·75 m. (2 ft. 5$\frac{1}{2}$ ins.), 0·76 or 0·762 m. (2 ft. 6 ins.) are built in series which are similar, except for minor variations peculiar to the various railway systems on which they are used.

The power of tank engines with four coupled axles for 0·60 m. gauge varies from 20 to 100 h.p. These last perfectly negotiate curves of 15 m. (49 ft.) radius.

For lines of gauges from 0·70 m. to 0·914 m. (2 ft. 3$\frac{5}{8}$ ins. to 3 ft.), four-axle locomotives from 100 to 300 h.p. have been built, and four-axle locomotives from 200 to 300 h.p.

Class A.—Klien-Lindner Locomotives with Three Coupled Axles

The advantage of this type is that as the rigid wheelbase is nil, the total wheelbase can be made as long as is desired. This is a great advantage for lines with light permanent way, where it is necessary to keep the load per foot run at a low figure.

0-6-0 Locomotives of the Matheran Ry. (India).—2 ft. gauge.

This railway connects Neral, altitude 132 ft. (40 m.), with

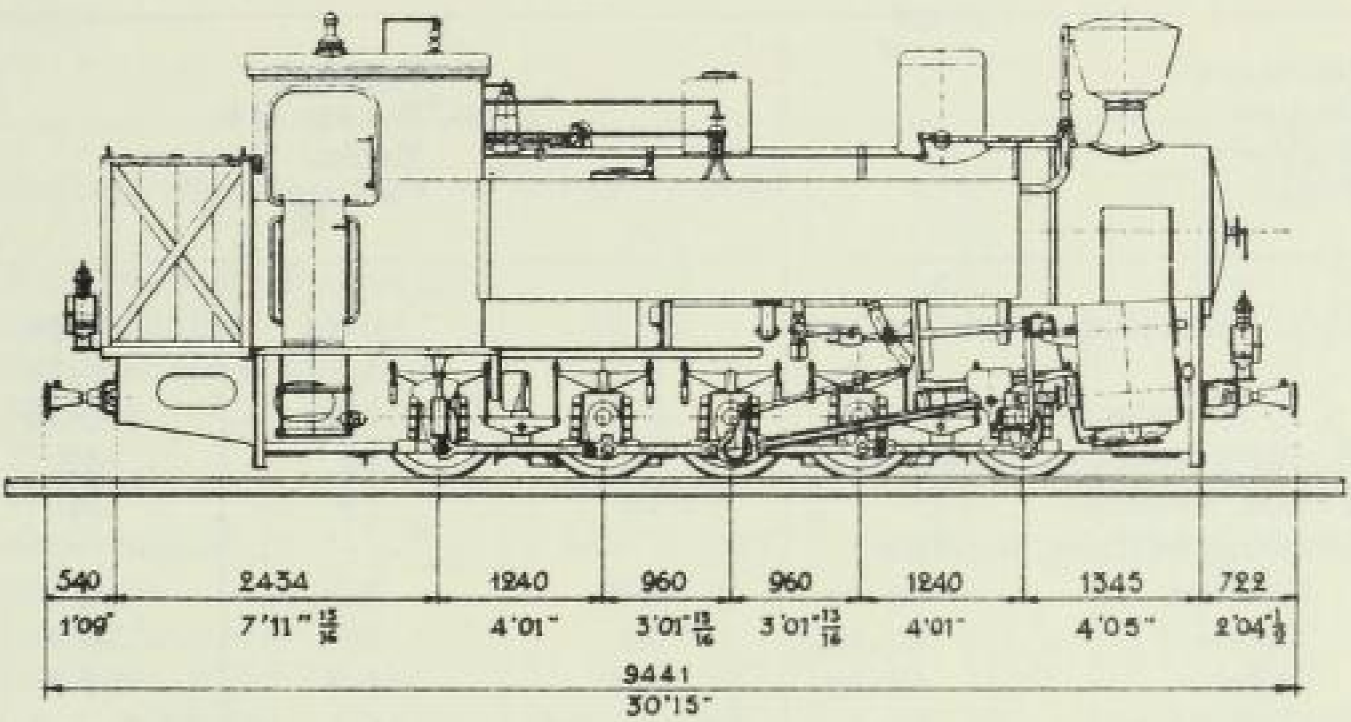


FIG. 112.—0-10-0 Tank Locomotive with Klien-Lindner Axles, Steinbeis Co., Bosnia.
(2 ft. 6 ins. Gauge.)
Built by Maffei, Munich.

the Matheran terminus, altitude 2,495 ft. (761 m.). It climbs the Western Ghauts to a hill station at no great distance from Bombay. The last 5 miles are steep and full of curves, the line rising 1,250 ft. (381 m.) in this distance, with maximum gradients of 5 per cent., and minimum radius of curvature of 60 ft. (18 m.). A very flexible locomotive is therefore necessary.

Class B.—Klien-Lindner Locomotives with Four Coupled Axles

Examples of this type are numerous.

Locomotives of the German Military Railways.—Gauge, 0·60 m. (1 ft. 11⅝ ins.).

These locomotives were much used during the Great War, and it is interesting to compare their dimensions with those of the twin locomotives also used by the German Army and of the Péchot-Bourdon type, also of 0·60 m. gauge, used by the French Army. This comparison is given in Table 23.

As in the case of the twin locomotives of the German and the Japanese armies, the *Klien-Lindner* locomotive can be provided with a bogie tender, the dimensions of which are given.

One of the tender locomotives is illustrated in Fig. 113.

TABLE 51.—PRINCIPAL DIMENSIONS OF **0-10-0-T** KLIEN-LINDNER LOCOMOTIVES

Railways	Various.		
Gauges	0m.750–0m.914.		
Builders	Maffei.		
Fuel	Various.		
Cylinders, diameter . m.	0·34	0·34	0·38
,, ,, . m.	0·51	—	0·57
,, stroke . m.	0·35	0·35	0·40
Boiler pressure kg. sq. cm.	13	13	13
Tubes, number . .	70	70	96
Heating surface, interior :			
Firebox . sq. m.	5·2	5·3	6·4
Tubes . . sq. m.	39	39	50·9
Total . . sq. m.	44·3	44·3	57·3
Superheater . sq. m.	18·1 + 3·4	18·1	21·7 + 3·4
Grate area . sq. m.	1·2	1·2	1·6
Wheels, diameter . m.	0·70	0·70	0·75
Wheelbase, rigid . m.	1·52	1·52	1·62
,, total . m.	3·70	3·70	3·90
Water tanks . cub. m.	2·75	4·45	4·70
Fuel bunkers . cub. m.	3·70	3·70	3·90
Weight, empty . t.	21·3	21·6	27·2
,, in service . t.	26·8	27·6	36·2
,, max. per axle t.	5·4	5·6	7·3
Tractive force . . t.	4·2	4·5	5·7
Normal power, . h.p.	200	220	300
Speed, normal . km./h.	13	13	14·6
,, maximum ,,	35	35	35
Min. radius of curve . m.	35	35	40
Gross load, level . t.	680	700	890
,, 1% grade t.	243	250	310
,, 2% ,, t.	143	146	178
,, 3% ,, t.	56	57	64

Class C.—Klien-Lindner Locomotives with Five Coupled Axles

The tank engines with five coupled axles have a rigid wheelbase of 1·52 m. to 1·62 m. (5 ft. to 5 ft. $3\frac{3}{4}$ ins.) and a total wheelbase of 3·70 m. to 3·90 m. (12 ft. $1\frac{1}{2}$ ins. to 12 ft. $9\frac{1}{2}$ ins.). They can therefore negotiate curves of 30 to 40 m. (98 ft. to 131 ft.) radius. Superheaters are fitted to some of them.

TABLE 51A.—PRINCIPAL DIMENSIONS OF **0-10-0-T** KLIEN-LINDNER LOCOMOTIVES

Railways	Various.		
Gauges	$2'\ 5\frac{1}{2}''$–$3'\ 0''$.		
Builders	Maffei.		
Fuel	Various.		
Cylinders, diameter	$13\frac{3}{8}''$ & $20\frac{1}{8}''$	$13\frac{3}{8}''$	$15''$ & $22\frac{1}{2}''$
,, ,,	$13\frac{3}{4}''$	$13\frac{3}{4}''$	$15\frac{3}{4}''$
Boiler pressure lbs./sq. ins.	185	185	185
Tubes, number	70	70	96
Heating surface, interior :			
Firebox sq. ft.	56	57	69
Tubes ,,	420	420	548
Total ,,	476	477	617
Superheater ,,	195 + 36·6	195	234 + 36·6
Grate area ,,	13	13	17·25
Wheels, diameter	$2'\ 3\frac{9}{16}''$	$2'\ 3\frac{9}{16}''$	$2'\ 5\frac{1}{2}''$
Wheelbase, rigid	$4'\ 11\frac{7}{8}''$	$4'\ 11\frac{7}{8}''$	$5'\ 3\frac{3}{4}''$
,, total	$12'\ 1\frac{5}{8}''$	$12'\ 1\frac{5}{8}''$	$12'\ 9\frac{5}{8}''$
Water cub. ft.	97	157	166
Fuel ,,	131	131	138
Weight, empty tons-cwt.	21–0	21–5	26–14
,, in service ,,	26–8	27–4	35–11
,, max. per axle ,,	5–6	5–10	7–4
Tractive force lbs.	9,260	9,930	16,100
Normal power h.p.	200	220	300
Speed, normal m.p.h.	8	8	9
,, max. ,,	22	22	22
Min. rad. of curvature	115′	115′	131′
Gross load on level tons	675	695	880
,, 1% grade ,,	240	246	306
,, 2% ,, ,,	140	144	175
,, 3% ,, ,,	55	56	63

TABLE 52.—PRINCIPAL DIMENSIONS OF MALLET AND KLIEN-LINDNER LOCOMOTIVES OF THE STEINBEIS CO.
(0m.76 Gauge Lines)

Type	Mallet.	Mallet.	Klien-Lindner.	Klien-Lindner.
Axles	**0-4 + 4-0**	**0-6 + 6-0**	**0-10-0**	**0-10-0**
Builders	Maffei.	Maffei.	Maffei.	Maffei.
Cylinders, diameter . m.	0·21	0·26	0·38	0·38
,, ,, . m.	0·34	0·52	0·51	0·57
,, stroke . m.	0·40	0·40	0·35	0·45
Boiler pressure kg./sq. cm.	12	14	13	13
Heating surface, firebox sq. m.	4·7	6·3	5·2	6·2
,, ,, tubes sq. m.	34·5	50·6	35·5	46
,, ,, total sq. m.	39·2	56·9	40·7	52·2
,, ,, superheater sq. m.	—	—	18·1	21·7
Grate area . sq. m.	1·3	1·7	1·2	1·6
Wheels, diameter . m.	0·75	0·75	0·70	0·75
Wheelbase, rigid . m.	1·20	1·67	1·52	1·62
,, total . m.	3·90	4·93	3·68	3·90
Overall dimensions :				
Height . m.	3·45	3·43	3·45	3·50
Width . m.	2·26	2·22	2·40	2·50
Length . m.	7·99	9·29	8·60	8·75
Water tanks . cub. m.	2·3	3·4	2·3	4·4
Wood . cub. m.	3·0	3·5	2·5	3·3
Weight, empty . t.	15·3	24	20·5	26
,, in service . t.	21·3	32	25·5	34
Tractive force . t.	3·5	5·3	2·9	5·2
Minimum radius of curves m.	50	50	40	40

TABLE 52A.—PRINCIPAL DIMENSIONS OF MALLET AND KLIEN-LINDNER LOCOMOTIVES OF THE STEINBEIS CO.
(Gauge 2 ft. 6 ins.)

Type	Mallet.		Klien-Lindner.	
Axles	**0-4 + 4-0**	**0-6 + 6-0**	**0-10-0**	
Builders	Maffei.		Maffei.	
Cylinders, diameter	$8\frac{5}{16}''$	$10\frac{1}{4}''$	15	$15''$
,, ,,	$13\frac{3}{8}''$	$20\frac{1}{2}''$	$20\frac{3}{16}''$	$22\frac{1}{2}''$
,, stroke	$15\frac{3}{4}''$	$15\frac{3}{4}''$	$13\frac{3}{4}''$	$17\frac{3}{4}''$
Boiler pressure lbs. sq. in.	171	199	185	185
Heating surface, firebox sq. ft.	50·5	67·8	56	66·7
,, ,, tubes ,,	371·5	544·7	382	495·3
,, ,, total ,,	422	612·5	438	552
Superheater ,,	—	—	195	233·5
Grate area ,,	14	18·3	13	17·2

TABLE 52A—*continued.*

Type Axles Builders	Mallet. **0-4 + 4-0** Maffei.	Mallet. **0-6 + 6-0** Maffei.	Klein-Lindner. **0-10-0** Maffei.	
Wheels, diameter	2′ 5½″	2′ 5½″	2′ 3½″	2′ 5½″
Wheelbase, rigid	3′ 11¼″	5′ 5¾′	4′ 11⅞″	5′ 3¾″
,, total	12′ 9½″	16′ 2″	12′ 1″	12′ 9½″
Overall, height	11′ 4″	11′ 3″	11′ 4″	11′ 5½″
,, breadth	7′ 5″	7′ 3½″	7′ 10″	8′ 2½″
,, length	26′ 2½″	30′ 5½″	28′ 2½″	28′ 8½″
Water . . . cub. ft.	81·2	120	81·2	155
Wood fuel . . ,,	106	124	88·6	116·5
Weight, empty . tons-cwt.	15–2	23–14	20–4	25–13
,, in service ,,	21–0	31–12	25–3	33–11
Tractive force . . lbs.	7,720	11,700	6,400	11,500
Minimum radius of curves	164′	164′	131′	131′

TABLE 53.—PRINCIPAL DIMENSIONS OF KLIEN-LINDNER LOCOMOTIVE WITH SEPARATE TENDER

Type Gauge Builders Fuel	**0-8-0** 0·75. Orenstei & Koppel. Wood	**0-8-0** 0·60. Orenstein & Koppel. Coal.	**0-8-0** 0·60. Orenstein & Koppel. Wood.	**2-8-0** Standard. Chemnitz. Coal.
Cylinders, diameter . m.	0·22	0·32	0·36	0·53 & 0·77
,, stroke . m.	0·30	0·35	0·35	0·63
Boiler pressure kg./sq. cm.	12	13	13	15
Heating surface, total sq. m.	23·5	68·0	75·2	197·0
Grate area . sq. m.	0·5	0·8	1·4	2·2
Wheels, diameter . m.	0·55	0·70	0·70	1·24 & 1·05
Wheelbase, rigid . m.	0·90	0·90	0·90	2·86
,, total . m.	2·40	3·00	2·90	7·76
Weight, empty . t.	8	17·5	20	64·1
,, in service . t.	9·2	19·5	24·5	70·8 *
Tractive force . . t.	1·9	4	5	10·7
Power . . . h.p.	—	160	—	1,000
Tender:				
Wheels, diameter . m.	0·45	0·50	0·50	—
Axles	4	2	4	—
Wheelbase . . m.	2·70	1·50	3·70	—
Water . . cub. m.	2·50	3·50	6·00	—
Fuel . . cub. m.	1·50	2·80	5·00	—
Weight, empty . t.	3·1	2·3	5·8	—
,, in service t.	8·2	8·3	13·5	—

* Of which 60 t. are available for adhesion.

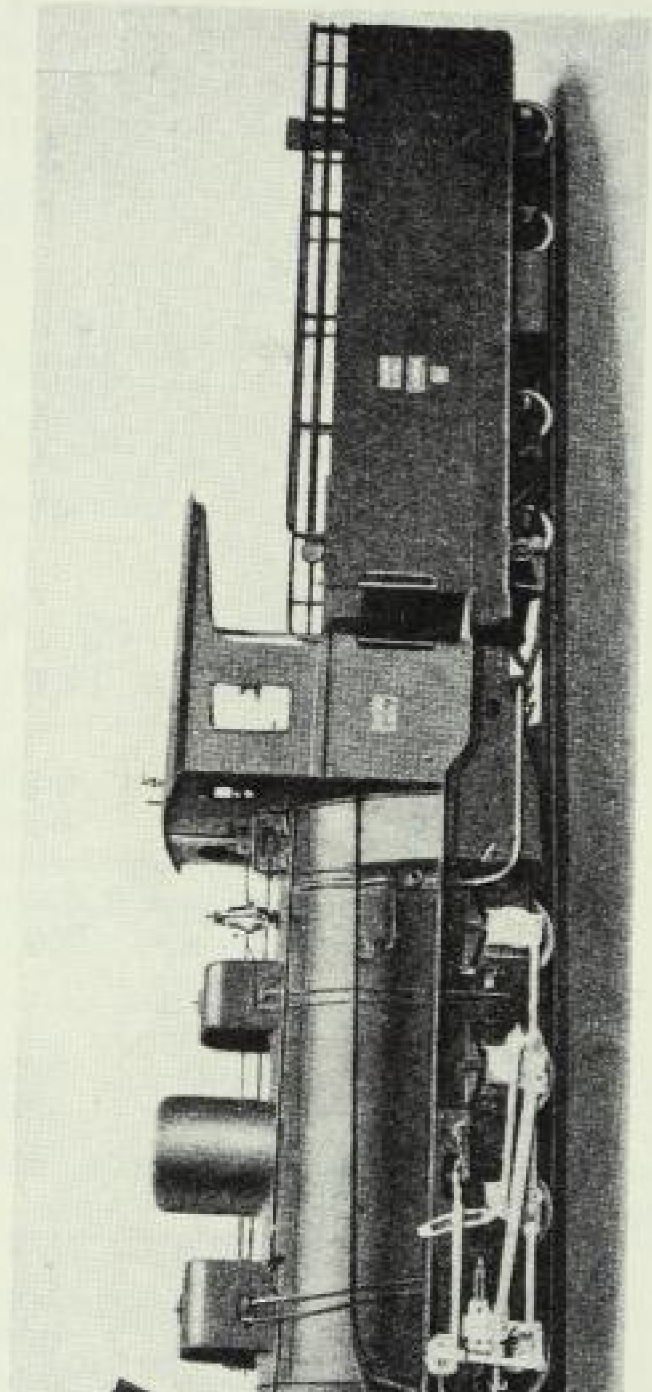


FIG. 113.—0-8-0 Tender Locomotive with Klien-Lindner Axles.
(0·60 m. Gauge.)

TABLE 53A.—PRINCIPAL DIMENSIONS OF KLIEN-LINDNER LOCOMOTIVES WITH SEPARATE TENDER

Type	**0-8-0**	**0-8-0**	**0-8-0**	**2-8-0**
Gauge	2′ 5½″	1′ 11⅝″	1′ 11⅝″	Standard.
Builders	Orenstein & Koppel.	Orenstein & Koppel.	Orenstein & Koppel.	Chemnitz.
Fuel	Wood.	Coal.	Wood.	Coal.
Cylinders, diameter	8¾″	12⅝″	14 3/16″	20⅞″ & 30⅜″
,, stroke	11 13/16″	13 13/16″	13 13/16″	24¾″
Boiler pressure lbs./sq. ins.	171	185	185	213
Heating surface :				
Total . . sq. ft.	253	732	809	2,120
Grate area . . ,,	5·3	8·6	15	23·7
Wheels, diameter	1′ 9⅝″	2′ 3½″	2′ 3½″	4′ 0¾″ & 3′ 5⅜″
Wheelbase, rigid	2′ 11½″	2′ 11½″	2′ 11½″	9′ 4½″
,, total	7′ 10½″	9′ 10½″	9′ 6½″	25′ 6″
Weight, empty tons-cwt.	7–18	17–5	19–15	63–5
,, in service ,,	9–1	19–5	24–4	69–17 *
Tractive force . . lbs.	4,190	8,820	11,000	23,600
Power . . . h.p.	—	160	—	1,000
Tender :				
Wheels, diameter	1′ 5¾″	1′ 7¾″	1′ 7¾″	—
Axles, number	4	2	4	—
Wheelbase	8′ 10½″	4′ 11″	12′ 1½″	—
Water . . cub. ft.	93·3	118	212	—
Fuel . . ,,	88·2	99	175·6	—
Weight, empty tons-cwt.	3–1	2–5	5–14	—
,, in service ,,	8–4	8–4	13–6	—

0-10-0-T Klien-Lindner Locomotives of the Steinbeis Ry. (Bosnia).—Gauge 0·76 m. (2 ft. 6 ins.) (Fig. 112).

These locomotives are interesting because they work side by side with some *Mallets*. As will be seen from Table 52, the earlier *Mallets* with four coupled axles and the lighter type of the *Klien-Lindner* had approximately the same tractive force. The same is true of the six-axles *Mallets* and of the heavy *Klien-Lindner*.

The conclusion to be drawn as to the use of the latter is obvious.

* Of which 59 tons 4 cwt. are available for adhesion.

TABLE 54.—PRINCIPAL DIMENSIONS OF 0-6-2-T LOCOMOTIVES WITH KRAUSS-HELMHOLTZ BOGIES

	Metric Dimensions.		English Dimensions.	
Railway	Bosnia.	Saxon State.	Bosnia.	Saxon State.
Builders	Krauss.	Chemnitz.	Krauss.	Chemnitz.
Gauge	0m.76.	0m.75.	2′ 6″	2′ 5½″
Cylinders, diameter	0m.29	0m.32	11 7/16″	12⅝″
,, stroke	0m.45	0m.40	17¾″	15¾″
Boiler pressure	—	10 kg./cm.²	—	142 lbs./sq.in.
Heating surface :				
Firebox	—	3·6 m.²	—	38·75 sq. ft.
Tubes	—	42·7 ,,	—	460 sq. ft.
Total	58·5 m.²	46·2 ,,	629·5 sq. ft.	498·54 sq. ft.
Wheels, diameter	0m.90	0m.86	2′ 11½″	2′ 9⅞″
,, ,,	—	0m.76	—	2′ 6″
Wheelbase, rigid	—	2m.80	—	9′ 1½″
,, total	6m.00	5m.75	19′ 8″	18′ 10″
Overall, height	—	3m.00	—	9′ 10″
,, width	—	2m.00	—	6′ 6¾″
,, length	—	9m.00	—	29′ 6½″
Weight, adhesive	—	19t.0	—	18 t. 14 cwt.
,, empty	—	20t.2	—	19 t. 15 cwt.
,, in service	25t.7	25t.6	25 t. 6 cwt.	25 t. 4 cwt
Water	2·65 m.³	2·0 m.³	—	70·6 cub. ft.
Coal	1t.5	1t.2	1 t. 9 cwt.	1 t. 4 cwt.

Type 3.—The Krauss-Helmholtz Bogie

This bogie (*vide* Figs. 114 and 115) establishes an integral connection between a pony axle and the first or second coupled axle. This is effected by connecting the bissel to the centre of a sleeve that surrounds one of the coupled axles, so that any displacement of the pony axle in one direction causes a similar displacement of the coupled axle in the opposite direction.

These bogies have an advantage over ordinary bogies in that the space between the axles is greater.

The pivot should be located a little behind the centre of the bogie.

The *Krauss-Helmholtz* bogie was invented in 1883, but not patented till 1887. It was first used in the spring of 1888 on two locomotives on the Reichenhall-Berchtesgaden section of the Bavarian State Rys.*

The *Krauss-Helmholtz* bogie can be used both in the front

* *Vide Organ*, 1889, p. 16.

and the rear (*e.g.*, in a 2-6-2-T locomotive where the central axle alone is fixed). Sometimes it is at the rear only, as in certain 0-8-2-T locomotives. Again, it is sometimes used for

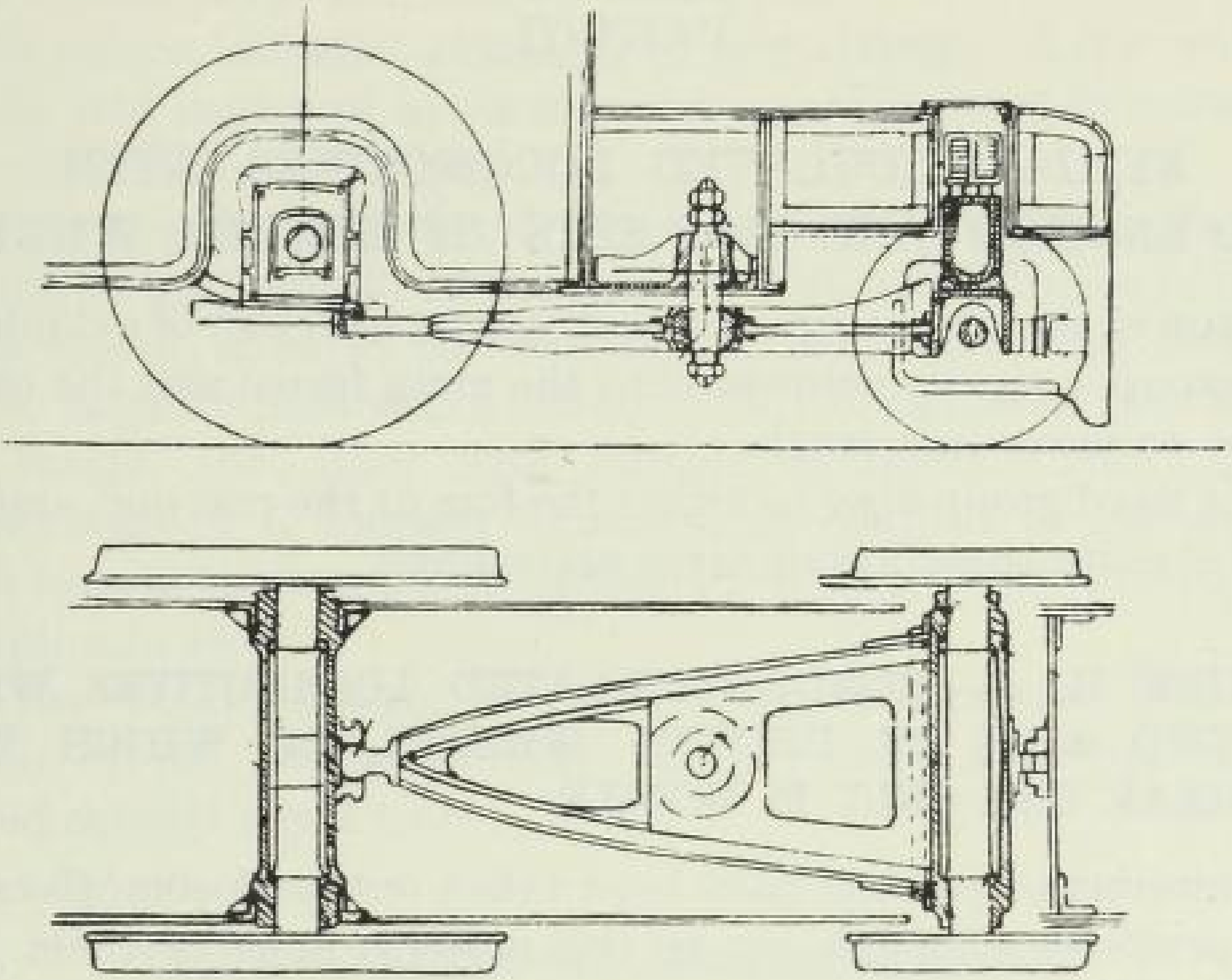


FIG. 114.—Krauss-Helmholtz Bogie.

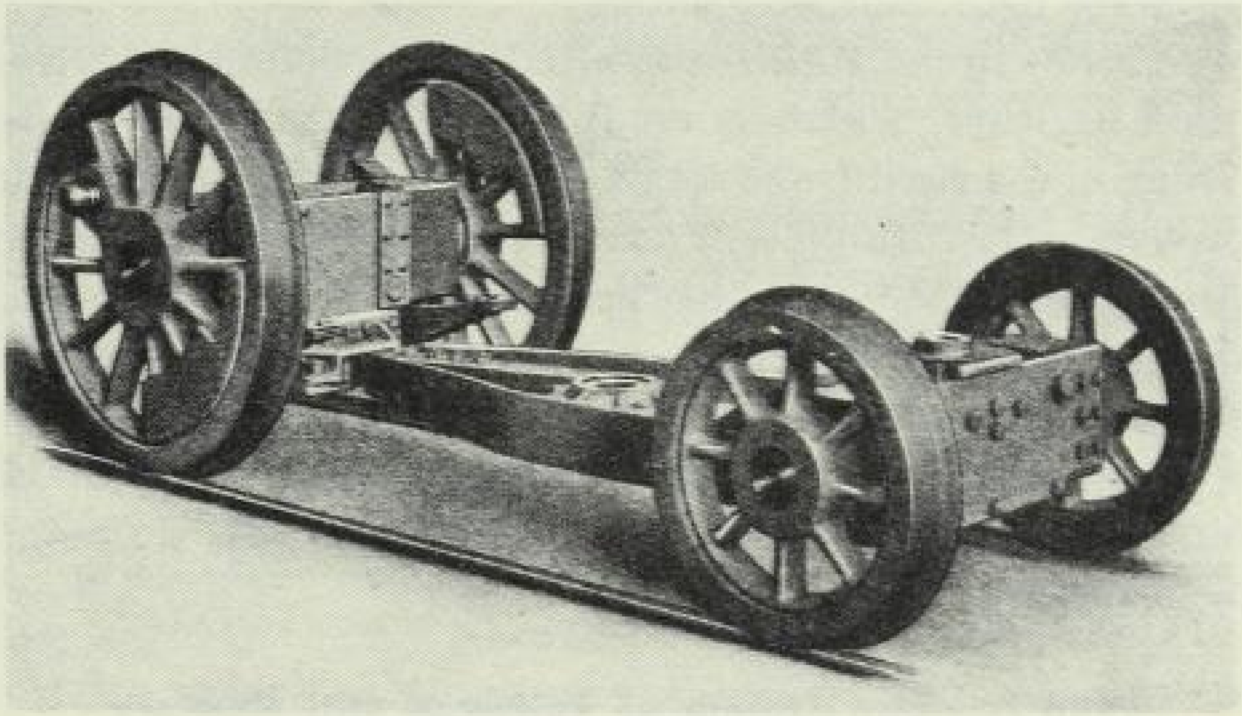


FIG. 115.—Krauss-Helmholtz Bogie.
Built by Messrs. Krauss, Munich.

two adjacent coupled axles as in the 0-8-0-T type. By this means it is even possible to connect the trucks of a pony axle with an adjacent axle coupled on the *Klien-Lindner* system, thus producing a very flexible arrangement.

PART II

SEMI-ARTICULATED LOCOMOTIVES WITH TWO ENGINES AND TWO SETS OF DRIVEN WHEELS

EACH of the two groups of wheels has its own pair of cylinders; one group is rigidly connected to the main frame and the other is free to move in a truck.

The fixed group may be either the fore or the rear one, and we shall classify these locomotives accordingly.

SECTION II. A.—SEMI-ARTICULATED LOCOMOTIVES WITH TWO SETS OF DRIVING WHEELS, OF WHICH THE REAR ONE ONLY IS MOBILE

A number of patents have been taken out for locomotives on this principle although, up to the present, none of them has been satisfactory.

They comprise those invented by *Tourasse and Hardery*, by the *Cockerill* firm, and by *Boutmy*.

About the time *Mallet* patented his locomotive, *Rimrott* proposed another, which is complementary to it, as it has a rear truck and a rigid front set of wheels, but little came of it.

Moreover, the *Hannover Locomotive Works* have recently patented a locomotive on this principle (which embraces some of the *Garratt's* characteristics as well), and which may prove more successful.

We shall also mention an *Esslingen* rack and adhesion combined semi-articulated locomotive, which was sent out to South America.

Type 1.—The System of Tourasse and Hardery

The name of Tourasse is but little known,* and yet this engineer is responsible for a number of new ideas both in locomotive and in marine engineering.

* In 1829 he built a special steamboat for towage. He was later Locomotive Superintendent of the Chemin de fer de Saint-Etienne à

Tourasse and Hardery took out a French patent (No. 1,102 of September 30th, 1842) for locomotives with two sets of wheels, each one comprising two coupled axles. The diameters of the wheels of the two sets were different.

This patent included a number of new claims. A few words may be said in regard to those which are of interest in connection with this subject.

In Tourasse and Hardery's design, the rigid train of wheels was driven by a simple vertical cylinder attached to the boiler.

The mobile train at the rear of the locomotive was driven by two slightly inclined cylinders. One design was provided with inside, the other with outside cylinders. The inside cylinders drove a cranked countershaft coupled to the axles which carried the wheels, an arrangement which was revived by Crampton in 1850.

In the second design, the rear of the locomotive bears a portion of the weight of the tender; this idea has been revived several times since.

Type 2.—The Cockerill-Semmering System

In addition to the *Seraing* locomotive, the Société John Cockerill presented at the Semmering Contest a design for a locomotive with four driven axles, of which the first two were rigid, and the last two formed a truck which could pivot on a point located in front of the firebox.

This locomotive had four cylinders—two at each end—each pair of axles being driven by one pair of cylinders. In addition, the three first axles were cranked at their centres and connected by a coupling bar located on the centre line of the locomotive. The central cranks were set at 90 degrees to the outside cranks.

The main frame rested on side brackets on the rear truck.

The advantage claimed for the supplementary central coupling bar was that it allowed the cranks of one group to be set to 180 degrees to those of the other group, thereby pro-

Lyon, where he introduced several new ideas and built the first French six-coupled locomotive. He presented two interesting designs at the Semmering Competition.

This information, together with much else referring to semi-articulated locomotives, has been furnished by our late lamented friend M. Anatole Mallet.

viding a more even turning moment. The water was contained in side tanks towards the front of the locomotives, and the fuel in a cross bunker at the rear.*

Type 3.—Boutmy's System

This was invented in 1862, and *Boutmy's* designs were exhibited at the Paris Exhibition of 1867.†

This locomotive was a tank engine and did not materially differ from that above described. The leading train of wheels was fixed and driven by cylinders placed at the front of the locomotive. The rear set was driven by the rear cylinders which received a direct supply of steam. *Boutmy's* aim was to improve *Engerth's* and *Sturrock's* designs (Fig. 116).

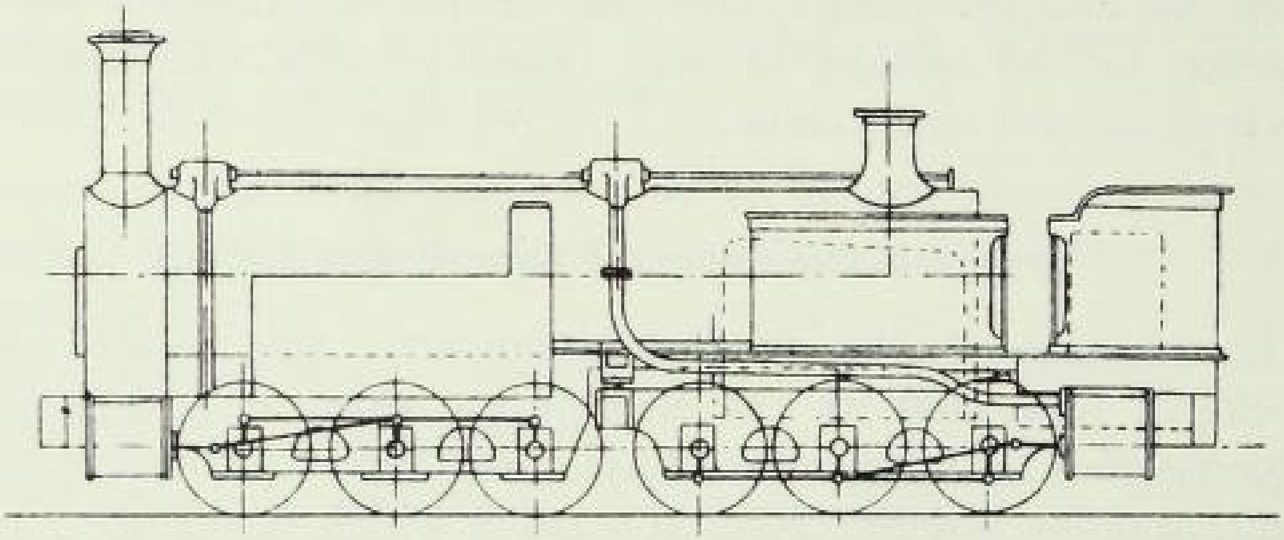


FIG. 116.—The Boutmy Locomotive.

The inherent elasticity of the steam pipes was sufficient for negotiating the easy curves for which this locomotive was designed. There were therefore no universal or telescopic joints in the pipework.

* The leading dimensions quoted were : Cylinders, $23\frac{1}{4}$ ins. × $27\frac{9}{16}$ ins. (0m.59 × 0m.70) ; heating surface, 1·625 sq. ft. (151 sq. m.) ; grate area, $16\frac{1}{4}$ sq. ft. (1·5 m.c.) ; diameter of wheels, 4 ft. $2\frac{3}{8}$ ins. (1m.28) ; wheelbase, rigid, 8 ft. $0\frac{1}{2}$ in. (2m.44) ; total, 23 ft. $11\frac{1}{2}$ ins (7m.30). Weight in service, 47 tons 7 cwt. (48 tonnes).

† Boutmy was an engineer at the Creusot Works, and subsequently at the Arles Locomotive Works of the P.L.M. Rys. He died in 1903.

The information concerning his invention is taken from "Etudes sur l'Exposition de 1867," by Jules Gaudry, and from the *Bulletin des Ingenieurs Civils de France* and *Zeitschrift des Vereines Deutsche Ingenieur* of September 5th, 1891, p. 1049.

TABLE 55.—PRINCIPAL DIMENSIONS OF BOUTMY LOCOMOTIVE

Type	0-6 + 6-0	0-6 + 6-0
Cylinders, diameter	0m.43	17″
,, stroke	0m.50	19¾″
Heating surface	200 sq. m.	2,153 sq. ft.
Boiler pressure	9 kgs. per sq. cm.	120 lbs. per sq. in.
Wheels, diameter	1m.20	3′ 11¼″
Wheelbase, rigid	2m.70	8′ 10⅜″
,, total	6m.90	22′ 7⅝″
Weight in service	70 tonnes	69 t. 1 cwt.
Tractive force	7,000 kg.	15,430 lbs.

Type 4.—Rimrott's System

In 1877, *Rimrott* designed a locomotive * with two groups of wheels, the leading one being fixed and the rear one mobile. Their respective frames were connected together by a vertical hinge joint. The locomotive had four cylinders.

Rimrott introduced the compound principle in 1881, but details of his locomotive were published in 1890 only.

Type 5.—The Hanomag System

The Maschinenbau A.G. of Hanover have recently taken out patents for an interesting type of locomotive of this class.†

This design is an endeavour to combine the advantages of the *Mallet* (which has been in use forty years) with those features which have conduced to the prosperity of the *Garratt* design, namely the facility which it offers for the provision of a large and deep firebox and a convenient ash-pan, and the fact that

* At about the same time that the first *Mallet* locomotive was exhibited at the Paris Exhibition of 1889, Glaser's *Annalen für Gewerbe und Bauwesen* (issues of July 1st, 1889, and March 15th, 1890) published descriptions of this system.

In spite of this, the *Mallet* locomotive has often been described in Germany as the *Mallet-Rimrott*, although the *Mallet* differs fundamentally from *Rimrott's* design, in that the rigid train is always at the rear and that compounding is an essential feature of the *Mallet* system.

† German patent, W. Thormann; French Patent No. 627,863; English Patent No. 267, 124.

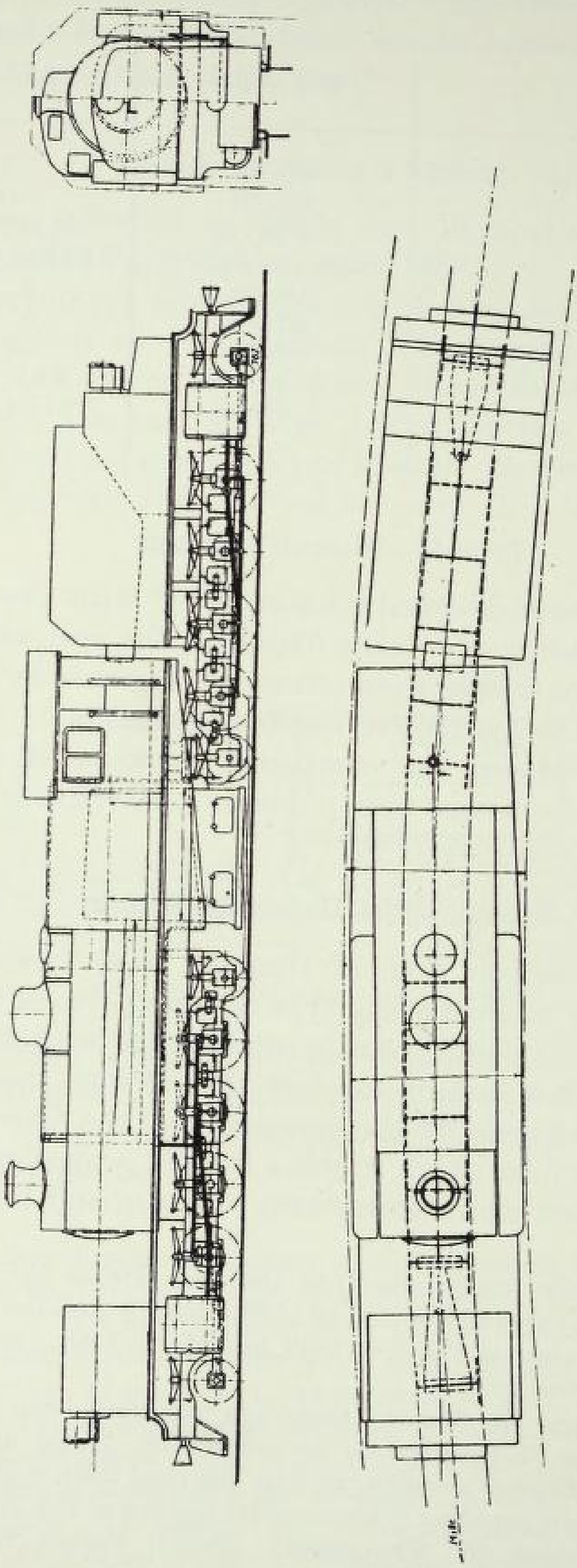


FIG. 117.—Project of Hanomag System of Articulated Locomotive (1927).

the boiler has an advantageous position when running through curves.

The *Hanomag* locomotive comprises two sets of driven axles. The cylinders are at the extremities of each group. A main frame carries the boiler, the cab, and that portion of the water supply which is contained in the tank in front of the smokebox (Fig. 117).

The leading set of wheels is rigidly connected to the main frame. The firebox descends clear of the wheel trains.

Behind the firebox, the main frame rests on two side brackets fixed to the rear truck. This truck carries the coal bunker and the balance of the water storage as in the *Garratt*.

It will be seen that the minimum distance between the two wheel groups need not exceed that which is necessary to give ample space for the firebox.

As the presence of the leading wheel group under the boiler is not a matter of any great inconvenience, this position is adopted, which results in a reduction of the total wheelbase.

The tanks are so designed that the load in the two groups of wheels remains approximately the same under all working conditions.

The locomotive negotiates curves satisfactorily, a certain amount of lateral play being given to some of the axles.

Compared with the *Mallet*, it has the advantage of a fixed boiler. The firebox, however, is subject to movement, which may cause inconvenience in firing.

It does not negotiate curves as freely as the *Garratt*. It would seem to be essentially a design for slow-speed goods engines. On the other hand, the length is less than that of the *Garratt*, and can therefore more easily be built in small workshops. The boiler and firebox are also satisfactory.

Type 6.—Esslingen Combined Rack and Adhesion Semi-articulated Locomotives

0-8-0 + 6-0-0 Combined Rack and Adhesion Locomotives, Transandine Ry. (Chile).—Metre gauge.

We have previously referred to this railway, which crosses the Andes and unites the broad gauge systems of the Argentine with those of Chile.

So as to cope with the traffic up the steep gradients, some *Meyer-Kitson* articulated locomotives were put into service in

1907, 1908 and 1909, and an *Esslingen* semi-articulated one was also supplied in 1909.

The rigid set of wheels, on which the boiler rests, is in front. The rear bogie is hinged directly to the back of the front frame, thus providing greater compactness than in the former articulated type. This was not without its drawbacks, as the firebox was rendered inaccessible and the valve gear was too near to it.

The adhesion set of wheels is the front one ; the rear truck carries the rack mechanism, which includes three pinions coupled by connecting rods. Two of these are situated between two of the axles, the third pinion being between the second and third axles.

Trouble was experienced in connection with the steam pipes to the adhesion cylinders ; the movement of the boiler at this point is as much as 7 ins. on curves of 100 m. radius (5 chains), and originally some curves (which have been straightened out since) had even less. Walking pipes, with a knuckle joint in the centre and ball joints at top and bottom, were substituted to the original ball and sliding joints and did away with the trouble.

This original locomotive weighed 87 tons ; a second one, furnished in 1911, weighed 90 tons.* Its principal dimensions were :—

TABLE 56

Cylinders, adhesion	15½″ by 19½″
,, rack	21¼″ by 17¾″
Boiler pressure	215 lbs.
,, diameter	5′ 7″
Heating surface, firebox	115 sq. ft.
,, ,, tubes	2,068 sq. ft.
,, ,, total	2,183 sq. ft.
Grate area	35 sq. ft.
Wheels, adhesion, diameter	36″
,, rack, number	3
Wheelbase, front set of wheels	10′ 11¼″
,, rear set of wheels	$9' 9\frac{13}{16}''$
,, between set of wheels	$6' 10\frac{11}{16}''$
Length overall	45′ 9½″
Weight, total	87 tons
Tractive force, adhesion	20,000 lbs.
,, ,, track	47,000 lbs.

* See Henderson, *Proceedings Institute of Civil Engineers*, Vol. CXCV., and Lucy, Vol. CCII.

Owing to the snow nuisance, this locomotive is used with the rack bogie (the rear one) end in front.

SECTION II. B.—LOCOMOTIVES WITH TWO SETS OF WHEELS, OF WHICH THE FIRST ONLY IS MOBILE

Several early patents were taken out for locomotives on this system, but the attainment of a practical solution had to await the introduction of compounding into locomotive practice.

GROUP I.—ANDRÉ KOECHLIN'S SYSTEM

This was patented by André Koechlin, of Mulhouse (French Patent No. 2095, January 27th, 1858).

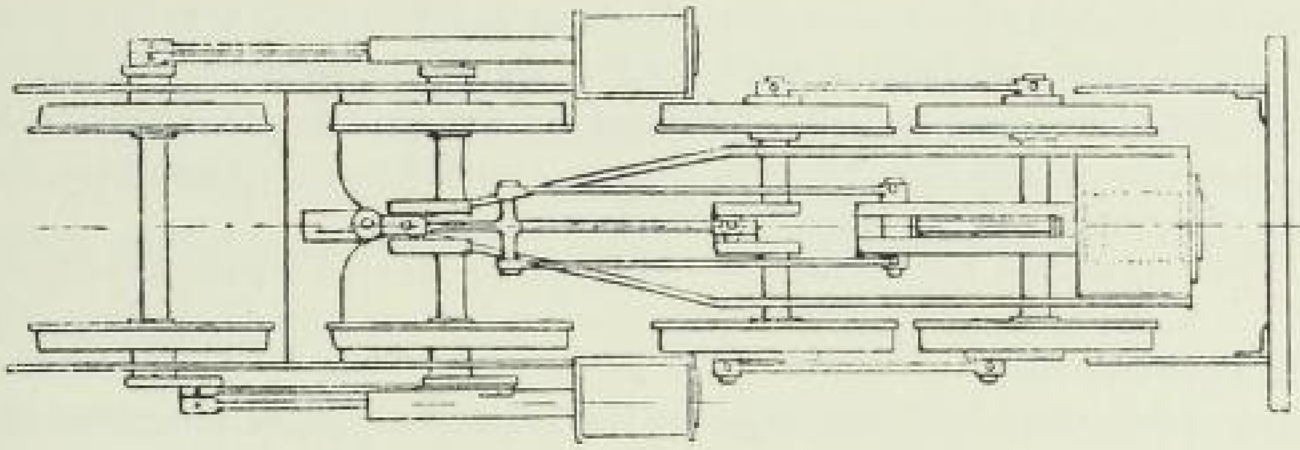


FIG. 118.—Koechlin Patent (1858).

This locomotive had two sets of wheels, each with two coupled axles. The rear set was rigid and was driven by two outside inclined cylinders. The leading set formed, in effect, a bissel. It was driven by a single inside cylinder located on the centre line of the locomotive. *Koechlin's* design comprised the same arrangement of double coupling as that formerly proposed in the *Cockerill-Semmering* locomotive, there being the usual outside coupling bars, and a central inside coupling rod which connected the adjacent axles of the two sets of wheels, namely, the trailing axle of the truck and the leading axle of the fixed set. This arrangement fixed the position of the centre of rotation of the bissel.

The cylinder driving the leading truck was inclined. As the outside coupling bars were horizontal, this facilitated the passage through the dead centres.

No details are available as to the way in which the boiler and the main frame were supported on the leading truck.

GROUP II.—THE MALLET SYSTEM

The first practical locomotives on this system were due to the eminent French engineer *Anatole Mallet.* His design answered so admirably to practical requirements that it has ever since held the field.

Mallet's semi-articulated locomotive was, in a sense, a side issue in the general application of compound working to the locomotive, which he was the first to bring into satisfactory practical use.*

As he experienced great difficulty in introducing compounding for ordinary locomotives, he proposed in 1877, to apply it to

* As in the case of all inventions, earlier but unsuccessful proposals are to be found.

We have already referred to the patent taken out by MM. Verpilleux and Baldeyrou (November 30th, 1857), which is generally unknown.

An English mechanic was allowed to apply compounding to two locomotives on the Great Northern Ry., but, after less than two years' trial, they were reconverted to simple engines.

Mallet patented his system in 1874, and applied it for the first time in 1877. Some information in regard to the first application may therefore be of interest.

This took place on the Bayonne to Biarritz Ry. in the year 1877, the locomotives being built at the Creusot Works. They were of the two-cylinder type, the H.P. and L.P. cylinders being of different diameters. It is interesting to place on record the leading dimensions of the two earliest types of compound locomotive. The two-cylinder compound had not, indeed, been much used, but three- and four-cylinder compounds have been used very extensively.

	Metric Measures.		English Measures.	
Type of locomotive .	**0-4-2**	**0-6-0-T**	**0-4-2**	**0-6-0-T**
Date . . .	1877	1878	1877	1878
Cylinders, diam. H.P.	0m.24	0m.30	$9\frac{1}{2}$ ins.	$11\frac{13}{16}$ ins.
,, ,, L.P. .	0m.40	0m.42	$15\frac{3}{4}$ ins.	$16\frac{9}{16}$ ins.
,, stroke .	0m.45	0m.55	$17\frac{3}{4}$ ins.	$21\frac{11}{16}$ ins.
Boiler pressure . .	10 kg./sq. cm.		142 lbs./sq. in.	
Wheels . . .	1m.05		3 ft. $5\frac{3}{8}$ ins.	
Wheelbase, total .	2m.70		8 ft. $10\frac{3}{8}$ ins.	
Weight, adhesive .	15 t.	24 t.	14 t. 16 cwt.	23 t. 14 cwt
,, empty . .	15 t.	20 t.	14 t. 16 cwt.	19 t. 16 cwt.
,, in service .	19 t.	24 t.	18 t. 15 cwt.	23 t. 14 cwt.

articulated locomotives on the *Meyer* and *Fairlie* systems ; his first attempts led, however, to inconclusive results.

Finally, on June 18th, 1884, *Mallet* took out the French Patent No. 162,876 for the system of articulated locomotives which has made his name famous throughout the world. The complete patent was granted on June 12th, 1885.

Sets of Wheels.—There are two sets of driving wheels ; the rear one is an integral part of the locomotive as in ordinary locomotives, and has the usual cylinders, valve gear and motion work.

The leading set of wheels constitutes a bissel truck, whose centre of rotation is located in front of the rear group of wheels between the centres of the rear cylinders. It is also provided with a pair of cylinders with the necessary valve gear, etc.

Articulation.—This is effected by a vertical hinge joint.

Buffing and Drawgear.—This is attached to the truck.

Boiler.—As the front end of the boiler moves relatively to the leading truck, it is supported thereupon by a special bearing saddle or saddles with or without spring centring gear.

Cylinders.—These are four in number. The two H.P. cylinders are located at the front of the rear (rigid) set of wheels, and are fed direct from the steam dome, which is immediately above them. The two L.P. cylinders are mounted on the front of the leading truck. The pipework between the H.P. and L.P. cylinders is rendered flexible by the introduction of universal and sliding joints.

Modifications of the Mallet Design.—These will be dealt with later.

Advantage of Compounding.—It is remarkable that, so far, the *Mallet* system of articulated locomotives is the only one where compounding has been successfully applied. This is due, of course, to the fact that the H.P. cylinders are rigidly attached to the boiler, and the L.P. cylinders only to the movable truck. Hence the L.P. steam only passes through the flexible joints, and until recently it was thought unadvisable to use H.P. steam in connection with such joints.

The principal advantages derived from compounding in articulated locomotives are, in the first place, the superior thermal efficiency obtained (which is the case in all compounds, whether articulated or not), and, in the second place, the fact that it provides a kind of elastic coupling between the two motor groups. Should the H.P. engine start slipping, the steam accumulated in the receiver pipe causes a back pressure against the H.P. cylinders. The contrary happens if the L.P. group starts slipping, as the draining of the steam from the receiver pipe causes a reduction of power behind the L.P. pistons.

Whilst longer cut-off for any degree is not a special feature of the *Mallet* articulated locomotives, it gives a more uniform M.E.P. in each cylinder and an improved torque and, as a corollary, a lower ratio of adhesion. This feature is particularly useful in *Mallet* tank locomotives, where the weight of fuel and water is variable.

Mallet always advised the use of compounding for articulated locomotives, and it has been tried long ago on other types, such as the *Meyer* and the *Fairlie*, but at the time trouble was experienced with the H.P. steam joints and nothing much came of these trials. Now that this difficulty has been overcome, there is little doubt that other types, such as the *Garratts*, may also find it advantageous to use compounding.

On the other hand, simple *Mallets* have been tried for many years, but with poor success. More recently, results have improved, as it has become possible to provide boilers adequate for supplying live steam to four H.P. cylinders.

The Development of the Mallet Locomotives

At the time when the first *Mallets* were put in service, in the year 1888, it was thought impracticable to have more than three coupled axles on narrow gauge "rigid" locomotives. Hence the *Mallet* with two independent groups, each of two axles, had a superior flexibility to such locomotives, and was found quite satisfactory.

Since then the use of the *Mallet* extended rapidly, first in Europe,* and then on narrow gauge railways overseas. Additional axles were added as necessary.

* The first *Mallet* locomotive was built for a Decauville railway and used at the Paris Universal Exhibition of 1889. The Decauville Works reproduced this type in large numbers.

In 1888 the Société Alsacienne des Constructions Mécaniques built some 0-4 + 4-0 *Mallets* for the Departmental Rys. (metre gauge). They were first used on the line between Montereau and Souppes, and subsequently on other sections.

At this time Maffei, of Munich, built the first standard gauge *Mallets*, In regard to *Mallet* locomotives for standard gauge lines, the object has been to provide a locomotive with more than five coupled axles, while avoiding the excessive stresses which are entailed by rigid locomotives.

The first standard gauge *Mallet* tank engine was built in 1890 for the St. Gothard Ry. It had six coupled axles (in two groups), and was used for banking. It was followed by another of the same class, built for the Belgian State Rys. in 1897, and a still more powerful specimen was built for the Central Aragon Ry. in 1902.

Nevertheless, the use of these locomotives on the standard and broad gauge lines of Europe is exceptional, although interesting examples of their use are to be found in Hungary, in Germany, in Russia and in the Balkans.

some with four coupled axles for the Central Swiss Ry., and some with six coupled axles for the Gothard Ry. These latter were at that time the heaviest locomotives in Europe.

They were followed by some metric gauge tank engines for the Chemins de fer Rhétiques.

About the same time, the Chemin de fer du Hérault, which possessed some *Meyers* which proved too heavy for their metre gauge track, ordered some *Mallets* of the Cail Locomotive Works, of Paris. Similar ones were also used on the Ch. de fer du Sud of France in 1891.

In the same year the Société Alsacienne, of Belfort, supplied some *Mallets* of greater power for the Corsican Rys. Similar locomotives were purchased by several railways, such as the Ch. de fer Economiques, the Ch. de fer du Sud, and the Bône-Guelma (Tunis).

In 1892, the Société Alsacienne supplied some 0-4 + 4-0 *Mallets* to the Prussian and to the Baden Rys. At this time there were some 110 *Mallets* in service, of which twenty-four were standard and forty-two metre gauge.

In 1894, Borsig, of Berlin, built some 0-6 + 6-0 *Mallets* for the Jaroslaw Ry. (Russia), and the Poutiloff Works built others for various Russian railways.

In 1897, the Saint-Léonard Works (Liège) built a 0-6 + 6-0 *Mallet* for the Belgian State Rys., which was the heaviest locomotive in Europe at the time.

In 1898, *Mallet* locomotives were introduced on the Hungarian State Rys., on the railway from Moscow to Kazan, and on the Trans-Siberian Ry.

In 1901, the Chemins de fer Départementaux adopted the 0-6 + 6-0 class, which has been widely used on these metre gauge lines.

By that time there were over 400 *Mallets* in service.

Some of the above information was kindly furnished by M. Mallet personally.

It is, however, quite different in America, where there is a continuous demand for locomotives of greater power. American designers have enlarged the diameter of their boilers

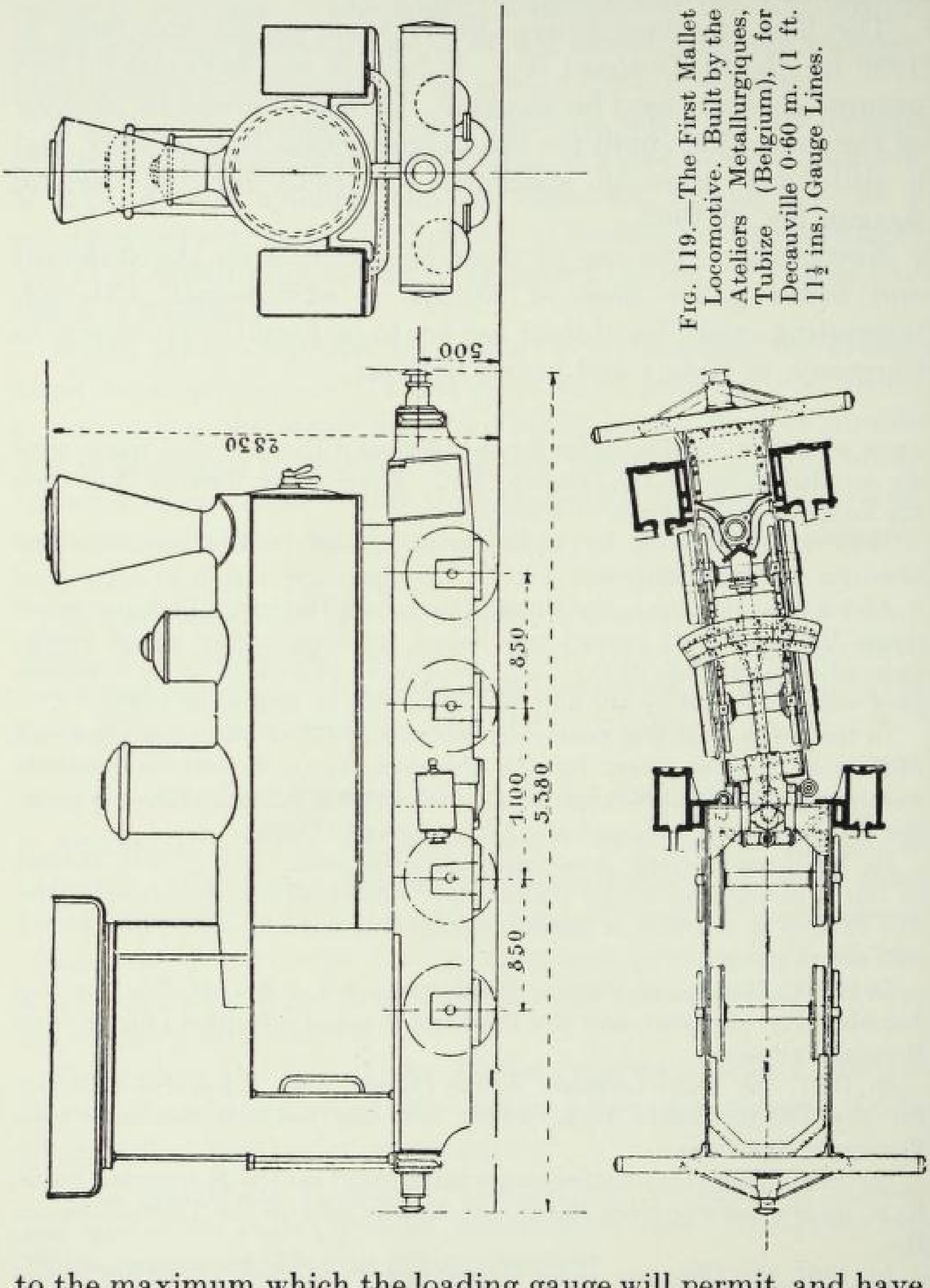


Fig. 119.—The First Mallet Locomotive. Built by the Ateliers Metallurgiques, Tubize (Belgium), for Decauville 0·60 m. (1 ft. 11⅝ ins.) Gauge Lines.

to the maximum which the loading gauge will permit, and have therefore had to increase the length to obtain additional evaporation. And after having used four, and then five coupled axles with rigid locomotives, they have had to use six coupled axles in two groups of three each (*e.g.*, the 0-6 + 6-0 locomotives of the Baltimore and Ohio Ry. and the American R.R. of Porto Rico, built in 1904).*

At this point the question of the stresses in the moving parts of the locomotive had to be taken into account. It therefore became necessary to increase the number of coupled axles in each group to four and subsequently to five,† and in some cases to add pony trucks.‡

The continued increase in the length of the boilers has led to the introduction of reheaters, with the object of compensating for the loss in evaporative efficiency in those portions of the boiler which are furthest from the firebox.

Utilisation of the Mallet Locomotive

As stated in regard to other articulated locomotives, the point at which rigid locomotives have to be superseded by articulated locomotives continually recedes. On standard gauge lines, the use of locomotives with five coupled axles is now normal practice, while on narrow gauge lines locomotives with four coupled axles are often met with. Therefore 0-4 + 4-0 *Mallets* are no longer built.

On the other hand, the great increase in the power of rigid locomotives has caused them to be substituted in some cases for existing *Mallets*, but this does not really affect the use of the latter, because, as the power of rigid locomotives grows, so can that of the *Mallet* be increased.

Mallets are employed for all kinds of service on narrow gauge lines.

On standard gauge lines, they are used, especially in America, for slow and heavy traffic, for banking, and for shunting purposes in large goods yards.

* About this time some *du Bousquet* locomotives were built for the Ch. de fer du Nord (of France), and the Pekin-Hankow Ry. (China). Shortly afterwards the Gt. Northern Ry. (U.S.A.) put into service a double-Mogul (2-6 + 6-2) *Mallet* to replace their Consolidation locomotives on the Cascade Mountain section, obtaining thereby a saving of 34 per cent. in coal consumption.

† The logical result of this development has been the appearance of a double-Decapod (2-10 + 10-2) *Mallet* built in 1918 for the Virginian Ry.

‡ Double-Consolidation (2-8 + 8-2) *Mallets* were used, and the Baltimore and Ohio R.R. introduced a 2-8 + 8-0 type.

Some attempts have been made to use them for high-speed passenger service, but they have not been successful.*

They are also used on logging railways under conditions which somewhat resemble those on secondary lines in Europe.

Some *Mallets* have also been built for use on rack railways, but this seems to be an undesirable application.

Comparison of the Mallet with other Articulated Locomotives

Unlike all other systems, compounding is an essential feature of the *Mallet* design. This reduces slipping, since the two sets of cylinders form a continuous unit as far as steam supply is concerned. If the rear group of wheels driven by the H.P. cylinders start slipping, the steam will pass over to the L.P. cylinders more rapidly than it can be used therein; a back pressure will therefore be set up against the H.P. cylinders, which will stop the slipping.

If the leading group of wheels driven by the L.P. cylinders begin to slip, the steam pressure in the receiver piping will drop, and slipping will cease when the pressure is in equilibrium.

Lastly, if both groups of wheels start slipping (which is unusual), slipping can be stopped by the usual means.

The *Mallet* design allows the use of lighter moving parts than a rigid locomotive of equal power, since the stresses are divided between the two groups. The wheelbase is also less than in most types of articulated locomotives.

On the other hand, the *Mallet* has certain disadvantages. It negotiates curves less satisfactorily than locomotives with two trucks, since the front of the boiler is displaced towards the outside of the curve. This may cause some difficulty in coupling to rolling stock, especially at points and crossings.

Furthermore, as the leading truck must be free to move laterally in reference to the front of the boiler, the centre line of the latter must be at a certain height, which is sometimes a matter of practical inconvenience on narrow gauge lines. It is for this reason that fully articulated locomotives have been most used on narrow gauge lines, while the *Mallet* has been chiefly employed on standard gauge railways.

* The Atchison, Topeka and Santa Fé Ry. has put into service some 4-4 + 6-2 *Mallet* locomotives with driving wheels of 6 ft. 11 ins. (1m.584) diameter.

The Southern Pacific Ry. uses *Mallets* for passenger service on branch lines.

General Features of American Mallet Locomotives

In Europe, *Mallet* locomotives have been, and are, built to the different specifications of various railway administrations. This is hardly the case of America, though the engineers of the various roads co-operate with the builders to some extent in getting out the designs. Although there are so many *Mallets* in use, they have all been built by two large Works, and have many features in common which have to a very great extent been standardised.

It is therefore of interest to study the chief features of these locomotives, the more so as their power is generally far greater than that of their European contemporaries. The first American-built *Mallet* was constructed in 1904.*

Types of American Mallet Locomotives

The great majority of American *Mallets* have separate tenders, and are used either on road service or for banking or shunting.

* It is interesting to note that up to March 15th, 1911, the two great American works had built 539 *Mallets*, of which a list is given in the December issue of the *Bulletin of the International Railway Congress*. The following list shows the locomotives classified according to type. Particulars of the railways using them are only given in the case of the less used types.

Type.	Number Built.	Railways on which these Locomotives were used.
0-4 + 4-0	6	Japan.
2-4 + 4-2	7	Little River Ry., Pekin-Kalagan Ry., Eastman, Gardner & Co.
4-4 + 6-2	2	Atchison, Topeka and Santa Fé Ry.
0-6 + 6-0	27	—
2-6 + 6-2	340	—
2-6 + 8-0	40	Alabama, Gt. Southern, Gt. Northern and Southern Rys.
0-8 + 8-0	36	—
2-8 + 8-2	63	—

It will be seen that at this date the 2-6 + 6-2 was by far the most common type.

At the present day most American *Mallets* are of the 2-8 + 8-2 type, and there are some with ten coupled axles.

There are, however, a small number of tank Mallets, mostly used in logging service or on short lines presenting exceptional conditions.

At the present day, the following classes, according to their wheel arrangements, are in use in America :—

Tank Mallet Locomotives

2-4 + 4-2 for logging roads ;
2-6 + 6-2 for logging roads and for short lines ;

Mallet Locomotives with Separate Tenders

2-4 + 4-2 for private lines and branch railways ;
4-4 + 6-2 for passenger service (Atchison, Topeka and Santa Fé Ry.) ;
0-6 + 6-0 for freight service and banking (American Locomotive Co.'s type) ;
2-6 + 6-0 for similar services (Baldwin type) ;
2-6 + 6-2 for similar services and for passenger traffic Southern Pacific Ry.) ;
2-6 + 8-0 for freight service and banking. These locomotives are reconstructions of earlier types ;
0-8 + 8-0 for freight service and banking (American Locomotive Co.'s type) ;
2-8 + 8-0 for freight service and banking (Baldwin type) ;
2-10 + 10-2 for freight service.

The American Locomotive Co. for a long time advocated total adhesion designs, while the Baldwin Works have always preferred to provide leading and trailing trucks. Occasionally both of these works have departed from their original practice, notably when building *Mallet* locomotives for export.*

* American-built *Mallet* locomotives have been ordered by the following foreign railways :—

5 ft. 6 ins. gauge .	North-Western Ry. (India).
5 ft. 3 ins. gauge .	Central of Brazil Ry.—0-6 + 6-0 and 0-8 + 8-0.
Standard gauge .	Ch. de fer de l'Est (France)—2-6 + 6-0.
	Pekin-Kalgan Ry.
	Pekin-Sunyan Ry.
	Mexican Central Ry.
	Mexican International Ry.
3 ft. 6 ins. gauge .	Imperial Rys. of Japan.
	Guayaquil and Quito Ry. (Ecuador).
	Natal Government Rys., Central South African Rys., and South African Rys.—2-6 + 6-2.

In the case of the larger locomotives, the great length of the boiler impedes the view of the locomotive crew. To remedy this, some of the locomotives which burn liquid fuel are arranged to run cab first, the tender being attached to the smokebox end of the locomotive. This arrangement was previously used on locomotives of the Italian State Rys. and the *Meyer-Kitson* locomotives of the Antofagasta Ry. It was adopted on the 2-6 + 6-2 and 2-8 + 8-2 *Mallets* of the Southern Pacific Ry.

Origin of Various Types

The 0-6 + 6-0 type was first introduced by the American Locomotive Co. on the Baltimore and Ohio R.R. These locomotives weighed 150 tons (152 tonnes). They were followed after some months by some of the same type for the metre gauge American R.R. of Porto Rico, which were built by Baldwin.

The 2-6 + 6-2 type was originated by Baldwin in 1906 for the Great Northern Ry. (U.S.A.). These locomotives weighed 159 tons (161 tonnes).

The 0-8 + 8-0 type was first built by the American Locomotive Co. for the Erie R.R. in 1907. It weighed 183 tons 10 cwt. (186 tonnes).

The 2-6 + 8-0 type was introduced in 1910 on the Gt. Northern Ry. (U.S.A.).

The 2-10 + 10-2 type was also introduced in 1910 by the Atchison, Topeka and Santa Fé Ry. It weighed no less than 275 tons 6 cwt. (279 tonnes).

The 4-4 + 6-2 type is exceptional, and was only used on the latter railway. It appeared in 1909.

The Chief Elements of the American Mallet Locomotives

Since the introduction of *Mallets* on American railways, endeavours have been made to standardise them, so as to reduce the number of types and to obtain interchangeability of their components, both between the *Mallets* themselves and also with the ordinary locomotives used on these railways.

Metre gauge .	The Mogyana and the Paulista Rys. (Brazil).
	Brazil Ry., Sorocabana Ry.
	American R.R. of Porto Rico.
	Burma Ry.
3 ft. gauge . .	Colombian National Rys.

Fuel.—The American *Mallet* locomotives are designed to burn coal (bituminous or lignite), wood or oil, according to the districts in which they are required to work. Oil fuel is much used on the railways in the Southern and Western States, which are in direct connection with the oil-fields of Texas and California.

The use of oil fuel avoids the complications of mechanical stokers. These are necessary for the larger *Mallets*, since a stoker cannot fire more than about $2\frac{3}{4}$ tons of coal per hour,

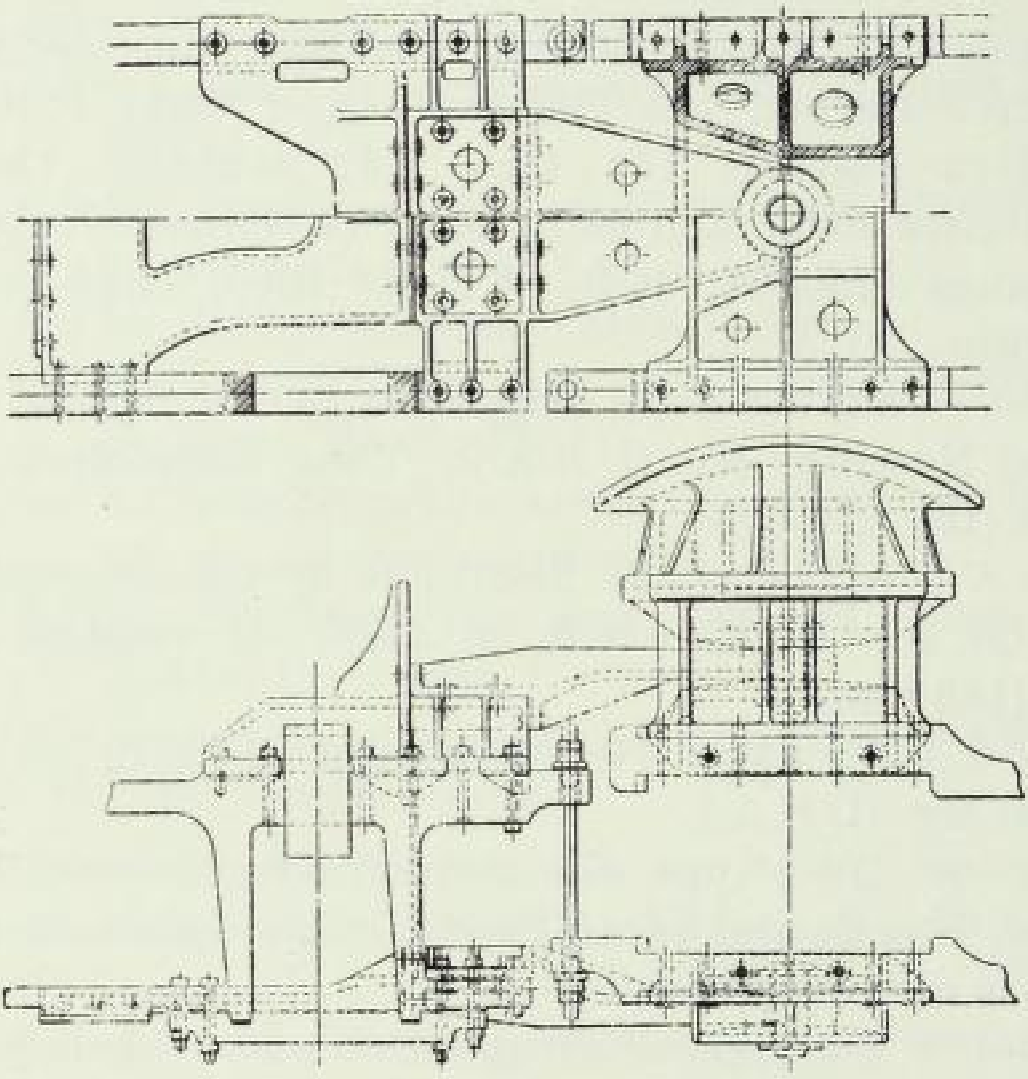


Fig. 120.—Frame Pivot Connection, Baldwin 1906 Mallet (Gt. Northern Ry.).

which produces an evaporation equivalent at most to a continous output of 1,500 h.p., which is considerably below the requirements of these large locomotives.

Frames.—As with rigid locomotives, moulded frames superseded the original built-up bar frames. There are as many as seventeen cross braces between the side members, including the castings of the H.P. and L.P. cylinders.

Articulated Connections.—The two trucks of a *Mallet* locomotive are hinged together by means of a vertical swivel pin, often located slightly ahead of a point midway between the two sets of wheels. This has the advantage of guiding the rear truck into the curves.

Early types of American *Mallets* had a spring centring device for restoring alignment on leaving a curve (see Fig. 124).

Originally, the *Baldwin* frame pivot connection had lateral play, the draft pin being held in a central position by a series of springs. This arrangement was first fitted to the Gt. Northern Ry. (1906) locomotives and was widely used afterwards (Fig. 120).

In subsequent types (1911) these arrangements were altered

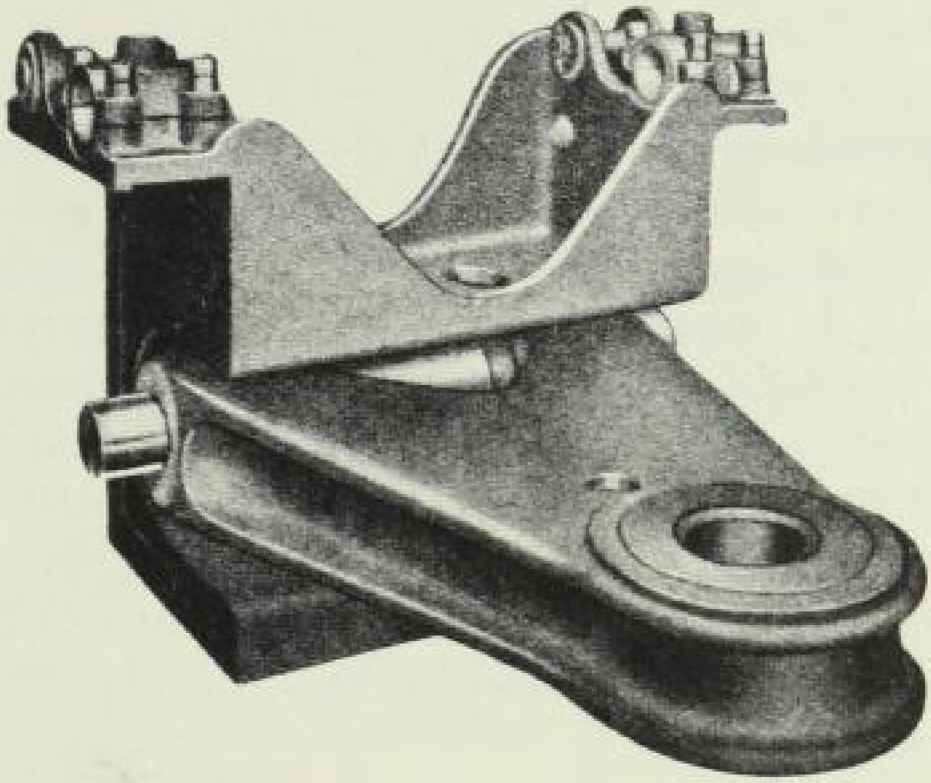


Fig. 121.—Baldwin Type of Flexible Radius Bar.

in accordance with the dictates of several years' practice. The H.P. cylinder saddle, which is made in two pieces separately, riveted to the boiler, carries the hinge pin, and contains a socket in which is placed the ball joint of the receiver pipe. The frame connection is effected by a single radius bar, which also constitutes a brace for the rear ends of the front frames.

The pin is inserted from below, all holes in the radius bar and saddle being bushed. Of course the centre of the hinge pin coincides with that of the ball joint.

The transference of weight between the front and rear frames takes place by simple contact, instead of by the vertical bolts previously used. To obtain this, the saddle is made with a forward extension at each side, which is fitted between the upper and lower rails of the back end of the front frames.

There is a little vertical play, but when this is absorbed, weight transference occurs.

In recent Baldwin *Mallets* (Fig. 121), the joint is formed by a radius bar which is attached at its forward end to a horizontal pin and at its rear end to a vertical pin, thus providing flexibility in a vertical as well as in a horizontal plane. The horizontal pin is supported by a steel casting, which forms a strong transverse brace at the rear of the front frames. As formerly, the vertical pin is placed in the centre line of the locomotive, in a socket formed in the H.P. cylinders. The frames are neither interlocked nor connected by hanger bolts as formerly.

The articulation used by the American Locomotive Co. is somewhat different. A single connection is used between the front and rear systems. It is formed by a radius bar bolted to a cross-tie between the rear ends of the front frame. This arm fits in a socket casting bolted to the bottom rails of the rear frames. A vertical pin, 6 ins. in diameter, makes the connection, and is inserted from the top ; the frames can move vertically in relation to each other without binding.

In the 2-8 + 8-0 *Mallet* of the Pennsylvania R.R., which has four H.P. cylinders, the articulation is effected thus :—

A steel casting having a jaw-shaped opening 11 ins. (0·28 m.) in width is bolted between the rear frames. This opening embraces a case-hardened steel sphere, through which passes a hardened steel pin.

The sphere works in a wrought-iron bearing carried on an extension of the saddle casting of the L.P. cylinders. This bearing is split on its horizontal diameter, the two halves being united by bolts.

Spring Buffers at Frame Union.—These were first applied by the American Locomotive Co. to locomotives built for the Erie R.R., and used for the large Delaware and Hudson *Mallets*. They are located in the pocket casting of the articulated connection and, on a tangent, they just touch the bumper castings bolted to the cross-tie at the rear end of the front frames. Compression of one of the buffers takes place as soon as the locomotive enters a curve.

Boiler Supports.—The boiler is rigidly attached to the rear frame, but must be supported on the front frame, the supports sliding laterally to allow the front truck to enter the curves.

In the earlier types, the boiler rested on the front system by means of three supports: a self-adjusting sliding bearing, a pair of columns and a pair of hinge bolts.

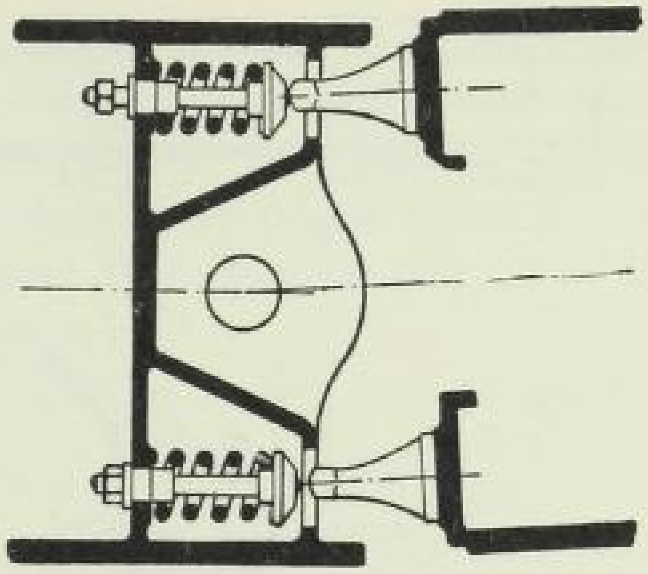


Fig. 122.—Spring Bearing Buffers at Frame Union (Delaware and Hudson Ry.).

In the American Locomotive Co.'s type (Delaware and Hudson Ry.), the sliding support consists of a saddle which,

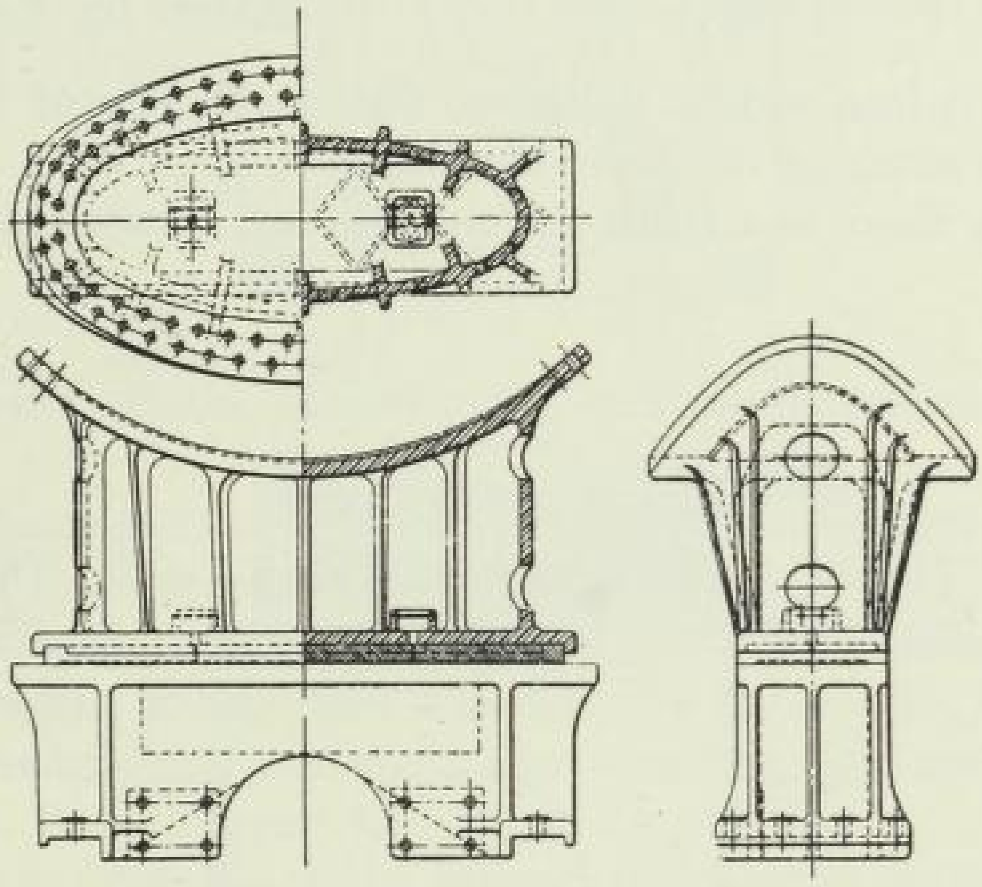


Fig. 123.—Main Boiler Bearing (1906 Gt. Northern Ry. Mallet).

through the intermediary of a case-hardened steel slide, carries a cast-steel transom (Fig. 125).

Further forward is a second sliding support which normally bears no weight and carries a floating balance device, consisting of elastically supported columns which are free to sway as the engine turns through curves (see Fig. 126). At their upper ends these columns have ball and socket connections

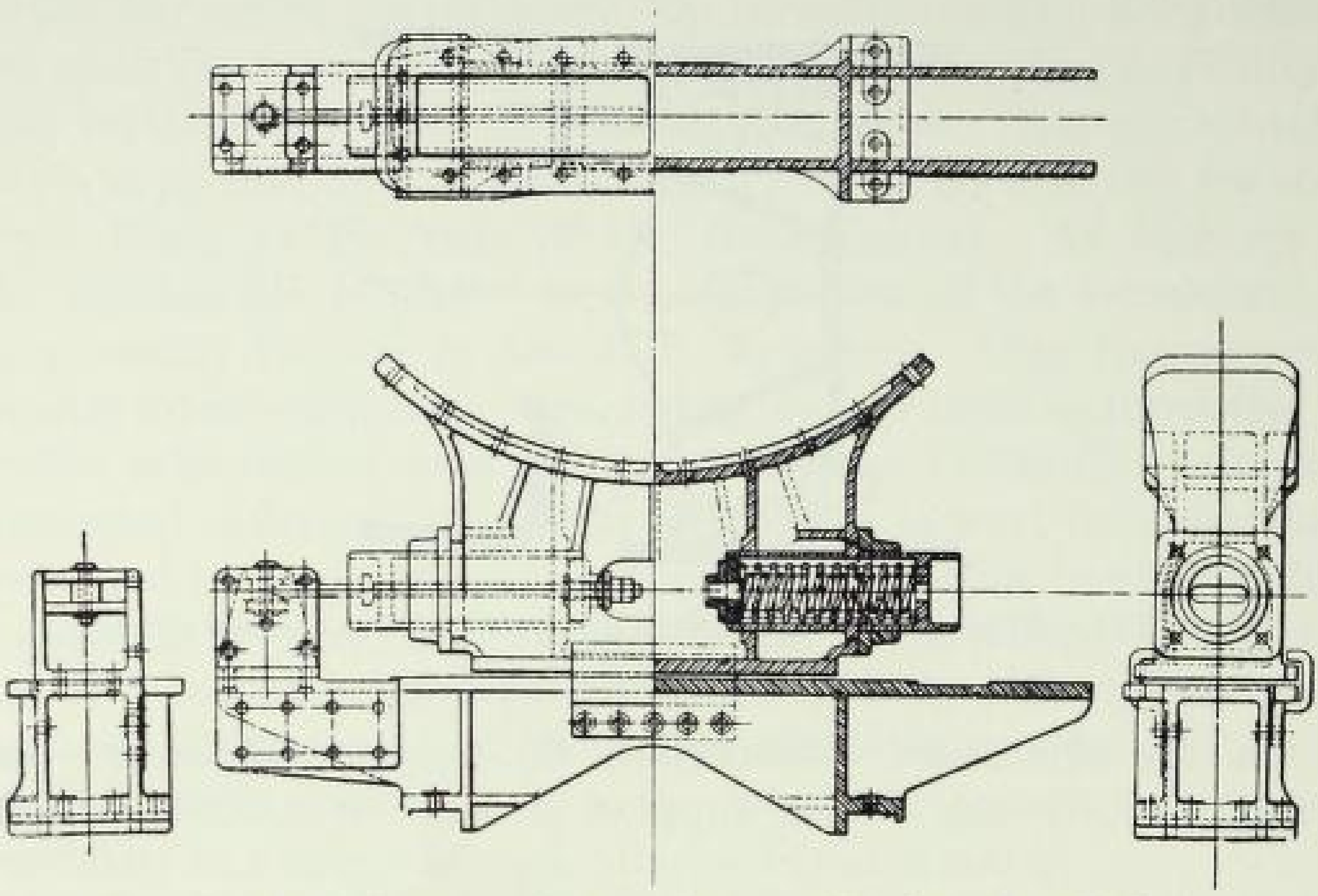


Fig. 124.—Spring Centring Device (Gt. Northern Ry. Mallet).

with a cast-iron saddle bolted to the under side of the boiler. There is a centring device to this support.

Finally, there is a third sliding support, consisting of a pair

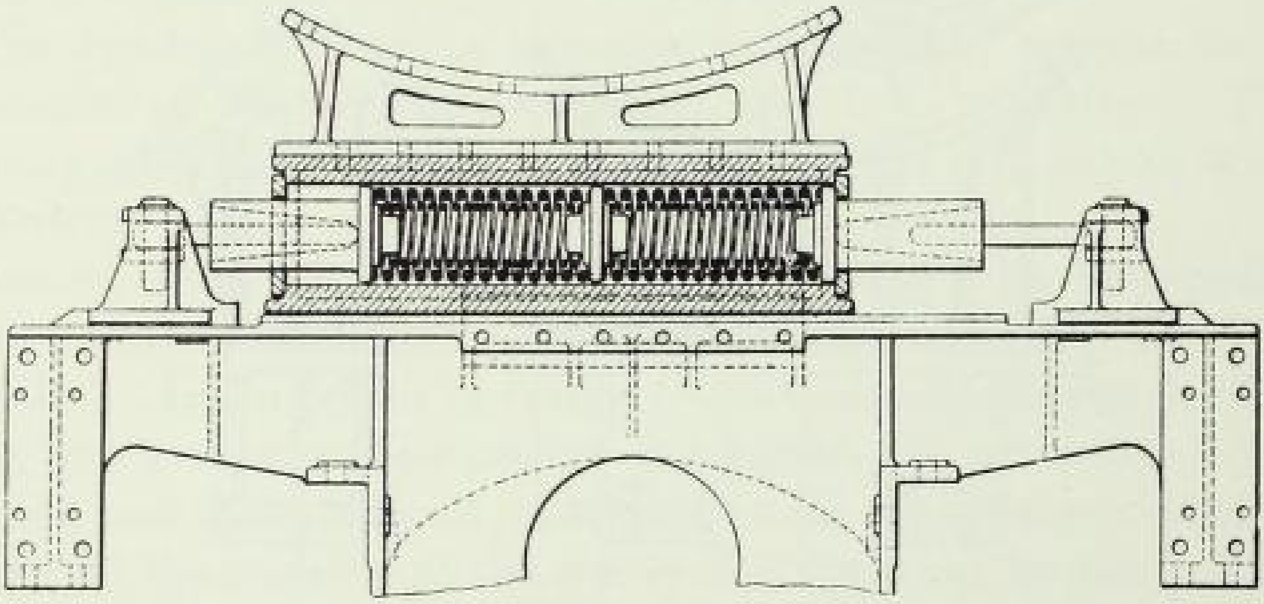


Fig. 125.—Spring Centring Device (American Locomotive Co.).

of adjustable hinge bolts which connect the top rails of the front frames and the bottom rails of the rear frames, and serve to equalise the two systems together and adjust the alignment of the truck in any position.

More recent types have but a single support for the boiler, in spite of the fact that its weight has so considerably increased and the complicated centring devices which were once used are now dispensed with.

The Boiler.—One of the reasons which first led to the adoption of the *Mallet* principle in America was the need for increasing the length of the boilers on the most powerful locomotives, which in some cases exceeds 46 ft. (14 m.). It is not therefore surprising that many modifications are to be found in these boilers.

The diameter of the boiler is necessarily limited by the

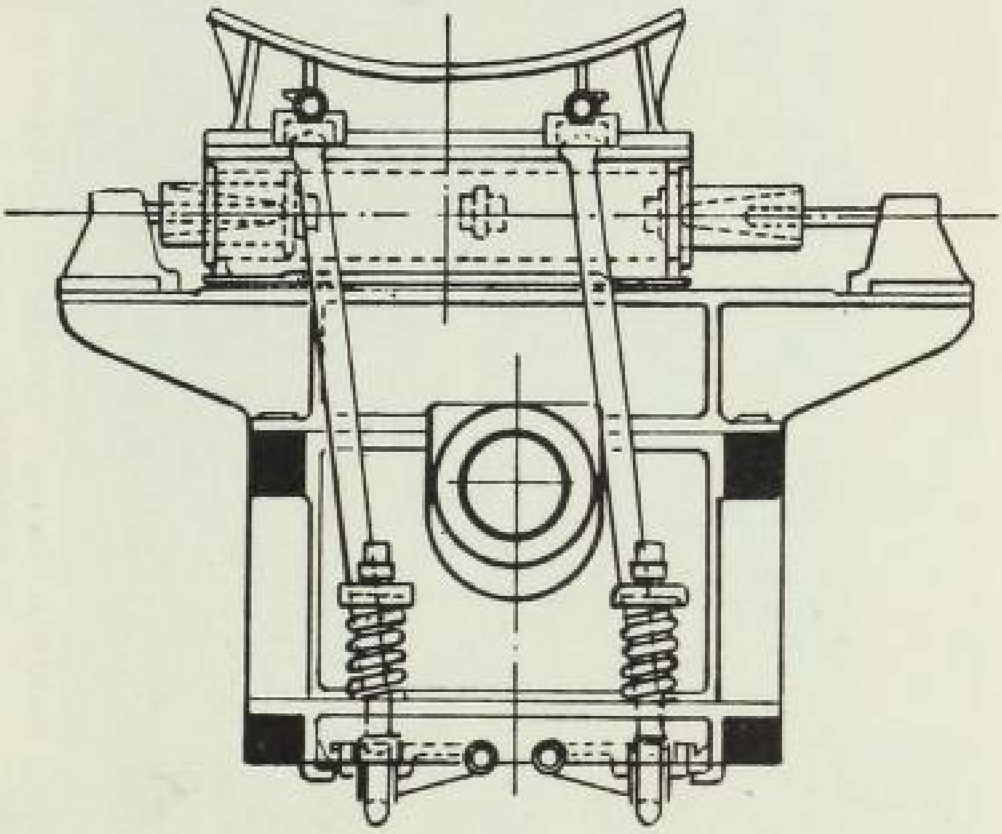


Fig. 126.—Floating Balance Device, Erie R.R. Mallet (American Locomotive Co.).

loading gauge, and in many cases the maximum diameter is 7 ft. 6 ins. (2·29 m.).*

The boiler diameter has increased to such an extent that, in recent *Mallets*, it has been necessary to flatten the lower part in order to provide sufficient clearance over the exhaust pipe and the L.P. cylinders when traversing curves.

Superheating has been almost universally applied to all *Mallet* locomotives, but in different ways.

Some early types had a superheater in the central portion

* Some boilers exceeding this diameter are, however, to be found, *e.g.*, the 2-8 + 8-2 *Mallets* of the Norfolk and Western Ry., 8 ft. 2 ins. (2·49 m.), those of the Virginian Ry., 9 ft. 2½ ins. (2·81 m.), and the 2-10 + 10-2 *Mallets* of the same railway, 9 ft. 5 ins. (2·87 m.).

of the boiler. It consisted of vertical double-coiled elements, which were fixed at their upper ends, allowing the lower ends to expand under the action of the heat.

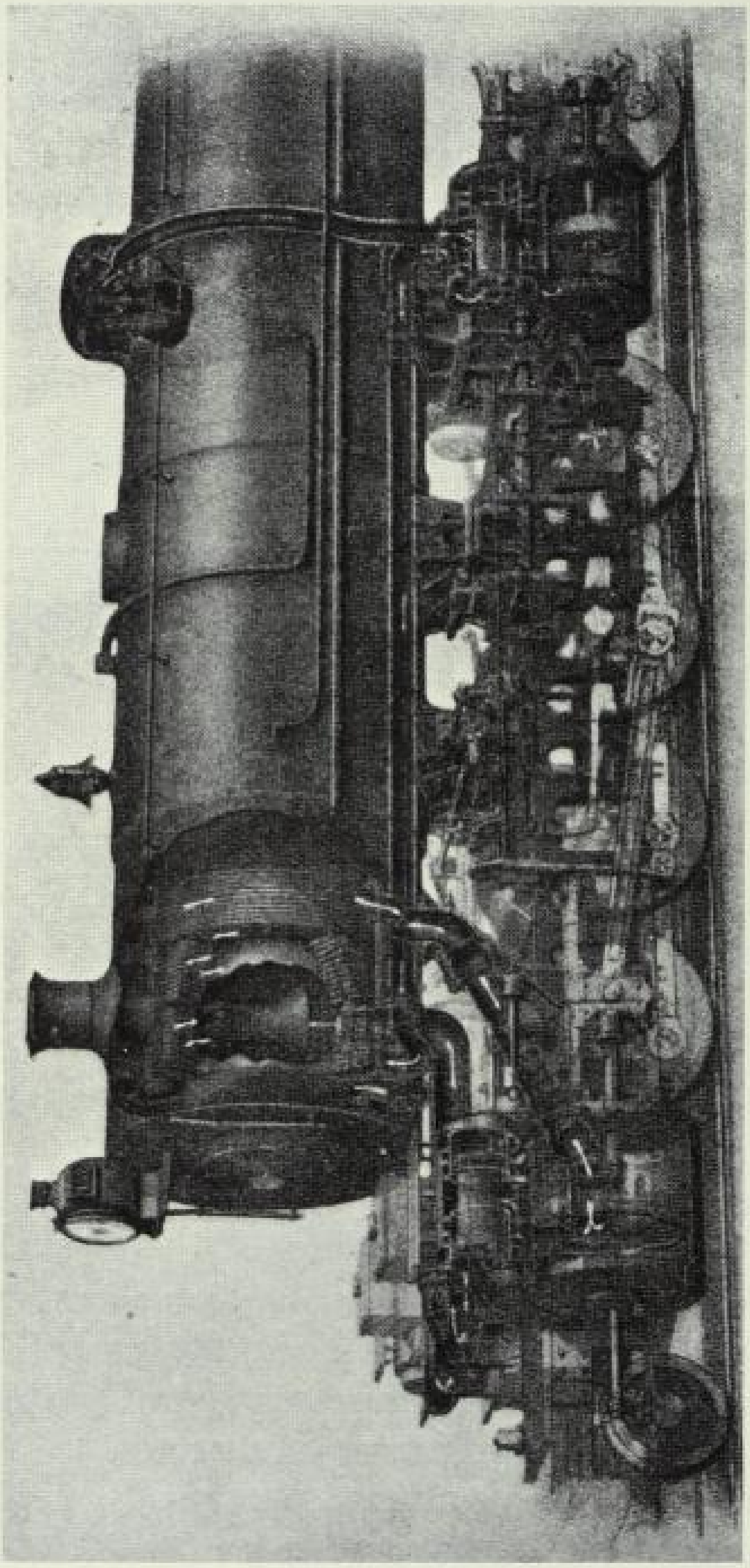


Fig. 127.—Piping Arrangement of Baldwin Mallet Locomotive equipped with Baldwin Reheater in Smokebox.

Emerson superheaters were used on some lines, but the *Schmidt* superheaters have been the more generally applied.

Mention must be made of the *Baldwin* reheater or L.P. (Fig. 127) superheater because of the number of locomotives it has been applied to. It was placed in the smokebox, the water being fed into it at its lower end, discharged at the top, and then forced into the evaporative section of the boiler.

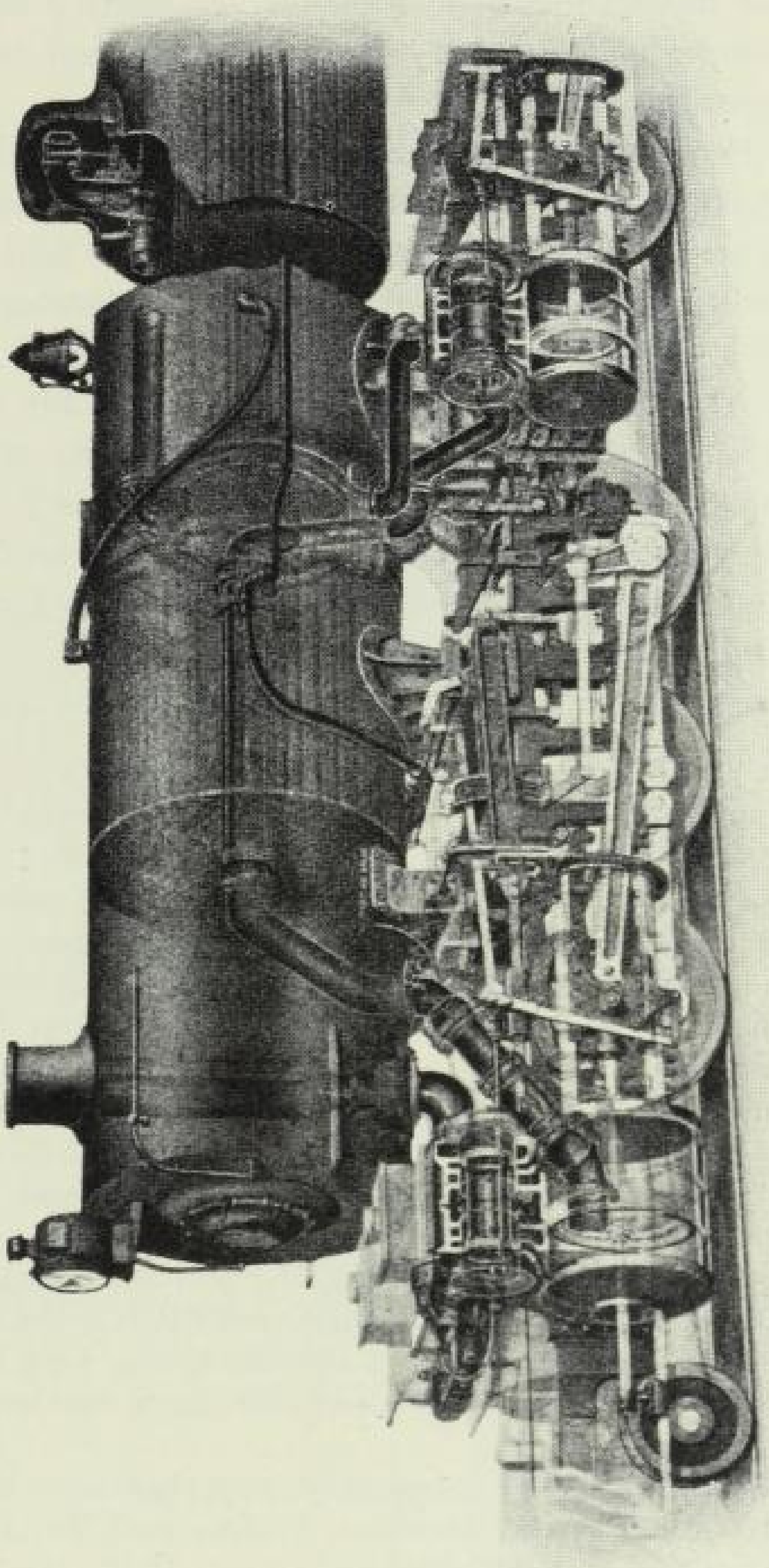


FIG. 128.—Front Portion of Baldwin Separable Boiler (Southern Pacific Passenger Locomotive).

Fire tubes cross the reheater and bring the feedwater to a temperature of some 250° F.

Improvements in the design of H.P. superheaters have enabled the builders to do away with these reheaters, and in modern locomotives the steam pipes extend back from the superheater header in the smokebox to the H.P. cylinders, where the distribution is controlled by piston valves. Piston or double-ported flat slide-valves are used on the L.P. cylinders.

Mention must nevertheless be made of *Baldwin's* separable boilers, which include a number of devices destined to economise or better employ steam (Fig. 128).

SEPARABLE BOILERS.—A number of the older Baldwin *Mallets* had separable boilers,* which were constructed in two sections united by a separable joint (Figs. 128, 129 and 130).

The front section usually contained a feedwater heater (L.P. reheater),† generally consisting of a complete tubular system. There was also sometimes a superheater for the L.P. steam, which was located in the smokebox and was analogous to the steam dryer of ordinary Baldwin locomotives.‡

There was an open chamber between the front section and the boiler proper. The separable joint, which was formed by two external rings, surrounded this open space.

The rear part of the barrel contained the tubes and often the H.P. superheater.§

* The following *Mallets* were provided with separable boilers: Types 2-6 + 8-2, 4-4 + 6-2, 2-8 + 8-2, 2-10 + 10-2 of the Atchison, Topeka and Santa Fé Ry.; the 2-6 + 8-0 of the Gt. Northern Ry.; the 2-8 + 8-2 of the Southern Pacific R.R., the Virginian Ry., the Duluth, Missabe and Northern Ry., the St. Louis, Iron Mountain and Southern Ry., the Norfolk and Western Ry., the Oregon R.R. and Navigation Co., etc.

† The following *Mallets* were fitted with feed-water heaters: the 2-6 + 6-2 of the Carolina, Clinchfield and Ohio Ry.; the 2-6 + 6-2, the 4-6 + 6-2 and the 2-8 + 8-2 of the Atchison, Topeka and Santa-Fé Ry.; the 2-6 + 8-0 of the Southern Ry. and of the Gt. Northern Ry.; the 2-6 + 6-2 and the 2-8 + 8-2 of the Southern Pacific R.R.; the 2-6 + 6-2 of the Chicago, Burlington and Quincy R.R.; the 2-8 + 8-2 of the Virginian Ry., the Duluth Ry., the St. Louis, Iron Mountain and Southern Ry., the Norfolk and Western Ry., and the Oregon R.R. and Navigation Co.

‡ The following *Mallets* had Baldwin L.P. superheaters: the 2-6 + 6-2, 4-4 + 6-2, 2-8 + 8-2 of the Atchison, Topeka and Santa Fé Ry.; the 2-6 + 6-2 of the Chicago, Burlington and Quincy R.R.; the 2-6 + 8-0 of the Alabama Great Southern R.R.; the 2-8 + 8-2 of the Southern Pacific R.R., the Virginian Ry., the Duluth Ry., the Norfolk and Western Ry., the Oregon R.R. and Navigation Co., etc.

§ Schmidt superheaters were used on the St. Louis, Iron Mountain and Southern Ry. Emerson superheaters on the Great Northern Ry., the Chicago, Burlington and Quincy R.R., etc.

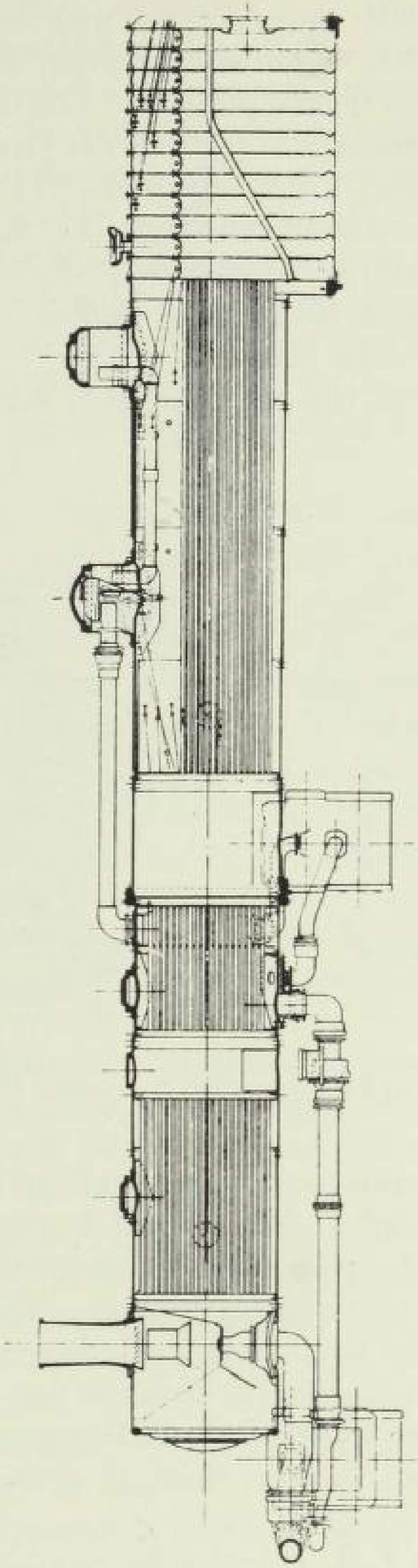


Fig. 129.—Longitudinal Section of Baldwin Separable Boiler. Passenger 2-6 + 6-2 Mallet Locomotive (Atchison, Topeka and Santa Fé Ry.).

In other locomotives the rear section of the boiler barrel contained both H.P. and L.P. superheaters, which were located in front of the firebox. They were separated from the feedwater heater on the one hand, and from the tube assemblage on the other, by combustion chambers. These two superheaters were only separated by a tube plate into which their tubes were dudgoned. The circulation of the gas was prolonged by means of baffle plates, so that a portion of the residual heat in the flue gases, after their passage through the main boiler tubes, was absorbed. A further portion was absorbed in the feed-water heater, the feed being thus raised to a temperature approximating to boiling point.

The boiler barrel, in this arrangement, contained therefore

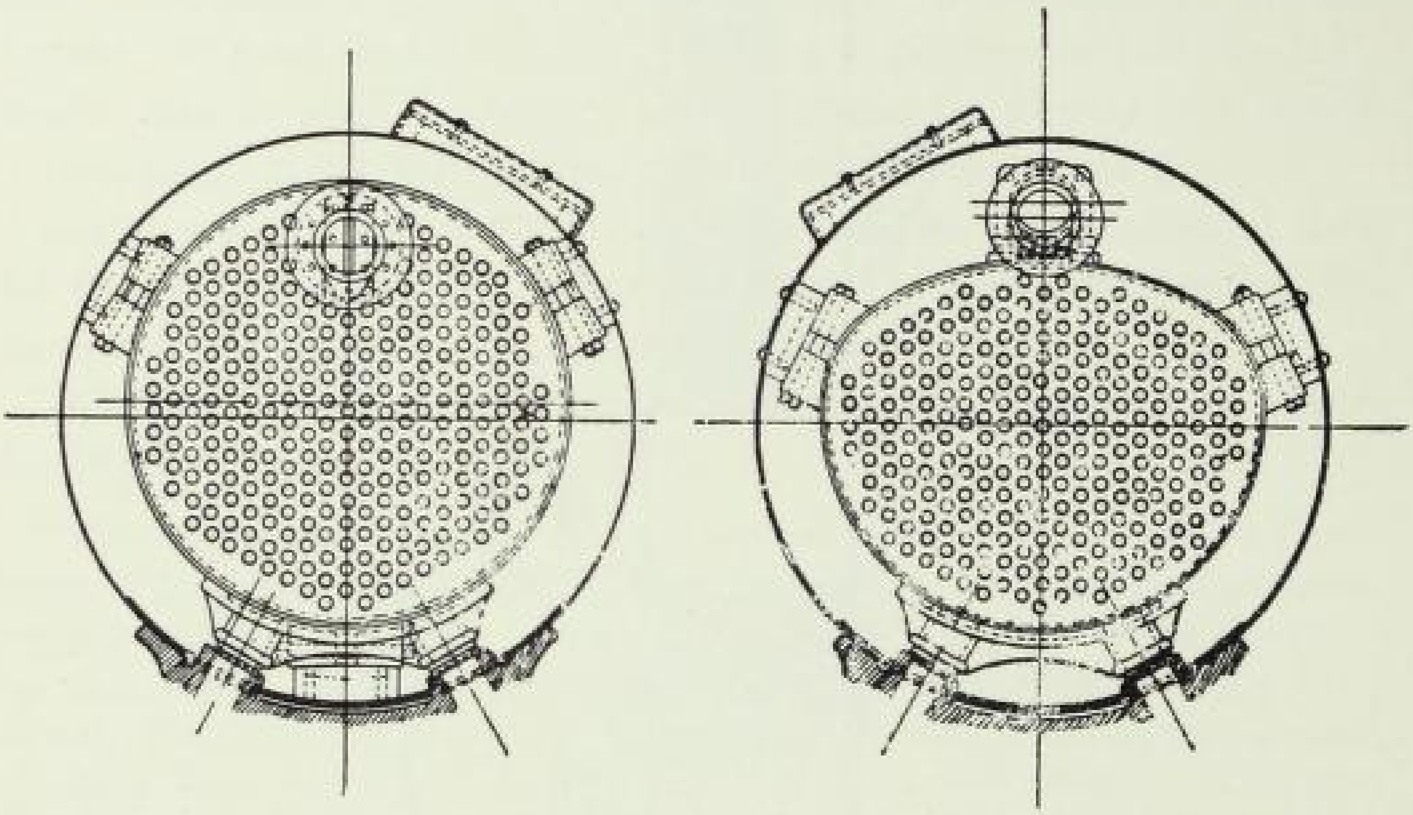


FIG. 130.—Cross Section of Separable Boiler, showing Baldwin Superheater and Reheater.

the following components (counting from front to rear) : a feed-water heater, a combustion chamber, a L.P. superheater, a H.P. superheater, a second combustion chamber, the tube assemblage of the boiler proper and the firebox. The water from the feed heater passed up to a dome and thence into the boiler proper. The steam generated was taken into a second dome, whence it passed successively to the H.P. superheater, the H.P. cylinders, the L.P. superheater, the L.P. cylinders, and thence to the exhaust.

In other cases the L.P. superheater consisted of a receiver pipe or a set of tubes situated in a large flue.*

* For example, in the case of the 2-6 + 6-2 of the Chicago, Burlington and Quincy R.R., and the 2-6 + 8-0 of the Gt. Northern Ry.

Between the H.P. cylinders and the reheater, which is arranged in the smokebox like a Baldwin superheater, the H.P. exhaust steam flows through external pipes, on the lower side of the boiler, which discharge it into the lower reheater drums. It then crosses both sections of the reheater either by means of a single flue (as on the *Southern Pacific*), or through a nest of small tubes (as on the *Virginian* and on the *Duluth, Missabe and Northern*) and connects by an elbow with the flexible receiver pipe which runs obliquely down and frontwards from the lower portion of the smokebox to the L.P. cylinders. This receiver pipe is flexible and has similar joints to those of the usual type.

The reheating surface is small (particularly in the case of the single flue), but it has been contended that this drawback is counterbalanced by the advantage accruing from the fact that protection is afforded by placing the flue inside the reheater. The nest of tubes seems to be a better arrangement, but this is discounted to a certain extent by drawbacks from the maintenance point of view.

The arrangement of the heaters is not always identical.

The rear section of the boiler contains the fire tubes and, occasionally, a superheater of the type " in the tubes."

THE CYLINDERS.—Most American *Mallets* are four-cylinder compounds. The arrangement of the cylinders is always the same : the H.P. cylinders driving the rear truck and the L.P. cylinders driving the front (mobile) truck. The steam passes from the H.P. to the L.P. cylinders by a long receiver pipe with a universal and telescopic joint. Similar pipe-work leads the exhaust into the blast pipe.

The diameter of L.P. cylinders has reached as much as 50 ins. (1·27 m.) on the Virginian Ry. locomotives. This may be considered the maximum for the present loading gauge.

The largest diameter yet attained for H.P. cylinders is $30\frac{1}{2}$ ins. (0·78 m.).*

The pistons are often fitted with tail rods. The stroke is generally 32 ins. (0·81 m.).†

In view of the increasing power of recent types of *Mallet* loco-

* On the 2-8 + 8-0 locomotives of the Pennsylvania R.R.

† The 2-8 + 8-2 locomotives built for the Atchison, Topeka and Santa Fé Ry. have a stroke of 34 ins. (0·87 m.), but this length of stroke has now been given up.

motives, it would seem necessary still further to increase the above dimensions. But it is a difficult matter to accommodate

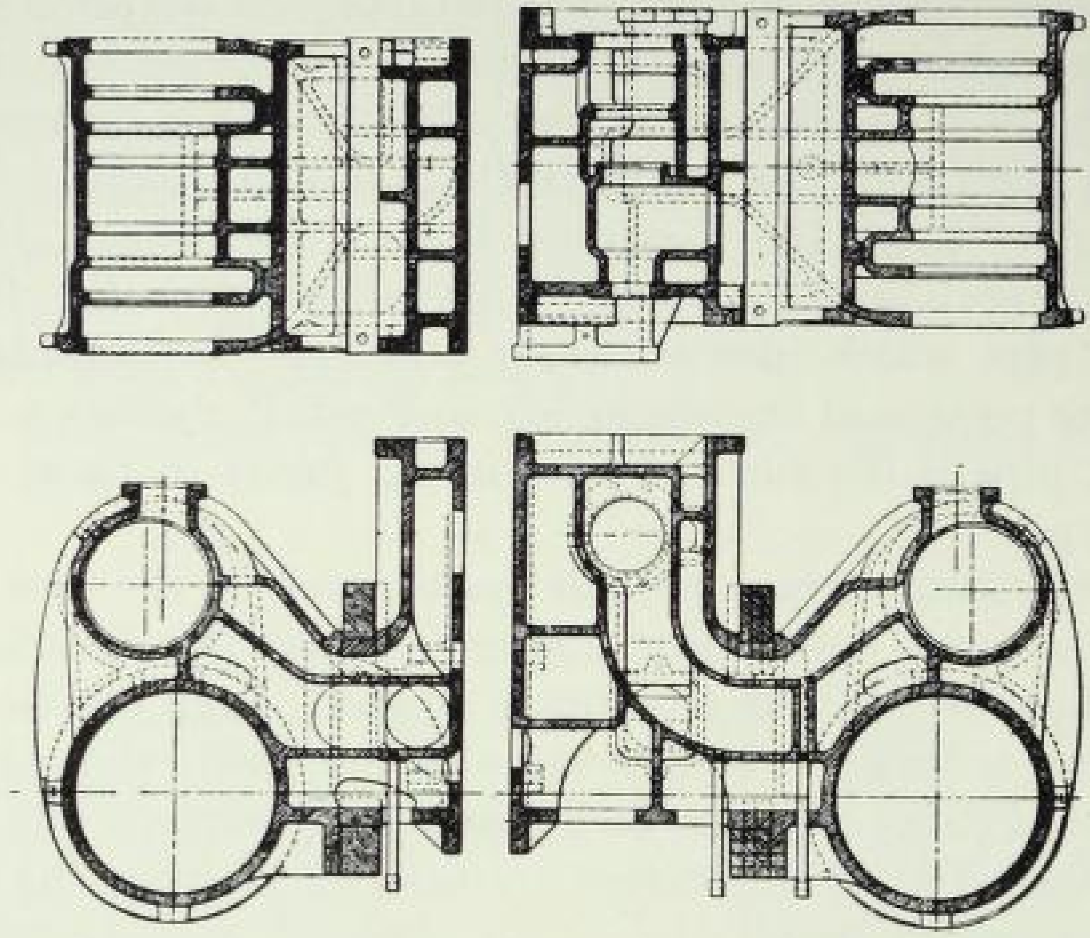


FIG. 131.—Cross Section of Right and Left Hand H.P. Cylinders (American Locomotive Co.).

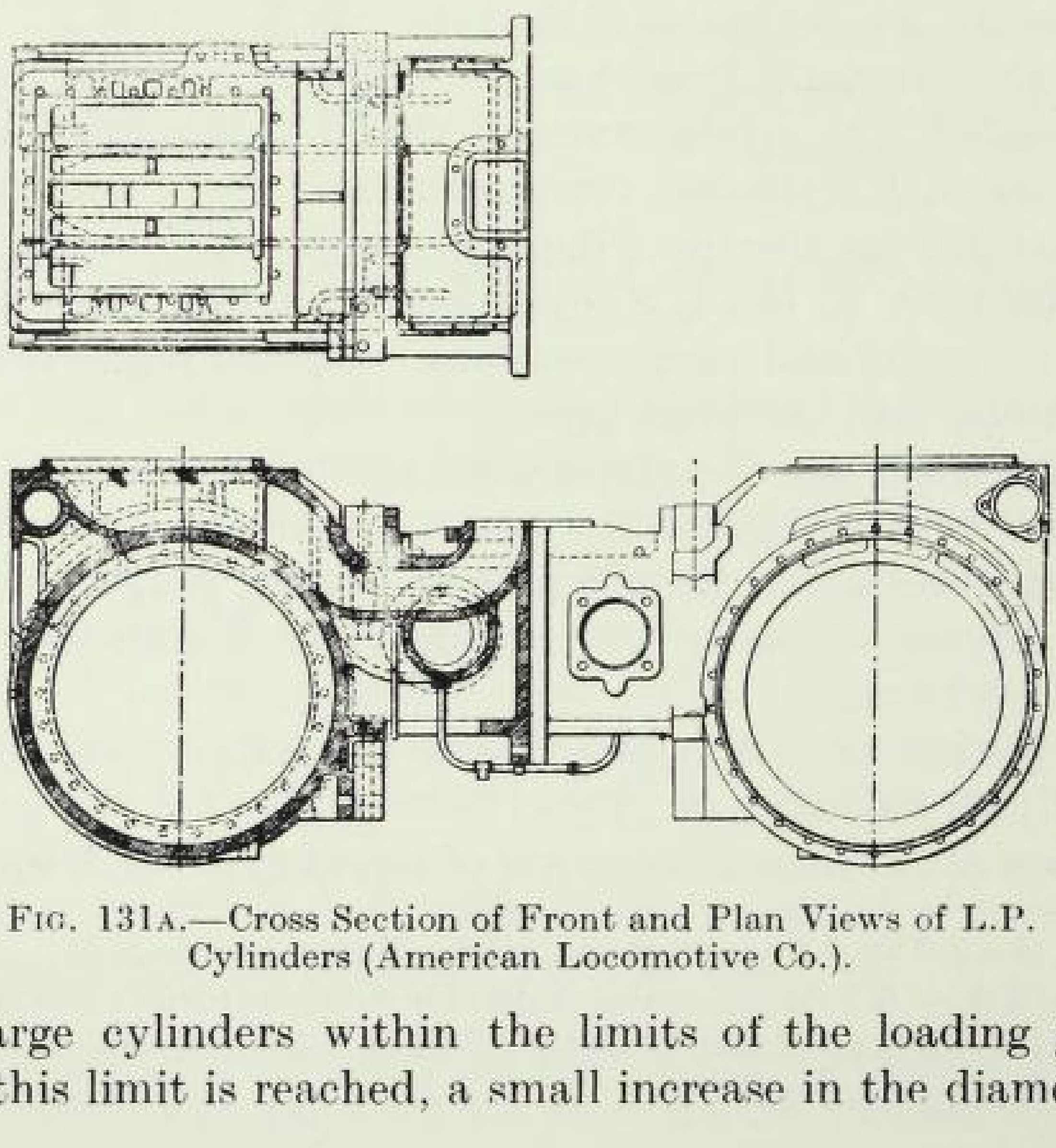


FIG. 131A.—Cross Section of Front and Plan Views of L.P. Cylinders (American Locomotive Co.).

such large cylinders within the limits of the loading gauge. When this limit is reached, a small increase in the diameter of the L.P. cylinders can be effected by inclining them. When this addition is still insufficient, recourse must be had to an increase in the boiler pressure, in order to obtain increased tractive force without increased cylinder diameter. Thus, while the boiler pressure was formerly 200 lbs./sq. ins. (14 kg./sq. cm.), pressures of 225 and even 240 lbs./sq. ins. (16 and 17 kg./sq. cm.) are now to be met with on standard American *Mallets*.

Finally, this necessity for very large L.P. cylinders has led several railway administrations to abandon compounding and revert to four-cylinder simple working, with which we deal separately hereafter, as this alters one of the basic principles of the *Mallet* locomotive.

In the past the H.P. cylinders have had piston valves with interior admission, while the L.P. cylinders have had flat slide valves, often of the Richardson type, but, since the introduction of superheat, piston valves have usually been fitted to all four cylinders.

In the earlier locomotives, the H.P. cylinders were often separate castings, bolted to the front ends of the double bars of the rear frame. The L.P. cylinders were likewise bolted to the box-shaped casting which formed part of the front truck (Atchison, Topeka and Santa Fé Ry.). In later types (Delaware and Hudson, 1911) (Fig. 131) each H.P. cylinder and its valve is a single casting with a half-saddle piece. They are united to the boiler barrel by a steel casting of the right-hand cylinder, by which the exhaust from this cylinder is directed backwards; thence it passes by an external U-pipe to a steam passage in the casting of the left-hand cylinder. This passage terminates in the chamber which contains the intercepting valve. The exhaust from the left-hand cylinder terminates in the same chamber.

The relief valve is located in the side of the left-hand cylinder casting, and an articulated pipe connects it to the rear of the blast pipe. It is operated by a three-way valve.

The L.P. cylinders are also cast integral with a half saddle.

The receiver pipe is connected to the H.P. cylinders by a universal joint. At the L.P. end it is connected to the rear of the L.P. cylinders by a cast U-pipe which leads the steam to the steam chests of the L.P. cylinders.

In the Baldwin *Mallets*, steam is either admitted to the receiver pipe through a manually controlled valve in the cab or by using an automatic valve which is placed in a pipe connecting one of the H.P. steam pipes with the receiver pipe. This valve closes as soon as the receiver pipe pressure builds up on account of the H.P. exhaust.

An arrangement of intercepting and reducing valves allows the *Mallets* to work as single expansion engines. The H.P. cylinders then exhaust directly into the chimney and the reduc-

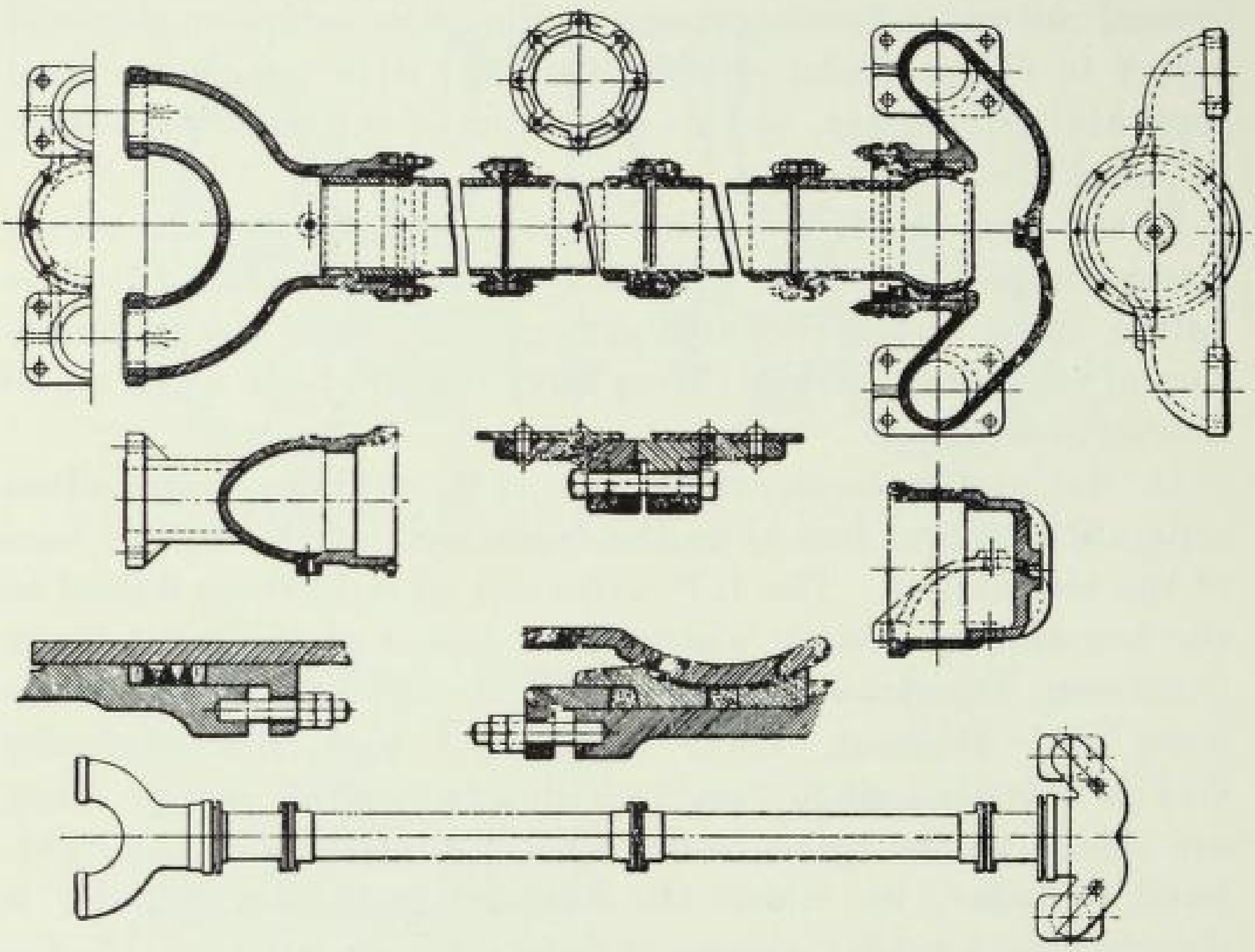


Fig. 132.—Receiver Pipe between the H.P. and L.P. Cylinders (Gt. Northern Ry. 1906 Mallet—Baldwin).

ing valves admit steam at a reduced pressure into the receiver pipe, from which it flows into the H.P. cylinders.

Steam Piping.—A great deal of care has been exercised in the location of the steam pipes. They should not be too much exposed, so as to reduce loss of heat, and they should have the fewest possible number of articulated connections, as these are necessarily weak points. This is the reason why for some years lower boiler pressures were in favour, but higher working pressures and fewer articulated joints are features of modern practice.

In the earlier types two outside pipes, one on either side of the boiler, led the steam directly from the dome to the cylinders. But when the dimensions of the firebox increased and the cab

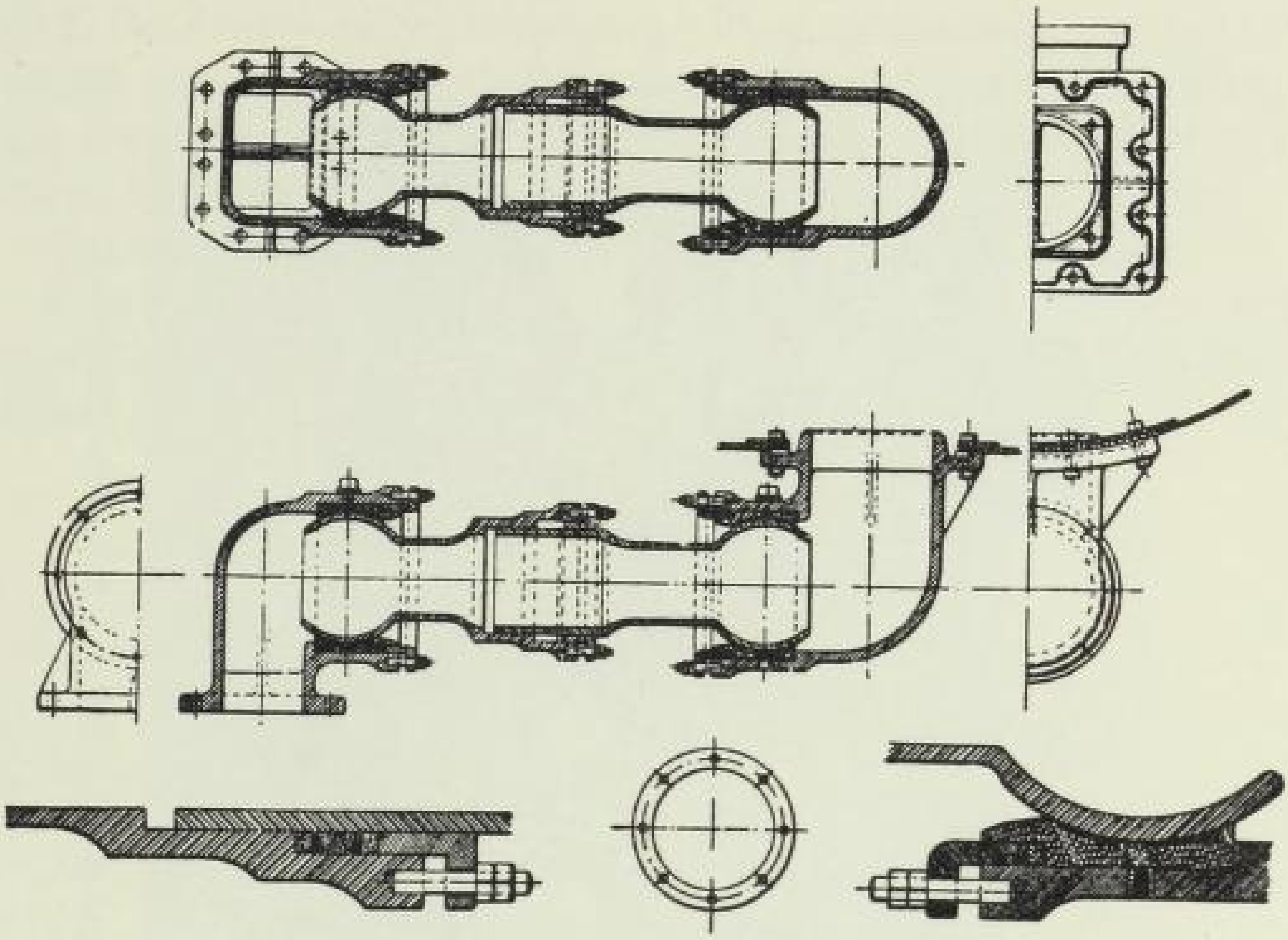


FIG. 133.—Exhaust Piping (Gt. Northern Ry. 1906 Mallet—Baldwin).

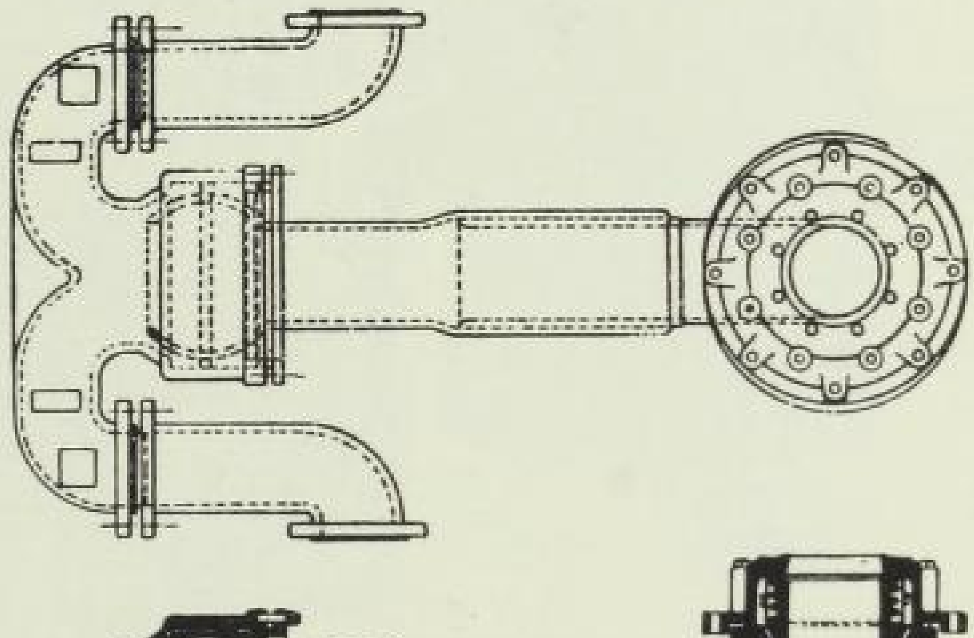


FIG. 134.—Flexible Exhaust Pipe (Baldwin Type).

was located above it, a different arrangement of piping became necessary.

In the Delaware and Hudson (1911) *Mallet*, steam is fed by a throttle to a dry pipe which runs to a tee head situated in the smokebox and thence to the two usual branch pipes on either side. These are in turn connected by means of ball joints with

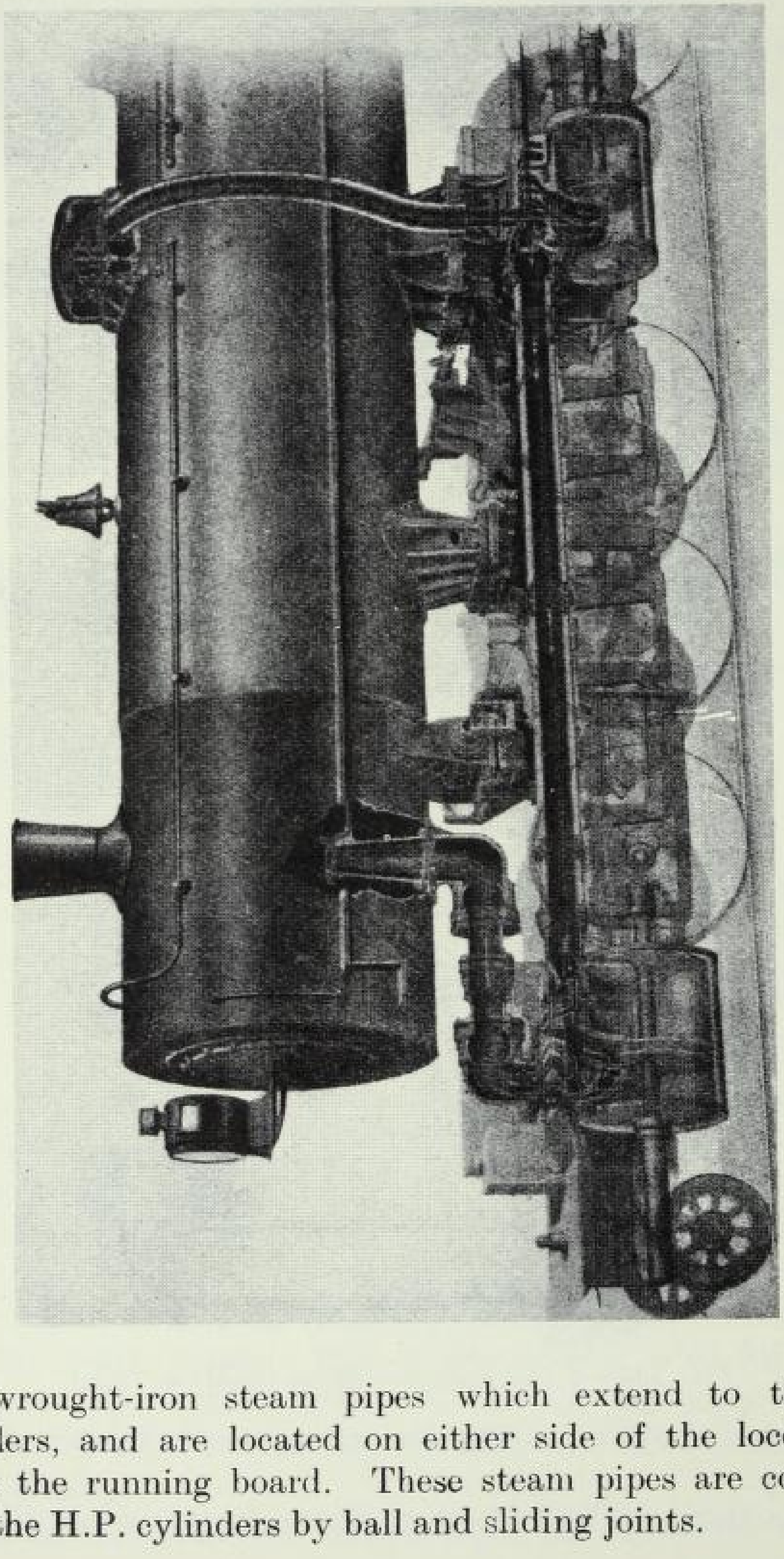


FIG. 135.—Arrangement of Piping (Gt. Northern Ry. 2-6 + 6-2 Mallet—Baldwin).

two wrought-iron steam pipes which extend to the H.P. cylinders, and are located on either side of the locomotive, under the running board. These steam pipes are connected with the H.P. cylinders by ball and sliding joints.

The receiver pipe between the two sets of cylinders is located along centre line of the locomotive with a ball joint at the back end (Gt. Northern Ry.). The centre of this joint coincides with the centre of the articulated frame connection, so that the length of the receiver pipe is constant whatever the position of the front truck may be. Expansion and contraction are provided for by a telescopic joint on the front end of this pipe.

Valve Gear of the Walschaert type is generally used.

Power Reverse Mechanism is, of course, fitted; it is operated either by compressed air or by means of an auxiliary steam connection.

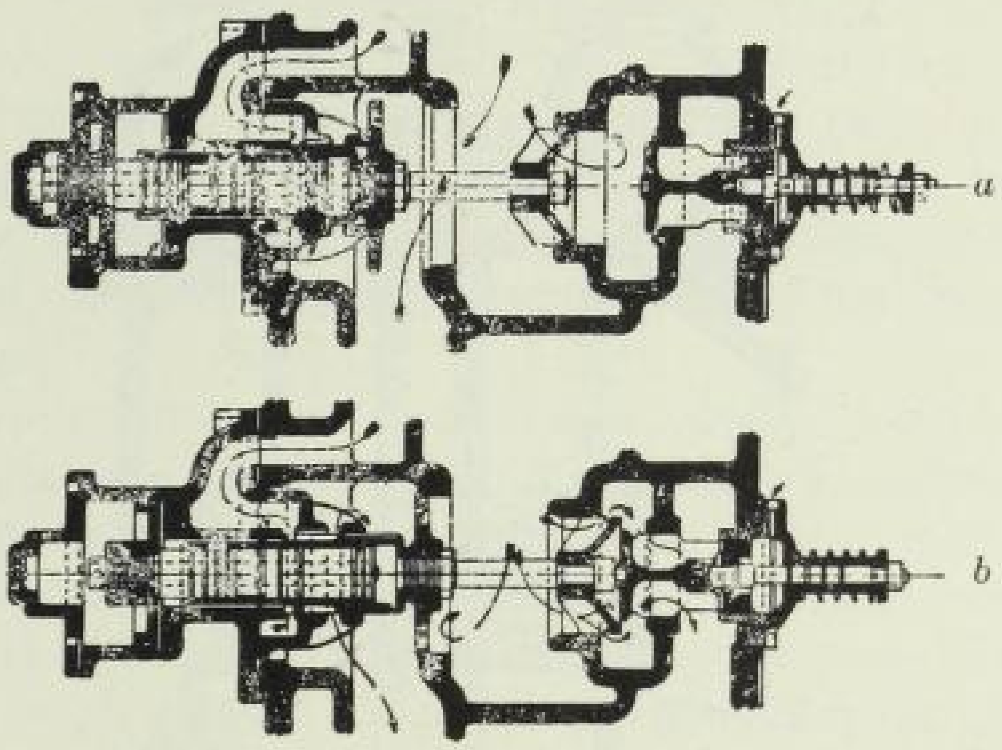


Fig. 136.—American Locomotive Co.'s Type of Intercepting Valve. (*a*) Compound Working; (*b*) Working Simple.

In the Baldwin locomotives, the reach-rod connection to the reverse shafts of the front and back engines is placed on the centre line of the locomotive, and is provided with a flexible joint which slides on guides secured to the inner walls of the H.P. saddle. This joint is placed immediately above the articulated frame connection.

Starting Valve.—This is located in the casting of the left-hand H.P. cylinder. As shown in Fig. 136, it has three elements. Two of these, the starting valve and the reducing valve, are rigidly interconnected and function automatically. The third element—the relief valve—is operated from the cab. The two former valves supply the receiver pipe and the L.P. cylinders with steam at a reduced pressure and, in order to avoid any reaction on the H.P. cylinders, the exhaust therefrom is sent direct to the atmosphere through the relief valve when the locomotive is working single expansion.

THE THROTTLE.—Fig. 137 is the standard American Locomotive Co.'s throttle. It is provided with a separator at the top, where alone steam is admitted. This steam immediately meets a sharp turn downwards, whereby the suspended water is entrapped and forced downwards by the inertia of the trap.

HEATING SURFACE.—The total heating surface is as much as 8,600 sq. ft. (800 sq. m.) in the double-Decapods of the Virginian Ry.

Incidentally, it should be noted that in these locomotives the

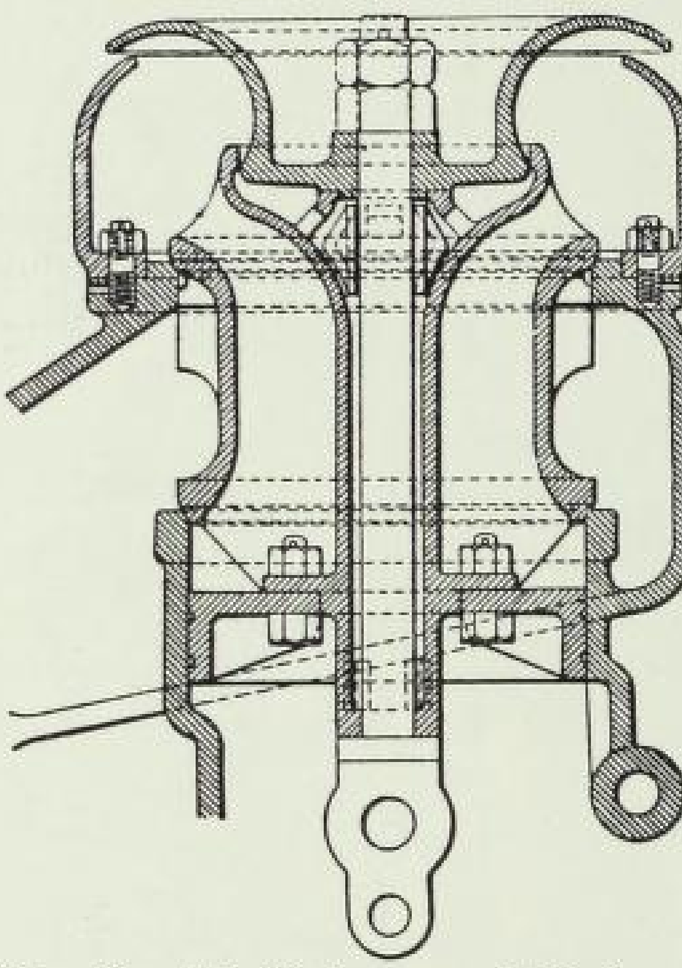


FIG. 137.—Throttle (Delaware and Hudson Mallet).

heating surface is measured externally, and is about 10 per cent. more than the actual surface in contact with the products of combustion. For their calculations, Americans use the "equivalent" heating surface, which is the total heating surface of firebox and tubes, plus one and a half times the surface of the superheater. This figure is obviously purely empirical. But the same remark applies to European figures for total heating surface, which is simply the surface of firebox and of the tubes, whatever may be the length of the latter and the ratio of their length to the dimensions of the firebox, and it also applies to the "combined" heating surface.

TUBES.—The maximum length of tubes has exceeded 24 ft.

7 ins. (7·50 m.) between tube plates, while 24 ft. (7·32 m.) is quite a common length in big locomotives.*

For some time past tubes of uniform diameter have been standard practice. The smaller tubes are $2\frac{1}{4}$ ins. (57 mm.) and the larger $5\frac{1}{2}$ ins. (140 mm.) diameter.

FIREBOX.—Fireboxes of the Wootten, Belpaire, Gaines and Jacobs-Schupert types are in use. They reach dimensions which a few years ago could hardly have been anticipated. For example, the firebox of the double-Decapod on the Virginian Ry. is no less than 15 ft. $1\frac{1}{16}$ ins. (5·52 m.) in length.

As the firebox is clear above the wheels, it has often a breadth of 8 ft. (2·18 m.). Even this considerable width is materially exceeded. Thus some locomotives on the Virginian Ry. have a firebox width of 12 ft. (3·66 m.). The depth of the firebox is often 6 ft. 11 ins. (2·11 m.) in front and 5 ft. 7 ins. (1·70 m.) at the rear, but these dimensions vary considerably according to the service for which the locomotives are designed.†

These large fireboxes are almost always built of $\frac{3}{8}$ in. (10 mm.) plates, except the tube plate, which is generally $\frac{5}{8}$ in. (16 mm.) thick, though occasionally $\frac{1}{2}$ in. (13 mm.) plate is used.

American designers rightly attach great importance to the width of the firebox water space. This is generally 5 ins. (0·13 m.) on all sides,‡ but is often wider in front than elsewhere, this extra width reaching $\frac{1}{2}$ in., 1 in. or even 2 ins. (13, 25 or 51 mm.).

A brick arch is often used in the firebox. It is sometimes supported by water-tubes running from front to back of the firebox. These add to the direct heating surface and improve the circulation.

Shallow fireboxes are often extended by a combustion chamber. This chamber is supported by articulated stay bolts arranged radially.§

* In the double-Decapod of the Virginian Ry. this dimension is 25 ft. (10·67 m.).

† On the Virginian Ry. *Triplex* the height of the firebox in front is 7 ft. $9\frac{5}{8}$ ins. (2·378 m.), but this is exceptional.

‡ *E.g.*, on the locomotives of the Pennsylvania R.R., the Missouri, Oklahoma and Gulf Ry., the Nashville, Chattanooga and St. Louis Ry., etc.

§ *E.g.*, on the locomotives of the Baltimore and Ohio R.R., the Delaware and Hudson Ry., etc.

A combustion chamber increases in effect the volume of the firebox and the boiler tubes are shorter. A brick wall is built across the throat of the chamber to baffle the gases.

THE GRATE.—This is fitted with the usual devices now found in connection with large grates in modern practice. The grate area is as much as 108 sq. ft. (10 sq. m.), not only in the *Triplex* locomotives, but also in the double-Decapods of the Philadelphia and Reading Ry.

MECHANICAL STOKERS.—These have for a long time been in use on *Mallet* locomotives. They are of various types, ranging from the early Street to the modern Duplex.

WHEELS.—The driving wheels are generally 4 ft. 8 ins. (1·43 m.) diameter, with tyres 3 ins. (0·076 m.) thick. The journals are 11 ins. by 13 ins. (0·28 by 0·35 m.). Flange lubricators are sometimes provided for the front and rear wheels. Occasionally driving wheels of larger diameter are used. Thus, the *Mallets* of the Atchison, Topeka and Santa Fé Ry. have wheels of 5 ft. 9 ins. (1·75 m.) diameter. Those of the Southern Pacific R.R. of 5 ft. 3 ins. (1·60 m.). The former railway has some *Mallets* for passenger traffic with wheels 5 ft. 11 ins. (1·854 m.) diameter. But the *Mallet* is hardly suitable for fast passenger service.

The leading and trailing truck wheels have the same diameter when only used for guidance. This is usually 2 ft. 9 ins. (0·84 m.) and, in a few cases, 2 ft. 6 ins. (0·76 m.). There is seldom any variation from these dimensions. The journals have a diameter of 6 ins. to 7 ins. (15 to 18 cm.), and a length of 11 ins. to 12 ins. (28 to 30 cm.).

When the rear axle supports more weight, the diameter of its wheels is increased.* In some cases this is identical with that of other wheels of the rear group, so as to couple it up with them, thus, for instance, producing the 2-6 + 8-0 type. Adhesion is thus increased, but there is a loss of interchangeability of the fore and rear mechanism.

The passenger *Mallet* of the Atchison, Topeka and Santa Fé Ry. above referred to is the only one which has a four-wheeled bogie in front.

RIGID WHEELBASE.—This is never large. It varies from

* It is 4 ft. $1\frac{5}{8}$ in. (1·26 m.) in the standard 2-8 + 8-2 of the Government Ry. administration.

10 ft. to 10 ft. 6 ins. (3·05 to 3·20 m.) for the 2-6 + 6-2 type.* In the double-Consolidations it is 14 ft. 11 ins. to 16 ft. 1 in. (4·55 to 4·90 m.), and in locomotives with ten coupled axles it reaches about 19 ft. 8 ins. (6 m.).

Of the two leading American builders, the American Locomotive Co. long advocated the total adhesion locomotive. On the other hand, the Baldwin Works have always preferred locomotives with bissels at either end.

It is true that in narrow gauge locomotives, as in some types for standard gauge, the provision of a rear pony truck makes the design of an ample firebox easier. But this does not apply in the case of the large *Mallets*, because the driving wheels are always of relatively small diameter. Hence there is no difficulty in locating their great fireboxes clear above the coupled wheels as well as the pony truck. But the utility of the trailing bissel lies in the guidance which it affords when the locomotive is running in reverse. It therefore follows that a symmetrical arrangement is logically correct for a locomotive which may have to run either way, *e.g.*, for *Mallets* used for banking and shunting.

We used the word "symmetrical" because, while the locomotives supplied by one of these leading builders have a bissel at each end, those of other builders have none at all. A single bissel is rarely used.

In order to negotiate sharp curves, the rigid wheelbase is made as short as possible. Where bissels are fitted, arrangements are often made for the lubrication of their flanges. Sometimes this provision is also extended to the adjacent wheels of the coupled groups of wheels. Flangeless wheels have been used on the centre axles of each group, but this practice is now being abandoned.

Axle Loads.—The load per axle is constantly increasing, and it is not unusual to meet with loads of 60,000 lbs. (27 metric tons) and more. Some of the maximum loads found in practice are given in Table 57. The load on the pony trucks is generally from 10 to 12 tons. But there are some exceptions to which attention is drawn. Thus in the double-Moguls of the Norfolk and Western Ry., the rear axle carries 21 tons 14 cwt. (22 metric tons), hence the diameter of its

* In the exceptional case of passenger *Mallets*, it may reach 12 ft. 2 ins. (3·71 m.), or even 13 ft. 8 ins. (4·17 m.).

wheels is increased to 3 ft. 8 ins. (1·11 m.). Such a distribution of weight is obviously unsound. The standard *Mallet* has 25 tons 13 cwt. (26 metric tons) on the rear axle, whose wheels are 3 ft. $11\frac{1}{4}$ ins. (1·20 m.) diameter. The rear axle of the "Triplex" locomotive of the Virginian Ry. carries 27 tons 13 cwt. (28 metric tons), but this is exceptional, like other features of this locomotive.

TABLE 57.—MAXIMUM AXLE LOADS OF SOME AMERICAN COMPOUND MALLETS

Railway.	Type.	Weight in lbs.		
		Total.	Adhesive.	1 Axle.
Atchison, Topeka and Santa Fé Ry.	4-4 + 6-2	376,000	268,000	53,600
Lake Terminal R.R.	0-6 + 6-0	350,000	350,000	58,300
U.S. Ry. Administration	2-6 + 6-2	447,800	358,000	60,000
Great Northern Ry.	2-6 + 8-0	378,500	359,000	51,400
Baltimore and Ohio R.R.	0-8 + 8-0	460,700	460,700	57,800
,, ,, ,,	2-8 + 8-0	480,600	462,500	57,800
Western Pacific Ry.	2-8 + 8-2	—	486,500	60,850
Norfolk and Western Ry.	2-8 + 8-2	587,000	—	—
Virginian Ry.	2–10 + 10-2	684,000	617,000	61,700

THE TENDER.—The tenders of the *Mallets* with six coupled axles have a water capacity of 8,000 to 9,000 U.S. gallons (30 to 34 cub. m.). Those of the *Mallets* with eight coupled axles have a capacity of 12,000 U.S. gallons (45 cub. m.), and those of the double-Decapods about 13,300 U.S. gallons (50 cub. m.).* These quantities are obviously subject to considerable variation.† Thus, the tender of the Virginian Ry. locomotive has a water capacity of 12,000 U.S. gallons (45 cub. m.).

In regard to fuel capacity, the tenders of the *Mallets* on the Baltimore and Ohio R.R., and the Pennsylvania R.R. carry 17 tons 16 cwt. (18 metric tons), those of the double-Consolidation locomotives on the Norfolk and Western Ry.

* The double-Decapods have a capacity from 13,050 to 14,300 U.S. gallons (49 to 54 cub. m.).

† The standard double-Moguls have often a tender of 12,000 U.S. gallons (45 cub. m.) capacity.

19 tons 15 cwt. (20 metric tons). But these figures are exceptional and do not represent normal practice.

As in the case of the wheels of pony axles, only two diameters of tender wheels are met with, namely 2 ft. 9 ins. (0m.84), and 3 ft. (0m.91). It will be observed that these are smaller than the tender wheels usual in European practice.

All the tenders referred to ride on two four-wheeled or six-wheeled bogies.

Auxiliary Engines have been applied to the tender and are dealt with in Book IV.

They have so far not been used on the locomotive itself,* the booster being primarily designed with the object of helping the locomotive when extra power is temporarily needed and being cut out above a certain speed. The conditions under which the *Mallets* usually work would call for constant employment of the booster ; in these circumstances it is more rational to permanently provide the *Mallet* with the extra latent power which it needs.

Not so for the tender, whose available adhesive weight helps the *Mallet* materially when its auxiliary engine is cut into action.

Tractive Power of Mallet Locomotives

In 1923, the American Committee adopted the following, wherein :

C = the diameter H.P. cylinder (in inches).
c = L.P. cylinder (in inches).
S = stroke (in inches).
P = boiler pressure (in pounds per square inch).
D = diameter of drivers (in inches).
H = the M.E.P. of H.P. cylinders (in pounds per square inch).
h = the M.E.P. of L.P. cylinders (in pounds per square inch).
R = ratio of cylinder volumes.
K = a constant :
0·85 for 90 per cent. cut-off locomotives.
0·75 for 50 per cent. cut-off locomotives.
Q = PK = total M.E.P. in cylinders.
T = tractive power (in pounds).

* With a single exception concerning the latest "simple" *Mallet* (see hereafter).

(1) Four cylinder simple *Mallet*—this is a combination of two two-cylinder locomotives with but one boiler. Hence,

$$T = \frac{2 \times K \times P \times C^2 \times S}{D}$$

in which 2K is 1·7 or 1·5 for 90 or 50 per cent. cut-off locomotives respectively.

(2) Four-cylinder compound *Mallets*. When operated as simple locomotives.

$$T = \frac{(H \times C^2 + h \times c^2)\, S}{D}$$

In practice *Mallets* are so designed that the total piston pressures are equal; hence M.E.P. varies inversely as the square of the diameters or

$$\frac{H}{h} = \frac{c^2}{C} = R = \frac{Q-h}{h}$$

because

$$H+h=Q.$$

Hence, taking the value of h and substituting in the formula

$$T = \frac{h \times c^2 \times S}{D} = \frac{Q \times c^2 \times S}{(R+1)\, D}.$$

As the L.P. and H.P. cylinders have equal power (or should), the total tractive power is

$$T = \frac{2 \times Q \times c^2 \times S}{(R+1)\, D}$$

and for locomotives with 90 per cent. cut off

$$T_2 = \frac{1{\cdot}7 \times P \times c^2 \times S}{D}$$

and for locomotives with 50 per cent. cut off

$$T_3 = \frac{1{\cdot}5 \times P \times c^2 \times S}{D}.$$

Formula of the Sub-Committee (T_4).—To simplify these formulæ, the sub-committee of the *Interstate Commerce Commission* proposes to use the co-efficient 1·5 for all cylinder ratios and all cut offs from 0·90 to 0·50.

The *Interstate Commerce Commission's Circular* 22 uses, for all cylinder ratios:

For two cylinder compounds applied to *Mallets.* $T_5 = \frac{2(\frac{2}{3} \times P \times C^2 \times S)}{D}$

For four cylinder compounds $T_6 = \frac{P(\frac{2}{3} \times C^2 + \frac{1}{4} \times c^2) S}{D}$.

The *Baldwin Locomotive Works* use two formulas.

On the assumption that equal power is developed in the H.P. and L.P. cylinders, and that the total mean effective pressure is 0·85 per cent. of the boiler pressure, the formula becomes, for any ratio of cylinders :

$$T_7 = \frac{2 \times 0{\cdot}85 \times P \times c^2 \times S}{(R+1)\,D} = \frac{1{\cdot}7 \times P \times c^2 \times S}{(R+1)\,D}$$

on the basis of the H.P. cylinder,

$$T_7 = 2 \times \frac{0{\cdot}85 \times P \times C^2 \times S}{R}$$

which for a cylinder ratio of 2 : 4, becomes

$$T_8 = \frac{1{\cdot}2P \times C^2 \times S}{D}.$$

This formula is used for cylinder ratios between 2·35 and 2·40.

Formula of the American Locomotive Co.—For full tractive force, the formula of this Company assumes a value of 0·52 for K^1, with a cylinder ratio of 2·5. Substituting these values in the formula (T).

$$T_9 = \frac{0{\cdot}52 \times P \times c^2 \times S}{D} = 2 \times \frac{0{\cdot}91 \times P \times c^2 \times S}{D \times 3{\cdot}5}.$$

The formula is therefore based on M.E.P. of 0·91 of boiler pressure.

G. R. Henderson's formula (T_{10}).—This formula is based on 8·80 per cent. of M.E.P. At the time Henderson proposed it, superheating was in its infancy. The value he uses seems somewhat low :

$$\frac{1{\cdot}6 \times c^2 \times S \times P}{(R + 1) \times D}.$$

As a summary, the following percentages of M.E.P. boiler pressure are those which are most usually used :

Henderson, 0·80 per cent.

Baldwin Works, 0·85 per cent.

The American Locomotive Co., 0·91 per cent.

Interstate Commerce Commission, 0·94 per cent.

Rigid Locomotives Converted to Mallets

We have already seen that the adoption of the *Mallet* has been brought about by the necessity of providing an increased number of driven axles without a sacrifice of flexibility.

There is, however, another cause for their appearance—namely, the endeavour to increase the output of the rigid locomotive by using the exhaust steam from the H.P. cylinders to drive supplementary groups of wheels.

Compound *Mallets* have shown a considerable saving in fuel consumption and even in repairs, as against the single expansion Consolidations and Mikados which they replaced. It was therefore natural that the conversion of the latter to the *Mallet* principle should be attempted, by adding a new set of leading wheels and an extension to the boiler which should comprise those organs to which the increased efficiency of the *Mallet* is due. The conversion was, therefore, carried out by removing the existing bissel and substituting for it a *Mallet* truck, and at the same time adding to the boiler barrel a section containing a superheater and a reheater. The original axle, thus removed, served as a bissel for the new motor-truck, the original cylinders became the H.P. cylinders, while new L.P. cylinders were fitted at the front of the truck. In this way, an ordinary single expansion rigid locomotive was converted into a semi-articulated locomotive, often with a superheater.

This conversion was first carried out on the Gt. Northern Ry. (U.S.A.), the completed locomotives becoming 2-6 + 8-0 *Mallets*. In 1910, a similar conversion was carried out on the Erie R.R.

Similarly, the Chicago Great Western R.R. converted some Prairie (2-6-2) locomotives to 2-6 + 6-2 *Mallets*.

On the Atchison, Topeka and Santa Fé Ry., two Prairies were first combined so as to form a 2-6 + 6-2 *Mallet*. The experiment having succeeded, fourteen other Prairies were converted to *Mallets* by adding complete new motor units in front.

Subsequently this railway also converted four Consolidations into 2-8 + 8-2 *Mallets* and ten locomotives of the Santa Fé (2-10-0) type into 2-10 + 10-2 *Mallets*, thus producing the most powerful types of that day.

Other railway administrations, such as the Baltimore and Ohio R.R., have done the same. This would seem to be an advantageous method of dealing with rigid locomotives which are still in good working order and which must cope with a flow of heavy traffic, as the increased fuel economy per indicated H.P. thereby effected is considerable.

Classification of Types of Mallet Locomotives

We shall group the *Mallets* in accordance with the number of their coupled axles and shall deal in succession with tank engines with four, five, six, eight and ten coupled axles, both those whose total weight is available for adhesion and those which have pony trucks.

We shall next examine, in the same sequence, the locomotives with separate tenders, and, finally, we shall give some information as to modified types, notably those with four H.P. cylinders.

From one point of view, it might be thought desirable to classify these locomotives according as to whether they are of European or American design and manufacture ; but this is unnecessary, nor is there any need to classify the locomotives in accordance with the various gauges on which they are used.

We quote a large number of examples in order that the reader may be able to draw valid conclusions as to present tendencies in this department of locomotive engineering.

As in the case of most types of articulated locomotives, the earliest *Mallets* were tank engines for use on 0·60 m. (1 ft. 11½ ins.) lines. Their use rapidly extended to lines of other gauges.

Mallets with separate tenders were soon introduced and their use also extended.

During this time attempts were made to improve the systems by introducing various modifications in principle.

In view of the above, these locomotives may properly be divided into three main groups :—

Sub-Group II. A.—Mallet Tank Engines.—The most interesting types of these will be briefly referred to.

Sub-Group II. B.—Mallet Locomotives with Separate Tenders.—As this is by far the most important group, considerable attention will be devoted thereto.

Sub-Group II. C.—Modified Mallet Locomotives—By collecting in one group all the various modifications of the standard type, it is hoped that their salient features will be more readily appreciated.

SUB-GROUP II. A.—MALLET TANK ENGINES

These have been chiefly employed on crooked branch lines of narrow and also of standard gauge. Side tanks are used, but additional water capacity is often provided behind the cab, where also the fuel bunkers are located.

These locomotives are used for passenger, freight and mixed services, also on industrial and forest railways.

The most usual type, on all gauges, is the 0-4 + 4-0. Pony axles, front or rear, are unusual, for the consumption of fuel and water has itself a material effect on the weight available for adhesion. When more power is needed, the 0-6 + 6-0 type is used and, very exceptionally, the 0-8 + 8-0 type.

The first *Mallet* ever constructed was built in Belgium in 1887 at the Ateliers Métallurgiques of Tubize. It was used on a 0·60 m. (1 ft. 11½ ins.) Decauville line. It was also tried on the military railways of the Place de Toûl concurrently with a *Péchot-Bourdon* locomotive. It was then taken to Laon, where it worked on a section with 7½ per cent. gradients and curves of 88 ft. (27 m.) radius. As the type gave satisfaction, it was placed on the line laid down at the Paris Exhibition of 1889. Since then this type has been reproduced very many times (Fig. 119). Like all other locomotives, the power of *Mallets* has increased even on these very narrow gauges. The first of the 0·60 m. *Mallets* weighed some 15 tons; now those for the same gauge weigh thrice that amount.

Generally the diameter of the driving wheels is about equal to the width of the gauge. This relation is not so entirely empirical as it might seem at first sight. The rigid wheelbase also varies directly with the gauge.

The working pressure of the earlier boiler was always 170 lbs.

per square inch (12 kg. per square centimetre). Present pressures reach 210 or 230 lbs. (15 or 16 kg.) and more.

There are not as many classes of *Mallet* tank engines as of tender locomotives, because the former are less widely used. We shall deal with them under the following heads :—

Locomotives with four coupled axles	(A)	0-4 + 4-0.
	(B)	2-4 + 4-0.
	(C)	0-4 + 4-2.
	(D)	2-4 + 4-2.
Locomotives with five coupled axles	(E)	2-4 + 6-0.
Locomotives with six coupled axles	(F)	0-6 + 6-0.
	(G)	2-6 + 6-0.
	(H)	2-6 + 6-2.
Locomotives with eight coupled axles	(I)	0-8 + 8-0.

Class A.—0-4 + 4-0 Mallet Tank Engines

For some years, this was the only type of *Mallet* tanks in use. It was first introduced on 2 ft. gauge lines, but it was subsequently employed on metre and even on standard gauge lines.

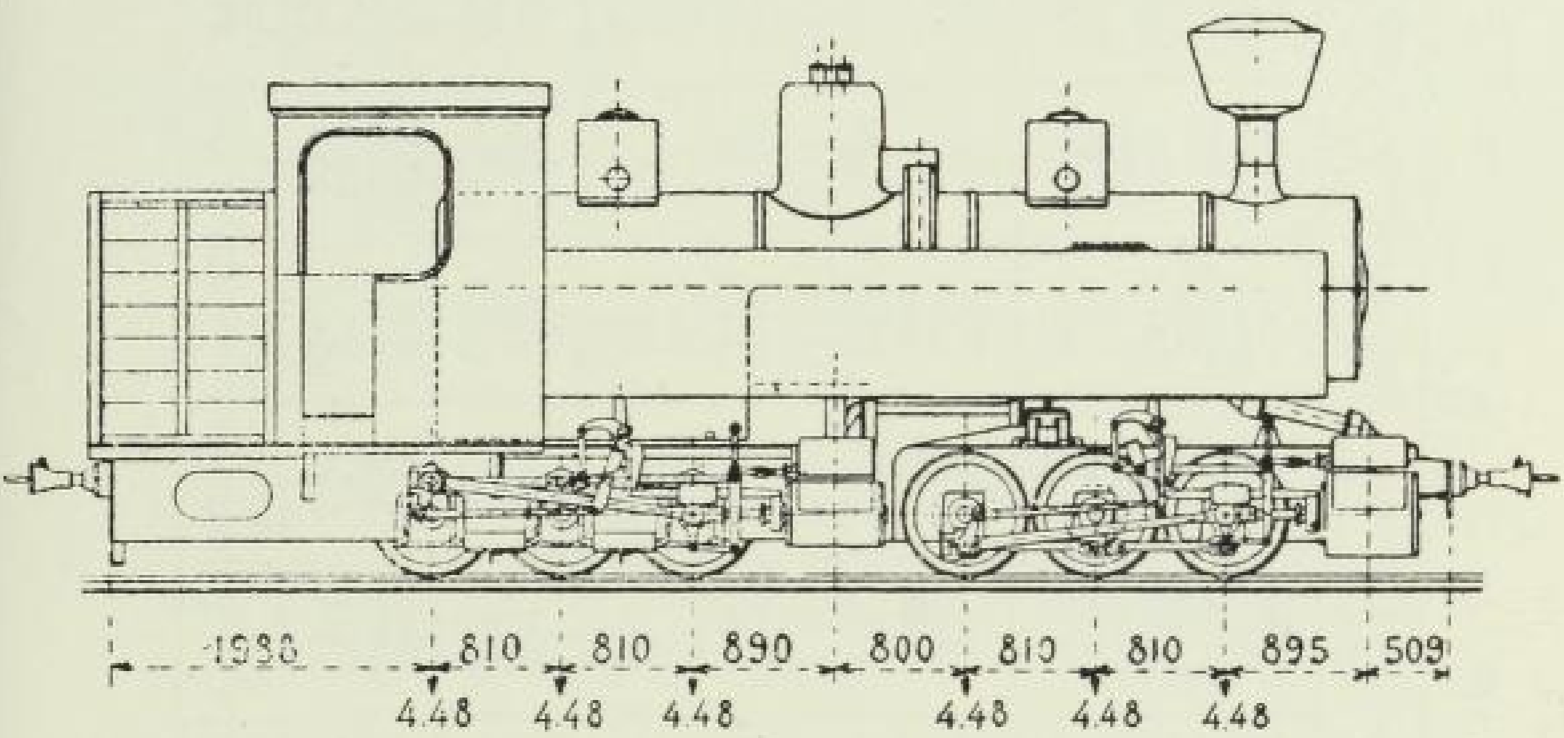


FIG. 138.—0-6 + 6-0-T Mallet Locomotive (Steinbeis Co.). (2 ft. Gauge.)

Many of these locomotives were built serially, the same types serving in most cases for various railways. It is, therefore, unnecessary to give detailed accounts of each of them, especially as they represent older forms of these locomotives. But owing to the favour with which they were received and the important part they played in the evolution of the articulated

TABLE 58.—PRINCIPAL DIMENSIONS OF **0-4 + 4-0-T** MALLET TANK LOCOMOTIVES

Gauge Railway Builder Date		0·60m. Paris Exhib.-tion Ry. Métallur-gique. Tubize. 1889.	0·75m. Mines of Queiros. Sté. Alsaci-enne. —	0·95. Amando-la Adri-atica. Borsig. 1910.	Metre. Départe-mentaux. Sté. Alsaci-enne. 1888–1893	1·067. Nippon Ry. Maffei. 1903.	Metre. South German Rys. Co. Sté. Alsaci-enne. —	Metre. F. C. de Utrillas. Orenstein and Koppel. —	Metre. Rhétique Ry. Maffei. 1891.	Metre. Rhétique Ry. Maffei. 1891.	Standard. Bavarian State Rys. Maffei. 1899–1900	Standard. Central Swiss Ry. Maffei. 1891.	Standard. Central Swiss Ry. Maffei. 1893.
Cylinders, diameter	m.	0·18	0·21	0·29	0·25	0·30	0·30	0·36	0·33	0·33	0·31	0·36	0·35
,, diameter	m.	0·28	0·37	0·45	0·38	0·49	0·46	0·56	0·49	0·55	0·49	0·55	0·54
,, stroke	m.	0·26	0·32	0·42	0·46	0·53	0·55	0·50	0·55	0·55	0·53	0·64	0·61
Boiler, height, cent. line	m.	1·30	1·55	1·81	1·65	2·12	1·90	—	1·80	—	2·05	2·15	2·20
,, diameter	m.	0·79	0·80	1·03	0·92	1·12	1·13	—	1·15	—	1·15	1·25	1·30
,, pressure	kg./sq. cm.	12	12	12	12	12	12	12	12	12	12	12	14
Tubes, number		90	90	116	89	138	140	—	143	—	138	171	164
,, diameter	mm.	37·5–40	41–46	41–46	41–46	41–45	40–45	—	42·5–46	—	41–45	46–50	46·4
,, length	m.	1·98	2·53	3·35	3·30	3·59	3·70	—	3·60	—	3·59	4·00	3·85
Firebox, length	m.	—	0·62	—	—	—	—	—	0·75	—	1·02	1·04	1·04
,, width	m.	—	1·00	—	—	—	—	—	1·95	—	1·37	1·74	1·60
Heating surface, firebox	sq. m.	2·4	2·9	4·6	4·1	6·9	6·6	—	6·1	6·0	5·4	7·9	7·3
,, ,, tubes	,,	20·2	25·1	56·1	37·8	63·0	65·1	—	68·6	68·0	63·7	101·1	99·2
,, ,, total	,,	22·5	28·0	60·7	42·0	69·9	71·6	109·0	78·6	74·0	69·1	109·0	106·4
Grate area	,,	0·5	0·6	1·2	0·8	1·4	1·5	1·9	1·4	1·4	1·4	1·8	1·7
Wheels, diameter	m.	0·60	0·70	0·90	0·90	1·00	1·08	1·00	1·04	1·05	1·00	1·20	1·20
Wheelbase, rigid	m.	0·85	1·00	1·40	1·15	1·60	1·70	1·90	1·60	1·60	1·60	1·90	1·68
,, total	m.	2·80	3·40	4·70	4·00	5·20	5·40	5·60	5·20	6·20	5·20	6·20	5·58
Overall, height	m.	3·58	2·48	3·45	—	3·70	—	—	3·22	3·68	3·86	4·24	4·24
,, width	m.	1·90	1·80	2·12	2·40	2·70	2·80	—	2·68	2·68	3·10	3·02	3·09
,, length	m.	5·30	6·50	8·74	7·70	10·20	10·00	—	10·12	10·01	11·01	11·72	10·40
Water tanks	t.	1·4	1·8	4·0	2·9	4·7	5·0	6·0	3·5	3·4	4·3	5·0	7·2
Coal bunkers	t.	0·5	0·6	2·0	1·3	1·3	1·0	2·0	1·0	1·0	1·3	2·0	3·3
Weight, empty	t.	9·0	12·5	24·0	19·0	32·5	34·1	39·0	—	—	32·5	48·0	43·5
,, in service	t.	11·3	15·8	32·0	24·7	43·9	43·6	50·0	40·5	—	42·5	59·5	58·5
Tractive force	t.	1·7	—	4·7	—	5·8	—	7·8	4·7	6·0	6·1	6·8	7·5

TABLE 58A.—PRINCIPAL DIMENSIONS OF **0-4 + 4-0-T** MALLET TANK ENGINES

Gauge Railway	1′ 11 5/8″ Paris Exhibition Ry.	2′ 5 1/2″ Mines of Queiros.	3′ 1 1/2″ Amandola Adriatica.	Metre. Départementaux (France).	3′ 6″ Nippon Co.	Standard. South German Ry. Co.	Metre. Utrillas (Spain).	Metre. Rhétique Ry. (Switzerland).	Metre. Rhétique Ry.	Standard. Bavarian State Rys.	Standard. Central Swiss Ry.	Standard. Central Swiss Ry.
Builders	Métallurgique.	Alsacienne.	Borsig.	Alsacienne.	Maffe	Alsacienne.	Orenstein & Koppel.	Maffei.	Maffei.	Maffei.	Maffei.	Maffei.
Date	1889.	—	1920.	1888–1893	1903.	—	—	1891.	1891.	1899–1900	1891.	1893.
Cylinders, diameter, H.P.	7 1/8″	8 5/16″	11 3/8″	9 7/8″	11 13/16″	11 3/16″	14 3/16″	13″	13″	12 1/4″	14 3/16″	13 3/4″
,, ,, L.P.	11″	12 5/8″	17 3/4″	15″	19 5/8″	18 1/8″	22 1/16″	19 5/16″	21 5/8″	19 5/16″	21 5/8″	21 1/4″
,, stroke	10 1/4″	12 5/8″	16 9/16″	18 1/8″	20 7/8″	21 5/8″	19 11/16″	21 5/8″	21 5/8″	20 7/8″	25 1/4″	24″
Boiler, height of centre line	4′ 3 1/4″	5′ 1 1/8″	5 11 1/4″	5 5″	6 11 1/2″	6 2 3/4″	—	5′ 10 7/8″	—	6′ 8 5/8″	7′ 0 5/8″	7′ 2 3/4″
,, diameter	2′ 7 1/4″	2 7 1/2″	3′ 4 5/8″	3′ 0 1/4″	3′ 8 1/8″	3′ 8 1/2″	—	3′ 9 1/4″	—	3′ 9 1/4″	3 9 1/4″	4′ 3 1/4″
,, pressure . lbs. per sq. in.	171	171	171	171	171	171	171	171	171	171	171	199
Tubes, number	90	90	116	89	138	140	—	143	—	138	171	164
,, diameter	1 7/16″–1 9/16″	1 5/8″–1 13/16″	1 5/8″–1 13/16″	1 5/8″–1 13/16″	1 5/8″–1 3/4″	1 9/16″–1 3/4″	—	1 11/16″–1 13/16″	—	1 5/8″–1 3/4″	1 13/16″–2″	1 13/16″
,, length	6′ 0″	8′ 3 1/2″	11′ 0″	10′ 10″	11′ 9″	12′ 1 3/4″	—	12′ 0″	—	11′ 9″	13′ 1 1/2″	12′ 7 1/2″
Firebox, width	—	2′ 0 5/8″	—	—	—	—	—	2′ 5 1/2″	—	3′ 4 1/4″	3 5″	3′ 5″
,, length	—	3′ 3 3/8″	—	—	—	—	—	6′ 4″	—	4′ 6″	5′ 8 1/2″	5′ 3″
Heating surface, firebox sq. ft.	25·8	31·2	49·5	44·3	74·3	71	—	65·7	64·6	58·1	85	78·6
,, ,, tubes ,,	217·5	270	603·7	407	678	700·5	—	738·3	731·8	707	1,088	1,068
,, ,, total ,,	243·3	301·2	653·2	451·3	752·3	771·5	—	804	796·4	765·1	1,173	1.146·6
Grate area ,,	5·4	6·8	13	8·6	15	16·1	20·5	15·1	15·1	15·1	19 4	8·3
Wheels, diameter	1′ 11 5/8″	2′ 3 1/2″	2′ 11 1/2″	2′ 11 1/2″	3′ 3 3/8″	3′ 6 1/2″	3′ 3 3/8″	3′ 5″	3′ 5 3/8″	3′ 3 3/8″	3′ 11 1/4″	3′ 11 1/4″
Wheelbase, rigid	2′ 9 1/2″	3′ 3 3/8″	4′ 7 1/8″	3′ 9 1/4″	5′ 3″	5′ 7″	5′ 10 7/8″	5 3″	5′ 3″	5′ 3″	6′ 2 3/4″	5′ 6 1/4″
,, total	9 1 3/4″	11′ 2″	15′ 5″	13′ 1 1/2″	17′ 1″	17′ 8 1/2″	18′ 4 1/2″	17′ 1″	20′ 4″	17′ 1″	20′ 4″	18′ 4″
Overall dimensions, height	11′ 9″	8′ 1 1/4″	11′ 3 3/4″	—	12′ 1 1/4″	—	—	10′ 6 1/2″	12′ 1″	12′ 8″	13′ 11″	13′ 11″
,, ,, breadth	6′ 2 3/4″	5′ 0 1/2″	6′ 11 1/2″	7′ 10 1/2″	8′ 10″	9′ 2″	—	8′ 9″	8′ 9″	10′ 2″	9′ 11″	10′ 1″
,, ,, length	17′ 4″	21′ 4″	28′ 8″	25′ 3″	33′ 6″	32′ 10″	—	33′ 2 1/2″	33′ 2 1/2″	32′ 10 1/2″	38′ 5 1/2″	34′ 5″
Water . tons-cwt.	1–8	1–16	3–19	2–17	4–13	4–18	5–18	3–9	3–7	4–5	4–18	7–2
Fuel ,,	0–10	0–12	2–0	1–6	1–6	1–0	2–0	1–0	1–0	1–6	2–0	3–5
Weight, empty ,,	8–17	12–6	23–12	18–14	32–0	33–10	38–7	—	—	31–19	47–4	42–16
,, in service ,,	11–2	15–10	31–10	24–6	43–3	42–18	49–3	39–13	—	41–16	58–10	57–11
Tractive force . lbs.	3,750	—	10,360	—	12,800	—	17,200	10,300	13,230	13,450	15,000	16,530

locomotive, we shall quote a number of instances in tabular form and only add short comments for such items as are unusual.

0-4 + 4-0 Tank Mallets for Decauville Lines.—0m.60 gauge (about 2 ft.) (Fig. 119).

This, the original type of *Mallet* locomotive, dates back from 1888. It was built experimentally by the Ateliers Métallurgiques, of Tubize, Belgium, and was entirely successful. Thereafter, these works proceeded to build this type in series, and the Ateliers Decauville (France) did the same.

Up to 1900 they had been supplied, *inter alia*, to the Phu-Lang Thuong and Langson Ry., to the French Military Authorities and to a number of steam tramway companies, such as those of Royan, of the Calvados, and of Toury-Pithiviers.

The Société Alsacienne, of Belfort, built a modified type with separate tender for the Mines of Alapaewsk's railway (Government of Perm) and, without separate tender, for the Queiros 0m.75 gauge railway (Spain).

No object would be served in describing these locomotives in detail, but it is necessary to quote them to show how the *Mallet* type was developed.

0-4 + 4-0 Mallets of the Blanzy Mines Ry.—0m.80 gauge (2 ft. 7½ ins.).

This new type was also built by the Ateliers Métallurgiques, who furnished similar locomotives, but without inner frames, to the metre gauge Kebao Collieries Ry. (Tonkin).* where the curves radius was only 50 m. (164 ft.).

These locomotives were duplicated by Vve. Corpet and Louvet, of Paris, for the Tramways d'Ille et Vilaine. †

0-4 + 4-0 Mallets for the Ch. de fer Départementaux.—Metre gauge.

Many of the French light railways are in the hands of important companies, who own and operate systems in several departments, several of which lie in mountainous districts. *Mallet* locomotives, of course, proved themselves exceptionally serviceable here, and when introduced their use spread rapidly.

* They weighed 18·6 tonnes empty and 23 tonnes in service (18 tons 6 cwt. and 22 tons 12 cwt.).

† Weights, 16 tonnes and 21 tonnes (15 tons 15 cwt. and 20 tons 13 cwt.); pressure increased to 12·5 kg. (178 lbs.).

As occasion demanded, the newer locomotives were more powerful than their predecessors.

The first of them were constructed at Belfort and placed on the Vivarais and on the Seine et Marne lines, and shortly afterwards on the Allier system of the Société Générale des Chemins de fer Economiques.

Others followed by other builders.*

The Belfort Works of the Société Alsacienne next turned out a more powerful type for the Corsican lines of the

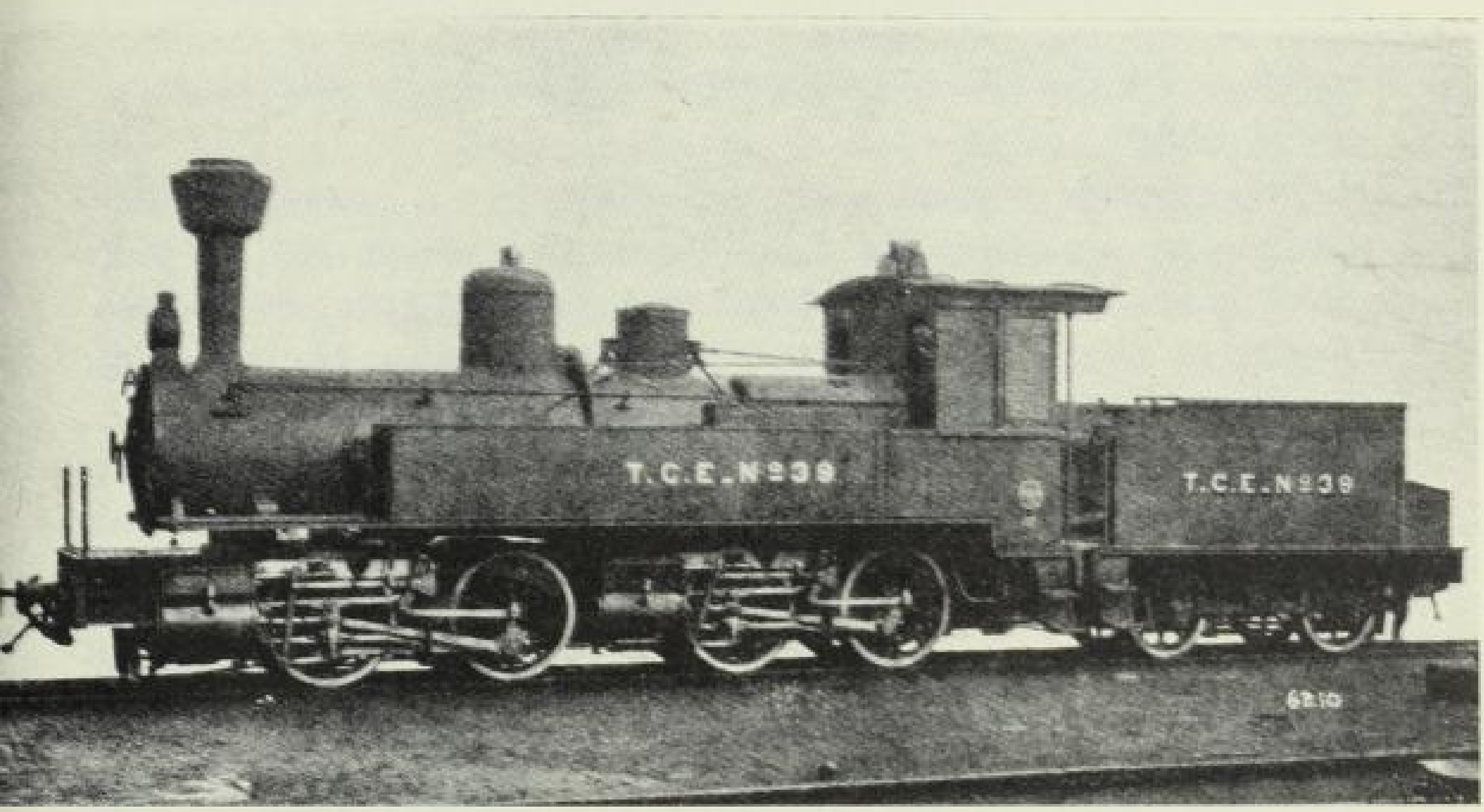


FIG. 139.—0-4 ; 4-0 Mallet Locomotive, Ch. de fer de Madagascar. (Metre Gauge.)

Départementaux, which had 3 per cent. grades and for the Sud de la France † and their Grafenstaden Works

* The Marcinelle and Couillet Works (Belgium) furnished similar locomotives to the Ch. de fer de Durango Zumarraga, and to the Madrid Villa del Prado Ry.

Messrs. Jung (of Kirchen, Germany), supplied others to a number of secondary railways, including the Ruhr-Lipp Kleinbahn, the Harz Transversal Ry., and the Régional de Saignelégier à La Chaux-de-Fonds (Switzerland).

† This was followed by a modified type for the Ch. de fer de l'Ouest's Brittany metre gauge lines, which are operated by the Economiques.

The Ateliers des Batignolles built others for the Bône-Guelma Ry. (Tunis).

furnished duplicates to the Yverdon Sainte-Croix Ry., which had 4·5 per cent. gradients and to the Zell Todnau Ry. (Baden).*

0-4 + 4-0 Mallet Tank Engines of the Madagascar Ry.—Metre gauge (Fig. 139).

These locomotives are similar to those of the Bône-Guelma line save for slight alterations to the boiler. Besides this, the fuel is wood, and as the bunkers would not allow of a sufficient supply being carried, a tender was added, though lateral water tanks containing 1,920 litres have been retained, the balance, some 2,100 litres (462 gallons), being carried in the tender.†

0-4 + 4-0 Mallet Tank Engines of the Ch. de fer Rhétiques.—Metre gauge.

Though this system consisted originally of a single metre gauge line entitled the Landquart and Davos Ry., it has developed into an important mountain system, with such works as the Albula Tunnel, but having also 4½ per cent. gradients and 100 m. (328 ft.) radius curves.

In these circumstances, it was natural that *Mallet* locomotives should have been tried early, and that such improvements as practice showed to be advisable should have been incorporated in subsequent classes.

The earliest of them, supplied in 1891 by Messrs. Maffei, weighed 40 tonnes (39 tons 7 cwt.).

It is worthy of note that the same builders supplied similar locomotives for the Bavarian Rys.' light standard gauge lines, the frames being interior in this case, whereas they were exterior in the Rhétiques locomotives.

Some fear had been entertained that compounding might cause trouble at high altitudes. But the Landquart-Davos then reached a height of 1,633 m. above sea level (5,358 ft.) and the apprehensions proved groundless.

On the other hand, it was deemed advisable to increase the capacity of the tanks, so the next orders placed with the Winterthur Works were for locomotives of the 0-4 + 4-2 type,

* The Carlsruhe Works built repeat orders.

† The tender, which weighs 5·4 tonnes empty and 10·5 tonnes in working order (5 tons 6 cwt. and 10 tons 7 cwt.), has a wheelbase of 1·80 m. (5 ft. 10⅞ ins.), and its overall length is but 4·44 m. (14 ft. 6½ ins.). The diameter of the tender's wheels is 0·81 m. (2 ft. 8 ins.).

These locomotives were built by Schwartzkopff and by Baldwin.

which did not give entire satisfaction, and the 2-4 + 4-0 type was substituted.

0-4 + 4-0 Mallet Locomotives for Standard Gauge Secondary Lines.

These were built about the same time as those we have described above and do not differ in principle from them. The earliest were furnished to the Ch. de Fer. de l'Hérault.

Others were supplied in 1896 by Maffei for the lighter lines of the Bavarian State Rys., and duplicated for the Palatinat (Pfalz) and Anatolian Rys.

When it became advisable to increase the amount of fuel and water space, an extra carrying axle was added, as with the Bavarian 0-4 + 4-2 *Mallet* which was exhibited in Paris.

The diameter of the coupled wheels ranges from 1 m. to 1·20 m. (3 ft. $3\frac{3}{8}$ ins. to 3 ft. $11\frac{1}{4}$ ins.) ; the boiler was pressed to 12 or 14 kgs. (171 lbs. to 199 lbs.), and, with few exceptions, the axle load ranged from 12 to 14 tons.

0-4 + 4-0 Mallets of the Central Swiss Ry.—Standard gauge.

The *Mallet* design made its way rapidly in Switzerland, as was natural, owing to the difficulty experienced in working its mountain railways, and already in 1889 a 0-6 + 6-0 banking engine was at work on the Gothard Ry.

But the Central Swiss main line also had hard climbs on the approaches of the Hauenstein Tunnel, between Olten and Sissach, on the Bern-Bâle main line, the gradients reaching 2·1 and 2·7 per cent.

In 1890, some 0-4 + 4-0 *Mallets* built by Maffei were put into service, and they were followed by larger locomotives designed by Maffei and by the Winterthur Works, the latter with separate tenders.

0-4 + 4-0 Mallets of the Prussian State Rys.—Standard gauge.

Towards 1894, the Grafenstaden Works of the Société Alsacienne (which has been frequently quoted in connection with early types of *Mallet* locomotives) supplied these locomotives to the Breslau Direction of the Prussian State Rys.

Other directions (Saarbruck, then Kattowitz) followed suit, and these locomotives are of importance, because they served as prototypes to a number of other German standard gauge railways as well.

In 1895, the same firm, and subsequently that of Carlsruhe, built similar locomotives for the Black Forest line of the Baden State Rys.*

The Chemnitz Works furnished others to the Saxon State Rys. and the Hungarian State Rys. built their own.

0-4 + 4-0 Mallet Tank Locomotives of the Italian Rys.—Standard gauge.

At the same time a number of *Mallet* locomotives were built in France, in Belgium, and in Germany for Italian lines.

The Nazionale di Roma's locomotives † had a heavy axle load but otherwise no special features.

Those of the Ferrovia Apennino Centrale and of the Ferrovia Arezzo-Zossaco differ little, save for the gauge, from those of the Ferrovia d'Amandola Adriatica.

Other 0-4 + 4-0 Mallet Locomotives

Besides those we have quoted, a large number of other *Mallets* of this class have been built. No object would be served in examining them in detail. But it may be useful, for future reference, to give a list of others, amongst which are the following :—‡

In Germany :

Ruhr-Lippe Ry., metre gauge. (5)
The Gera Meuselyvitzer Rys., metre gauge. (2)
Halle Hettestedter Ry., standard gauge. (6)
Neubrandebourg Ry., standard gauge. (7)
The Brockenbahn, metre gauge. (7)
The Brölthal Ry., 0m.78 gauge. (7)
The Mullheim Badenweiler Ry. (3)
The Wurtemberg Ry.'s 2 ft. gauge lines. (1)

* The Hansach section of the Black Forest line has maximum gradients of 1·9 per cent. with curves 400 m. (1,312 ft.) radius on more than half its length.

Diameter of cylinders reduced from 0·40 m. to 0·39 m. (15⅜ ins.), and boiler pressure increased from 12 to 13 kg. (171 to 185 lbs.).

† Built by Borsig, of Berlin.

‡ The builders were—(1) The Alsacienne Co. (2) Borsig. (3) Henschel. (4) Maffei. (5) The Hohenzollern Works. (6) The German Vulcan Works, Stettin. (7) Arnold Jung, at Kirchen. (8) Les Ateliers Métallurgiques, Tubize. (9) Schichau, at Elbing. (10) The Esslingen Works.

In France :

Avricourt, Blanmont, Cirey Ry., metre gauge. (3)

Monceau les Mines, 0m.80 gauge. (8)

In Italy : The Sardinian 0m.954 gauge lines. (9)

In the ex-German Colonies: The Daressalam Ry., metre gauge. (3) and the Usambara Ry., metre gauge. (7)

The Serbian State 2 ft. 6 ins. gauge lines. (3)

In Sumatra : The Atjeh narrow gauge system. (10)

In Portugal : The State Rys. and the Povoa Famalicaõ Ry. (3)

The Luxemburg Secundary Rys., metre gauge. (1)

TABLE 59.—PRINCIPAL DIMENSIONS OF **0-4 + 4-2-T** MALLET TANK LOCOMOTIVES

Type	**0-4 + 4-2**	**0-4 + 4-2**	**0-4 + 4-2**
Gauge	Metre.	1·05 m.	1·067 m.
Railways	Rhétique.	Damas-Hamah.	Java.
Builders	Winterthur.	Chemnitz.	Schwartzkopff, also Chemnitz.
Cylinders, diameter, H.P. m.	0·32	0·34	0·30
,, ,, L.P. m.	0·49	0·52	0·46
,, ,, stroke m.	0·55	0·51	0·51
Boiler, height of C/L . m.	1·95	2·15	1·90
,, diameter . . m.	1·14 ext.	1·30	1·21
,, pressure kg. per sq. cm.	14	12	12
Tubes, number . . .	139	179	224
,, diameter . . mm.	42/46	45/50	37/41
,, length . . m.	3·65	4·10	3·60
Heating surface, firebox sq. m.	7	7·3	7·7
,, ,, tubes sq. m.	72	103·8	93·7
,, ,, total sq. m.	79	111·1	101·4
Grate area . . sq. m.	1·3	1·3	1·5
Wheels, diameter . m.	1·05	1·07	1·10
,, ,, . m.	0·74	0·76	0·78
Wheelbase, rigid . . m.	1·60	1·35	1·40
,, motor . m.	—	—	4·80
,, total . m.	6·60	6·25	6·00
Overall dimensions :			
Height . . . m.	3·70	3·85	3·70
Width . . . m.	2·50	2·78	2·70
Length . . . m.	10·63	11·31	10·90
Weight, adhesive . t.	42	46·1	34·7
,, empty . . t.	38·9	41·6	33·4
,, in service . t.	46·3	54·1	42·9
Tractive force . . t.	6·2	6·6 (= 600 h.p.)	5·9 (50%)
Fuel bunkers . cub. m.	3·4	5·5	4·0
Water tanks . . t.	1·0	2·5	1·4

Table 59a.—Principal Dimensions of **0-4 + 4-2-T** Mallet Tank Locomotives

Type	**0-4 + 4-2**	**0-4 + 4-2**	**0-4 + 4-2**
Railway	Rhétiques Rys.	Damas-Hamah Ry.	Java State Rys.
Gauge	Metre.	$3' 5\frac{3}{8}''$	$3' 6''$
Builder	Winterthur.	Chemnitz.	Schwartz-kopff.
Cylinders, diameter, H.P.	$12\frac{5}{8}''$	$13\frac{3}{8}''$	$11\frac{13}{16}''$
,, ,, L.P.	$19\frac{5}{16}''$	$20\frac{1}{2}''$	$18\frac{1}{8}''$
,, stroke	$21\frac{11}{16}''$	$20\frac{1}{8}''$	$20\frac{1}{8}''$
Boiler, height of centre line	$6' 4\frac{1}{2}''$	$7' 0\frac{1}{2}''$	$6' 3''$
,, diameter	$3' 8\frac{7}{8}''$ ext.	$4' 3\frac{1}{4}''$	$3' 11\frac{5}{8}''$
,, pressure lbs. per sq. in.	199	171	171
Tubes, number	139	179	224
,, diameter	$1\frac{5}{8}''/1\frac{13}{16}''$	$1\frac{3}{4}''/2''$	$1\frac{7}{16}''/1\frac{5}{8}''$
,, length	$11' 11''$	$13' 5\frac{1}{2}''$	$11' 9\frac{5}{8}''$
Heating surface :			
Firebox . . sq. ft.	75·4	78·6	83
Tubes . . ,,	775·6	1,116·4	1,090
Total . . ,,	851	1,195	1,173
Grate area . . ,,	14	14	16
Wheels, diameter	$3' 5\frac{3}{8}''$	$3' 6\frac{1}{8}''$	$3' 7\frac{5}{16}''$
,, ,,	$2' 5\frac{1}{8}''$	$2' 5\frac{7}{8}''$	$2' 6\frac{3}{4}''$
Wheelbase, rigid	$5' 3''$	$4' 5\frac{1}{4}''$	$4' 7\frac{1}{8}''$
,, driving	—	—	$15' 9''$
,, total	$21' 7\frac{1}{2}''$	$20' 6''$	$19' 8''$
Overall, height	$12' 1\frac{3}{4}''$	$12' 7\frac{1}{2}''$	$12' 1\frac{3}{4}''$
,, width	$8' 2\frac{1}{2}''$	$9' 1\frac{1}{2}''$	$8' 10\frac{1}{2}''$
,, length	$34' 11''$	$37' 1''$	$35' 9''$
Weight, adhesive tons-cwt.	41–6	45–6	34–2
,, empty ,,	38–5	40–19	33–17
,, in service ,,	45–11	53–6	42–4
Tractive force . . lbs.	13,670	14,550 (600 h.p.)	13,000 (50%)
Water tanks . . galls.	220	550	300
Fuel bunkers . tons-cwt.	1–0	2–9	1–8

Classes B and C.—0-4 + 4-2 and 2-4 + 4-0 Mallet Tank Locomotives

These locomotives are not typical: they are, in fact, simply modifications of the original type. The extra rear axle was added to provide a better distribution of loads and to carry larger tanks or bunkers.

But it was found more satisfactory to build these locomotives with a front pony axle, as the same results could be obtained and, at the same time, better guidance into curves resulted.

0-4 + 4-2 and 2-4 + 4-0 Mallet Tank Locomotives of the Rhétiques Rys.—Metre gauge.

An instance of these modifications is to be found here, where the Winterthur Locomotive Works at first supplied 0-4 + 4-2 locomotives, which were quickly superseded by the 2-4 + 4-0 arrangement. Both have now disappeared, the line having been converted to electrical traction.

2-4 + 4-0 Mallet Tank Locomotives of the Central Swiss Ry.—Standard gauge.

As an example on normal gauge lines, it is interesting to quote the transformation of *Mallet* types on this road.

After the original 0-4 + 4-0 locomotives, Messrs. Maffei built others, with an extra pony axle, which was provided to reduce axle loads.

Winterthur built a new class, one of which was exhibited in Paris in 1900, and in this case a separate tender was provided so as to be able to use the adhesive weight thus available for increasing the capacity of the boiler.

Class D.—2-4 + 4-2 Mallet Tank Locomotives

This type has been little used, for, when the earlier locomotives with four coupled axles became inadequate, the obvious procedure was to pass on to six coupled axles.

We quote, however, an example of this type recently supplied to the Nordhausen Wernigerode Ry., which shows characteristics of recent European practice in the design of *Mallet* tank locomotives.

TABLE 60.—PRINCIPAL DIMENSIONS OF **2-4 + 4-0-T** MALLET TANK LOCOMOTIVES

Type		**2-4 + 4-0**	**2-4 + 4-0**	**2-4 + 4-0**	**2-4 + 4-0**
Gauge		0·75 m.	Metre.	Metre.	Metre.
Railway		Antivari.	Rhétiques.	Départementaux. (France).	Ex-Central East African Ry.
Builder		Borsig.	Winterthur.	Alsacienne.	Henschel.
Date		—	—	1908.	—
Cylinders, diameter	m.	0·23	0·32	0·28	0·29
,, ,,	m.	0·36	0·49	0·43	0·45
,, stroke	m.	0·40	0·55	0·50	0·56
Boiler, height of centre line	m.	1·65	1·95	2·00	2·05
,, diameter	m.	0·93	1·14	1·12	1·02
,, pressure	kg. per sq. cm.	12	14	13	14
Tubes, number		96	139	134	137
,, diameter	mm.	41/46	42/46	41	44
,, length	m.	3·40	3·60	3·55	4·00
Heating surface, firebox	sq. m.	2·8	—	5·5	5·9
,, ,, tubes	sq. m.	47·2	—	61·3	62·3
,, ,, total	sq. m.	50	80	66·8	68·2
Grate area	sq. m.	0·9	1·3	1·2	1·3
Wheels, diameter	m.	—	0·70	0·73	0·68
,, ,,	m.	0·80	1·05	1·03	0·95
Wheelbase, rigid	m.	1·00	1·60	1·40	1·50
,, driving	m.	3·60	—	4·70	—
,, total	m.	5·15	6·60	6·52	6·60
Overall height	m.	3·26	—	3·40	—
,, width	m.	2·20	—	2·40	—
,, length	m.	8·26	—	9·54	—
Weight, adhesive	t.	25	42·5	32	37·6
,, empty	t.	23	38	30·7	29·8
,, in service	t.	29	45	38	42·1
Tractive force	t.	3·6	—	6·1	6·5
Water tanks	cub. m.	2·5	3·4	3·4	8·0
Coal bunkers	t.	0·8	1·0	1·0	3·5

TABLE 60A.—PRINCIPAL DIMENSIONS OF 2-4 + 4-0-T MALLET TANK LOCOMOTIVES

Type	**2-4 + 4-0**	**2-4 + 4-0**	**2-4 + 4-0**	**2-4 + 4-0**
Gauge	$2' 5\frac{1}{2}''$	Metre.	Metre.	Metre.
Railway	Antivari.	Rhéti-ques.	Départe-mentaux. (France).	Ex-Central East African Ry.
Builder	Borsig.	Winter-thur.	Alsa-cienne.	Henschel.
Date	—	—	1908.	—
Cylinders, diameter, H.P.	$9\frac{1}{16}''$	$12\frac{5}{8}''$	$11''$	$11\frac{3}{8}''$
,, ,, L.P.	$14\frac{3}{16}''$	$19\frac{1}{8}''$	$16\frac{15}{16}''$	$17\frac{3}{4}''$
,, stroke	$15\frac{3}{4}''$	$21\frac{5}{8}''$	$19\frac{11}{16}''$	$22\frac{1}{8}''$
Boiler, height of centre line	$5' 5''$	$6' 4\frac{3}{4}''$	$6' 4\frac{1}{2}''$	$6' 8\frac{1}{2}''$
,, diameter	$3' 0\frac{5}{8}''$	$3' 8\frac{7}{8}''$	$3' 8\frac{1}{8}''$	$3' 4\frac{1}{4}''$
,, pressure lbs. per sq. in.	171	199	185	199
Tubes, number	96	139	134	137
,, diameter	$1\frac{5}{8}''/1\frac{13}{16}''$	$1\frac{9}{16}''/1\frac{13}{16}''$	$1\frac{5}{8}''$	$1\frac{11}{16}''$
,, length	$11' 1\frac{3}{4}''$	$11' 9\frac{3}{8}''$	$11' 8''$	$13' 1\frac{1}{2}''$
Heating surface :				
Firebox . . sq. ft.	30	—	59	63·5
Tubes . . ,,	508	—	665	670·5
Total . . ,,	538	861	724	734
Grate area . . ,,	9·7	13·9	12·9	14
Wheels, diameter	—	$2' 3\frac{1}{2}''$	$2' 4\frac{3}{4}''$	$2' 2\frac{13}{16}''$
,, ,,	$2' 7\frac{1}{2}''$	$3' 5\frac{1}{2}''$	$3' 4\frac{1}{2}''$	$3' 1\frac{1}{2}''$
Wheelbase, rigid	$3' 3\frac{3}{8}''$	$5' 3''$	$4' 7\frac{1}{8}''$	$4' 11\frac{1}{8}''$
,, driving	$11' 9\frac{1}{2}''$	—	$14' 5''$	—
,, total	$16' 10\frac{1}{2}''$	$21' 8\frac{1}{8}''$	$21' 4''$	$21' 8\frac{1}{8}''$
Overall height	$10' 8\frac{1}{4}''$	—	$11' 1\frac{3}{4}''$	—
,, width	$7' 2\frac{1}{2}''$	—	$7' 10\frac{1}{2}''$	—
,, length	$27' 1''$	—	$31' 3\frac{1}{2}''$	—
Weight, adhesive . tons-cwt.	24–12	41–18	31–9	47–0
,, empty ,,	22–12	37–8	30–4	29–6
,, in service ,,	28–10	44–6	37–7	41–15
Tractive force . . lbs.	7,936	—	13,450	14,330
Water . . . . galls.	550	750	750	1,760
Fuel . . . tons-cwt.	0–16	1–0	1–0	3–9

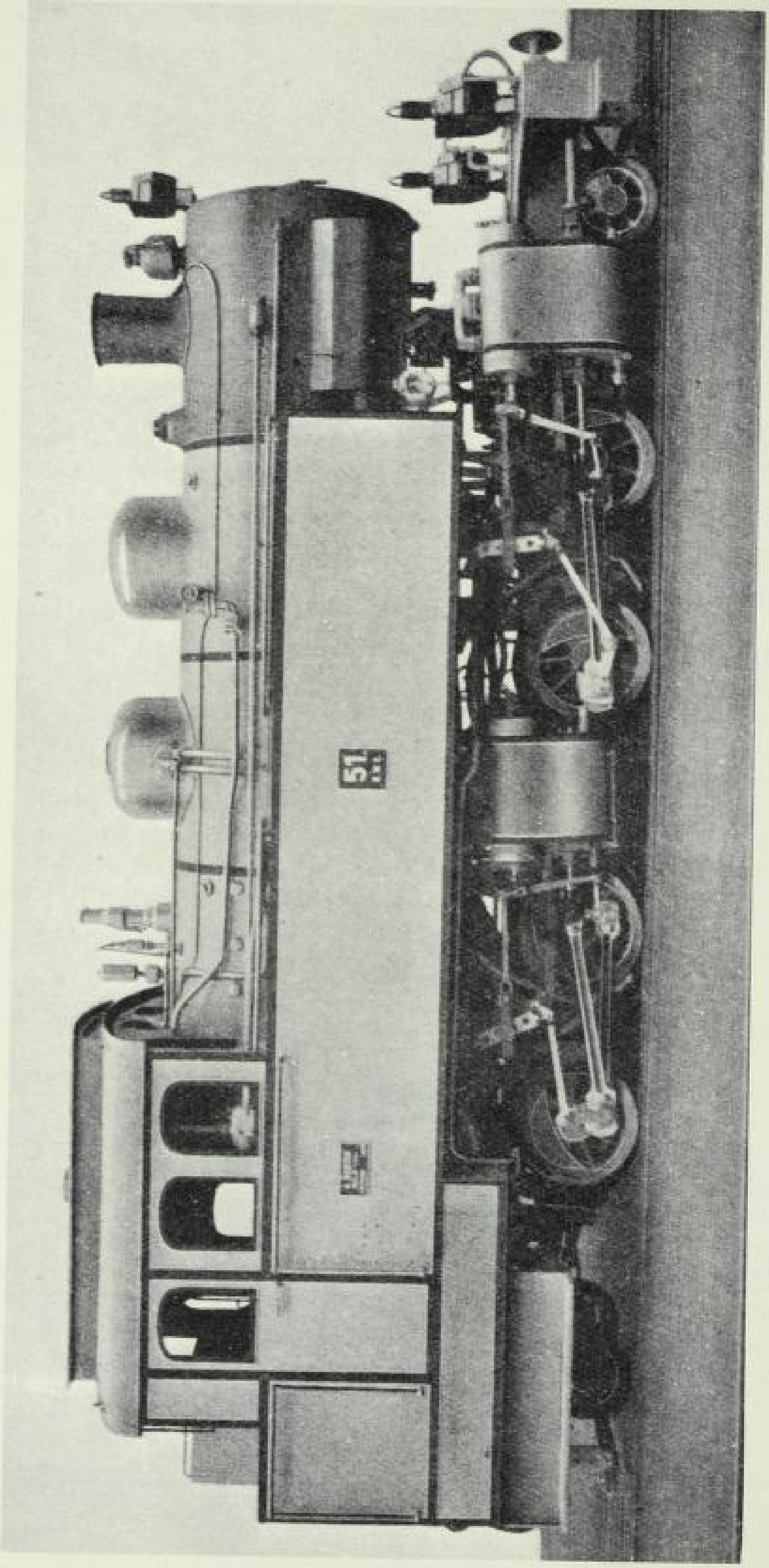


FIG. 140.—2.4 + 4.2 Mallet Tank Locomotive, Nordhausen Wernigerode Ry.
(Metre Gauge.)
Built by Borsig, of Berlin.

Tables 61 & 62.—Principal Dimensions of 2-4 + 4-2 and 2-4 + 6-0 Mallet Tank Locomotives

Type		**2-4 + 4-2-T**	**2-4 + 6-0-T**
Gauge		Metre.	Metre.
Railway		Nordhausen Brockenbahn.	Portuguese State Rys.
Builders		Borsig.	Henschel.
Date		1926.	1910 and 1913.
Cylinders, diameter, H.P.	m.	0·36	0·35
,, ,, L.P.	m.	0·56	0·50
,, stroke	m.	0·40	0·55
Boiler, centre line	m.	2·40	2·20
,, diameter	m.	1·40	1·35
,, pressure	kg. per sq. cm.	—	14
Tubes, number		24–146	224
,, diameter	mm.	100/108–35/40	41/46
,, length	m.	2·90	4·00
Heating surface, firebox	sq. m.	9·0	14
,, ,, tubes	,,	53·2 + 23·6	123
,, ,, total	,,	86·0	137
,, ,, superheater	,,	22·0	None
Grate area	,,	2·0	2·0
Wheels, diameter	m.	0·60	0·75
,, ,,	m.	0·85	1·00
,, ,,	m.	0·60	None
Wheelbase, rigid	m.	1·30	1·36–3·41
,, total	m.	7·80	8·27
Tractive force	t.	8·8 (60%)	8·77
Water tanks	cub. m.	7·3	6
Coal bunkers	t.	2·5	2·3
Weight, adhesive	t.	38	52
,, empty	t.	40	47
,, in service	t.	53	59

Tables 61a & 62a.—Principal Dimensions of 2-4 + 4-2 and 2-4 + 6-0 Mallet Tank Locomotives

Type	**2-4 + 4-2-T**	**2-4 + 6-0-T**
Gauge	Metre.	Metre.
Railway	Nordhausen Brockenbahn.	Portuguese State Rys.
Builders	Borsig.	Henschel.
Date	1926.	1910 and 1923.
Cylinders, diameter, H.P.	$14\frac{3}{16}''$	$13\frac{13}{16}''$
,, ,, L.P.	$22\frac{1}{16}''$	$19\frac{11}{16}''$
,, stroke	$15\frac{3}{4}''$	$21\frac{11}{16}''$
Boiler, height of centre line	$7'\ 10\frac{3}{4}''$	$7'\ 2\frac{1}{2}''$

TABLES 61A AND 62A.—PRINCIPAL DIMENSIONS OF **2-4 + 4-2** AND **2-4 + 6-0** MALLET TANK LOCOMOTIVES—*continued*

Type	**2-4 + 4-2-T**	**2-4 + 6-0-T**
Gauge	Metre.	Metre.
Railway	Nordhausen Brockenbahn.	Portuguese State Rys.
Builders	Borsig.	Henschel.
Date	1926.	1910 and 1923.
Boiler diameter	4′ $7\frac{1}{4}$″	4′ $5\frac{3}{16}$″
,, pressure . lbs. per sq. in.	—	199
Tubes, number	24–146	224
,, diameter	$3\frac{15}{16}$″/$4\frac{1}{16}$″/$1\frac{3}{8}$″ $1\frac{9}{16}$″	$1\frac{19}{32}$″/$1\frac{13}{16}$″
,, length	9′ $6\frac{1}{4}$″	13′ $1\frac{1}{2}$″
,, superheater, diameter	$\frac{29}{32}$″/$1\frac{1}{8}$″	—
Heating surface, firebox . sq. ft.	97	151
,, ,, tubes ,,	573 + 254	1,324
,, ,, total ,,	824	1,475
,, ,, superheater ,,	237	—
Grate area ,,	21·5	21·5
Wheels, diameter	1′ $11\frac{5}{8}$″	2′ $5\frac{1}{2}$″
,, ,,	2′ $9\frac{1}{2}$″	3′ $3\frac{3}{8}$″
,, ,,	1′ $11\frac{5}{8}$″	—
Wheelbase, rigid	4′ $3\frac{3}{16}$″	4′ $5\frac{1}{2}$″
,, total	25′ 7″	28′ 6″
Tractive force . lbs.	19,400 (60%)	19,200
Water . galls.	1,600	1,320
Fuel . tons-cwt.	2–9	2–5
Weight, adhesive ,,	37–7	51–3
,, empty ,,	39–7	46–5
,, in service ,,	52–3	58–0

Class E.—2-4 + 6-0 Mallet Tank Locomotives

As will be readily inferred, this is a transition type. Dissymmetrical trucks have never been persevered with and, on the other hand, it is advisable, when guidance is necessary (as is usually the case on narrow gauge lines), to have a pony truck at either end, especially for tank engines, which should be double-enders. Such being the case, these locomotives were bound to be superseded first by 2-6 + 6-0 and later by 2-6 + 6-2 types.

The instance we quote was built for the Portuguese State Rys. for use on their metre gauge system. We understand that it was soon provided with a separate two-axle tender, which further altered it. A few locomotives of this latter type have also been built for other lines.

Class F.—0-6 | 6-0 Mallet Tank Locomotives

These do not differ in principle from the 0-4 + 4-0-T type previously noticed. They are adopted when additional power is needed.

0-6 + 6-0-T Mallet Locomotives of Gothard Ry.—Standard gauge (Fig. 141).

These locomotives were built by Maffei at Munich and, with those of the Central Swiss Ry., were the first standard gauge *Mallets* built and were, at the same time, the most powerful. They were followed, at a short interval, by similar locomo-

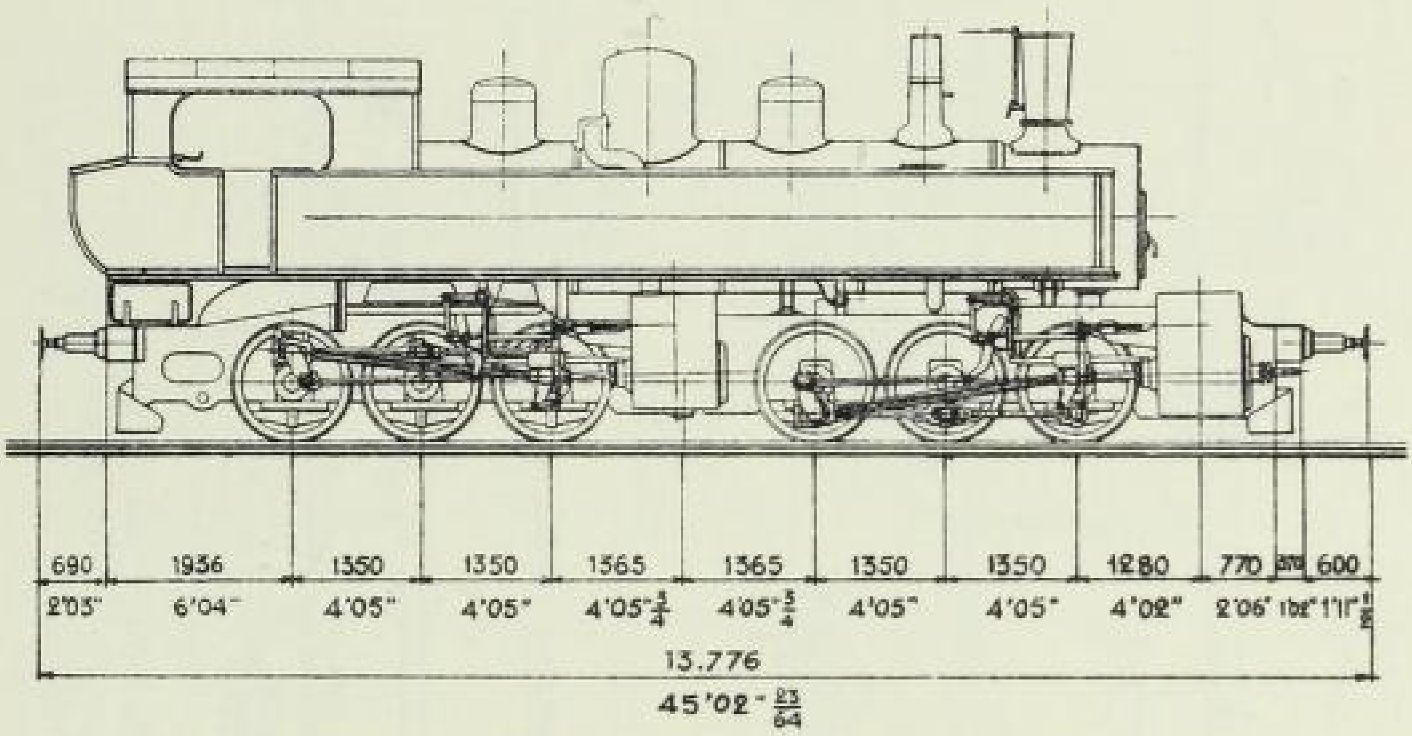


FIG. 141.—0-6 + 6-0 Mallet Tank Locomotive.
(Standard Gauge.)
Built by Messrs. Maffei, of Munich, for the Gothard Ry.

tives for the Belgian State and for the Central Aragon Rys. They preceded by fourteen years the first *Mallets* built in America. Anatole Mallet himself considered that the cylinders of the Gothard locomotive were too small.

0-6 + 6-0-T Mallet of the Belgian State Rys.—Standard gauge (Fig. 142).

This locomotive was exhibited in 1897 at the Tervueren Annexe of the Brussels International Exhibition. It subsequently was allocated for banking service up the Ans incline,*

* The incline from Liège to Ans has maximum gradients of 3·2 per cent. At Haut-Pré Station it is divided into two sections, each of which ascends 55 m. (180 ft.). In earlier days, a fixed haulage installation with an endless cable was installed here by Maus. This was

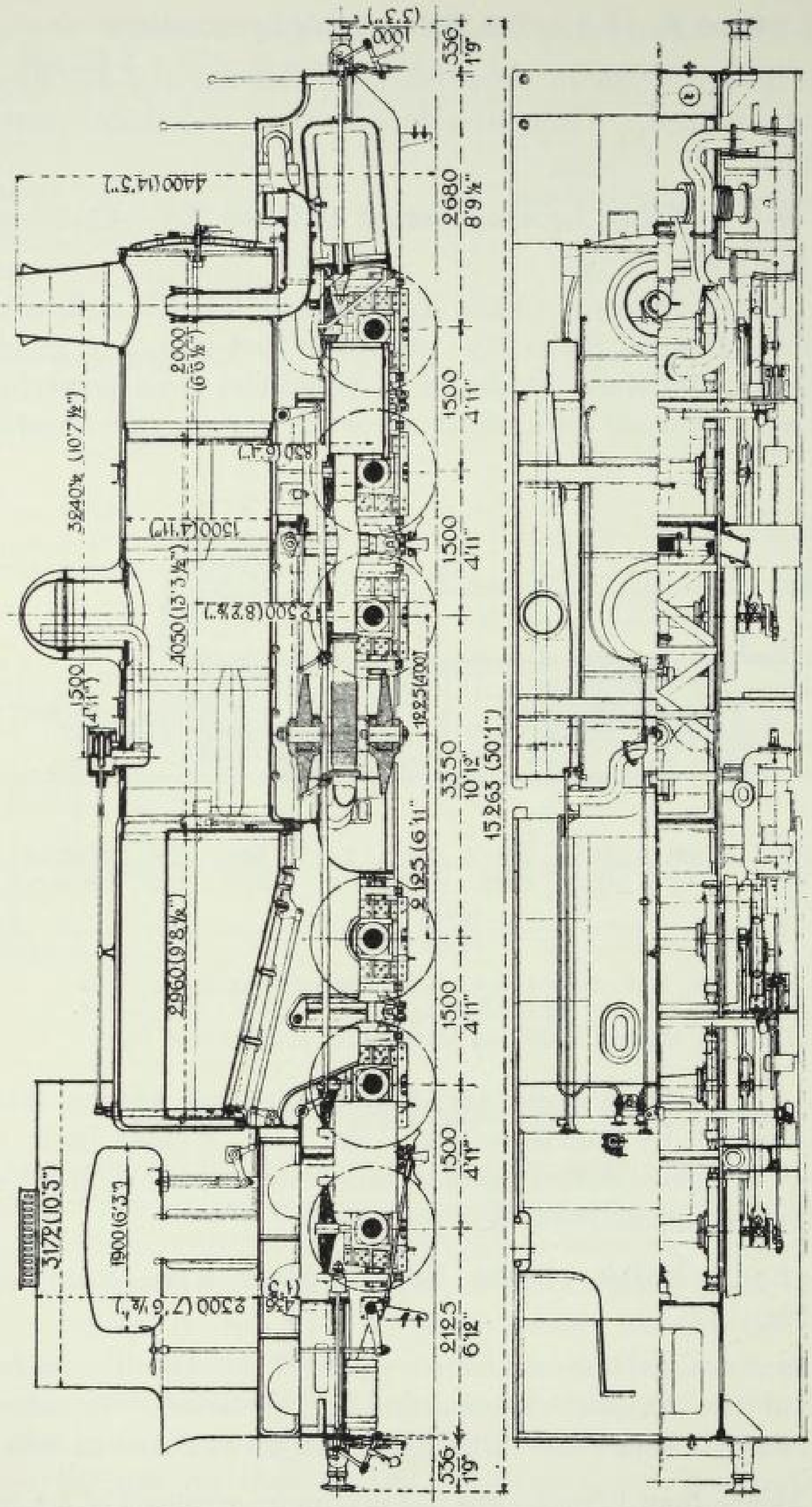


FIG. 142.—0-6 + 6-0-T Mallet Locomotive, Belgian State Rys. (Standard Gauge.) Built by the St.-Léonard Works, Liège.

abandoned in 1867, after having given good service for a quarter of a century, and was the model after which the earlier Santos inclines were established in Brazil.

TABLE 63.—PRINCIPAL DIMENSIONS OF 0-6 + 6-0-T MALLET TANK LOCOMOTIVES

Gauge . Railway Builders Date	0m.76. Steinbeis Co. Maffei. —	0m.91. Girardot Tolima. American Loco. Co. —	1 m. F. C. de Utrillas. Baldwin. —	1 m. Départementaux. Winterthur. —	1 m. Zell to Todnau. Hanomag. —	1 m. Algerian State. Alsacienne. 1909.	1 m. Bône-Guelma. Various. —	1m.435. Gothardbahn. Maffei. 1890.	1m.435. Belgian State. St.-Léonard. 1897.	1m.672. Central Aragon. Borsig. —
Cylinders, diameter, H.P. . m.	0·26	0·33	0·41	0·31	0·40	0·35	0·38	0·40	0·50	0·47
,, ,, L.P. . m.	0·52	0·52	0·64	0·55	0·62	0·53	0·58	0·58	0·81	0·71
,, stroke . . . m.	0·40	0·51	0·56	0·55	0·45	0·50	0·56	0·64	0·65	0·60
Boiler, height of centre line m.	1·77	1·98	2·03	—	2·20	2·20	2·03	2·32	2·45	6·60
,, diameter . . . m.	1·09	1·22	1·27	—	1·40	1·21	—	1·47	1·50 int.	1·60
,, pressure kg. per sq. cm.	14	14·1	14·1	14	14	12	15	12	15	12
Tubes, number	86	150	152	—	202	173	162	190	164 (serve)	266
,, diameter . . mm.	58/64	51	57	—	40/45	40/45	40/45	48·5/54	65/70	45/50
,, length . . . m.	2·91	4·27	4·72	—	4·30	3·80	4·00	4·50	4·05	5·45
Firebox, width . . . m.	—	1·46	1·35	—	—	0·97	—	1·04	—	1·53
,, length	2·22	2·20	2·44	—	—	1·97	—	2·12	—	2·80
Heating surface, firebox sq. m.	6·3	6·1	9·4	—	7·3	8·1	9·8	9·3	14·8	—
,, ,, tubes sq. m.	50·6	101·5	114	—	122·7	82·6	86·5	146·3	242·4	—
,, ,, total sq. m.	56·9	107·7	123·4	85·3	130·0 ext.	90·7	96·3	155·6	256·9	219·3
Grate area . . sq. m.	1·7	2·2	3·3	1·9	1·9	1·9	1·6	2·2	7·3	4·3
Wheels, diameter . . m.	0·75	0·96	1·04	1·01	0·90	1·01	1·10	1·23	1·30	1·10
Wheelbase, rigid . . m.	1·62	·33	2·44	2·20	2·50	2·35	2·44	2·70	3·00	3·00
,, total . . m.	4·93	7·71	7·16	6·40	7·00	6·60	6·90	8·13	9·35	8·60
Overall, height . . . m.	3·43	3·41	3·70	—	3·70	3·90	4·06	4·30	4·40	—
,, width . . . m.	2·22	2·69	2·79	—	2·70	2·60	—	3·89	3·02	4·20
,, length . . . m.	9·27	12·72	11·33	—	11·40	11·10	11·61	13·78	14·16	—
Tractive force . . . t.	5·3	12·5 & 10·4	15	—	—	—	12·8	8·0	13·5	16
Water tanks . . cub. m.	3·4	8·2	8·2	4·0	6·0	6·5	6·5	7·1	9·0	20·0
Fuel bunkers . . . t.	3·5 (wood)	5·6	1·8	1·0	1·5	1·6	1·8*	4·8	3·0	4·0
Weight, empty . . . t.	24	—	—	36·0	46·1	40·8	47·2	69·2	—	76
,, in service . . . t.	32	58·7	75	44·2	56·5	52·4	59·6	87·0	109·6	108

* Oil.

TABLE 63A.—PRINCIPAL DIMENSIONS OF **0-6 + 6-0-T** MALLET TANK ENGINES

Gauge / Railway	2 ft. 6 ins. Steinbeis Co.	3 ft. F. C. de Giradot Tolima.	Metre. F. C. de Utrillas.	Metre. Departmental.	Metre. Zell-Todnau.	Metre. Algerian State Rys.	Metre. Bône-Guelma Co.	Standard. Gothard Ry. Co.	Standard. Belgian State Rys.	5 ft. 6 ins. Central Aragon Ry.
Builders	Maffei.	American Loco. Co.	Baldwin.	Winterthur.	Hanomag.	Alsacienne.	Baldwin.	Maffei.	St.-Léonard.	Borsig.
Date	—	—	—	—	—	1909.	—	1890.	1897.	—
Cylinders, diameter, H.P.	10¼″	13″	16″	12¼″	15¾″	13 13/16″	13½″	15¾″	19¾″	18½″
,, ,, L.P.	20½″	20½″	25″	21⅝″	24 7/16″	20⅞″	21″	22⅞″	32″	28″
,, stroke	15¾″	20″	22″	21⅝″	17¾″	19 11/16″	22″	25¼″	25⅝″	23⅝″
Boiler, height of centre line	—	6′ 6″	7′ 6″	—	—	—	—	—	—	—
,, diameter	3′ 7″	4′ 0″	4′ 2″	—	4′ 7⅛″	3′ 11⅝″	3′ 10″	4′ 9⅞″	4′ 11¼″ (int.)	5′ 3″
,, pressure lbs. per sq. in.	199	200	200	199	199	171	210	171	213	171
Tubes, number	86	150	152	—	202	172	115	190	164 (Serve)	266
,, diameter	2¼″/2½″	2″	2″	2 1/32″	2 9/32″	1 9/16″/1¾″	2″	1⅞″/2 5/32″	2 9/16″/2¾″	1 25/32″/2″
,, length	9′ 6½″	14′ 0″	15′ 6″	—	14′ 1″	12′ 6″	16′ 6″	14′ 9″	13′ 3″	17′ 10″
Firebox, width	—	4′ 0¼″	4′ 5″	—	—	3′ 2¼″	4′ 6″	3′ 5″	—	5′ 0″
,, length	6′ 3⅜″	6′ 0¼″	8′ 0″	—	—	6′ 5½″	7′ 3″	6′ 11½″	—	9′ 2″
Heating surface, firebox sq. ft.	67·8	67	109	—	78·6	87·2	98	100	159	—
,, ,, tubes ,,	545	1,093	1,227	—	1,320·4	888·8	989	1,575	2,610	—
,, ,, total ,,	612·8	1,160	1,336	—	1,409	976	1,087	1,675	2,769	—
Grate area ,,	18·3	24·1	35·3	20·5	20·5	20·5	16·3	24	78·6	46·3
Wheels, diameter	2′ 5½″	3′ 2″	3′ 5″	3′ 3¾″	2′ 11½″	3′ 3¾″	3′ 7¼″	4′ 0½″	4′ 3¼″	3′ 7¼″
Wheelbase, rigid	2′ 0½″	7′ 8″	8′ 0″	7′ 5½″	8′ 2½″	7′ 8½″	8′ 0″	8′ 10¼″	9′ 10″	9′ 10″
,, total	16′ 2″	23′ 4″	23′ 6″	21′ 0″	23′ 0″	21′ 8″	22′ 8″	26′ 8″	30′ 8″	28′ 2″
Overall, height	11′ 1¾″	11′ 2½″	12′ 4½″	—	12′ 1½″	12′ 9½″	—	14′ 1″	14′ 5½″	—
,, width	7′ 3½″	8′ 10″	9′ 2″	—	8′ 10½″	8′ 6½″	—	12′ 9″	9′ 11″	13′ 9½″
,, length	30′ 5″	—	37′ 7¼″	—	37′ 5″	36′ 5½″	—	45′ 2⅝″	46′ 6″	—
Tractive force lbs.	11,700	13,400	33,200	—	—	—	23,300	17,650	29,800	35,300
Water galls.	750 (imp. galls.)	1,800 (imp. galls.)	2,245 (U.S. galls.)	880	1,320 (imp. galls.)	1,430 (imp. galls.)	1,330 (imp. galls.)	1,560 (imp. galls.)	1,980 (imp. galls.)	4,400 (imp. galls.)
Fuel tons-cwt.	3–9 (wood)	100 cu. ft.	1–16	1–0	1–10	1–12	385 (imp. galls.*)	4–15	2–19	3–19
Weight, empty ,,	23–12	—	—	35–8	45–6	40–3	46–12	68–1	—	74–15
,, in service ,,	31–10	127,500 lbs.	165,200 lbs.	43–11	55–11	51–11	59–12	85–11	107–16	106–4

* Oil.

where it replaced two ordinary eight-coupled locomotives (0-8-0-T). These were the first locomotives in which the side tanks were divided mid-way in their length so as to allow easier access to the cylinders.

In trials, the locomotive drew a load of 490 tons at a speed of 12 km. (7½ miles) per hour. Nevertheless, it gave but poor service owing to its new (and defective) system of valve gear. It was then taken out of service and subsequently split up and most of it scrapped. This was the more regrettable as the whole *Mallet* system was condemned with it and, even to the present day, the Belgian railway administration refuses to reconsider it. Nevertheless, there are several sections of the Belgian National Rys. for which the *Mallet* locomotive or some

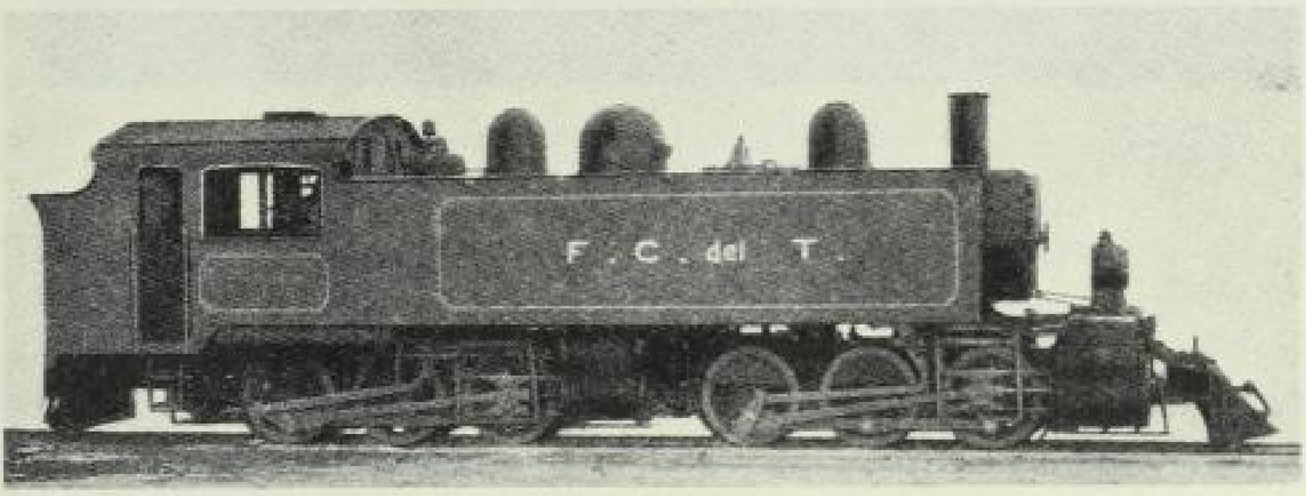


FIG. 143.—0-6 + 6-0-T Mallet Locomotive, F. C. de Tolima. (3 ft. Gauge.)
Built by the American Locomotive Co.

other type of articulated locomotives would seem eminently suitable, such as the Luxembourg line,* where double heading is frequent.

0-6 + 6-0 Mallet Tank Locomotives of the Central Aragon Ry. —Gauge, 1m.671 (5 ft. 6 ins.).

When they were built, these were the heaviest locomotives in Europe. They were intended for mineral traffic, but their axle load of 18 tonnes (17 tons 14 cwt.) proved too great for the road, so they have been converted into tender locos.

0-6 + 6-0-T Mallet of the Utrillas Ry. (Spain).—Metre gauge.

These superseded locos. of the 0-4 + 4-0-T type. They

* This section has gradients of 1·6 per cent. in both directions ; they reach 32 km. (20 miles) at a stretch.

have plate frames, those of the rear truck being external, so as to increase stability and allow of a wide firebox.*

0-6 + 6-0-T Mallets of the Harz Ry.—The same thing occurred here.

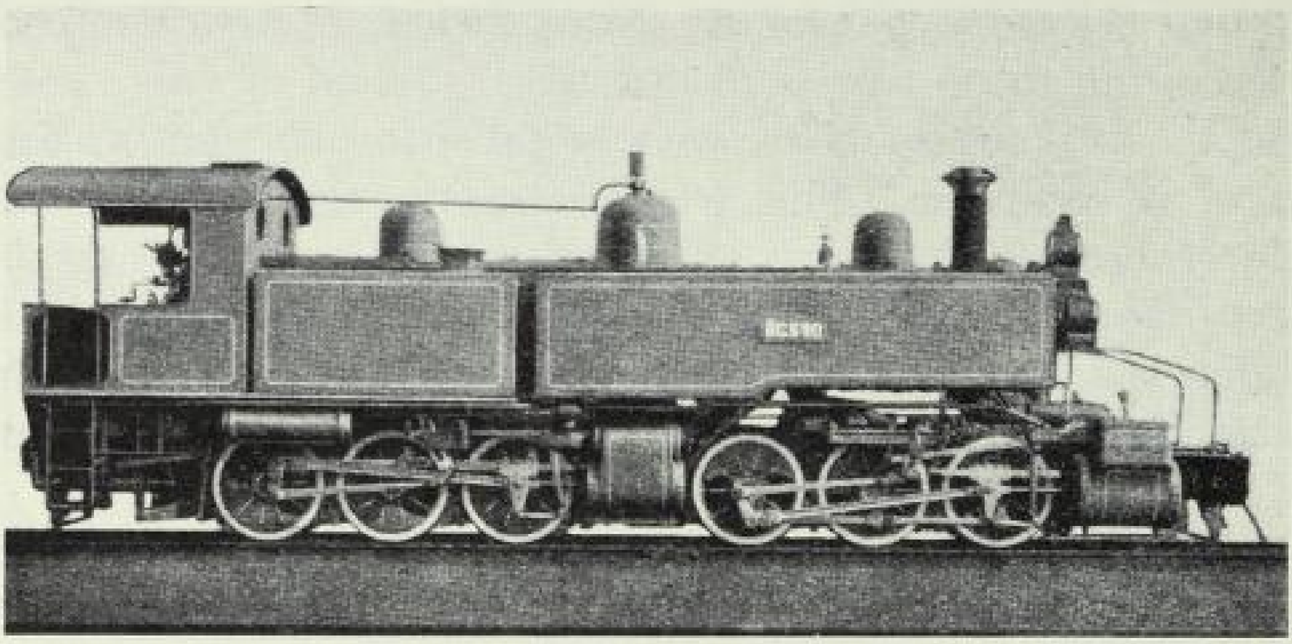


FIG. 144.—0-6 + 6-0-T Mallet Locomotive, Bône-Guelma Ry. (Metre Gauge.) Built by the Baldwin Locomotive Works.

Class G.—2-6 + 6-0 Mallet Tank Locomotives

This class is but a modification of the 0-6 + 6-0 type, obtained by the addition of a leading pony truck, with a view of securing better guidance in curves.

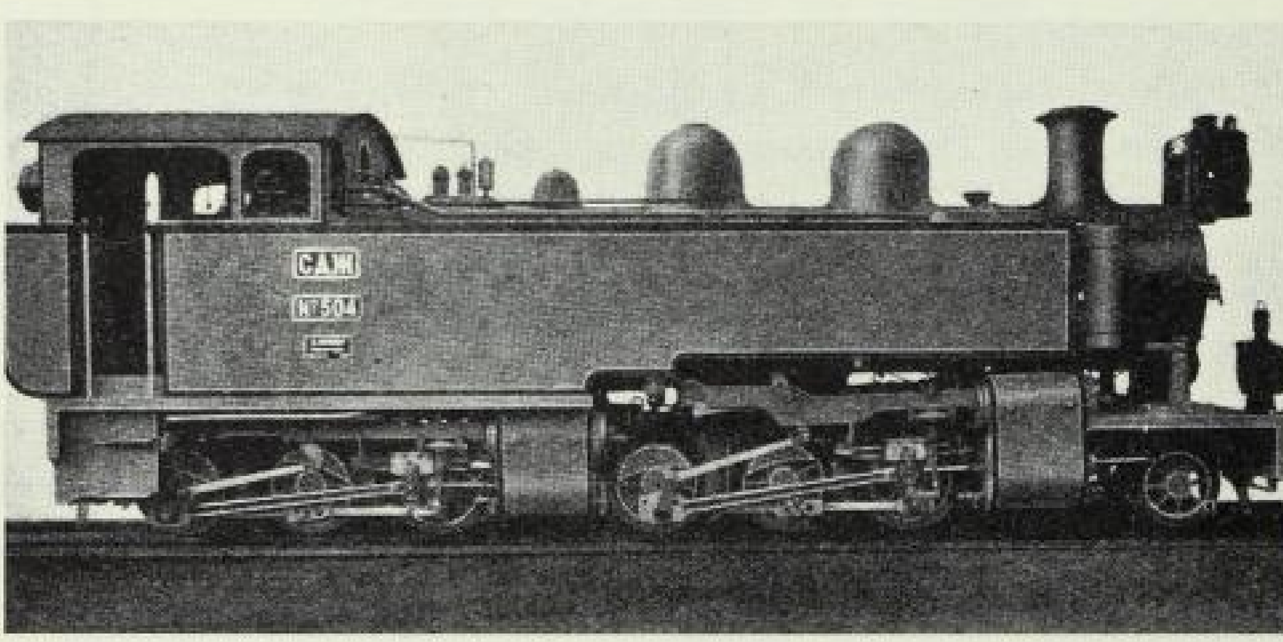


FIG. 145.—2-6 + 6-0-T Mallet Locomotive, Serbian State Rys. (2 ft. 6 ins. Gauge.) Built by Borsig, Berlin.

* This line has 3 per cent. grades. The track is light, being laid with 66-lb. rails.

2-6 + 6-0-T Mallets of the Serbian State Rys.—Gauge, 0m.76 (2 ft. 6 ins.). Fig. 145.

These locos. were built by Borsig to draw 180-ton trains at a speed of $9\frac{1}{2}$ miles (15 km.) an hour on a line having 2 per cent. grades and 197 ft. (60 m.) radius curves. These conditions obviously justified the addition of a leading bissel. The L.P. cylinders were brought back as far as possible in order to reduce the total wheelbase.

2-6 + 6-0-T Mallets of the Java State Rys.—Gauge, 3 ft. 6 ins. (1m.067).

These locos. preceded the above and have no outstanding features.

Class H.—2-6 + 6-8 Mallet Tank Locomotives

2-6 + 6-2-T Mallets for Logging Roads.—Standard gauge.

A special class of secondary railroads has been developed in American timber districts where the ground is usually rough and mountainous.

When the saw mills had cleared their immediate vicinity, they very soon found that horse power was inadequate, and laid very light railways to carry the timber to the mills. The traffic being slight at first, the rails were light, the gradients heavy, and the curves sharp, so geared locomotives appeared in the early 'eighties and performed the work asked from them satisfactorily.

But as the mills grew in importance, the railroads that served them were extended and became main lines from which spurs were shot into the better-timbered regions. The conditions of the main lines were improved and their output increased by various means, including increased speed and, for both reasons, direct connected locomotives often superseded the former geared locomotives for this particular service, the geared engines being maintained on the branches and on the rougher sections.

The rigid locomotives were 2-6-2 and 2-8-2 locomotives, usually tank engines. Extreme flexibility being indispensable, pony trucks were employed at either end, and the outer pairs of drivers only had flanged tyres.

Each of the trucks is of the radial swing bolster type, equalised with the neighbouring pair (or pairs) of coupled wheels. The diameter of the driving wheels is small so as to increase the tractive force, high speeds being out of the question.

When traffic grew, it became necessary to increase the power of the locomotives. As the axle load was limited, locomotives with an increased number of axles were provided, hence the appearance of the articulated locomotive for this particular class of work, where one is astonished at first sight to meet it. As a matter of fact, it has two further advantages over the rigid type. In the first instance, its weight is spread over a larger number of lineal feet, which is a great advantage in the case of trestle bridges that have been lightly constructed; secondly, *Mallet* engines are compound locomotives; this economises fuel and water and gives the locomotive a larger working range.

The question of using tank locomotives or locomotives with separate tenders arose at the outset, and though the former have been usually employed, each type presents its own advantages.

For the same adhesive weight, the range of work of the tender engine is larger, because it is necessary to calculate the tractive effort of the tank engine that corresponds to very depleted tanks and bunkers. But on grades of more than 4 per cent. the dead weight of the tender becomes an important factor, and the tank engine becomes preferable. The latter can run 10 or 15 miles without filling its tanks; hence, when water is available at suitable points, this type of engine is certainly preferable to the tender locomotive. This explains why it is far more extensively used than the latter.

The first *Mallet* locomotives were ordered from the Baldwin Locomotive Works by the *Booth-Kelly Lumber Co.* in 1910, and were tank locomotives. They deserve far more than a mere passing mention, because they were so well thought out and designed that the type has remained unchanged until this day, except for the adoption of some of the special devices that have been introduced since that date—such as superheaters and arch tubes—which tend to increase efficiency or to reduce maintenance costs. A certain number of other modern improve-

Tables 64 and 65.—Principal Dimensions of 2-6 + 6-0 and of 2-6 + 6-2 Mallet Tank Locomotives

Gauge		0·76 m.	1·067 m.	1·067 m.	Standard.	Standard.
Railway		Serbian State Rys.	Java State Rys.	Java State Rys.	Booth-Kelly.	Weyer-haeuser Timber Co.
Builder		Borsig.	Schwartz-kopff.	Chem-nitz.	Baldwin.	Baldwin.
Type		2-6 + 6-0	2-6 + 6-0		2-6 + 6-2	2-6 + 6-2
Date		—	1908.		—	1928.
Cylinders, diameter, H.P.	m.	0·33	0·34		0·43	0·43
,, ,, L.P.	m.	0·52	0·52		0·63	0·66
,, stroke	m.	0·40	0·51		0·61	0·61
Boiler, height of centre line	m.	1·90	2·30*		2·39	—
,, pressure	kg. per sq. cm.	13	12		14·1	14·1
Tubes, number		181	109 (Serve)		221	18–224
,, diameter	mm.	40/45	60/65		51	136–51
,, length	m.	4·00	4·64		5·18	5·18
Heating surface :						
Firebox	sq. m.	6·4	9·3	9·4	12·3	11·9
Tubes	sq. m.	102·4	185·6	125·8	181·8	141·8
Total	sq. m.	108·8	197·9	135·3	194·1	153·7
Superheater	sq. m.	None	None	None	None	32·2
Grate area	sq. m.	2·2	2·1	2·0	2·7	2·4
Wheels, diameter	m.	0·68	0·77		0·61	0·61
,, ,,	m.	0·80	1·10		1·12	1·11
,, ,,	m.	None	None		0·66	0·61
Wheelbase, rigid	m.	2·00	2·60		2·44	2·44
,, driving	m.	—	—		7·19	7·21
,, total	m.	7·80	9·40		11·50	11·50
Overall dimensions :						
Height	m.	3·35	3·70		4·59	—
Width	m.	2·42	2·62		—	—
Length	m.	10·10	13·20		—	—
Weight, adhesive	t.	48	52·9	51·6	80·4	85·1
,, empty	t.	43·5	46·1	45·6	80·0	—
,, in service	t.	55	59·7	58·8	93·4	103·7
Tractive force	t.	7·9	6·4 (0·5)	6·4	17·2 C.	
Tender, water	cub. m.	6	6	6	7·6	9·5
,, coal or oil	t.	2·2	2	2	8	5·7

Gauge		2 ft. 6 ins.	3 ft. 6 ins.		Standard.	Standard.
Railway		Serbian State Rys.	Java State Rys.	Java State Rys.	Booth-Kelly.	Weyer-haeuser Timber Co.
Builder		Borsig.	Schwartz-kopff.	Chem-nitz.	Baldwin.	Baldwin.
Type		2-6 + 6-0	2-6 + 6-0		2-6 + 6-2	2-6 + 6-2
Date		—	1908.		—	1928.
Cylinders, diameter, H.P.		13"	13¾"		17"	17"
,, ,, L.P.		20¼"	20½"		24 13/16"	26"
,, stroke		15¾"	20⅛"		24"	24"
Boiler, height of centre line		6' 3"	7' 6½"†		7' 10½"	—
,, pressure	lbs. per sq. in.	185	171		200	200
Tubes, number		181	109 (Serve)		221	18–124
,, diameter		1 11/16–1¾"	2⅜–2 9/16"		2¼"	5⅜"–2"
,, length		13' 1½"	15' 0"		17' 0"	17' 0"
Heating surface :						
Firebox	sq. ft.	69	100	102	132	128
Tubes	,,	1,105	2,000	1,360	1,950	1,526
Total	,,	1,174	2,100	1,462	2,082	1,654
Superheater	,,	None	None	None	None	346
Grate area	,,	24	22·5	21·5	29	26·2
Wheels, diameter		2' 2¾"	2' 6⅜"		2' 0"	2' 0"
,, ,,		2' 7½"	3' 7⅜"		3' 8¼"	3' 8"
,, ,,		—	—		2' 2"	2' 0"
Wheelbase, rigid		6' 6¼"	8' 6"		8' 0"	8' 0"
,, driving		—	—		23' 7"	23' 8"
,, total		25' 8"	30' 10"		37' 9"	37' 9"
Overall dimensions :						
Height		11' 0"	12' 2"		15' 1"	—
Width		7' 10½"	8' 7½"		—	—
Length		33' 2"	43' 6"		—	—
Weight, adhesive	tons-cwt.	47–4	52–0	50–14	79–1	83–16
,, empty	,,	42–15	45–17	44–17	78–17	—
,, in service	,,	54–2	58–14	57–18	92–0	—
Tractive force	lbs.	16,000	13,500	13,500	—	—
Tender, water	galls.	1,320	1,320	1,320	1,670	—
,, coal or oil	tons-cwt.	2–4	2–4	2–4	7–18	—

* The diameter of the boiler is 1·27 m.

† The diameter of the boiler is 4 ft. 2 ins.

ments cannot be applied to them either because of the nature of the service required, because their complication would not, in this case, be compensated by any appreciable advantage, or because the class of labour available is of too low a quality to be entrusted with the working of delicate mechanism.

The question of the water supply is very important. It is generally carried in side tanks, occasionally in saddle tanks. In the earlier locomotives, the lateral tanks were interrupted above the H.P. cylinders and were there divided into two portions, thus giving easy access to the mechanism, piping, etc. The earlier tender engines have the usual American tender; the 1924 Caspar Lumber Co.'s tenders are of the Vanderbilt type.

With hardly any exceptions, all *Mallets* destined for lumber service have twice three coupled axles. The 2-4 + 4-2 type is sometimes but very rarely met with.

The 2-6 + 6-2 Tank Mallets of the Booth-Kelly Lumber Co.—Standard gauge.

Three of these locomotives were ordered in 1910, and one of them was a tank locomotive. The line, which aggregates 26 miles of track, has 30-degree curves and gradients ranging from 1 to 5 per cent.* The locomotives were required to haul eleven 35 (short) ton cars.

Other 2-6 + 6-2 Mallets for Logging Service.—Standard gauge.

The St. Paul and Tacoma Lumber Co. formerly operated its lines with three geared locomotives. In 1922 and 1923 the Company replaced them by two *Mallets* each of which accomplished three round trips a day instead of the two trips of the geared locomotives. This saved one train and engine crew, and the cost of maintenance of one of the locomotives.† These locomotives differ but slightly from the former. They weigh 99 short tons, of which 81½ are adhesive, instead of 92 and 79 tons.

* The maximum gradients have now been reduced to 1 in 30.

† The line has a length of 14 miles (22·5 km.). The locomotives haul thirty-eight flat 12½-ton cars over 3 per cent. grades and around 20-degree curves. On another section having 5 per cent. gradients and the same curves, the rating is cut down to eighteen cars.

A further development of the same type took place in 1923, when the Hammond Lumber Co. ordered similar locomotives equipped with superheaters and piston instead of flat slide valves. This type saved over 20 per cent. of water and fuel as compared with the older one.

Class I.—0-8 + 8-0-T Mallet Tank Locomotives

0-8 + 8-0-T Mallets of the Bavarian State Rys.—Standard gauge. Figs. 146 and 147.

These are the only locomotives of this type which have yet been built.

In their day they were the most powerful locos. in Europe. Doubts were expressed as to the desirability of this new type, owing to the considerable variation in the weight available for adhesion as the fuel and water become exhausted. To offset this drawback, it must be remembered that the dead weight of a separate tender is saved. Attention is directed to the manner in which the weight of the water and fuel is distributed, so that the variation in weight due to their consumption shall be distributed over the two sets of wheels as uniformly as possible. This object has been achieved by carrying a large part of the water in rear tanks and a relatively small portion in the side tanks. This also improves the accessibility to the mechanism. All these locomotives are fitted with Schmidt superheaters, and the usual arrangements for admitting H.P. steam to the L.P. cylinders when starting. Walschaert valve gear is fitted, driving the third axle of each group of wheels.

In order to facilitate the negotiation of curves of 180 m. (190 ft.) radius, the second axle of each group has a lateral play of $\pm$ 15 mm. ($\frac{19}{32}$ in.).

Though the 1923 class was an improvement on the earlier one, it was found, when the Bavarian railway system had been incorporated in that of the Reich, that the *Mallet's* tractive force was no greater than that developed by tank locomotives of the T-20 class, which weighed some 30 tons less (95·3 tonnes; 94 tons).

This seemed to have been caused by the fact that as these locomotives were used as gradient pushers only, their weight was thrown back (and this was further increased by the back-

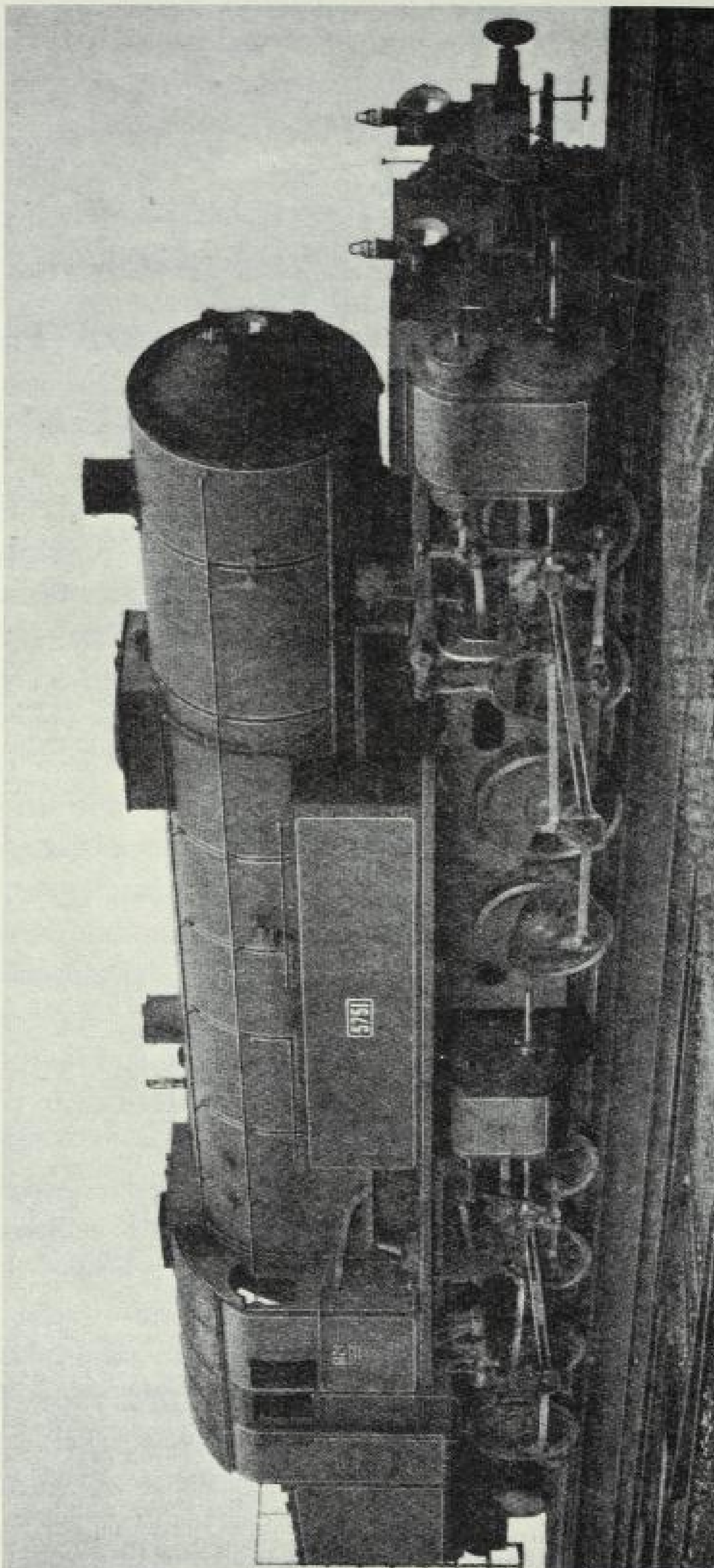


FIG. 146.—0·8 + 8·0 Mallet Locomotive, Bavarian State Rys. Built by Maffei & Co., Munich. (Standard Gauge.)

TABLE 66.—PRINCIPAL DIMENSIONS OF **0-8 + 8-0-T** MALLET TANK LOCOMOTIVES AND OF OTHER MALLET LOCOMOTIVES OF THE BAVARIAN STATE RYS.

Gauge		Standard.	Standard.	Standard.	Standard.	Standard.	Standard.
Railway		Bavarian State Rys	Bavarian State Rys.	Bavarian State Rys.	Bavarian State Rys.	Bavarian State Rys.	Bavarian State Rys.
Builder		Maffei.	Maffei.	Maffei.	Maffei.	Alsacienne.	Maffei.
Date		1899–1900.	1913.	1923.	Convert. 1925.	1896.	
Type		**0-4 + 4-0-T**	**0-8 + 8-0-T**	**0-8 + 8-0-T**	**0-8 + 8-0-T**	**0-4 + 4-0**	**0-4 + 4-2**
Cylinders, diameter		0·31	0·52	0·52	0·60	0·42	0·40
,, diameter		0·49	0·80	0·80	0·80	0·64	0·64
,, stroke		0·53	0·64	0·64	0·64	0·63	0·63
Boiler, centre line		2·06	2·96	2·96	2·96	2·30	—
,, diameter		1·17	1·80	1·80	1·80	1·39	—
,, pressure	kg. per sq. cm.	12	15	15	15	11	15
Tubes, number		138	24–213–6	24–213–6	34–147	192	—
,, diameter		40/55	126/135	48·5/53–42/50	126/135–48·5/53	46/52	—
,, length		3·59	5·08	5·08	5·08	4·09	—
Heating surface, firebox	sq. m.	5·4	14·6	14·6	14·6	9·0	11·9
,, ,, tubes	sq. m.	63·7	168 + 48·1	171·1 + 48·1	113·2 + 72·7	113·4	145·5
,, ,, total	sq. m.	69·1	230·9	233·9	200·4	122·4	167·4
Superheater	sq. m.	None.	55·4	57·8	65·4	None.	None.
Grate area	sq. m.	1·4	4·3	4·3	4·3	2·1	2·7
Wheels, diameter		1·00	1·22	1·22	1·22	1·34	1·34
,, diameter		None.	None.	None.	None.	None.	—
Wheelbase, rigid		1·60	4·50	4·50	4·50	1·73	1·73
,, driving		5·20	12·20	12·20	12·20	5·91	—
,, total		5·20	12·20	12·20	12·20	5·91	8·20
Overall, height		3·80	4·65	4·30	4·55	4·11	—
,, width		3·10	3·15	3·15	3·15	2·90	—
,, length		10·01	17·55	17·55	17·55	10·49	—
Weight, adhesive	t.	42·8	123·2	127·6	132·3	56·2	—
,, empty	t.	32·5	99·4	101·7	106·5	50·6	60·5
,, in service	t.	42·8	123·2	127·6	132·3	56·2	67·0
,, tender	t.	None.	None.	None.	None.	43·0	41·2
Water tanks	t.	1·3	11·0	12·3	12·4	18·0	—
Coal bunkers	t.	4·3	4·5	4·5	4·5	6·5	—

* Locomotives of this class have been put into service from 1899 to 1908 and differences of detail occur.
† Figures communicated by the Bavarian State Rys. ‡ Figures communicated by M. Mallet.

TABLE 66A.—PRINCIPAL DIMENSIONS OF **0-8 + 8-0** MALLET TANK LOCOMOTIVES AND OF THE MALLETS OF THE BAVARIAN STATE RYS.

Gauge	Standard.	Standard.	Standard.	Standard.	Standard.	Standard.
Railway	Bavarian State Rys.	Bavarian State Rys.	Bavarian State Rys.	Bavarian State Rys.	Bavarian State Rys.	Bavarian State Rys.
Builder	Maffei.	Maffei.	Maffei.	Maffei.	Alsacienne.	Maffei.
Date	1899–1900.	1913.	1923.	Converted 1925.	1896.	—
Type	**0-4 + 4-0-T**	**0-8 + 8-0-T**	**0-8 + 8-0-T**	**0-8 + 8-0-T**	**0-4 + 4-0**	**0-4 + 4-2**
Cylinders, diameter	12¼″	20½″	20½″	23⅝″	16¼″	15¾″
,, diameter	19⅞″	31½″	31½″	31½″	25″	25″
,, stroke	20⅞″	25¼″	25¼″	25¼″	24 13/16″	24 13/16″
Boiler, centre line	6′ 8⅝″	9′ 8½″	9′ 8½″	9′ 1½″	7′ 6½″	—
,, diameter	3′ 9¼″	5′ 11″	5′ 11″	5′ 11″	4′ 7¼″	—
,, pressure . . lbs. per sq. in.	171	213	213	213	156	213
,, number	138	24–213–6	24–213–6	34–147	192	—
,, diameter	1⅝″–2¼″	5″–5⅜″	1 15/16″/2 1/16″–1 11/16″/2 1/16″	5″/5⅜″–1 15/16″/2 1/16″	1 13/16″–2 3/16″	—
,, length	11′ 9″	16′ 5¾″	16′ 9″	16′ 9″	—	—
Heating surface firebox . . sq. ft.	58·1	160	157	157	97	122·7
,, ,, tubes . . ,,	707	1810+518	1840+518	1220+783	1230	1566·2
,, ,, total . . ,,	765·5	2,488	2,515	2,160	1,327	1,688·9
Superheater . . ,,	None	595	623	705	None	None
Grate area . . ,,	15·1	46·5	46·5	46·5	22·5	29·0
Wheels, diameter	3′ 3⅜″	4′ 0″	4′ 0″	4′ 0″	4′ 4⅜″	4′ 4⅜″
,, diameter	None	None	None	None	None	—
Wheelbase, rigid	5′ 3″	14′ 9″	14′ 9″	14′ 9″	5′ 8½″	5′ 8½″
,, driving	17′ 1″	40′ 0″	40′ 0″	40′ 0″	19′ 4″	—
,, total	17′ 1″	40′ 0″	40′ 0″	40′ 0″	19′ 4″	26′ 10⅞″
Overall, height	12′ 8″	15′ 3″	14′ 1″	14′ 10″	13′ 6″	—
,, width	10′ 2″	10′ 7″	10′ 7″	10′ 7″	9′ 8″	—
,, length	32′ 10½″	57′ 6″	57′ 6″	57′ 6″	34′ 4″	—
Weight adhesive . . t.-cwt.	41–16	121–0	125–10	130–2	55–6	—
,, empty . . ,,	31–19	98–15	100–0	103–16	49–16	59–12
,, in service . . ,,	41–16	121–0	125–10	130–2	50–6	66–0
,, tender . . ,,	None	None	None	None	42–8	40–12
Water tanks . . galls.	280	2,420	2,700	2,730	3,960	—
Coal bunkers . . t.-cwt.	4–5	4–9	4–9	4–9	6–8	—
	*	†	†	†		‡

* Locomotives of this class have been put into service from 1899 to 1908 and differences of detail occur.
† Figures communicated by the Bavarian State Rys. ‡ Figures communicated by M. Mallet.

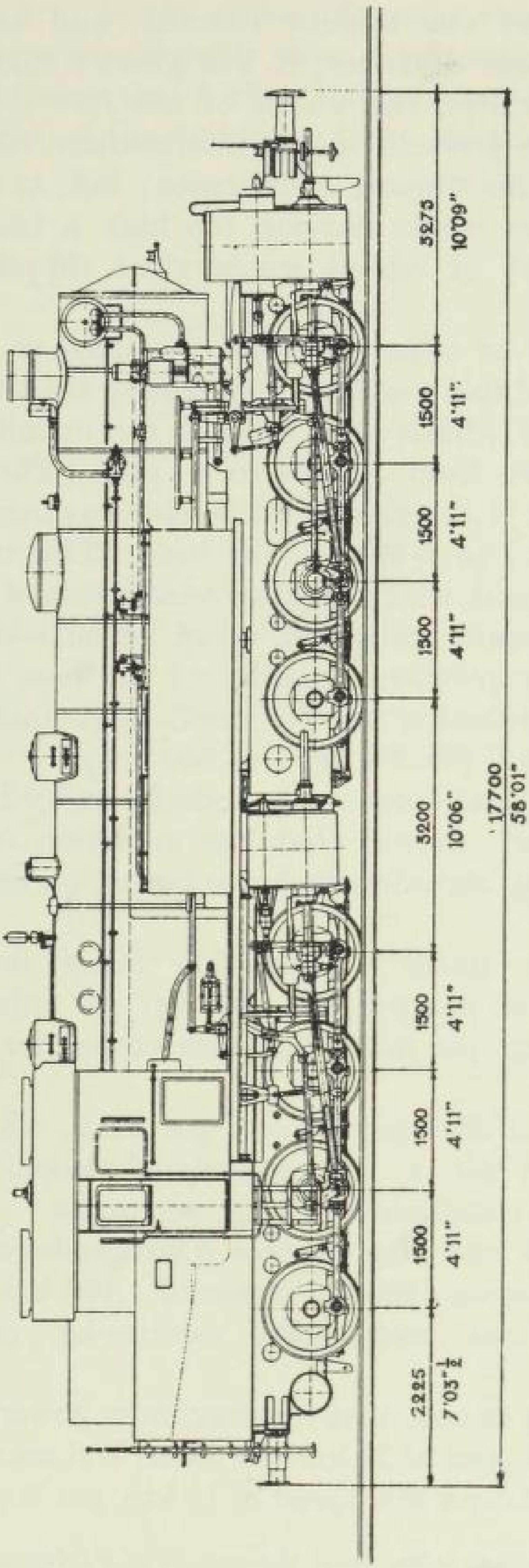


Fig. 147.—0-8 + 8-0 Mallet Tank Locomotive, built by Maffei, of Munich, for the Bavarian State Rys. (Standard Gauge.)

ward flow of the water in the tanks), thus diminishing the adhesive weight on the fore bogie. The tractive force due to the L.P. cylinders was thereby reduced, and as normally, owing to their large diameter, it was greater than that due to the H.P. cylinders, the wheels of the fore bogie slipped immediately. The pressure in the intermediate receiver pipe would drop and this slipping would cease ; but, as a corollary, the H.P. cylinders would develop too high a tractive force and the back set of wheels would start slipping in their turn.

Some locomotives were therefore converted so as to cure this tendency, and this was done by reducing the tractive force of the fore set of wheels ; the ratio of the cylinder volumes was brought down from 1 : 2·28 to 1 : 1·78. The L.P. were retained, and the H.P. cylinder's diameter was increased from 0·52 m. (20½ ins.) to 0·60 m. (23⅝ ins.). The superheating surface was increased, which entailed a reduction of the heating surface and a reheater provided, all of which added weight. The improved evaporative qualities of the new locomotives enable all the adhesion to be used, thus increasing the actual drawbar pull (20,200 kg. ; 44,500 lbs.).

Trials with a dynamometer car, undertaken by Professor H. Nordmann in 1927, showed that the minimum consumption of coal was 9·6 kg. per effective horse power, corresponding to 1,250 h.p.

The minimum steam consumption (after deduction of that used by the pumps) was 9·2 kg. per effective horse power and 8·5 kg. per indicated horse power, for a power of 1,150 h.p.

The mechanical efficiency was 94 per cent., which is enormous, especially for a semi-articulated locomotive. This corresponds to a resistance of 12 kg. per tonne.*

Three hundred and fifty degrees (Centigrade) of superheat were registered for an effective power of 1,100 h.p.

Minimum calories used : 6,300 calories-kg. per effective horse power.

It is interesting to note that the maximum power (1,200 h.p.) corresponds to a speed of 26 km. per hour, and maximum tractive force (22,200 h.p.) to a speed of 12 km. per hour.

* All these figures are taken from the results of Professor Nordmann's experiments.

For a tractive effort of 24,000 kg., the 6 per cent. loss is 1,440 kg. This gives 12 kg. per tonne for the locomotive's 120 tonnes.

In conclusion, as the steam diagrams show that the H.P. group develops considerably more horse power than the L.P. one, it would seem that further improvements are possible and that the ratio of the volumes of the cylinders is a little too small.

SUB-GROUP II. B.—MALLET TENDER LOCOMOTIVES

When the adoption of *Mallet* locomotives is due to the necessity of distributing the weight of the locomotive over a greater number of coupled axles than is possible with a rigid loco. (whether or no the line has many curves) the tank engine has to be abandoned, both because it cannot carry sufficient water and fuel and because its adhesive weight is not constant. Tender locomotives are then called upon.

Mallet tender locomotives are generally used for freight traffic and banking service and infrequently for passenger traffic. There are essential differences between the European and American designs. Furthermore, European builders have chiefly produced *Mallets* for narrow gauge railways, while in America large numbers of *Mallets* have been built for the standard gauge.

In the Colonies and overseas, conditions are often very severe, and traffic has to be concentrated into relatively few trains, each of considerable weight.

Locomotives for narrow and metre gauges are often built in series, but this is seldom done in other cases, as the conditions to be met with vary too greatly.

Nevertheless, every endeavour has been made to standardise the big American *Mallets*, and this standardisation has been rendered easier by the fact that nearly all of them have been produced by two builders—the Baldwin Locomotive Works and the American Locomotive Co.

A few locos. have two axle tenders (*e.g.*, the Java Rys. and the Warsaw Ry.). But usually the tenders are carried on two four-wheeled bogies and in the case of the large American locos. on two six-wheeled bogies, sometimes provided with *boosters*.

CLASSES OF MALLET TENDER LOCOMOTIVES

The leading dimensions of the most interesting examples of each class are given in the tables which follow. We shall examine in due order locos. with four, five, six, seven, eight and ten coupled axles, taking first in each group those in which the total weight is available for adhesion, and then those which have one or more carrying axles.

The total number of classes to be dealt with is therefore as follows :—

I.	Locomotives with four coupled axles	(A)	0-4 + 4-0
		(B)	2-4 + 4-0
		(C)	0-4 + 4-0
		(D)	2-4 + 4-2
II.	Locomotives with five coupled axles	(E)	2-4 + 6-0
		(F)	4-4 + 6-2
III.	Locomotives with six coupled axles	(G)	0-6 + 6-0
		(H)	2-6 + 6-0
		(I)	2-6 + 6-2
IV.	Locomotives with seven coupled axles	(J)	2-6 + 8-0
V.	Locomotives with eight coupled axles	(K)	0-8 + 8-0
		(L)	2-8 + 8-0
		(M)	2-8 + 8-2
VI.	Locomotives with ten coupled axles	(N)	2-10 + 10-2

Class A.—0-4 + 4-0 Mallet Tender Locomotives

Most of the early *Mallets* with separate tenders belonged to this class, the first of which appear to have been the 2 ft. gauge locomotives built for the Alapaewsk Mines Ry. (Russia).

Others built for narrow gauge lines were the following :—

Jaffa Jerusalem Ry.,* 1·05 m. gauge.

Horsens Bryrup Jernbane, Denmark,† metre gauge.

Vasilatul Soc. Lotru (Roumania), 0·695 gauge.

0-4 + 4-0 Mallets of the Queiros Ry.‡—0·75 m. (2 ft. 5½ ins.) gauge.

0-4 + 4-0 *Mallets* used to be built serially. This occurred with the type under review ; others similar in all respects, but without separate tender, being supplied by the builders to other railways.

* Builders : Borsig, Berlin.

† Builders : Arnold Jung, of Kirchen.

‡ The owning company was the "Société des Usines de Mières Asturies."

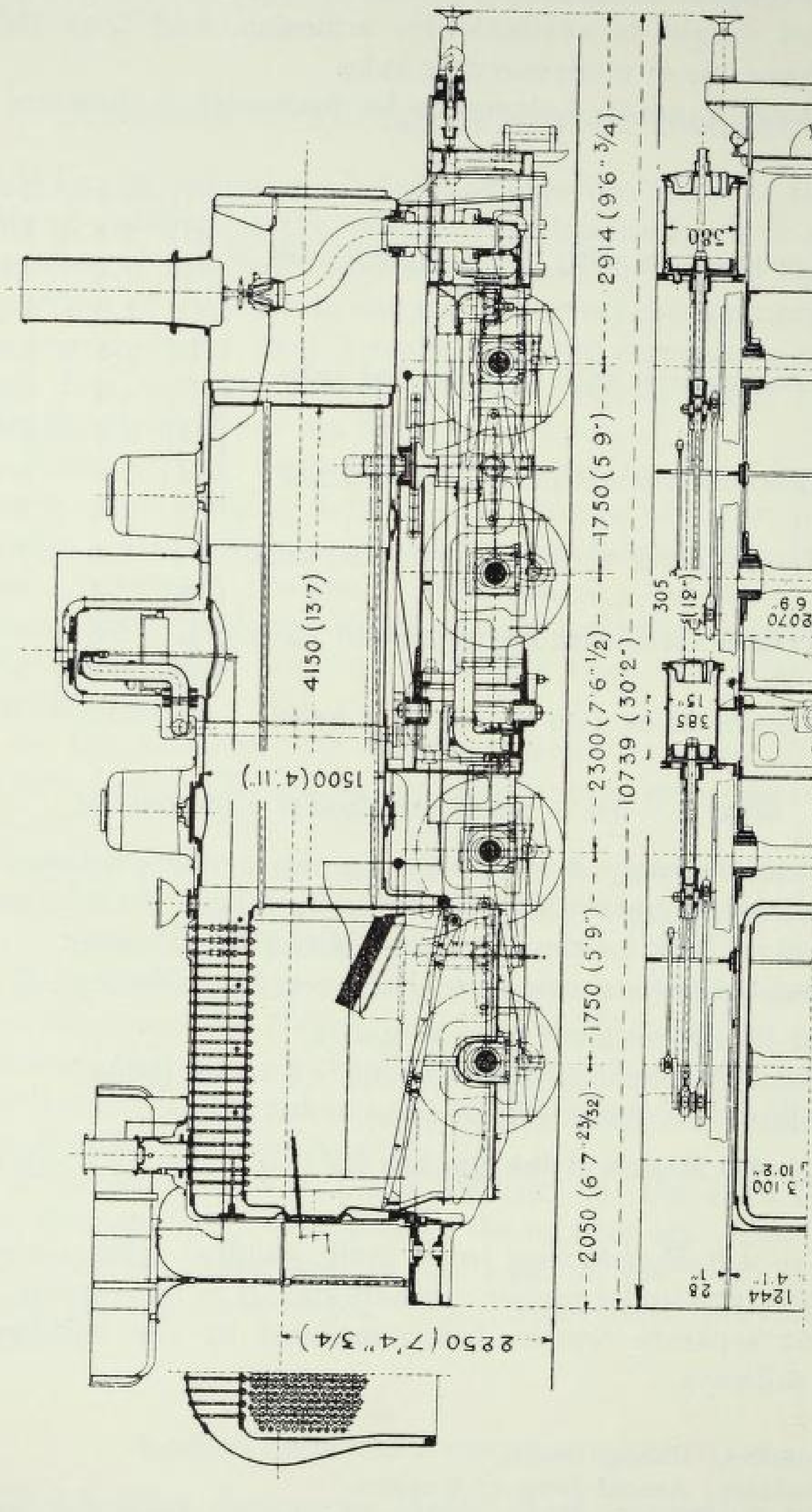


FIG. 148.—0.4 + 4.0 Locomotive, Hungarian State Rys. (Standard Gauge).

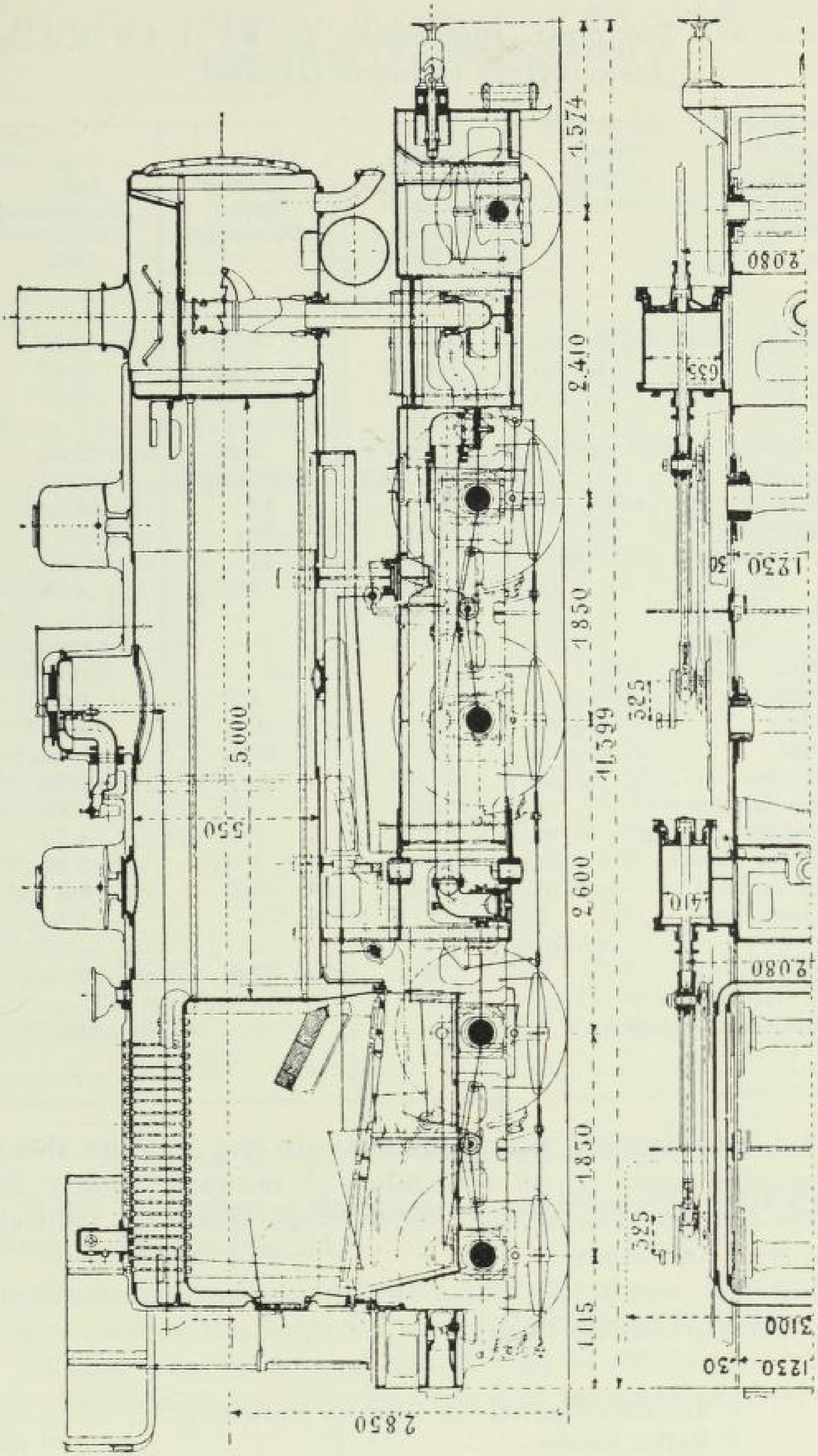


FIG. 149.—2-4 + 4-0 Mallet Locomotive, Hungarian State Rys. (Standard Gauge).

TABLE 67.—PRINCIPAL DIMENSIONS OF **0-4 + 4-0** MALLET LOCOMOTIVES (NARROW GAUGES)

Gauge	0·60 m.	0·75 m.	1 m.
Railway	Java State Rys.	Queiros (Spain).	Jaffa-Jerusalem.
Builder	Henschel.	Alsacienne.	Borsig.
Date	1905–9	—	1904.
Cylinders, diameter, H.P. m.	0·16	0·21	0·29
,, ,, L.P. m.	0·24	0·32	0·45
,, stroke . m.	0·30	0·32	0·55
Boiler :			
Height of centre line m.	1·39	1·60	2·05
Diameter . . m.	0·74 (int.)	0·90 (mean)	1·17
Pressure kg. per sq. cm.	12	12	12
Tubes, number . .	62	86	120
,, diameter . mm.	34/38	41	45/50
,, length . . m.	2·25	3·20	4·38
Firebox, breadth . m.	0·60	—	—
,, length . m.	0·74	—	—
Heating surface :			
Firebox . sq. m.	1·9	4·2	9
Tubes . . sq. m.	14·8	36·3	80
Total . . sq. m.	18·5	40·5	89
Grate area . sq. m.	0·42	0·76	1·60
Wheels, diameter . m.	0·61	0·70	1·10
Wheelbase, driving . m.	0·75	1·20	1·50
,, total . m.	2·67	3·80	5·30
Water tanks . cub. m.	1·8	2·6	8·5
Coal bunkers . . t.	1	—	4·5
Wood . . cub. m.	—	1	—
Weight, empty . t.	9	13·6	32
,, in service . t.	10	15·2	35
Tender, weight empty t.	—	4·5	9·5

0-4 + 4-0 Standard Gauge Mallets.—In the 'nineties these locomotives appeared on a number of railways, mostly in Central Europe, such as the Baden State Rys.* the Central Swiss Ry.† and others.

They were also to be found on light railways of standard gauge, such as the Mosellbahn.‡

* The Chemnitz Works, formerly Hartmann.

† Maffei, builder.

‡ The Hohenzollern Works, builders.

TABLE 67A.—PRINCIPAL DIMENSIONS OF **0-4 + 4-0** MALLET LOCOMOTIVES (NARROW GAUGES)

Gauge	2 ft.	2 ft. 5½ ins.	3 ft. 5½ ins.
Railway	Java State Rys.	Queiros (Spain).	Jaffa-Jerusalem.
Builder	Henschel.	Alsacienne.	Borsig.
Date	1905-9.	—	1904.
Cylinders :			
Diameter, H.P.	$6\frac{5}{16}''$	$8\frac{5}{16}''$	$11\frac{1}{2}''$
,, L.P.	$9\frac{1}{2}''$	$12\frac{5}{8}''$	$17\frac{3}{4}''$
,, stroke	$11\frac{13}{16}''$	$12\frac{5}{8}''$	$21\frac{1}{2}''$
Boiler, height of centre line	$4'\ 6\frac{1}{2}''$	$5'\ 3''$	$6'\ 8\frac{1}{4}''$
,, diameter	$2'\ 5\frac{1}{4}''$ (int.)	$2'\ 11\frac{7}{16}''$(mean)	$3'\ 10\frac{1}{8}''$
,, pressure lbs./sq. in.	171	171	171
Tubes, number	62	86	120
,, diameter	$1\frac{5}{16}''$–$1\frac{1}{2}''$	$1\frac{19}{32}''$	$1\frac{3}{4}''$–$1\frac{31}{32}''$
,, length	$7'\ 5''$	$10'\ 6''$	$14'\ 4''$
Firebox, width	$1'\ 11\frac{5}{8}''$	—	—
,, length	$2'\ 5\frac{1}{4}''$	—	—
Heating surface :			
Firebox sq. ft.	21	45	97
Tubes ,,	159	390	860
Total ,,	180	435	967
Grate area ,,	4·5	8·25	12
Wheels, diameter	$2'\ 0''$	$2'\ 3\frac{9}{16}''$	$3'\ 7\frac{3}{8}''$
Wheelbase, rigid	$2'\ 5\frac{5}{8}''$	$3'\ 11\frac{1}{4}''$	$4'\ 11''$
,, total	$8'\ 9''$	$12'\ 6''$	$17'\ 4''$
Water tanks . galls.	400	570	1,870
Coal bunkers . tons-cwt.	1	—	4–9
Wood cub. ft.	—	35	—
Weight :			
Loco., empty . tons-cwt.	8–17	13–8	31–10
,, in service ,,	9–17	14–19	34–8
Tender, empty ,,	—	4–9	9
,, in service ,,	—	—	21

Class B.—2-4 + 4-0 Mallet Locomotives

2-4 + 4-0 Mallets of the Bulgarian and Hungarian State Rys.—Standard gauge (Fig. 149).

There are some recent examples of this type. Two notable cases occur on the Bulgarian and the Hungarian State Rys.

Mallets were introduced with a view to effecting economies by the replacement of the five-axle rigid locomotives previously in use.

The 2-4 + 4-0 Hungarian locomotives were allocated to the

TABLE 68.—PRINCIPAL DIMENSIONS OF **0-4 + 4-0** MALLET LOCOMOTIVES (STANDARD GAUGE)

Railway / Builder / Date		Prussian. State Rys. Alsacienne (Grafenstaden). 1898.	Baden State Rys. Alsacienne. 1893.	Bavarian State Rys. Alsacienne. 1899–1908.	Saxon State Rys. Chemnitz. —	Hungarian State Rys. Railway Workshops. 1898.	Central Swiss Ry. Winterthur. —
Cylinders, diameter, H.P.	m.	0·42	0·39	0·42	0·45	0·39	0·36
,, ,, L.P.	m.	0·63	0·60	0·64	0·65	0·58	0·55
,, stroke	m.	0·60	0·60	0·63	0·60	0·61	0·64
Boiler, height of centre line	m.	2·25	2·25	2·30	2·30	2·25	—
,, diameter, mean	m.	1·50	1·50	1·39	—	1·50	—
,, pressure	kg. per sq. cm.	12	12	11	12	13	14
Tubes, number		218	206	192	205	228	184
,, diameter	mm.	45/50	45/50	46/52	45/50	52 (ext.)	46/50
,, length	m.	4·30	4·30	4·09	4·50	4·15	4·26
Heating surface, firebox	sq. m.	10·1*	10·4*	9·0	10·7	12·3	10
,, ,, tubes	sq. m.	132·1	127·4	113·4	130·4	154·6	121·5
,, ,, total	sq. m.	142·2	137·8	122·4	141·1	166·9	131·5
Grate area	sq. m.	2	2	2·1	2	2·6	2·0
Wheels, diameter	m.	1·27	1·26	1·34	1·24	1·22	1·28
Wheelbase, rigid	m.	1·75	1·75	1·73	1·70	1·75	1·90
,, driving	m.	5·80	5·80	5·91	5·75	5·80	6·20
Overall dimensions, height	m.	4·15	4·15	4·11	4·15	4·58	—
,, ,, length	m.	10·07	9·95	10·49	11·60	11·46	10·21
,, ,, width	m.	3·00	3·00	2·90	3·10	3·10	2·80
Water tanks	cub. m.	18	18	18	9·0	12·5	13
Coal bunker	t.	6	6	6·5	4·0	8	4
Weight, empty	t.	49·2	49·5	50·6	53·6	50·8	52
,, in service	t.	55·2	55·3	56·2	59·6	56·9	57·2
,, tender, empty	t.	20·9	20·9	17	—	13·7	13·0
,, tender, in service	t.	44·7	44·7	4·3	—	20	30·5

* Firebox: Length, 1·94 m.; width, 1·01 m.

TABLE 68A.—PRINCIPAL DIMENSIONS OF **0-4 + 4-0** MALLET LOCOMOTIVES (STANDARD GAUGE)

Railway	Prussian State Rys.	Baden State Rys.	Bavarian State Rys.	Saxon State Rys.	Hungarian State Rys.	Central Swiss Ry.
Builder	Alsacienne Co.	Alsacienne Co.	Alsacienne Co.	Chemnitz.	Railway Workshops.	Winterthur.
Date	1898.	1893.	1899-1908.	—	1898.	—
Cylinders, diameter, H.P.	$16\frac{1}{2}''$	$15\frac{3}{8}''$	$16\frac{9}{16}''$	$17\frac{3}{4}''$	$15\frac{3}{8}''$	$14\frac{1}{4}''$
,, ,, L.P.	$24\frac{13}{16}''$	$23\frac{5}{8}''$	$25\frac{3}{16}''$	$25\frac{5}{8}''$	$22\frac{7}{8}''$	$21\frac{11}{16}''$
,, stroke	$23\frac{5}{8}''$	$23\frac{5}{8}''$	$24\frac{3}{4}''$	$23\frac{5}{8}''$	24″	$25\frac{1}{4}''$
Boiler, height of centre line	7′ 5″	7′ 5″	$7'\ 6\frac{1}{2}''$	7′ 7″	7′ 5″	—
,, mean diameter	4′ 11″	4′ 11″	$4'\ 6\frac{3}{4}''$	—	—	—
,, pressure . . . lbs./sq. in.	171	171	156	171	185	199
Tubes, number	218	206	—	205	228	184
,, diameter	$1\frac{3}{4}''$–2″	$1\frac{3}{4}''$–2″	$1\frac{13}{16}''$–$2\frac{1}{16}''$	$1\frac{3}{4}''$–2″	$2\frac{1}{16}''$ (ext.)	$1\frac{13}{16}''$–$5\frac{15}{16}''$
,, length	14′ 1″	14′ 1″	$13'\ 5\frac{1}{16}''$	14′ 9″	$13'\ 7\frac{1}{2}''$	13′ 11″
Heating surface, firebox . . sq. ft.	109*	112*	97	115	132	108
,, ,, tubes . . ,,	1,420	1,370	1,121	1,410	1,660	1,310
,, ,, total . . ,,	1,529	1,482	1,318	1,525	1,792	1,418
Grate area . . ,,	21·5	21·5	22·6	21·5	28	21·5
Wheels, diameter	4′ 2″	$4'\ 1\frac{5}{8}''$	$4'\ 4\frac{3}{4}''$	$4'\ 0\frac{13}{16}''$	4′ 0″	$4'\ 2\frac{3}{8}''$
Wheelbase, rigid	5′ 9″	5′ 9″	$5'\ 8\frac{1}{8}''$	5′ 7″	5′ 9″	6′ 3″
,, driving	19′ 0″	19′ 0″	$19'\ 4\frac{11}{16}''$	18′ 10″	19′ 0″	20′ 4″
Overall height	12′ 8″	12′ 8″	$13'\ 5\frac{13}{16}''$	12′ 8″	14′ 0″	—
,, length	32′ 10″	32′ 6″	34′ 5″	39′ 0″	37′ 9″	33′ 7″
,, width	9′ 11″	9′ 11″	$9'\ 6\frac{3}{16}''$	10′ 3″	10′ 3″	9′ 3″
Water tanks . . . galls.	3,960	3,960	3,960	1,980	2,750	2,860
Coal bunkers . . . tons-cwt.	5–18	5–18	6–8	3–19	7–18	3–19
Weight, locomotive, empty . ,,	48–10	48–15	49–19	52–17	50–0	51–5
,, ,, in service ,,	54–8	54–9	55–6	58–16	56–0	56–5
,, tender, empty ,,	20–6	20–6	16–16	—	13–10	12–16
,, ,, in service ,,	44–0	44–0	42–6	—	19–13	—

* Firebox, length $6'\ 4\frac{1}{2}''$; width, $3'\ 3\frac{3}{4}''$.

TABLE 69 & 70.—PRINCIPAL DIMENSIONS OF **2-4 + 4-0** AND **0-4 + 4-2** MALLET LOCOMOTIVES (STANDARD GAUGE)

Type		**2-4 + 4-0**	**2-4 + 4-0**	**0-4 + 4-2**
Railway		Bulgarian State.	Hungarian State.	Bavarian State.
Builder		Maffei.	Railway Workshops.	—
Date		1900.	1905.	—
Cylinders, diameter, H.P.	m.	0·40	0·39	0·40
,, ,, L.P.	m.	0·64	0·64	0·64
,, stroke	m.	0·63	0·65	0·63
Boiler, height of centre line	m.	2·65	2·85	—
,, diameter, int.	m.	—	1·55	—
,, pressure	kg. per sq. cm.	15	16	15
Tubes, number		227	267–5	—
,, diameter	mm.	48/52	52 & 140	—
,, length	m.	4·30	5·00	—
Firebox, width	m.	1·03	—	—
,, length	m.	2·58	—	—
Heating surface :				
Firebox	sq. m.	11·9	13·6	11·9
Tubes	sq. m.	145·6	222·2	145·5
Total	sq. m.	157·5	235·8	157·4
Grate area	sq. m.	2·7	3·7	2·7
Wheels, diameter	m.	0·95	1·04	1·34
,, ,,	m.	1·34	1·44	—
Wheelbase, rigid	m.	1·73	1·85	1·73
,, driving	m.	5·91	6·30	—
,, total	m.	8·20	8·71	8·20
Overall dimensions :				
Length	m.	10·63	11·40	—
Width	m.	3	3·10	—
Height	m.	4·27	—	—
Tender wheels, diameter	m.	1·01	1·04	—
Wheelbase	m.	5	3·16	—
Water tanks	cub. m.	18	14·5	—
Coal bunkers	t.	6	7	—
Weight, locomotive, adhesive	t.	57·2	—	—
,, ,, empty	t.	60·5	68·4	60·5
,, ,, in service	t.	67·1	75·3	67·0
,, tender, empty	t.	20·7	15	—
,, ,, in service	t.	44·7	36·8	41·2

Fiume-Cameral-Morawicz section. They had the same heating surface and grate area as the 0-8-0 rigid locomotives which they replaced, and which had given trouble by excessive flange friction.

TABLES 69A & 70A.—PRINCIPAL DIMENSIONS OF **2-4 + 4-0** AND **0-4 + 4-2** MALLET LOCOMOTIVES (STANDARD GAUGE)

Type	**2-4 + 4-0**	**2-4 + 4-0**	**0-4 + 4-2**
Railway	Bulgarian State.	Hungarian State.	Bavarian State.
Builder	Maffei.	Railway Workshops.	—
Date	1900.	1905.	—
Cylinders, diameter, H.P.	15¾″	15⅜″	15¾″
,, ,, L.P.	25¼″	25¼″	25¼″
,, stroke	24 13/16″	25⅝″	24 13/16″
Boiler, height of centre line	8′ 8½″	9′ 5″	—
,, diameter	—	5′ 1″	—
,, pressure . lbs. per sq. in.	213	228	213
Tubes, number	227	267–5	—
,, diameter	1 15/16″/2 1/16″	2 1/16″ & 5½″	—
,, length	14′ 1″	15′ 3″	—
Firebox, width	3′ 4⅝″	—	—
,, length	8′ 6″	—	—
Heating surface :			
Firebox . . sq. ft.	128	147	128
Tubes ,,	1,570	2,395	1,568
Total ,,	1,698	2,542	1,696
Grate area ,,	29	39	29
Wheels, diameter	3′ 1½″	3′ 5″	—
,, ,,	4′ 4¾″	4′ 8¾″	4′ 4¾″
Wheelbase, rigid	5′ 8¼″	6′ 1″	5′ 8¼″
,, driving	19′ 5″	20′ 9″	—
,, total	26′ 10″	28′ 7″	26′ 10″
Overall, length	34′ 11″	37′ 1″	—
,, width	9′ 10″	10′ 2″	—
,, height	14′ 0″	—	—
Tender, wheels, diameter	3′ 3¾″	3′ 4 5/16″	—
,, wheelbase	16′ 5″	10′ 4″	—
,, water . galls.	3,960	3,200	—
,, coal . . tons-cwt.	15–18	16–18	—
Weight, locomotive, adhesive ,,	56–5	—	—
,, ,, empty . ,,	59–10	67–5	59–10
,, ,, in service ,,	66–0	74–1	65–18
,, tender, empty ,,	20–0	14–15	—
,, ,, in service ,,	44–0	36–4	40–16

Both the *Mallets* and their predecessors could draw trains of 390 tons at 9½ miles (15 km.) per hour over a line having gradients of 1·6 per cent., with curves of 275 m. (900 ft.) radius. The maximum speed was 28 miles (45 km.) per hour.

It will be noted that the adoption of the *Mallet* on these railways was due solely to its flexibility. It was obvious that if the first *Mallets* gave good results, the use of this type would be rapidly extended.

Class C.—0-4 + 4-2 Mallet Tender Locomotives

0-4 + 4-2 Mallets of the Bavarian State Rys.—Standard gauge.

An increase in power having become imperative, new *Mallets* were designed in which the heating surface was increased from 122 to 167 sq. m. (1,314 to 1,800 sq. ft.) This necessitated the addition of an extra pair of pony wheels, and a 2-4 + 4-0 *Mallet* succeeded to the previous 0-4 + 4-0 type.

It is curious to note that in this locomotive, which was exhibited in Paris in 1900, the leading carrying axle is rigid and has no lateral play at all.

Class D.—2-4 + 4-2 Mallet Tender Locomotives

2-4 + 4-2 Mallets of the Trans-Siberian Ry.—Gauge, 1m.52 (5 ft.).

As elsewhere in Russia, *Mallet* locos. were introduced on this system owing to the lightness of the permanent way, which was originally laid with rails of 21 kgs. per metre ($42\frac{1}{2}$ lbs. per yard) only. The *Mallets* were used both for passenger and for freight service. The first locos. used on this section were of the 2-4 + 4-2 type. They were succeeded by locomotives of the 0-6 + 6-0 type.*

Mallet Tender Locomotives for Logging Service

In the year 1910, the Baldwin Locomotive Works first built a *Mallet* tank engine and two with separate tenders for use on the railways of the lumber mills. The latter had two different wheel arrangements : 2-4 + 4-2 and 2-6 + 6-2.

The 2-4 + 4-2 locomotive of the Larkin Green Lumber Co. (formerly Whitney, Ltd.) is exceptionally flexible.

The double-Moguls of the Casper Lumber Co. do not differ in essentials from the tank *Mallets* of similar arrangement, and which we have previously dealt with.

* Some of these were built with 4 H.P. cylinders, but did not give satisfaction.

TABLES 71 & 72.—PRINCIPAL DIMENSIONS, MALLET TENDER LOCOMOTIVES FOR LOGGING SERVICE

Type	2-4 + 4-2	2-6 + 6-2	2-6 + 6-2	2-6 + 6-2	2-4 + 4-2	2-6 + 6-2	2-6 + 6-2	2-6 + 6-2
Gauge	Standard.	Standard.	Standard.	Standard.	Standard.	Standard.	Standard.	Standard.
Company	Larkin Green Lumber Co.	Casper Lumber Co.	Casper Lumber Co.	Long Bell Lumber Co.	Green Lumber Co.	Casper Lumber Co.	Casper Lumber Co.	Long Bell Lumber Co.
Builder	Baldwin.	Baldwin.	Baldwin.	Baldwin.	Baldwin.	Baldwin.	Baldwin.	Baldwin.
Date	1910.	1910.	1924.	—	1910.	1910.	1924.	—
Cylinders, diameter	15″	13″	13″	18″	0·38 m.	0·30 m.	0·30 m.	0·46 m.
,, diameter	23″	19″	20″	28″	0·64 m.	0·48 m.	0·51 m.	0·71 m.
,, stroke	22″	20″	20″	24″	0·56 m.	0·51 m.	0·51 m.	0·61 m.
Boiler, pressure . lbs. per sq. in.	200	200	220	200	14·1 m.²	14·1 m.²	15·5 m.²	14·1 m.²
Heating surface, firebox . sq. ft.	—	—	—	—	—	—	—	—
,, ,, tubes . ,,	—	—	—	—	—	—	—	—
,, ,, superheater . ,,	None	None	218	466	None	None	20·2	43·2
,, ,, total . ,,	1,959	1,193	1,016	1,927	182·0 m.²	110·8 m.²	94·4 m.²	179·0 m.²
Grate area . ,,	28·2	18·2	17·6	31·5	2·6 m.²	1·7 m.²	1·6 m.²	2·9 m.²
Wheels, diameter	4′	3′ 1″	3′ 1″	3′ 8″	1·22 m.	0·94 m.	0·94 m.	1·11 m.
Wheelbase								
Weight, adhesive . lbs.	130,000	105,000	114,000	180,000	58·9 t.	47·7 t.	51·7 t.	81·6 t.
,, total . ,,	162,600	124,000	134,000	210,000	73·5 t.	56·2 t.	60·8 t.	95·3 t.
Tractive force . ,,	24,000	21,300	24,100	42,500	11·3 t.	10·8 t.	11·3 t.	19·3 t.

Class E.—2-4 + 6-0 Mallet Locomotives

This arrangement of axles is only in use on a few lines of metre and 1m.05 (3 ft. 5¼ ins.) gauges. The type was adopted when the guidance of a leading bissel was needed and when, at the same time, it was desired that the largest possible portion of the locomotive weight should be available for adhesion.

2-4 + 6-0 Mallets of the Argentine Central Northern Ry.*— Metre gauge.

These locomotives are used on those portions of the line which are worked by simple adhesion.

Where gradients do not exceed 2½ per cent., the rails are comparatively light, the maximum permissible load per axle being 8 tonnes (7 tons 17 cwt.). The 2-4 + 6-0 locomotives are used for passenger service and haul 120 tons at a speed of 25 km. (15½ miles) per hour. The locomotives used for freight service are of the 0-6 + 6-0 type, and draw 150 tons at 20 km. (12½ miles) per hour. Both types burn wood fuel.

2-4 + 6-0 Mallets of the Hedjaz Ry.—Gauge 1m.05 (3 ft. 5¼ ins.).

These locomotives haul 250 tons over a line with 1·8 per cent. grades and curves of 92 m. (302 ft.) radius.†

Class F.—4-4 + 6-2 Mallet Locomotives

4-4 + 6-2 Mallets of the Atchison, Topeka and Santa Fé Ry.— Standard gauge.

These locomotives were built at the end of the year 1900 together with some of the 2-8 + 8-2 type, with which they have many points of similarity. They were intended for express passenger service. This explains the large diameter of the driving wheels and the presence of a leading bogie. At that

* This railway is a State-owned line. Its main section runs from Santa Fé *viâ* Tucuman to the Bolivian frontier. The last section is in the mountains.

Jujuy is at + 1,259 metres (4,130 ft.) above sea level ; La Quiaca, km. 1,239 (772 miles) is at + 3,442 metres (11,293 ft.). There are 10 km. (6·2 miles) of rack railway in this section.

† The Hedjaz Ry. connects Damascus with Medina, and is about 1,300 km. (807 miles) in length.

South of Maan, at about 400 km. (248 miles) from Damascus, the line descends from a plateau of 1,100 m. (3,610 ft.) altitude to the bottom of a valley only 150 m. (492 ft.) above sea level. It then regains approximately the same altitude at the other end of the valley.

TABLES 73 & 74.—PRINCIPAL DIMENSIONS OF MALLET LOCOMOTIVES WITH 2 + 3 DRIVING AXLES

Type		2-4 + 6-0		4-4 + 6-2
Gauge		1·05 m.	Metre.	Standard.
Railway		Hedjaz Ry.	Central Northern Argentine.	Atchison, Topeka and Santa Fé.
Builder		Henschel.	Borsig.	Baldwin.
Date		1906.	—	1909.
Cylinders, diameter, H.P.	m.	0·32	0·32	0·61
,, ,, L.P.	m.	0·51	0·52	0·96
,, stroke	m.	0·58	0·55	0·71
Boiler, height of centre line	m.	2·30	2·20	3·00
,, diameter, mean	m.	1·38	1·32	1·82
,, pressure	kg. per sq. cm.	12	12	14·1
Tubes, number		200	207	294–314
,, diameter (int.)	mm.	50	51	57–57
,, length	m.	4·90	4·80	5·79–2·14
Heating surface :				
Firebox	sq. m.	9·9	11	18·8*
Tubes	sq. m.	152·4	158	304·3
Total	sq. m.	162·3	169	323·0
Superheater	sq. m.	None	None	30
Reheater	sq. m.	None	None	118·8
Grate area	sq. m.	2·7	3·3	4·9
Wheels, diameter	m.	0·72	0·80	0·79
,, ,,	m.	1·07	1·30	1·85
,, ,,	m.	None	None	1·27
Wheelbase, rigid	m.	1·45	3·62	1·93–3·86
,, driving	m.	1·45–2·75	6·83	9·25
,, total	m.	8·55	9·00	15·82
,, loco. & tender	m.	15·83	16·25	28·79
Tender, number of axles		4	4	4
,, wheels, diameter	m.	—	—	0·77
,, water tanks	cub. m.	18	15	45·4
,, coal	t.	6	10	15 (oil)
Weight, locomotive, empty	t.	47	41	—
,, ,, in service	t.	53	48	170·7
,, ,, adhesive	t.	46	47·5	121·6
,, tender, empty	t.	15	12	—
,, ,, in service	t.	38·5	32	106·4
Tractive force	t.	7·1	7·0	24·0 C

time they were the only *Mallets* designed for fast runs. The boiler has a separable joint. The front portion contains, behind the smokebox, a feedwater heater, a combustion

* Firebox width, 1·61 m.; length, 3·04 m.

Tables 73a & 74a.—Principal Dimensions of Mallet Locomotives with 2 + 3 Driving Axles

Type	**2-4 + 6-0**	**2-4 + 6-0**	**4-4 + 6-2**
Gauge	3 ft. $5\frac{3}{8}$ ins.	Metre.	Standard.
Railway	Hedjaz Ry.	Central Northern Argentine.	Atchison, Topeka and Santa Fé.
Builder	Henschel.	Borsig.	Baldwin.
Date	1906.	—	1909.
Cylinders, diameter, H.P.	$12\frac{5}{8}$″	$12\frac{5}{8}$″	24″
,, ,, L.P.	$20\frac{1}{8}$″	$20\frac{1}{2}$″	38″
,, stroke	$22\frac{1}{8}$″	$21\frac{11}{16}$″	28″
Boiler, ht. of centre line	7′ $6\frac{1}{2}$″	7′ 3″	9′ $10\frac{1}{2}$″
,, mean diameter	4′ $6\frac{3}{8}$″	4′ 4″	6″
,, pressure lbs./sq. in.	171	171	200
Tubes, number	200	207	294–314 (feedwater)
,, diameter (int.)	$1\frac{31}{32}$″	$1\frac{19}{32}$″–$1\frac{13}{16}$″	$2\frac{1}{4}$″–$2\frac{1}{4}$″
,, length	16′ 0″	15′ 9″	19′ 0″–7′ $6\frac{1}{4}$″
Heating surface :			
Firebox . sq. ft.	105	118	202*
Tubes ,,	1,545	1,700	3,275 + 1,279 (feedwater)
Total ,,	1,750	1,818	4,756
Superheater ,,	None	None	323
Reheater ,,	None	None	728
Grate area ,,	29	37	52·7
Wheels, diameter	2′ $4\frac{3}{8}$″	2′ $7\frac{1}{2}$″	2′ $7\frac{1}{4}$″
,, ,,	3′ $6\frac{1}{4}$″	4′ $3\frac{1}{4}$″	6′ 1″
,, ,,	—	—	4′ 2″
Wheelbase, rigid	4′ 9″	11′ 10″	6′ 4″–12′ 8″
,, driving	4′ 9″–9′ $0\frac{1}{4}$″	22′ 6″	30′ 4″
,, total	28′ 0″	29′ 6″	51′ 11″
,, loco. & tender	52′ $0\frac{1}{2}$″	53′ 6″	94′ $3\frac{1}{4}$″
Tender, number of axles	4	4	4
,, wheels, diameter	—	—	2′ $6\frac{3}{8}$″
,, water . galls.	3,960 Imp.	3,300 Imp.	12,000 U.S. galls.
,, coal . tons-cwt.	—	—	4,000 ,, ,, †
Weight :			
Locomotive, empty ,,	46–4	40–6	—
,, in service ,,	52–3	47–4	168–1
,, adhesive ,,	45–15	40–6	119–13
Tender, empty ,,	14–15	11–16	—
,, in service ,,	37–17	31–10	104–5
Tractive force . lbs.	15,700	15,500	—

* Firebox width, 1·61 m. ; length, 3·04 m.

† Oil.

TABLE 75. — COMPARATIVE DIMENSIONS OF EARLY AND RECENT MALLETS ON RAILWAYS OF 1·067 M. (3 FT. 6 INS.) GAUGE

Railway	Japanese State Rys.		Russian State Rys. (Archangel-Jaroslaw).		
Type	0-4 + 4-0	0-6 + 6-0	0-6 + 6-0	0-6 + 6-0	0-6 + 6-0
Builder	—	Baldwin.	Borsig.	Baldwin.	Baldwin.
Date	—	1912.	1895.	1915.	1917.
Cylinders :					
Diameter, H.P. . m.	0·39	0·41	0·35	0·35	0·33
,, L.P. . m.	0·62	0·64	0·45	0·46	0·48
Stroke . . m.	0·61	0·61	0·55	0·56	0·56
Boiler :					
Diameter . . m.	1·50	1·47	1·32	1·32	
Pressure . kg./sq. cm.	12·7	14·1	12	12·7	
Tubes, number . .	176	101+16	162	142	
,, diameter . mm.	57	57+140	45/50	57	
,, length . m.	4·57	4·98	4·50	4·89	
Firebox, width . m.	0·76	0·74	0·76	0·80	
,, length . m.	2·62	2·60	2·35	2·58	
Heating surface :					
Firebox . sq. m.	10·9	11·3	7·6	11·3	11·6
Tubes . sq. m.	143·7	124·6	105·0	109·7	109·9
Total . sq. m.	154·5	136	112·6	121·0	121·5
Superheater . sq. m.	None	30	None	None	None
Grate area . sq. m.	2·0	2·0	1·8	1·8	
Wheels, diameter . m.	1·25	1·25	1·10	1·12	
Wheelbase, rigid . m.	2·14	2·74	2·32	2·62	
,, driving. m.	6·91	7·98	6·52	7·62	
,, total . m.	6·91	7·98	6·52	7·62	
Weight, in service . t.	59·7	64·7	47·5	47·8	49·9
Tender :					
Wheels, diameter m.	0·94	0·94	0·81	0·76	0·71
Water . . t.	—	12·3	9·0	10·0	8·3
Coal . . t.	—	3·0	4·1	—	4·5
Weight, empty . t.	—	—	10·9	—	—
,, in service t.	—	—	23·7	24·4	23·1

chamber, a reheater for the steam on its passage from the H.P. to L.P. cylinders, a H.P. superheater and, lastly, a combustion chamber which lies immediately in front of the boiler proper, which occupies the rear section of the barrel.

The centre line of the boiler is relatively low—9 ft. 9½ ins. (2m.98)—in accordance with the usual practice of this railway. The firebox is of the Jacobs-Schupert type.

Table 75a.—Comparative Dimensions of Early and Recent Mallets on Railways of 1·067 m. (3 ft. 6 ins.) Gauge

Railway	Japanese State Rys.		Russian State Rys. (Archangel-Jaroslaw).		
Type	0-4 + 4-0	0-6 + 6-0	0-6 + 6-0	0-6 + 6-0	0-6 + 6-0
Builder		Baldwin.	Borsig.	Baldwin.	Baldwin.
Year	—	1912.	1895.	1915.	1917.
Cylinders, diameter, H.P.	$15\frac{3}{8}''$	$16\frac{1}{8}''$	$13\frac{3}{4}''$	$13\frac{3}{4}''$	13″
,, ,, L.P.	$24\frac{3}{8}''$	$25\frac{1}{4}''$	$17\frac{3}{4}''$	$18\frac{1}{8}''$	$18\frac{7}{8}''$
,, stroke	24″	24″	$21\frac{3}{4}''$	22″	22″
Boiler :					
Diameter	4′ 11″	4′ 10″	4′ 4″	4′ 4″	
Pressure . lbs./sq. in.	180	200	171	180	
Tubes, number	176	101 + 16	162	142	
,, diameter	$2\frac{1}{4}''$	$2\frac{1}{4}'' + 5\frac{1}{2}''$	$1\frac{3}{4}''/2''$	$2\frac{1}{4}''$	
,, length	15′ 0″	$16'\ 4\frac{1}{8}''$	14′ 9″	16′ 0″	
Firebox, width	$2'\ 5\frac{3}{4}''$	$2'\ 5\frac{1}{8}''$	$2'\ 5\frac{3}{4}''$	$2'\ 3\frac{3}{8}''$	
,, length	$8'\ 7\frac{3}{16}''$	$8'\ 6\frac{3}{8}''$	$7'\ 8\frac{3}{8}''$	$8'\ 5\frac{5}{8}''$	
Heating surface :					
Firebox . sq. ft.	117·8	122	82	124	125
Tubes ,,	1,546	1,341	1,130	1,181	1,183
Total ,,	1,663·8	1,463	1,243	1,305	1,308
Superheater ,,	None	323	None	None	None
Grate area ,,	21·4	21·2	19·3	19·3	
Wheels, diameter	4′ 1″	4′ 1″	3′ 7″	3′ 8″	
Wheelbase, rigid	7′ 0″	9′ 0″	7′ 7″	8′ 7″	
,, total	22′ 8″	26′ 2″	21′ 5″	25′ 0″	
Weight :					
Loco., in service t.-cwt.	58–15	63–14	46–4	47–1	49
Tender :					
Wheels, diameter	3′ 1″	3′ 1″	—	2′ 6″	2′ 4″
Water-tanks imp. galls.	—	2,700	1,980	2,200	1,830
Fuel bunkers ,,	—	3–0	—	$3\frac{1}{2}$ cords.	1,200 (U.S.)
Weight, empty t.-cwt.	—	—	10–4	—	—
,, in service ,,	—	—	23–12	24–0	23–0

The cylinders are bolted to the frames and are not cast integral with the saddle pieces.

The tender is semi-cylindrical in section, as oil fuel is used.

These locomotives ran at 25 miles (40 km.) per hour. They climbed 5,233 ft. (1,595 m.) in altitude by means of gradients of 1·7 per cent. to 1·8 per cent.

Class G.—0-6 + 6-0 Mallet Locomotives

These locomotives, in which the whole weight is available for adhesion, are a logical development of the original type. Very many are in use on narrow gauge lines, but they are also to be found on standard, and even on broad gauge lines.

It is an interesting coincidence that the first *Mallets* built both in England and America were of this type.

0-6 + 6-0 Mallets of the American Porto Rico Ry.—Metre gauge.

These were the first narrow gauge *Mallets* built in U.S.A. They were delivered by the Baldwin Works in 1904.

0-6 + 6-0 Mallets of the Argentine Central Northern Ry.—Metre gauge.

These freight locomotives are used concurrently with the 2-4 + 6-0 passenger locomotives already referred to. Many of the components of both types are interchangeable.

0-6 + 6-0 Locomotives of the Arica-La Paz Ry.—Metre gauge (Fig. 150).

This line runs from the port of Arica up to Guaqui, situated on the Bolivian plateau at an altitude of about 14,000 ft. (4,267 m.) above sea level, in which district these locomotives operate. They have Gaines copper fireboxes with combustion chambers.

0-6 + 6-0 Mallets of the Burma Rys.—Metre gauge.

These locomotives, delivered in 1924, were required to draw 150-ton trains up 4 per cent. grades at 10 miles (16 km.) an hour, or 220-ton trains up 2½ per cent. grades at an increased speed. They weighed 60 tons approximately. They were tried in competition with the *Garratt* locomotives already referred to.

0-6 + 6-0 Mallets of the Archangel-Jaroslaw Ry.—Gauge, 1m.067 (3 ft. 6 ins.).

The first of these locomotives date from 1896. As this was the only Russian railway of 3 ft. 6 ins. gauge,* they were

* This line connects Archangel with Vologda ; it is 530 miles (850 km.) long. The rails being only 37½ lbs. per yard (18·5 kilos per metre), the axle load was restricted to 6 tons 18 cwt. (7 tonnes).

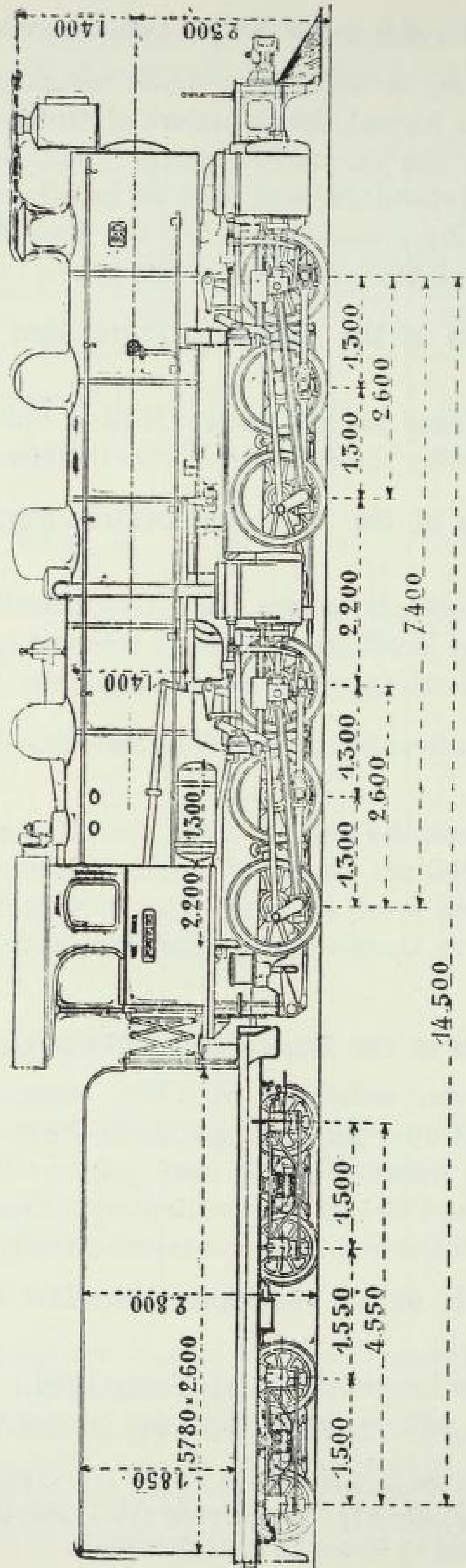


FIG. 150.—0-6 + 6-0 Mallet Locomotive, Arica-La Paz Ry. Built by the Hanover Works. (Metre Gauge.)

TABLE 76.—PRINCIPAL DIMENSIONS OF 0-6 + 6-0 MALLET LOCOMOTIVES FOR METRIC GAUGES

Gauge		Metre.	Metre.	Metre.	Metre.	Metre.	Metre.	3′ 6″
Railway		Dakar-St. Louis.	American R.R. of Porto Rico.	Central Norte. (Argentine)	Arica-La Paz.	Burma Rys., S. Mahratta, Uganda Ry.	Burma Rys.	Japanese State Rys.
Builder		Batignolles.	Baldwin.	Borsig	Hanomag and Baldwin.	N. British.	Beardmore.	Henschel, Baldwin.
Date		—	1904.	—	1913.	—	1924.	1912.
Cylinders, diameter	m.	0·31	0·32	0·33	0·40	0·39	0·41	0·42
,, diameter	m.	0·48	0·48	0·52	0·61	0·62	0·62	0·65
,, stroke	m.	0·55	0·51	0·55	0·55	0·51	0·51	0·61
Boiler, centre line	m.	2·00	1·91	2·15	2·30	2·21	—	2·34
,, diameter	m.	1·15	1·37	1·32	1·40	1·44	—	1·51
,, pressure	lbs./sq. cm.	15	14·1	12·0	14·0	12·7	12·7	14·0
Tubes, number		140	155	191	198	15+97	—	16+100
,, diameter	mm.	45–50	51	51	45–52	133–51	—	140–57
,, length	m.	3·65	4·72	4·50	5·50	4·57	—	4·95
Heating surface, firebox	sq. m.	9·8	9·8	11·0	9·7	10·7	10·7	12·3
,, ,, tubes	,,	76·9	116·2	135·0	177·6	129·9	98·8	123·1
,, ,, total	,,	86·7	126·0	146·0	187·6	140·6	109·5	135·4
Superheater	,,	None	None	None	None	None	20·8	35·5
Grate area	,,	1·6	1·7	3·0	2·8	3·1	3·1	2·6
Wheels, diameter	m.	1·00	0·94	1·10	1·11	0·99	0·99	1·25
Wheelbase, rigid	m.	2·44	2·08	2·46	2·60	2·51	2·74	2·74
,, driving	m.	6·40	6·20	6·89	7·40	7·40	8·08	8·08
,, total	m.	6·40	6·20	6·89	7·40	7·40	8·08	8·08
Overall height	m.	3·50	—	—	3·70	3·40	—	3·85
,, width	m.	2·50	—	—	2·70	—	—	2·54
,, length	m.	10·50	—	—	11·92–18·80	19·17	—	17·55
Weight, empty	t.	40·6	41·7	40·7	54·0	53·3	—	61·2
,, in service	t.	44·1	48·4	47·5	60·0	59·1	61·9	67·9
Tractive force	t.	7·2	—	8·0	—	8·3	13·6–11·8	—
Tender, empty	t.	13·5	—	12·0	15·8	15·8	—	10·9
,, in service	t.	29·3	22·7	32·0	40·0	40·1	36·5	28·1
,, water	cub. m.	9·5	8·3	15·0	—	9·7	—	—
,, fuel	t.	6·0	4·5	10·0	6·0	—	—	2·7
,, diameter of wheels	m.	—	0·76	—	0·84	0·72	—	0·93

TABLE 76A.—PRINCIPAL DIMENSIONS OF 0-6 + 6-0 MALLET METRIC GAUGE LOCOMOTIVES

Gauge	Metre.	Metre.	Metre.	Metre.	Metre.	Metre.	3′ 6″	Metre.
Railway	Dakar-St. Louis.	American R.R. of Porto Rico.	Arica-La Paz.	Burma Rys. S. Mahratta Uganda Ry.	Sierra-Mineira.	Burma Rys.	Japanese State Rys.	Central Norte. (Argentine).
Builder	Batignolles.	Baldwin.	Baldwin, Hanomag.	N. British.	N. British.	Beardmore.	Henschel, Baldwin.	Borsig.
Date	—	1904.	1913.	—	—	1924.	1912.	—
Cylinders, diameter	12 3/16″	12½″	16″	15½″	18″	16″	16″	13″
,, diameter	18½″	19″	25″	24¼″	28″	24½″	23	20½″
,, stroke	21⅝″	20″	21⅝″	20″	24″	20″	24″	21⅝″
Boiler, centre line	6′ 7¼″	6′ 2 13/16″	7′ 6″	7′ 3″	—	—	7′ 8½″	7′ 0¾″
,, diameter	3′ 8⅜″	4′ 6″	4′ 8″	4′ 8 5/16″	—	—	4′ 10″ (mean)	4′ 4″
,, pressure lbs. per sq. in.	213	200	200	180	180	180	200	199
Tubes, number	140	155	18–105	15–97	—	—	16–101	191
,, diameter	1⅞″	2″	5⅜″–2″	5¼″–2″	—	—	5½″–2¼″	2″
,, length	11′ 11⅝″	15′ 6″	16′ 10″	14′ 0″	—	—	16′ 4″	14′ 8″
Heating surface, firebox sq. ft.	106	106	118+16	115	135	115	122	107·6
,, ,, tubes ,,	828·8	1,251	1,345	1,327	2,070	1,064	1,341	1,453·1
,, ,, total ,,	934·8	1,357	1,479	1,442	2,205	1,179	1,463	1,560·7
Superheater ,,	None	None	363	None	None	224	323	None
Grate area ,,	17·2	18	31·3	33	40	33	27·9	32·3
Wheels, diameter	3′ 3⅜″	3′ 1″″	3′7½″	3′ 3″	3′ 9″	3′ 3″	4′ 1″	—
Wheelbase, rigid	2′ 0 1/16″	6′ 10	8′ 6″	8′ 3″	8′ 11″	9′ 0″	9′ 0″	3′ 7⅜″
,, driving	21′ 0¼″	20′ 4″	24′ 5″	24′ 5″	26′ 4″	26′ 2″	26′ 2″	7′ 1¾″
,, total	21′ 0¼″	20′ 4″	24′ 5″	24′ 5″	50′ 8″ (1+t)	26′ 2″	26′ 2″	21′ 2¼″
Overall height	11′ 4⅝″	—	12′ 1⅝″	12′ 3½″	—	11′ 3″	12′ 7½″	21′ 2¼″
,, width	8′ 2¾″	—	8′ 10¼″	8′ 7″	—	—	8′ 4″	—
,, length	34′ 5⅜″	—	39′ 1⅜″ 61′ 8¼″	63′ 6⅝″	26′	62′ 10⅞″	57′ 7″	—
Weight, in service t.	43–8	42–0	57–14	59–10	81–9	61–0	63–8	46–16
Tender, water galls.	2,090	1,720	3,740	2,130	3,080	2,140	—	3,300
,, fuel t.-cwt.	5–19	24–5	12,000 lbs.	11	202 cub. ft.	11	2·5	11–17
,, weight t.-cwt.	28–18	22–10	35–14	15–10	35–5	36–0	27–18	31–11
,, wheels, diameter	—	2′ 2″	2′ 9″	2′ 4½″	—	—	3′ 0⅝″	—
Tractive force lbs.	15,800	—	—	26,600 (60%)	37,300 (60%)	26,000	—	7–19

TABLE 77.—PRINCIPAL DIMENSIONS OF EUROPEAN-BUILT 0-6 + 6-0 MALLET LOCOMOTIVES (STANDARD AND BROAD GAUGES)

Gauge	Standard.	Standard.	1·52 m.	1·672 m.	1·672 m.
Railway	Hungarian State.	Pekin-Kalgan.	Trans-Siberian.	Central Aragon.	Huelva-Zafra.
Builder	Railway Work-shops.	North British Loco. Co.	Briansk.	Henschel & Winterthur.	Maffei.
Date	1908.	—	1900.		—
Cylinders:					
Diameter, H.P. . m.	0·40	0·46	0·48	0·40	0·45
,, L.P. . m.	0·62	0·73	0·71	0·60	0·70
,, stroke m.	0·61	0·71	0·65	0·60	0·64
Boiler:					
Height of centre line m.	2·75	3·05	—	2·60	2·80
Diameter . . m.	1·55 (int.)	1·86	—	1·45 (mean)	1·56
Pressure kg. per sq. cm.	16	14·1	12	12	14
Tubes, number . .	272	169	—	102+21	264
,, diameter . mm.	52 (ext.)	57	—	50–127 (ext.)	46/51
,, length . m.	5·00	5·38	—	4·50	4·51
Heating surface:					
Firebox . sq. m.	13·9	15·4	—	11·6	10·1
Tubes . sq. m.	221·3	225·3	—	101·4	172
Total . sq. m.	235·2	240·7	204	113	182·1
Superheater . sq. m.	None	None	None	37·8	None
Grate area . sq. m.	3·6	4·2	3·5	2·9	2·8
Wheels, diameter . m.	1·22	1·30	1·18	1·20	1·23
Wheelbase:					
Rigid . . m.	2·70	2·94	2·60	2·70	2·66
Driving . . m.	8·00	8·50	7·70	7·65	7·97
Total . . m.	8·00	8·50	7·70	7·65	7·97
Loco. and tender m.	—	—	—	13·76	14·16
Overall dimensions:					
Height . . m.	4·57	4·57	—	4·30	4·50
Width . . m.	3·10	3·05	—	3·00	3·20
Length . . m.	12·88	13·06	—	11·71	12·54
Weight, empty . t.	64·5	87·3	—	67·4	72·9
,, in service t.	71·5	97·4	81	73·1	79·8
Tractive force . t.	—	—	—	11·3	13·5
Tender, water cub. m.	20·3	—	—	15	15
,, coal . . t.	9	—	—	4·5	6
,, weight . t.	23·8–52·8	—	—	—	16–37

designed so that they could be converted into metre gauge locomotives if the gauge of the line was changed to metre.

TABLE 77A.—PRINCIPAL DIMENSIONS OF EUROPEAN-BUILT **0-6 + 6-0** MALLET LOCOMOTIVES (STANDARD AND BROAD GAUGES)

Gauge	Standard.	Standard.	5 ft.	5 ft. 6 ins.	5 ft. 6 ins.
Railway	Hungarian State.	Pekin-Kalgan.	Trans-Siberian.	Central Aragon.	Huelva-Zafra.
Builder	Railway Work-shops.	North British. Loco.Co.	Briansk.	Henschel.	Maffei.
Date	1908.	—	1900.	—	—
Cylinders :					
Diameter, H.P.	$15\frac{3}{4}''$	$18\frac{1}{8}''$	$18\frac{7}{8}''$	$15\frac{3}{4}''$	$17\frac{3}{4}''$
,, L.P.	$24\frac{3}{8}''$	$28\frac{3}{4}''$	28	$23\frac{5}{8}''$	$27\frac{9}{16}''$
Stroke	24″	28″	$25\frac{5}{8}''$	$23\frac{5}{8}''$	$25\frac{1}{4}''$
Boiler :					
Height of centre line	$9'\ 0\frac{1}{2}''$	10′ 1″	—	$8'\ 6\frac{1}{2}''$	$9'\ 2\frac{3}{4}''$
Diameter	5′ 1″	$6'\ 1\frac{1}{2}''$	—	4′ 9″ (mean)	$5'\ 1\frac{1}{2}''$
Pressure lbs./sq. in.	228	200	171	771	199
Tubes, number	272	169	—	102+21	264
,, diameter	$2\frac{1}{16}''$ (ext.)	$2\frac{1}{4}''$	—	$1\frac{31}{32}''$–$5\frac{1}{32}''$	$1\frac{13}{16}''$–2″
,, length	16′ 5″	17′ 0″	—	14′ 10″	$14'\ 10\frac{3}{8}''$
Heating surface :					
Firebox . sq. ft.	150	165	—	125	109
Tubes ,,	2,380	2,430	—	1,100	1,830
Total ,,	2,530	2,595	2,200	1,225	1,939
Superheater ,,	None	None	None	407	None
Grate area ,,	39	45	38	31	30
Wheels, diameter	4′ 0″	$4'\ 3\frac{1}{4}''$	$3'\ 10\frac{1}{2}''$	$3'\ 11\frac{1}{4}''$	$4'\ 0\frac{3}{8}''$
Wheelbase :					
Rigid	$8'\ 10\frac{1}{4}''$	9′ 9″	$8'\ 6\frac{1}{2}''$	$8'\ 10\frac{1}{4}''$	8′ 9″
Driving	26′ 3″	27′ 10″	25′ 3″	25′ 1″	26′ 2″
Total	26′ 3″	27′ 10″	25′ 3″	25′ 1″	26′ 2″
Loco. and tender	—	—	—	45′ 2″	46′ 3″
Overall, height	15′ 1″	15′ 1″	—	$14'\ 1\frac{1}{2}''$	14′ 9″
,, width	$10'\ 2\frac{1}{2}''$	10′ 0″	—	$9'\ 1\frac{1}{2}''$	10′ 6″
,, length	42′ 3″	42′ 9″	—	38′ 6″	41′ 0″
Weight :					
Loco.,empty t.-cwt.	63–9	85–17	—	66–2	71–14
In service ,,	70–6	95–16	79–14	71–18	78–4
Tractive force. lbs.	—	—	—	25,000	30,000
Tender :					
Water. galls.	4,460	—	—	3,300	3,300
Coal . t.-cwt.	8–17	—	—	4–9	5–18
Weight, empty ,,	23–1	—	—	—	15–11
,, in service ,,	52–0	—	—	—	36–8

The light nature of the permanent way was the reason which first led to the adoption of the *Mallets*. Later, the Baldwin Works supplied some locomotives of the same type, but of greater power (they were generally similar to the locomotives supplied by the same builders to the Timbó-Propria Ry., Brazil). The tenders were carried on three axles, two of which formed a bogie. As the minimum radius of curvature exceeded 1,150 ft. (350 m.), a leading bissel was unnecessary, and the whole weight could be made available for adhesion.

The latest locomotives, supplied during the War, used oil fuel instead of wood, but otherwise differed little from those above described.

0-6 + 6-0 Mallets of the Japanese State Rys.—Gauge, 1m.067 (3 ft. 6 ins.).

These locomotives have Schmidt superheaters. Their tenders are similar to those of the Archangel locomotives, and have a single axle in front and a four-wheeled bogie behind. They work on sections having curves of 400 ft. radius and grades of 1 in 30.

0-6 + 6-0 Mallets of the Russian Rys.—Gauge, 1m.52 (5 ft.).

A locomotive for use on the Moscow-Kazan section was built by the Briansk Works, following generally the design of the Gothard locomotives. It weighed 78 tonnes (76 tons 14 cwt.) empty and 84 tonnes (82 tons 12 cwt.) in service.

This design was reproduced for use on the Russian State and on the Trans-Siberian Rys. The latter being laid with 50-lbs. (24·5 kilos) rails, the axle load had to be reduced. This was effected by reducing the size of various components and also reducing the heating surface to 2·045 sq. ft. (190 sq. m.).

0-6 + 6-0 Mallets of the Pekin-Kalgan Ry.—Standard gauge.

These were the first *Mallets* built in England. They were in service concurrently with some American-built *Mallets*, and some *Shay* geared locomotives on a long 3 per cent. incline with curves of 500 ft. (152 m.) radius.

0-6 + 6-0 Mallets of the Baltimore and Ohio R.R.—Standard gauge (Fig. 151).

These locomotives, delivered in 1904, were the first American-built *Mallets*.

They were allocated to the Connesville section (between

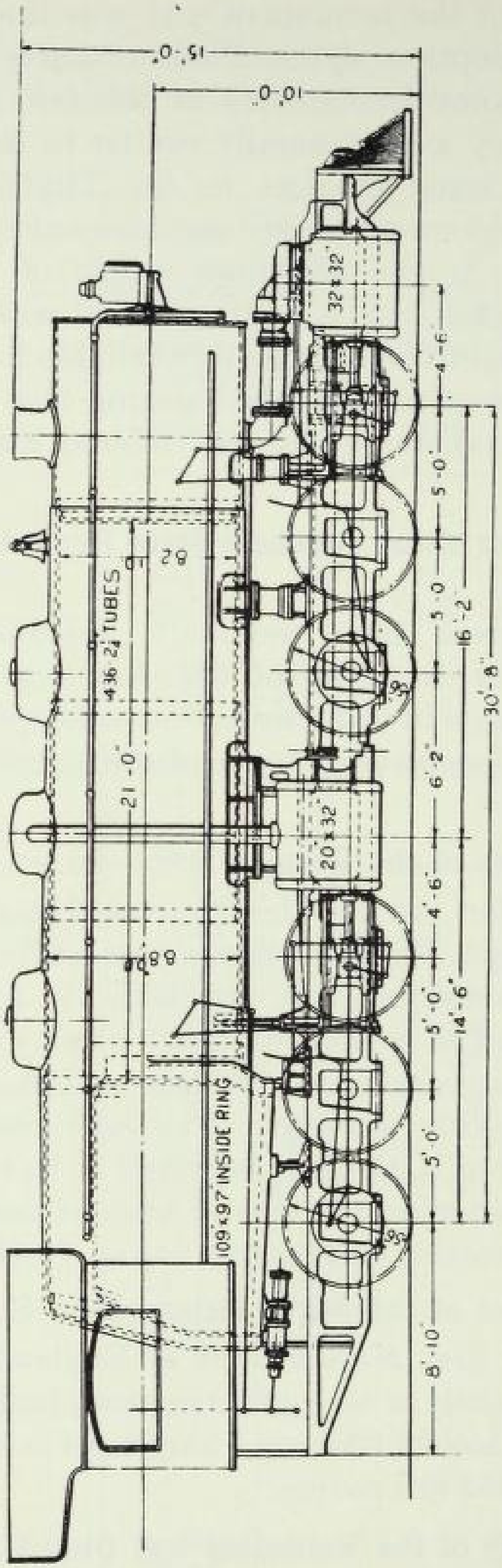


Fig. 151.—Baltimore and Ohio R.R. 0-6 + 6-0 Mallet Locomotive. (Standard Gauge.) Built by the American Locomotive Co.

Rockwood and Saint-Pitch, a distance of 16 miles (26 km. approximately). This section has 1 per cent. grades and curves of 820 ft. (250 m.) radius. The trains of 1,940 tons approxi-

TABLE 78.—PRINCIPAL DIMENSIONS OF AMERICAN-BUILT 0-6 + 6-0 MALLET LOCOMOTIVES

Gauge	Standard.	Standard.	Standard.	Standard.	5 ft. 3 ins.
Railway	Lake Terminal Ry.	Baltimore and Ohio R.R.	Denver and N. Western.	Canadian Pacific Ry.	Central Ry. of Brazil.
Builder	Baldwin.	American Loco. Co.	American Loco. Co.	—	American Loco. Co.
Date	1909.	1904.*	—	1910.	—
Cylinders :					
Diameter, H.P.	24″	20″	20½″	33⅞″	17½″
,, L.P.	37″	32″	33″	33⅞″	28″
Stroke	32″	32″	32″	26″	26″
Boiler :					
Height of centre line	10′ 0″	10′ 0″	10′ 0″	9′ 3″	8′ 9¾″
Diameter	7′ 0″	6′ 10″	7′ 0″ (ext.)	9′ 3″	5′ 4¼″ (int.)
Pressure lbs./sq. in.	205	235	225	199	200
Tubes, number	437	436	409	281 + 12	234
,, diameter	2¼″	2¼″	2¼″	2¼″	2″
,, length	21′ 0″	21′ 0″	21′ 0″	8′ 0½″	18′ 0″
Heating surface :					
Firebox sq. ft.	230	219	206	140	122
Tubes ,,	5,380 + 30	5,366	5,035	2,650	2,195
Total ,,	5,640	5,585	5,241	2,790	2,317
Superheater ,,	None	None	None	420	None
Grate area ,,	78·3	72	72·2	—	41
Wheels, diameter	4′ 7″	4′ 8″	4′ 7″	4′ 10¼″	4′ 3″
Wheelbase :					
Driving	10′ 0″	10′ 0″	10′ 0″	10′ 9″	9′ 0″
Total	29′ 8″	30′ 8″	30′ 8″	35′ 2″	27′ 8″
Loco. and tender	61′ 2¾″	—	—	—	55′ 2¼″
Overall, height	—	15′ 0″	15′ 9½″	15′ 2½″	13′ 9″
,, width	—	10′ 5″	10′ 8″	—	10′ 2″
Weight, in service lbs.	350,100	334,500	327,500	26,300	206,000
Tractive force ,,	—	71,500	73,900	—	42,400
,, ,, ,,	—	85,500	93,500	—	50,000
Tender :					
Wheels, diameter	2′ 9″	—	2′ 9″	—	2′ 6″
Water. U.S. galls.	7,000	—	9,000	—	4,500
Fuel . U.S. tons	12	—	12	—	8·5
Weight, in service lbs.	129,900	—	161,100	190,000	98,300

mately were previously handled by three *Consolidation* locomotives, one in front and two behind. The single *Mallet* replaced the two latter locomotives.†

* This is a four-cylinder simple locomotive.

† It is stated that between the years 1905 and 1910 an economy of 38 per cent. was obtained.

0-6 + 6-0 Mallets of the Lake Terminal Ry.—Standard gauge.

These were used for banking on a branch line near the town of Lorane (Ohio). The maximum gradient was 1·65 per cent. The load dealt with consisted of twenty-one wagons giving a total weight of 1,460 tons approximately.

0-6 + 6-0 Mallets of the Canadian Pacific Ry.—Standard gauge.

These locomotives had four cylinders centrally located between the two groups of wheels, and are described hereafter in the section dealing with " modified *Mallets*."

0-6 + 6-0 Mallets of the Central of Brazil Ry.—Gauge, 1m.60 (5 ft. 3 ins.).

Mallets with six,* and others with eight axles coupled in two groups work on the Serra section, where gradients are 1·8 per cent. and the curves 181 m. (593 ft.) radius.

Class H.—2-6 + 6-0 Mallet Locomotives

This type is employed chiefly for mixed traffic, especially on narrow gauge lines.

2-6 + 6-0 Mallets of the Madrid-Aragon Ry.—Metre gauge.

This railway is destined to connect Madrid with Saragossa. It is now open for traffic as far as Alocen (km. 142). The maximum grade is 2·2 per cent., and the curves of 394 ft. (120 m.) radius, except on the original section, where the grade is 2½ per cent. and the radius of curvature 361 ft. (110 m.).

2-6 + 6-0 Mallets of the South African Rys.—Gauge, 3 ft. 6 ins. (1m.067).

This railway is by far the most interesting of this gauge, for on no other system has so sustained an attempt been made to utilise the capacity of the gauge to the uttermost ; it therefore deserves particular attention from every point of view.

* Some of the locomotives built by Baldwin differ in details from those quoted in Table 78.

The diameter of the cylinders is increased to 18 ins. (0m.46). The total heating surface is raised to 2,332 sq. ft. (1,040 sq. m.). The total wheelbase is lengthened to 54 ft. 9½ ins. (16m.70). The weight is increased to 92 tons 10 cwt. (93·9 tonnes).

TABLE 79.—PRINCIPAL DIMENSIONS OF 2-6 + 6-0 MALLET LOCOMOTIVES (VARIOUS GAUGES)

				1·067 m. South African Rys.				
Gauge / Railway / Builder / Date		0·75 m. Serbian State. Henschel. —	Metre. Madrid-Aragon. Haine-St. Pierre. 1914.	N. British Loco. Co. Type MC1. —	Maffei. Type MJ. —	1·067 m. Java State. Winterthur. 1927–28.	Standard. Eastern (France). American Loco. Co. 1908.	Standard. Hungarian State. Railway Workshops. —
Cylinders, diameter, H.P.	m.	0·36	0·40	0·46	0·42	0·42	0·44	0·52
,, ,, L.P.	m.	0·56	0·60	0·71	0·66	0·65	0·71	0·79
,, stroke	m.	0·40	0·56	0·66	0·61	0·61	0·66	0·66
Boiler, height of centre line	m.	2·05	2·30	—	2·36	2·45	2·90	3·12
,, diameter	m.	1·32	1·50	—	1·56	1·52	1·63 (int.)	2·10
,, pressure	kg. per sq. m.	14	14	—	14·1	14	14·1	16·2
Tubes, number		79–6–18	115–18–72	252–27	18–151	21–116–21	269	176–36
,, diameter	mm.	46–46–133 (ext.)	50–127–34	146–63	140–51 (ext.)	55–39–133	49	52–133 (ext.)
,, length	m.	5·00	5·00	4·95	5·18	5·20	5·48	5·62
Heating surface, fire-box	sq. m.	9·7	10	14·3	12·1	11·4 + 1·6	12·4	23
,, ,, tubes	sq. m.	90	125·9	191·4	165·6	104 + 46	224·2	252·3
,, ,, total	sq. m.	99·7	136·2	205·7	177·7	163	236·6	275·3
Superheater	sq. m.	40	35·2	53·9	43	50	—	66·5
Grate area	sq. m.	3	2·8	4	3·7	3·3	4·2	5·5
Wheels, diameter	m.	0·68	0·75	0·72	0·72	0·78	0·85	0·96
,, diameter	m.	0·80	1·10	1·16	1·08	1·11	1·27	1·44
Wheelbase, rigid	m.	2·00	2·50	2·54	2·54	2·70	2·74	3·41
,, driving	m.	—	7·20	7·80	—	4·73	8·38	9·46
,, total	m.	7·80	9·20	10·19	9·96	10·05	10·62	11·92
,, loco. and tender	m.	15·35	16·60	18·29	18·00	17·30	—	—
Overall dimensions, height	m.	3·45	3·70	3·79	2·82	3·68	4·20	4·65
,, ,, width	m.	2·44	2·68	2·82	—	3·00	3·05	3·14
,, ,, length	m.	10·96	12·90	12·40	12·66	13·10	12·75	14·48
Weight, adhesive	t.	48 6	60	90·3	78·6	66	82·6	97·4
,, empty	t.	50	60·5	85·9	79·5	73·6	84·8	97·8
,, in service	t.	55	66	99·3	86·6	11·3	93·5	109·6
Tractive force	t.	10·1	11·4	21·1 (75)	17·3	—	19·2–23	—
Tender, diameter, wheels	m.	0·68	0·75	0·85	0·85	0·78	0·85	1·05
,, wheelbase	m.	4·35	—	5·11	5·11	4·75	3·0	4·77
,, water	cub. m.	10	19	18·2	19·3	16·4	13	26
,, coal	t.	5	6	10·2	10·2	5	5	8
,, weight, empty	t.	14	18·4	22·5	—	16·2	14·6	22·8
,, ,, in service	t.	33	43·4	58·8	51·4	38·2	32·9	57·5

TABLE 79A.—PRINCIPAL DIMENSIONS OF 2-6 + 6-0 MALLET LOCOMOTIVES (VARIOUS GAUGES)

Gauge Railway Builder Date	2′ 5½″ Serbian State. Henschel. —	Metre. Madrid-Aragon. Haine-St. Pierre. 1914.	3′ 6″ Java State. Winterthur. 1927–8.	3′ 6″ South African Rys. N. British Loco Co. Type MC1. —	3′ 6″ South African Rys. Maffei Type MJ. —	Standard. Eastern (France). American Loco. Co. 1908.	Standard. Hungarian State. Railway. Workshops. —
Cylinders, diameter, H.P.	14¼″	15¾″	16½″	18″	16½″	17½″	20½″
,, ,, L.P.	22″	23⅝″	25⅝″	28½″	26″	28″	31⅛″
,, stroke	15¾″	22″	24″	26″	24″	26″	26″
Boiler, height of centre line	6′9¼″	7′ 6½″	8′ 0½″	7′ 6″	7′ 9″	9′ 6″	10′ 5″
,, diameter	4′ 4″	4′ 11″	4′ 11¾″	5′ 8″	5′ 1″	5′ 5⅜″	6′ 10¼″
,, pressure . lbs./sq. in.	199	199	199	200	200	200	230
Tubes, number	79–6–18	115–18–72	21–116–21	27–252	18–151	269	176–36
,, diameter	1 13/16″-1 13/16″-5¼″ (ext.)	1 31/32″–5 1/64″–1 5/16″	2 1/16″–2⅜″–5 5/16″	5¾″–2¼″	5½″–2″ (ext.)	1 13/16″	2 1/16″–5 5/16″
,, length	16′ 4¾″	16′ 4¾″	17′ 0″	16′ 2¼″	17′ 0″	18′ 0″	18′ 5½″
Heating surface, firebox sq. ft.	100	107	123 + 17	154	130	133	247·6
,, ,, tubes ,,	975	1,355	1,120 + 495	2,060	1.783	2,414	2,700
,, ,, total ,,	1,085	1,462	1,750	2,214	1,913	2,547	2,947·6
Superheater ,,	430	380	538	580	462	—	715·7
Grate area ,,	32·4	30	35·5	42·5	40	40·5	59·2
Wheels, diameter	2′ 2¾″	2′ 5½″	2′ 6¾″	2′ 4½″	2′ 4½″	2′ 9½″	3′ 1¾″
,, ,,	2′ 7½″	3′ 7⅜″	3′ 7¾″	3 9½″	3′ 6½″	4′ 2″	4′ 8¾″
Wheelbase, rigid	6 ′6½″	8′ 2½″	8′ 10¼″	8′ 4″	8′ 4″	9′ 0″	11′ 2½″
,, driving	—	23′ 7″	14′ 6½″	25′ 7″	25′ 5″	27′ 6″	31′ 0½″
,, total	25′ 7″	30′ 2″	32′ 11″	33′ 5″	32′ 8″	34′ 10″	39′ 0″
,, loco. and tender	50′ 5″	54′ 6″	57′ 9″	60′ 0″	65′ 4″	—	—
Overall height	11′ 5″	12′ 1″	12′ 0″	12′ 5 3/16″	12′ 6″	13′ 9⅛″	15′ 3⅝″
,, width	8′ 0″	8′ 8″	9′ 10″	8′ 10¾″	8′ 10¾″	10′ 0″	10′ 3⅝″
,, length	36′ 0″	42′ 5″	43′ 0″	68′ 5⅜″	67′ 5⅛″	41′ 0″	47′ 6⅛″
Weight, adhesive . tons-cwt.	47–18	59–4	65–2	88–19	77–3	81–5	96–0
,, empty ,,	49–4	59–12	65–2	—	—	83–8	96–8
,, in service ,,	54–2	65–2	72–8	97–2	85–3	91–16	108–0
Tractive force . lbs.	23,000	25,200	25,000	46,414 (75%)	38,170	42,300	—
Tender, wheels, diameter	2′ 2¾″	2′ 5½″	2′ 6¾″	2′ 9½″	2′ 9½″	2′ 9½″	3′ 5½″
,, wheelbase	14′ 3″	—	15′ 10½″	16′ 9″	16′ 9″	9′ 10½″	15′ 7¾″
,, water . Imp. galls.	2,200	4,180	4,000	4,250	4,250	2,860	5,720
,, coal . tons-cwt.	4–18	5–18	4–18	10–0	10–0	5–0	7–18
,, weight, empty ,,	13–16	18–2	15–19	22–4	—	14–8	22–16
,, ,, in service ,,	32–9	42–14	37–9	51–7	51–7	32–8	56–12

The railways of the Union comprise several lines which lend themselves to interesting applications of articulated locomotives. The subject was studied systematically; hence various stages in the development of the types used took place.

After experimenting with a *Meyer-Kitson* locomotive, the railway administration introduced *Mallets* on its 3 ft. 6 ins. lines. There are now eighty of these locomotives on the railway, including several classes of the 2-6 + 6-0 and 2-6 + 6-2 types, built both in Europe and in America.

This railway has also tried two types of 2-6 + 6-2 modified *Mallets*. In one of them all four cylinders are H.P., in the other driving wheels of two different diameters are used.

The 2-6 + 6-0 type was introduced in Natal in 1909. As this type was giving good service when the Natal Rys. were incorporated into the South African system, its use was extended both in Natal and in the Transvaal. The later examples have shorter boilers of larger diameter. Axle loads reached 17 tons.

These locomotives were built partly by the North British Locomotive Co. and partly by the American Locomotive Co.

During the War, further locomotives of the same type, but provided with superheaters, were supplied by the Montreal Locomotive Works (Canada) and the American Locomotive Co. The boiler, grate and cylinders of these locomotives were somewhat smaller.

The tractive force of the above locomotives (working compound) is as follows :

Natal locomotives . . .	46,060 lbs.	(21,137 kg.)
North British Co.'s locomotive .	42,700 lbs.	(19,051 kg.)
Montreal locomotives . . .	39,700 lbs.	(18,000 kg.)

2-6 + 6-0 Mallets of the Lourenço-Marquez Ry. (Portuguese East Africa).—Gauge, 3 ft. 6 ins. (1m.067).

These locomotives are very similar to those supplied by the American Locomotive Co. to the Natal Rys.

2-6 + 6-0 Mallets of the Java State Rys.—Gauge, 3 ft. 6 ins. (1m.067) (Fig. 152).

Some lines of this very important system call for heavy locomotive power, and at an early stage the administration

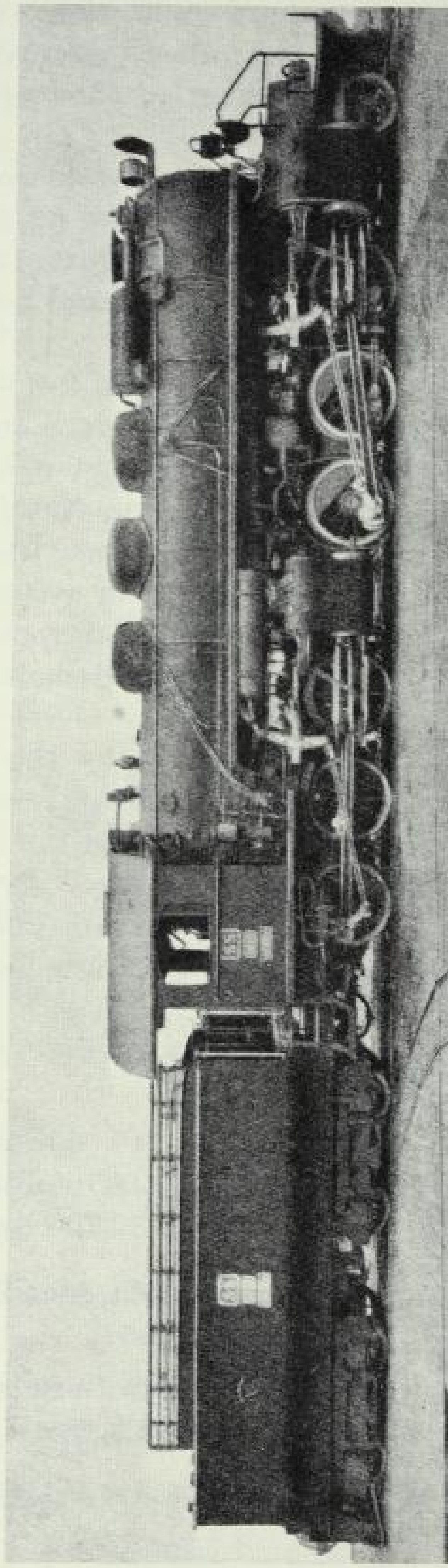


Fig. 152.—2-6 + 6-0 Mallet Locomotive, Java State Rys.
(3 ft. 6 in. Gauge.)
Built by the Winterthur Locomotive Works.

put *Mallet* locomotives into service. It has constantly adhered to this type, each successive class having greater power. The only time another type was tried was when some twelve coupled rigid tank engines were introduced. This is remarkable owing to the gauge and to the small radius of the curves they had to negotiate, but the cost of their upkeep offset any advantages they claimed owing to the relative simplicity of their design, and *Mallets* were reverted to.

The latest addition (1927–1928) consisted in 2-6 + 6-0 *Mallet* locomotives, fourteen of which were built by the Werkspoor Co. of Amsterdam, and sixteen by the Winterthur Locomotive Works.

They negotiate 150 m. radius curves ($6\frac{1}{4}$ chains), and reach a speed of 45 km. an hour (27·9 miles) up 6·5 per cent. inclines, with 250 tons behind the tender.

2-6 + 6-0 Mallets of the Eastern Ry. (France).—Standard gauge.

These are the only *Mallets* used on the large French railway systems, where *Du Bousquet* articulated locomotives are also to be found. A comparison between them is of interest, but neither system has been retained, as rigid locomotives of greater power have been provided.

2-6 + 6-0 Mallets of the Hungarian State Rys.—Standard gauge (Fig. 153).

Parts of this railway system have severe gradients, notably the Cammeral-Moravicz-Fiume section of the main line from Budapesth to Fiume. As the rails were comparatively light, *Mallets* have been in use since the year 1898.

The first locomotives were of the 0-4 + 4-0 type, weighing 56 tons (57 tonnes) in service.

In 1914 more powerful *Mallets* were put into service. Those for passenger service were of the 2-4 + 4-0 type and those for freight service had the 0-6 + 6-0 wheel formation.

The latest *Mallets* are 2-6 + 6-0. They were built by the State Rys. in their Budapesth workshops. The axle load is 15 tons 15 cwt. (16 tonnes), and the total adhesive weight is 94 tons 10 cwt. (96 tonnes). The leading axles have a lateral play of $\pm \frac{5}{8}$ in. ($\pm$ 15 mm.). The flanges of the middle wheels are reduced in thickness.

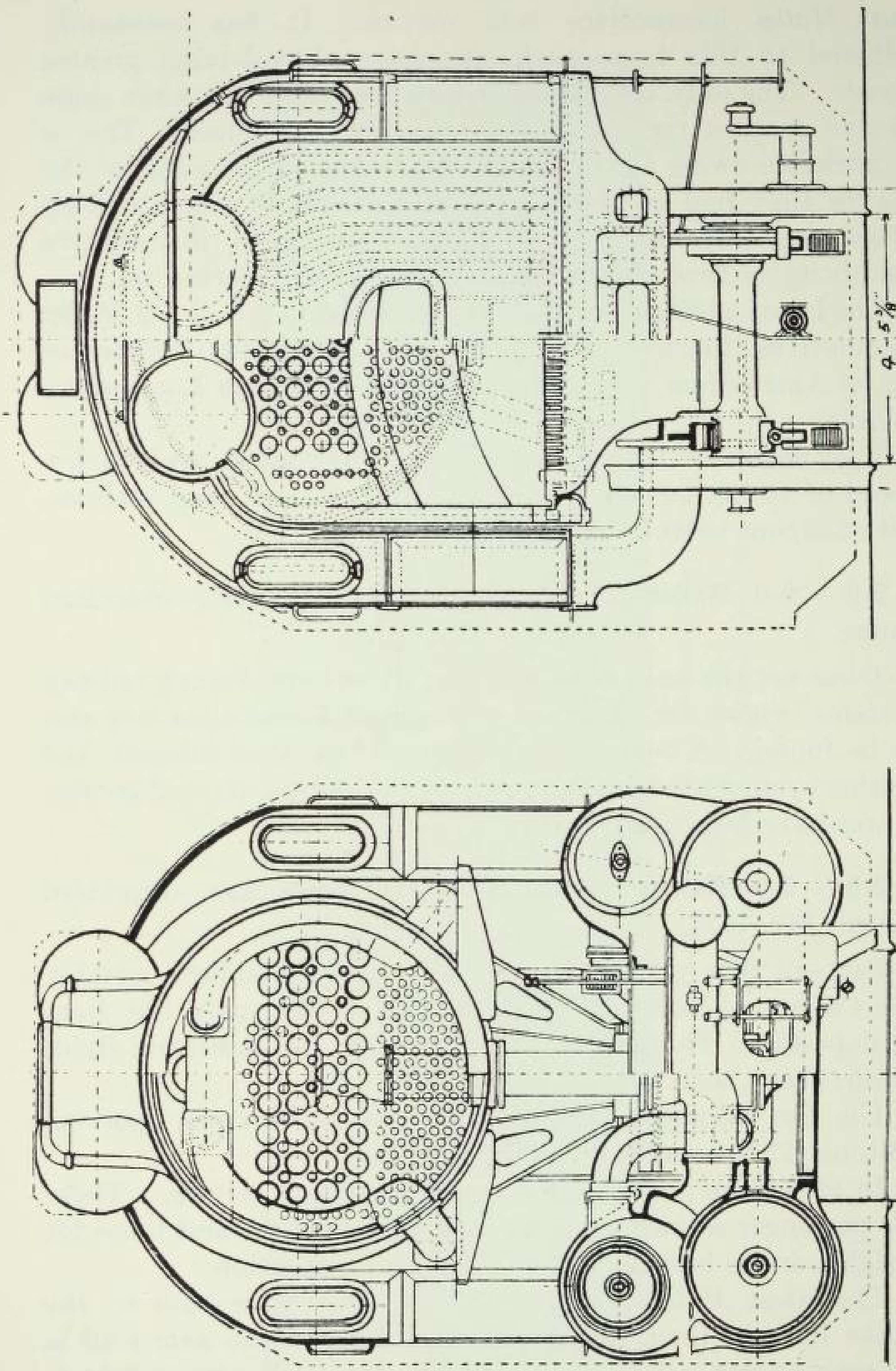


FIG. 153.—Cross Sections, 2-6 + 6-0 Mallet, Hungarian State Rys. (Standard Gauge.)

As the feed-water is generally hard, Brotan boilers are used. The firebox is the largest of this type hitherto constructed,

TABLE 80.—PRINCIPAL DIMENSIONS OF MALLET LOCOMOTIVES OF THE HUNGARIAN STATE RYS. (STANDARD GAUGE.)

Type		0-4 + 4-0	2-4 + 4-0	0-6 + 6-0	2-6 + 6-0
Cylinders, diameter, H.P.	m.	0·39	0·39	0·40	0·52
,, ,, L.P.	m.	0·58	0·64	0·62	0·79
,, stroke . .	m.	0·61	0·65	0·61	0·66
Boiler, height of centre line	m.	2·25	2·85	2·85	3·12
,, diameter . .	m.	—	1·55(int.)	1·55	2·10
,, pressure .	kg./sq. cm.	13	16	16	16·2
Tubes, number . . .	.	228	267–5	272	176–36
,, diameter, ext. .	mm.	52	52–40	52	52–133
,, length. . .	m.	4·15	5·00	5·00	5·62
Heating surface, firebox	sq. m.	12·3	13·6	13·9	23·0
,, ,, tubes	sq. m.	154·6	222·2	221·3	252·3
,, ,, total	sq. m.	166·9	235·8	235·2	275·3
Superheater . .	sq. m.	None	None	None	66·5
Grate area . .	sq. m.	2·6	3·55	3·6	5·5
Wheels, diameter . .	m.	None	1·04	None	0·96
,, ,, . .	m.	1·22	1·44	1·22	1·44
Wheelbase, driving . .	m.	5·80	6·30	8·00	9·46
,, rigid . .	m.	1·75	1·85	2·70	3·41
,, total . .	m.	5·80	8·71	8·00	11·90
Overall dimensions, height	m.	4·58	4·57	4·57	4·65
,, ,, width	m.	3·10	3·10	3·10	3·14
,, ,, length	m.	11·46	11·40	12·88	14·48
Weight, adhesive . .	t.	56·9	65·3	71·5	97·4
, empty . .	t.	50·8	68·1	64·5	97·8
,, in service . .	t.	56·9	75·1	71·5	109·6
Tender, water .	cub. m.	12·5	14·5	20·3	26
,, coal	t.	8	7·0	9	8

being 3m.10 (122 ins.) by 2m.02 (79½ ins.). The foundation ring is of cast steel and the side walls are solid drawn wrought-iron water tubes, bent inwards at their upper ends so as to enter two longitudinal headers. These project some 0m.58 ($22\frac{9}{16}$ ins.) into the boiler, where angle bars support them. Two longitudinal water tubes are built in between the headers, and both these tubes and the headers are connected at the rear by a coupling piece.

The front portion of the boiler rests, by means of a cast steel girder riveted to it, on bushed guides fixed to the front truck, in front of the middle axle. This truck is brought back to its mid-position by plate springs having appropriate side-play.

TABLE 80A.—PRINCIPAL DIMENSIONS OF MALLET LOCOMOTIVES OF THE HUNGARIAN STATE RYS. (STANDARD GAUGE)

Type	0-4 + 4-0	2-4 + 4-0	0-6 + 6-0	2-6 + 6-0
Cylinders, diameter, H.P.	$15\frac{3}{8}''$	$15\frac{3}{8}''$	$15\frac{3}{4}''$	$20\frac{1}{2}''$
,, ,, L.P.	$22\frac{7}{8}''$	$25\frac{1}{4}''$	$24\frac{3}{8}''$	$31\frac{1}{8}''$
,, stroke	24″	$25\frac{5}{8}''$	24″	26″
Boiler, height of centre line	$9'\ 3\frac{3}{4}''$	$9'\ 3\frac{1}{2}''$	$9'\ 3\frac{1}{2}''$	10′ 3″
,, diameter	—	5′ 1″ (int.)	5′ 1″	$6'\ 3\frac{3}{4}''$
,, pressure . lbs./sq. in.	185	227	227	230
Tubes, number	228	267–5	272	176–36
,, diameter, ext.	$2\frac{1}{16}''$	$2\frac{1}{16}''–5\frac{1}{2}''$	$2\frac{1}{16}''$	$2\frac{1}{16}''–5\frac{5}{16}''$
,, length	13′ 7″	16′ 5″	16′ 5″	$18'\ 4\frac{1}{2}''$
Heating surface, firebox sq. ft.	133	146	150	248
,, ,, tubes ,,	1,670	2,400	2,380	2,730
,, ,, total ,,	1,803	2,546	2,530	2,978
Superheater ,,	None	None	None	717
Grate area ,,	28	38·5	39	59·5
Wheels, diameter	None	3′ 5″	None	$3'\ 1\frac{3}{4}''$
,, ,,	4′ 0″	$4'\ 8\frac{3}{4}''$	4′ 0″	$4'\ 8\frac{3}{4}''$
Wheelbase, driving	19′ 0″	20′ 8″	26′ 3″	31′ 0″
,, rigid	5′ 9″	$6'\ 1\frac{1}{2}''$	8′ 10″	11′ 4″
,, total	19′ 0″	28′ 8″	26′ 3″	39′ 2″
Overall, height	$15'\ 0\frac{1}{2}''$	15′ 0″	15′ 0″	15′ 5″
,, width	10′ 3″	10′ 3″	10′ 3″	$10'\ 4\frac{1}{2}''$
,, length	37′ 8″	37′ 6″	42′ 6″	47′ 6″
Weight, adhesive t.-cwt.	56–0	64–5	70–2	95–18
,, empty ,,	50–0	67–0	63–9	96–2
,, in service ,,	56–0	73–18	73–18	107–15
Water . galls.	2,750	3,200	4,610	5,720
Coal t.-cwt.	7–18	6–18	8–17	7–18

Both end-coupled axles are rigid. The last wheels of the forward truck have smaller flanges ; the first wheels of the rear truck have ½ in. lateral play. The wheels of the pony truck and of the first coupled axle of each driving group are flange lubricated.

These locomotives haul the following loads up $2\frac{1}{2}$ per cent. grades :

400 tons at $12\frac{1}{2}$ miles an hour (20 km.).
,, 19 ,, ,, (30 km.).
,, 25 ,, ,, (40 km.).

The dimensions of the *Mallets* used on this railway are given in Tables 80 and 80A.

TABLE 81.—PRINCIPAL DIMENSIONS OF 2-6 + 6-2 MALLET LOCOMOTIVES (METRE AND NARROW GAUGES)

Gauge	0·76 m.	0·914 m.	Metre.	Metre.	Metre.	Metre.	1·067 m.	1·067 m.
Railway	Serbian State.	Manata Sugar Co.	Brazil Ry.	Chilean State Ry. *	Mogyana Rys. and Nav. Co.	Mogyana Rys. and Nav. Co. †	S. African Rys. ‡	Lourenço-Marquez Ry.
Builder	American Loco. Co.	Baldwin.	Amer. Loco.Co. and Henschel	Henschel.	Hanoversche; also Baldwin.	American Loco. Co.	— Type MH.	American Loco. Co.
Date	1915.	—	1913–15.		—	—	—	—
Cylinders, diameter . . m.	0·33	0·37	0·41		0·43	0·42	0·57	0·44
,, diameter . . m.	0·52	0·56	0·64		0·67	0·67	0·80	0·71
,, stroke . . m.	0·51	0·51	0·51		0·56	0·61	0·66	0·66
Boiler, height of centre line . m.	—	—	2·04		2·04	2·31	2·40	—
,, diameter . . m.	1·32	1·27	1·4		1·78	1·52 (int.)	—	1·65 (int.)
,, pressure kg./sq. cm.	14·1	14·1	14·1		14·1	14·1	14·7	14·1
Tubes, number .	157	150	200	121 + 16	194	104 + 21	168 + 25	230
,, diameter . mm.	57	51	51	137–57	57	57–137	57–140	57
,, length . . m.	4·61	5·18	5·18	5·18	6·40	6·10	6.70	5·49
Firebox, width . . m.	0·99	1·18	1·33	1·34	1·42–1·34	1·34	—	1·52
,, length . . m.	2.16	2·04	2·19	2·19	2·76–2·17	2·58	—	2·44
Heating surface, firebox sq. m.	8·8	8·0	10·4	10·4	13·3	13·0	—	11·6
,, ,, tubes sq. m.	114·9	123 5	164·5	134·9	222·3	113 + 53·9	—	225
,, ,, total sq. m.	123·8	131·5	174·9	145·5	235·6	179·9	298·3	236·6
Superheater . . sq. m.	None	None	None	28·8	None	47·1	57·4	None
Grate area . . sq. m.	2·6	2·4	2·9	2·9	3·9	3·4	4·9	3·7
Wheels, diameter . . m.	0·61	0 61	0·62		0·62	0·62	0·72	—
,, diameter . m.	0·91	1·04	1·06		1·14	1·14	1·22	1·15
,, diameter . . m.	0·61	0·61	0·62		0·62	0·62	0·72	—
Wheelbase, rigid . . m.	2.28	2·38	2·44		3·05	2·54	2·54	2·54
,, driving . m.	6·86	6·96	7·07		8·76	—	8·10	—
,, total . . m.	10·52	10·72	10·97		13·03	11·94	13·29	10·11
,, loco. and tender m.	16·58	17·45	19·24		20·22	19·27	21·59	18·36
Weight, adhesive . . t.	46·8	56·2	59·9		73·1	70·9	—	80·0
,, in service . . t.	57·2	65·4	71·2		86·5	83 9	—	88·5
Tractive force . . . t.	13·2–10·9	—	13·4		15·4	21·3–17·7	—	21·2 (max.)
Factor of adhesion . . t.	3·5–4·3	—	4·5		4·7	4 0	4·4	3·8
Tender, wheels, diameter . m.	0·66	0·66	0·71		0·71	0·84	0·85	—
,, water . . cub. m.	9·5	—	17		17	15·2	19·3	18·8
,, coal . . . t.	4·5	5·4	6·8		4·5	4 cords (wood)	10·8	9 1
,, weight in service . t.	27·7	31·6	40·8		40·8	42·6	52·1	45·0

* † ‡ See footnotes, p. 416.

TABLE 81.—PRINCIPAL DIMENSIONS OF 2-6 + 6-2 MALLET LOCOMOTIVES (METRE AND NARROW GAUGES)

Gauge	2′ 6″.	3′ 0″	Metre.	Metre.	Metre.	Metre.	3′ 6″	3′ 6″
Railway	Serbian State.	Manata Sugar Co.	Brazil Ry.	Chilean State Rys. *	Mogyana Rys. and Nav. Co.	Mogyana Rys. and Nav. Co. †	S. African Rys. ‡	Lourenço-Marquez Ry.
Builder	American Loco. Co.	Baldwin.	American Loco. and Henschel.	Henschel.	Baldwin.	American Loco. Co.	— Type MH.	American Loco. Co.
Date	1915.	—	1913–15.		—	—	—	—
Cylinders, diameter, H.P.	13″	14½″	16″		17″	16½″	20″	17½″
,, ,, L.P.	20¼″	22″	25¼″		26½″	26½″	31½″	28″
,, stroke	20″	20″	20″		22″	24″	26″	26″
Boiler, height of centre line	—	—	6′ 8⅜″		6′ 8⅜″	7′ 6¼″	7′ 10¼″	—
,, diameter	5′ 2″	4′ 2″	4′ 7¼″		5′ 0″	5′ 0″	5′ 10″	5′ 5¼″
,, pressure . lbs./sq. in.	200	200	200		200	200	200	200
Tubes, number	157	150	200	121 + 16	194	104–21	168–25	230
,, diameter	2¼″	2″	2″	5⅜″–2″	2¼″	5⅜″–2″	5½″–2″	2¼″
,, length	15′ 1½″	17′ 0″	17′ 0″	17′ 0″	21′ 0″	20′ 0″	22′ 0″	18′ 0″
Firebox, width	3′ 3¼″	3′ 10⅜″	3′ 4⅜″	4′ 4⅜″	4′ 7½″	4′ 4¼″	—	5′ 0″
,, length	8′ 8½″	6′ 0¼″	7′ 2¼″	7′ 2¼″	8′ 11¾″	8′ 6⅝″	—	15′ 5⅜″
Heating surface, firebox sq. ft.	95	86	113	113	142	131	250	125
,, ,, tubes ,,	1,236·5	1,329	1,770·5	1,412·1	2,386	587 + 1,216	2,961	2,422
,, ,, total ,,	1,331·5	1,415	1,883·5	1,525·1	2,528	1,934	3,211	2,547
Superheater ,,	None	None	None	310	None	506	618	None
Grate area ,,	23·1	25·6	32	32	41·6	36·9	53	40
Wheels, diameter	2′ 0″	2′ 0″	2′ 0½″		2′ 0½″	2′ 0½″	2′ 4½″	—
,, ,,	3′ 2″	3′ 5″	3′ 6″		3′ 9″	3′ 9″	4′ 0″	3′ 9½″
,, ,,	2′ 0″	2′ 0″	2′ 0½″		2′ 0½″	2′ 0½″	2′ 4½″	—
Wheelbase, rigid	7′ 6″	7′ 10″	8′ 0″		10′ 0″	8′ 4″	8′ 8″	8 4″
,, driving	22′ 6″	22′ 10″	23′ 2″		28′ 9″	—	26′ 7″	—
,, total	34′ 6″	35′ 2″	36′ 0″		42′ 9′	39′ 2″	43′ 7″	33′ 2″
,, loco. and tender	54′ 4¾″	57′ 3¼″	60′ 2″		66′ 4″	63′ 3″	70′ 10¼″	60′ 2¾″
Tractive force . lbs.	29,200 / 24,300	— / —	— / 29,400		46,800 / 39,000	51,700 / 53,750	53,750 (50%)	— / 46,600
Weight, adhesive ,,	103,000	123,900	131,000		161,100	156,000	101 tons 3 cwt.	177,000
,, in service ,,	126,000	140,300	157,000		189,800	185,000	128 tons 5 cwt.	195,000
Tender, weight ,,	—	69,700	96,000		90,200	93,900	51 tons 7 cwt.	99,200
,, wheels, diameter	2′ 2″	2′ 2″	2′ 4″		2′ 4″	—	2′ 9½″	—
,, water	2,500 U.S. galls.	3,500 U.S. galls.	4,000 U.S. galls.		4,500 U.S. galls.	4,000 U.S. galls.	4,250 imp. galls.	4,000 U.S. galls.
,, fuel	5 U.S. tons.	6 U.S. tons.	1,800 U.S.		2½ cords.	4 cords.	10 tons.	9 U.S. tons.

* Very similar locomotives have been supplied by Baldwin to the South Minas System and slightly different ones by the American Locomotive Co. to the Brazil Ry. (Sorocabana). Their tractive force is 31,000 lbs. and they weigh 161,500, of which 137,500 adhesive. South Minas tenders hold 4,500 galls. of water and 3½ cords of wood fuel; those of the Sorocabana 4,500 galls. and 2½ cords.

† Similar locomotives were also supplied to the Brazil Ry.

‡ Maximum height, 12 ft. 10 ins.; length, 79 ft. 5 ins.

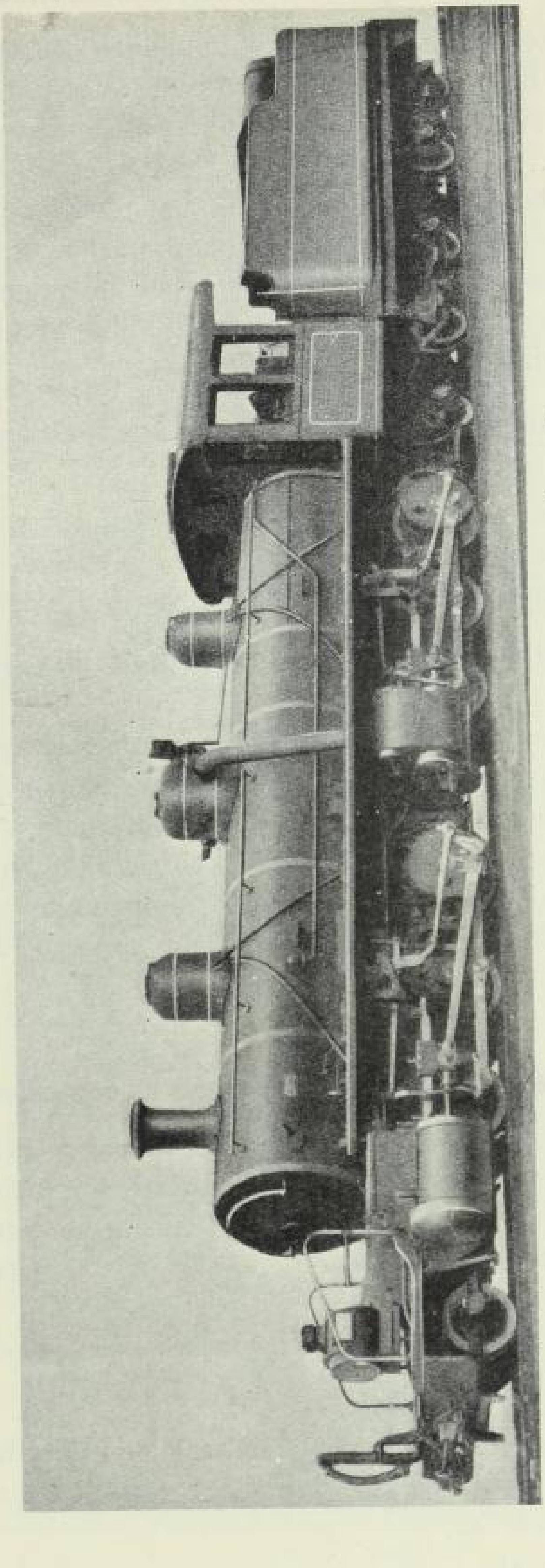


FIG. 154.—2-6 + 6-2 Mallet Locomotive, Serbian State Rys.
(2 ft. 6 ins. Gauge.)
Built by the American Locomotive Co.

Class Ha.—2-6 + 6-2 Mallet Locomotives

This is one of the most important classes of *Mallet* locomotives. It was first built by the Baldwin Works for the Great Northern Ry. (U.S.A.), in 1906. The adhesive weight, distributed over six axles, exceeded by 20 per cent. the adhesive weight of the standard gauge locomotives previously employed, and by 50 per cent. that of the previous narrow gauge locomotives. The bissels at each end gave the necessary guidance, whether running forward or backward. This fact explains the popularity of this wheel arrangement.

2-6 + 6-2 Mallets of the Serbian State Rys.—Gauge, 2 ft. 6 ins. (0m.76) (Fig. 154).

These were supplied, in 1915, by the American Locomotive Co. They are of great power for so small a gauge. They have outside bar frames and the firebox is provided with arch tubes.

2-6 + 6-2 Mallets of the South African Rys.—Gauge, 3 ft. 6 ins. (1m.067).

Before the amalgamation of the railway systems of South Africa, this type existed on the Central South African Ry. Its use has been maintained and extended. The latest examples have a load of 18 tons per driving axle, the maximum hitherto reached by *Mallet* locomotives on narrow gauge lines.

The comparative dimensions of all the types of *Mallets* used on these railways are given in Table 82.

Class Hb.—2-6 + 6-2 American Locomotives

This class was introduced on an American railway some twenty years ago; it is now supplanted by locomotives of greater power. Furthermore, recent improvements in rigid locomotives often enable them to be used instead of the 2-6 + 6-2 type.

Nevertheless, it is still to be found on less important lines of difficult profile.

2-6 + 6-2 Mallets of the Gt. Northern and Northern Pacific Rys.—Standard gauge (Fig. 156). See details, Figs. 120, 123, 124, 132, 133 and 135.

These locomotives are used as banking engines for

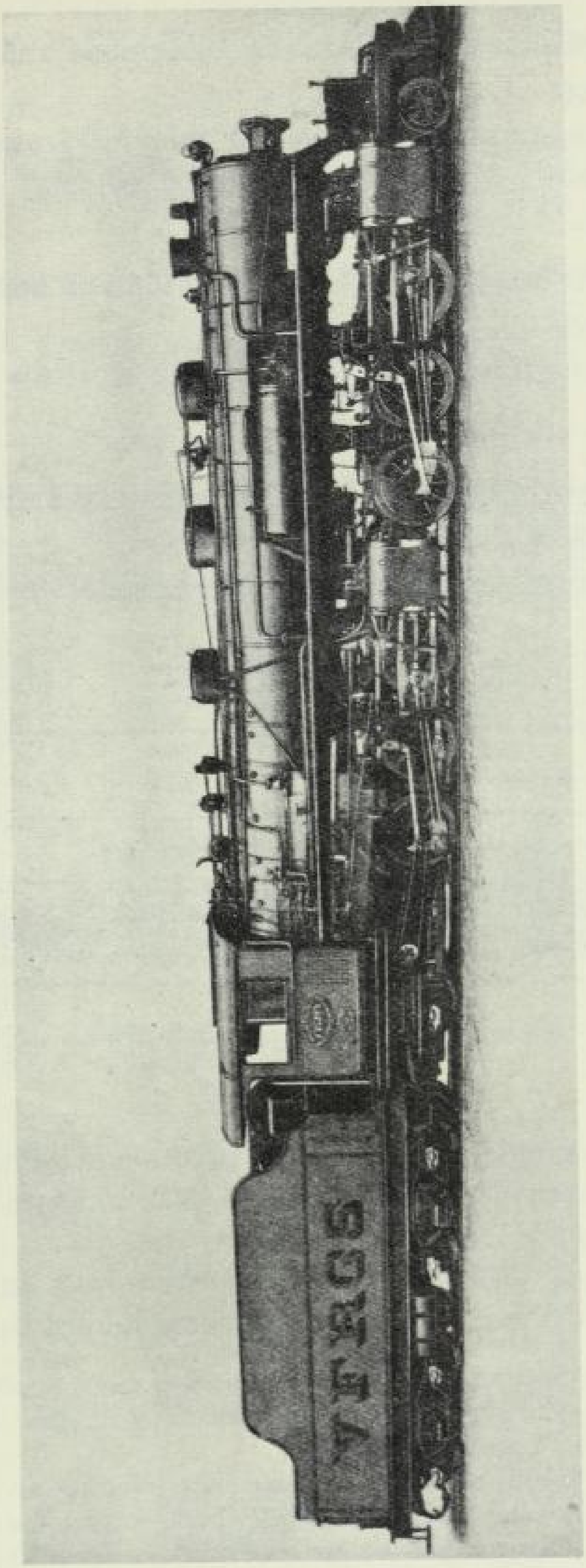


FIG. 155.—2-6 + 6-2 Mallet of the Rio Grande do Sul (Brazil) Ry. System. (Metre Gauge.)

freight trains drawn by Consolidation or Mikado locomotives.*

2-6 + 6-2 Mallets of the Carolina, Clinchfield and Ohio Ry.—Standard gauge.

These locomotives have handled mineral trains up 5 per cent. grades since 1909. They were fitted with reheaters in the smokebox.

2-6 + 6-2 Mallets of the Atchison, Topeka and Santa Fé Ry.—Standard gauge.

This company now possesses a number of these locomotives

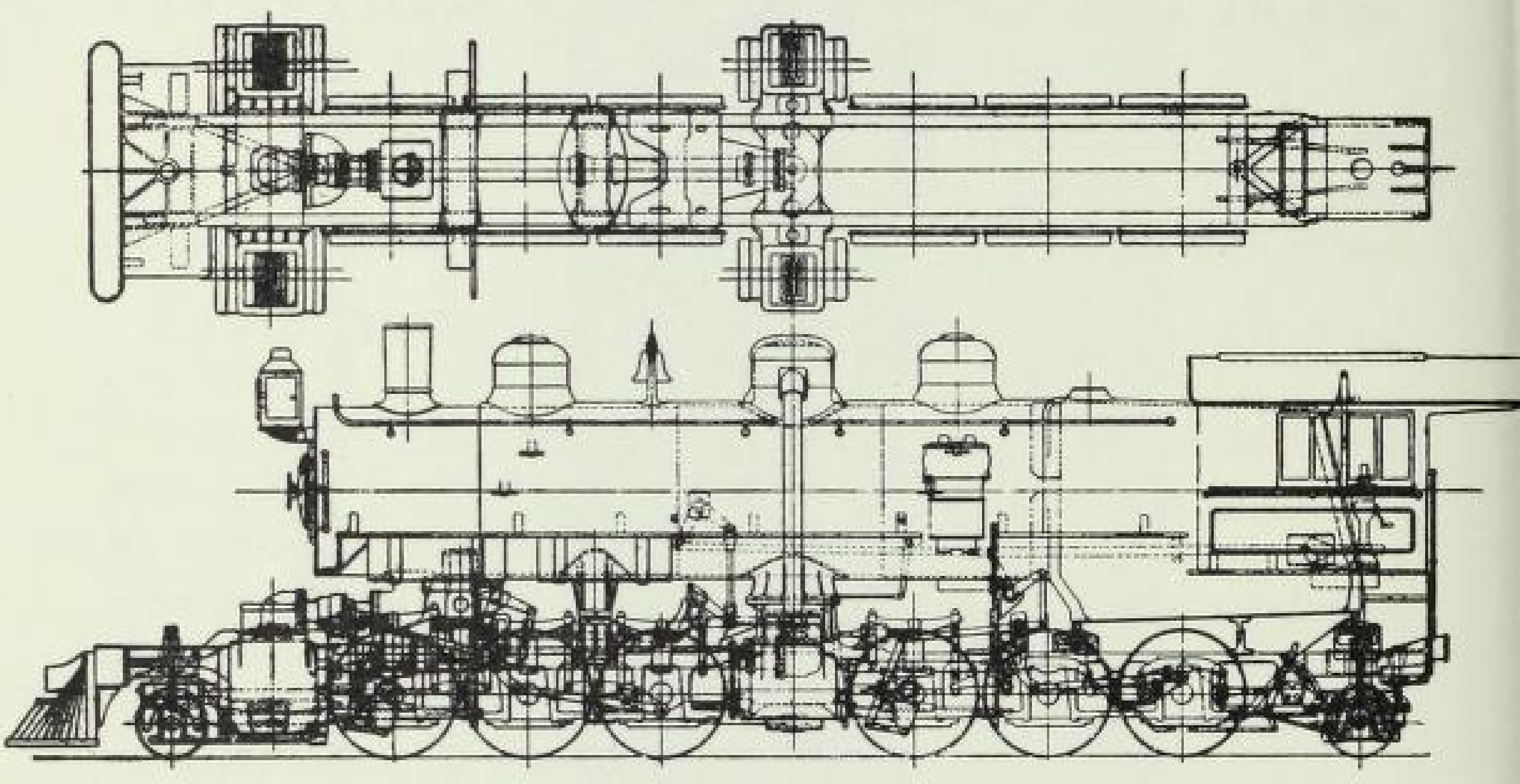


FIG. 156.—2-6 + 6-2 Baldwin Mallet Locomotive, built in 1906 for the Gt. Northern Ry. (U.S.A.).
(Standard Gauge.)

which were adopted after the satisfactory results obtained with the first four *Mallets* (two 4-4 + 6-2 and two 2-8 + 8-2) tried on the line.

In 1910, forty 2-6 + 6-2 *Mallets* were put into service. Twenty-eight of these had straight boilers, ten of them wagon-

* The first *Mallets* of the Gt. Northern Ry. gave good results. A second more powerful series was put in service, and later *Mallets* with eight coupled axles were introduced.

The Northern Pacific *Mallets* were used for banking on the division from Livingstone to the Bazeman Pass Tunnel, a distance of 12½ miles (20 km.), with a ruling grade of 2·2 per cent. and curves of 714 ft. (218 m.) radius. The train engine was a Consolidation or a Mikado. The share of the load taken by the *Mallet* was reckoned at about 770 tons.

TABLE 82.—PRINCIPAL DIMENSIONS OF 2-6+6-2 MALLET LOCOMOTIVES (STANDARD AND BROAD GAUGES)

Gauge / Railway / Builder / Date		Standard. Denver and Rio Grande R.R. American Loco. Co. —	Standard. Atchison, Topeka and Santa Fé. Baldwin. 1909.	Standard. Atchison, Topeka and Santa Fé. Baldwin. (With articulated boiler.) 1909.	Standard. Norfolk and Western Ry. Baldwin. —	Standard. U.S. Ry. Administration.* Baldwin. 1918.	Standard. Chesapeake and Ohio R.R. American Loco. Co. 1910.	5 ft. 6 ins. North-Western Ry. (India). Baldwin. 1924.
Cylinders, diameter, H.P.		20½″	24″	—	22″	23″	22″	19″
,, ,, L.P.		33″	38″	—	35″	35″	35″	29¾″
,, stroke		32″	28″	—	32″	32″	32″	30″
Boiler, height of centre line		—	8′ 11″	—	10′ 0¼″	—	12′ 7¾″	—
,, diameter		6′ 9¾″	5′ 10″	—	6′ 11⅞″	7′ 6″	7′ 3⅞″	6′ 0″
,, pressure	lbs./sq. in.	210	220	200	200	225	225	210
Tubes, number		395	29–340	294–322	26–224	45–247	36–244	35–217
,, diameter		2″	2¼″	—	5½″–2¼″	5½″–2¼″	5½″–2¼″	5⅜″–2″
,, length		19′ 0″	19′ 7″ & 7′ 8″	19′ 7″ & 9′ 10″	24′ 0″	24′ 0″	24′ 0″	18′ 0″
Firebox, width		5′ 5¼″	6′ 4¼″	—	8′ 0¼″	8′ 0¼″	8′ 0⅛″	6′ 3″
,, length		10′ 0⅛″	9′ 11⅛″	—	9′ 0½″	9′ 6⅜″	9′ 0⅛″	12′ 0″
Heating surface, firebox	sq. ft.	250	237	234	212+134	227+155	344	233
,, ,, tubes	,,	3,894	3,390 + 1,533	3,376 + 1,893	4,396	5,027	4,674	2,910
,, ,, arch-tubes	,,	—	16	—	29	34	23	33
,, ,, total	,,	4,144	5,176	3,610	4,771	5,443	5,041	3,176
Superheater	,,	—	318+637	390+719	1,022	1,260	911	708
Grate area	,,	54·4	63	52·5	72	76·3	72	56·3
Wheels, diameter		—	2′ 7¼″ & 3′ 4″	—	2 8″ & 3′ 8″	2′ 6″ & 3′ 7″	2′ 6″ & 3′ 8″	2′ 4″
,, ,,		4 9″	5′ 9″	—	4′ 8″	4′ 9″	4′ 8″	4′ 4″
Wheelbase, rigid		10′ 0″	13′ 8″	—	10′ 0″	10′ 6″	10′ 0″	10′ 0″
,, driving		—	37′ 10″	—	30′ 6″	31′ 0″	30′ 6″	28′ 10″
,, total		46′ 4″	56′ 5″	—	48′ 10″	49′ 9″	48′ 10″	44′ 4″
,, locomotive and tender		74′ 6¼″	89′ 3″	—	79′ 2½″	89′ 5″	80′ 9¼″	72′ 8¼″
Overall height		—	15′ 6″	—	15′ 6″	—	12′ 5 7/16″	13′ 5½″
,, width		—	—	—	10′ 8″	—	—	—
,, length		—	71′ 6½″	—	88′ 1½″	—	60′ 8¼″	82′ 10¼″
Tractive force	lbs.	66,600	—	61,500	67,500	—	82,000	—
Weight, adhesive	,,	291,500	319,000	317300	341,000	358,000	337,000	235,000
,, in service	,,	335,000	390,200	392,200	411,700	448,000	400,000	274,500
Tender, weight	,,	152,000	174,800	169,700	159,300	214,000	163,000	147 500
,, water	U.S. galls.	8,000	9,000	—	9,000	12,000	9,000	6,300
,, fuel	U.S. tons.	12	12	—	14	16	15	8·9
,, wheels, diameter		2′ 9″	2′ 10½″	—	2′ 9″	2′ 9″	2′ 9″	2′ 9″

* These standard locomotives were apportioned to the Wheeling and Lake Erie R.R.

top boilers and two locomotives were furnished experimentally with articulated boilers (Figs. 169 to 173), the articulation being effected, in one case, by a bellows piece, in the other by a universal joint ring.

A further batch of twenty *Mallets* followed, and the fleet was completed by the conversion of some Prairie locomotives to *Mallets*, the work being carried out in the company's own shops at Topeka.

The boilers of these locomotives had a separate joint. They were fitted with Jacobs-Schupert fireboxes similar to those of the 1909 *Mallets* (Figs. 129, 130). The front section of the boiler barrel contained immediately behind the smokebox a feed-water heater, consisting of a tubular assemblage. It also contained H.P. and L.P. superheaters of the Bucks-Jacobs type, with combustion chambers on either side. These superheaters have the same set of tubes separated by a tube sheet, into which they were expanded.*

Experience has shown that in wagon-top boilers it is desirable that the steam should be taken from a position as near the firebox as possible. As it was found desirable to make the connection between the steam dome and the H.P. superheater by an external pipe, these locomotives were provided with two domes.

Besides these, an auxiliary dome is provided for the safety valves and steam whistle.

The path of the steam is therefore as follows : it passes first into the rear dome ; it leaves this dome (first traversing a perforated plate, which serves as a steam separator) by two 5-in. (0m.127) pipes, which lead to the front dome. A single pipe from the front dome runs outside at the top of the boiler to a point just beyond the separable joint between the two halves of the boiler, and thence the steam is led into the top of the H.P. superheater. Two pipes lead from the bottom of the superheater to the H.P. cylinders.

The steam from the H.P. cylinders reaches the receiver through two pipes located in the L.P. superheater. The

* The feed-water heater has 340 tubes, $2\frac{1}{4}$ ins. (57 mm.) diameter, and 7 ft. 8 ins. (2m.34) in length. Its heating surface is 1·516 sq. ft. (140·8 sq. m.).

The surface of the H.P. superheater is 300 sq. ft. (28·9 sq. m.), and of the L.P. superheater 650 sq. ft. (60·4 sq. m.).

receiver is provided with a universal joint, and thus the steam reaches the L.P. cylinders. The exhaust from these cylinders passes to the blast pipe through ordinary joints.

2-6 + 6-2 Mallets of the Chicago, Burlington and Quincy R.R. —Standard gauge.

The first of these was introduced in 1908. A new type was put into service in 1910. It had a separable boiler, an "Emerson" H.P. superheater in the rear section, a L.P. superheater in the front section and an exceptionally large reheater of 2,175 sq. ft. (202 sq. m.) surface. These locomotives burnt lignite.

The superheater tubes are grouped in a flue which passes through it.

2-6 + 6-2 Mallets of the Southern Pacific Ry.—Standard gauge.

In the year 1910, this company put into service some 2-8 + 8-2 locomotives for passenger and some 2-6 + 6-2 for freight service. The latter had a separable boiler containing a feed-water heater, but no reheater. To give better protection to the receiver pipe, it was led through a flue which traversed the feed heater.

These locomotives, which replaced two Ten-wheels were oil-fired. They could therefore run cab foremost, the tender being attached to the smoke-box end. This arrangement gives the driver a better view of the road, and has been retained in later classes. The semi-cylindrical tender is carried in two six-wheeled bogies.

2-6 + 6-2 Mallets of the Missouri, Oklahoma and Gulf R.R. —Standard gauge.

We have here an interesting example of the substitution of articulated for rigid locomotives in order to distribute the weight over a large number of axles. These *Mallets* run on weak tracks laid with 70-lb. (35 kilos) rails. Their tractive force is equivalent to that of the Consolidation or Mikado locomotives which run on 100-lb. (50 kilos) rails.

2-6 + 6-2 Mallets of the United States Railway Administration.—Standard gauge.

In 1918, this administration fixed the specification of several standard locomotive types, notably *Mallets* with six and others with eight driven axles, and a load of 26 tons 11 cwt. (27 tonnes) per axle. The locomotives, of which dimensions are given in Table 68, were allocated to the Wheeling and Lake Erie Ry.

2-6 + 6-2 Mallets of the Norfolk and Western Ry.—Standard gauge.

These replaced Twelve-wheels and Consolidation rigid locomotives. Their rigid wheelbase is very short, being only 10 ft. (3m.05).

2-6 + 6-2 Mallets of the Denver and Rio Grande R.R.—Standard gauge.

The main line of this railway has a ruling gradient of 1 per cent. up to Thistle. Beyond that station there are banks of 4 per cent. and curves of 525 ft. (161 m.) radius until the summit level of the line is reached. Originally the trains were headed by one or two Consolidations, two more of these locomotives being used as helpers on the heavy grades.

A single *Mallet* replaced the two Consolidations.*

2-6 + 6-2 Mallets of the North-Western Ry. (India).—Gauge, 5 ft. 6 ins. (1·67 m.) (Fig. 157).

This railway administration obtained these *Mallets* † in 1924

* In 1912, fourteen trains a day were handled, corresponding to a total of 8,600 tons approximately. The trains consisted of 105 loaded wagons or 195 empties. Thirty-seven locomotives were needed for this service.

In 1913, the introduction of the *Mallets* enabled the same total tonnage to be dealt with in thirteen trains only, and the number of locomotives in service was reduced to twenty-five, of which eight were *Mallets*.

† They were to operate on the 4 per cent. grades of the Bolan Pass, on the line from Sibi to Kolpur, where they were to haul 640-ton trains and to replace two rigid locomotives previously used on each train between Mach and Kolpur, where the heavy gradients occurred. This tonnage constituted exactly half a military unit.

Though the limitation of the axle load to a maximum of 18 tons prevented the builders from designing a locomotive having more than 160 per cent. of the tractive effort of the previous rigid locomotives, the freer steaming of the *Mallets* enabled them to deal with double the rating of the former types.

A *Mallet* hauls 640 tons from Sibi to Abigum over 1 in 55 grades.

It has a helper on to Mach, there being 3 per cent. grades.

It has two helpers from Mach to Kolpur over the 4 per cent. grades.

This saves the mileage of one locomotive over the entire section.

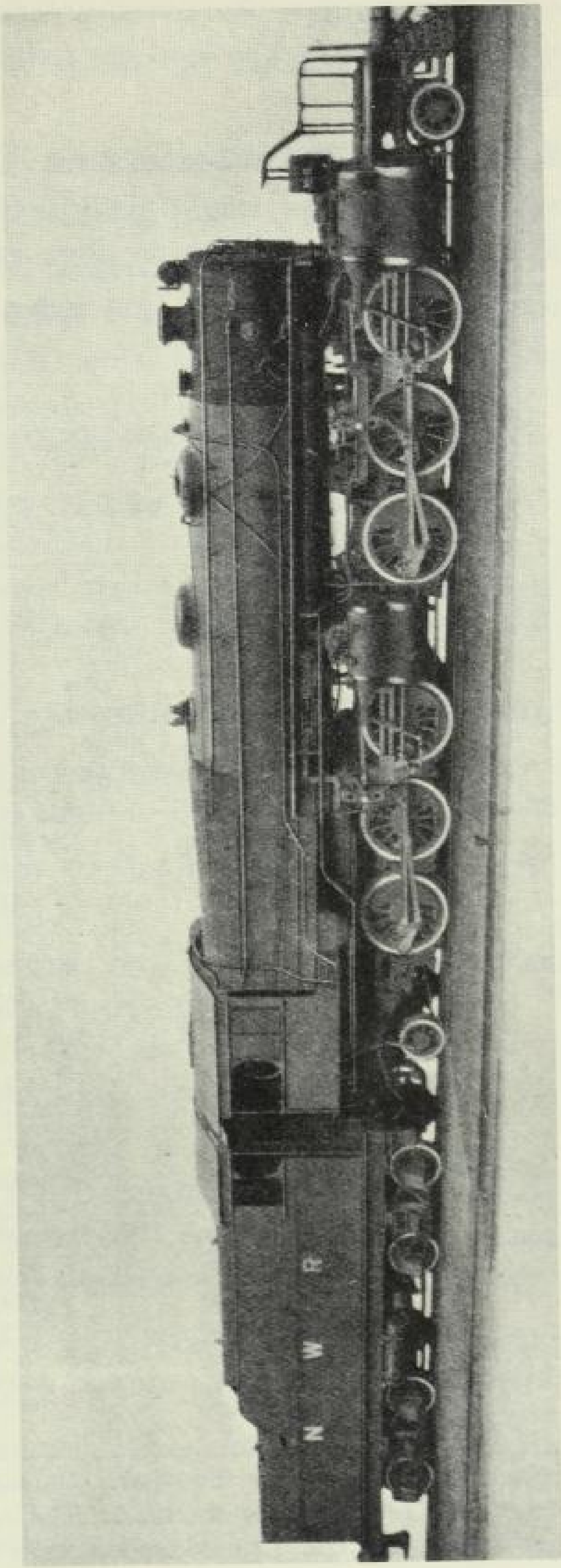


FIG. 157.—2-6 + 6-2 Mallet of the North Western Ry. (British India).
(Broad Gauge, 5 ft. 6 ins.)
Built by the Baldwin Locomotive Works.

in order to compare their performances with those of *Garratt* locomotives. They follow ordinary American practice, except that they have copper fireboxes. The load per axle is 17 tons 10 cwt. (17·8 tonnes).

Class I.—2-6 + 8-0 Mallet Locomotives

This design necessitates that the weight shall be distributed between the two groups, so that the tractive force exerted by

TABLE 83.—PRINCIPAL DIMENSIONS OF 2-6 + 8-0 MALLET LOCOMOTIVES

Gauge	Standard.	Standard.
Railway	Southern (U.S.A.) and Alabama Gt. Southern.	Gt. Northern Ry. (U.S.A.).
Builder	Baldwin.	Baldwin.
Cylinders, diameter, H.P.	23″	
,, ,, L.P.	35″	
,, stroke	32″	
Boiler, diameter	7′ 0″	
,, pressure . lbs./sq. in.	200	
Firebox, width	8′ 0″	
,, length	9′ 9″	
Tubes, number	437	32–275
,, diameter	2¼″	5″–2¼″
,, length	21′ 0″	15′ 0″
Heating surface, firebox sq. ft.	221*	225
,, ,, tubes ,,	5,380	3,038 + 1,777†
,, ,, total ,,	5,601	5,040
Superheater ,,	638	480
Grate area ,,	78	78
Wheels, diameter	2′ 6″	2′ 6″
,, ,,	4′ 8″	4′ 7″
Wheelbase, rigid	10′ 0″ & 15′ 0″	10′ 0″ & 15′ 0″
,, driving	34′ 5″	35′ 0″
,, total	43′ 4″	43′ 11″
,, loco. and tender	71′ 6½″	76′ 2½″
Weight, adhesive . lbs.	332,700	359,600
,, in service ,,	363,500	378,300
,, tender ,,	171,500	147,700
Tender, wheels	2′ 9″	3′ 0½″
,, water . U.S. galls.	9,000	8,000
,, fuel . U.S. tons	13	13

* These heating surfaces are those of the Southern Ry. locos. The corresponding figures for the Alabama Gt. Southern R.R. locos. are slightly different. Both types have Baldwin smokebox superheaters.

† These locos. have Emerson superheaters. The second figure quoted is the tube surface of the feed-water heater.

the cylinders driving them shall be in proportion to the adhesive weight of each group.

2-6 + 8-0 Mallets of the Southern Ry. (U.S.A.).—Standard gauge.

These have a reheater in the smokebox. The frames are of vanadium alloy steel.*

2-6 + 8-0 Mallets of the Gt. Northern Ry. (U.S.A.).—Standard gauge.

The boiler contains an Emerson superheater in the tubes. In the front part of the barrel is a feed-water heater, which traverses a large flue containing the receiver pipe.

2-6 + 8-0 Mallets of the Alabama Gt. Southern R.R.—Standard gauge.

These work on a section with 1·3 per cent. gradients. They are fitted with L.P. superheaters placed in the smokebox.

Class J.—0-8 + 8-0 Mallet Locomotives

On a number of railway systems, this type has succeeded and superseded the 0-6 + 6-0 type previously employed.

0-8 + 8-0 Locomotives of the Baltimore and Ohio R.R.—Standard gauge.

On this line, the *Mallets* are used as banking engines on a succession of heavy gradients.

The boiler contains a superheater in the tubes. The firebox is extended by a combustion chamber 3 ft. 3⅜ ins. (1 m.) in length.

0-8 + 8-0 Locomotives of the Erie R.R.—Standard gauge (Figs. 158 and 159).

These locomotives appeared in 1907 after 0-6 + 6-0 *Mallets*

* These locos. are used on a section 6¼ miles (10 km.) in length east of Newburg, and another 11¾ miles (19 km.) long between Rowlesburg and Cranberry. The ruling gradients on these sections are 2·3 per cent. and 2·2 per cent. respectively, and the curves are of 475 ft. (145 m.) radius. The train load is 1,560 tons approximately, of which the Consolidation train engine takes 420 tons and the *Mallet* at the rear deals with the balance.

Table 84.—Principal Dimensions of 0-8 + 8-0 Mallet Locomotives

Gauge / Railway / Builder	Standard. Delaware and Hudson. American Loco. Co.	Standard. Norfolk and Western. American Loco. Co.	Standard. Erie R.R. American Loco. Co.	Standard. Pennsylvania R.R. Baldwin.	Standard. Pennsylvania R.R. Baldwin.	5' 3". Central of Brazil. American Loco. Co.
Cylinders, diameter, H.P.	26"	24½"	25"	25"	26"	20"
,, ,, L.P.	41"	39"	39"	39"	40"	32"
,, stroke	28"	30"	28"	30"	28"	26"
Boiler, height of centre line	10' 0"	10' 0"	10' 0"	10' 6"	—	—
,, diameter	7' 6"	6' 11⅞" (ext.)	7' 0"	6' 10¼"	7' 2⅛"	6' "
,, pressure . . . lbs. per sq. in.	220	200	215	205	225	220
Tubes, number	446	367	404	36–259 + 144	52–209 + 208	350
,, diameter	2¼"	2¼"	2¼"	5½"–2¼"–1½"	5½"–2½"–1½"	2
,, length	24' 0"	24' 0"	21' 0"	22' 11"	21' 10"	20' 0"
Firebox, width	9' 6"	7' 4¼"	9' 6"	8' 0"	8' 0¼"	5' 6¼"
,, length	10' 6⅛"	10' 0⅛"	10' 6⅛"	9' 9"	12' 0⅛"	12' 0⅛"
Heating surface, firebox . . . sq. ft.	353	200	342	237	278	176
,, ,, arch tubes . . . ,,	—	—	—	32	42	32
,, ,, tubes . . . ,,	6,276	5,188	4,971	4,684	4,635	3,652
,, ,, total . . . ,,	6,629	5,388	5,313	4,953	5,013	3,860
Superheater . . . ,,	—	—	—	988	1,379	—
Grate area . . . ,,	100	75	100	78	96·3	51·8
Wheels, diameter	4' 3"	4' 8"	4' 3"	4' 8"	4' 3"	4' 2½"
Wheelbase, rigid	14' 9"	15' 6"	14' 3"	15' 0"	14' 9"	13' 6"
,, total	40' 2"	41' 2"	39' 2"	39' 6"	40' 1½"	36' 8"
,, locomotive and tender	75' 7½"	72' 10"	70' 5¼"	71' 10¼"	78' 8¾"	64' 3¼"
Overall, height	16' 0"	15' 5⅜"	15' 5¾"	15' 3"	—	13' 8½"
,, width	11' 4"	10' 9"	11' 0"	10" 8"	—	10' 10"
,, length	90' 6⅝"	88' 11¾"	114' 0¼"	87' 6¾"	—	78' 7"
Tractive force . . . lbs.	106,000	85,000 102,000	94,000 120,000	82,200	99,792	60,400
Weight in service . . . lbs.	445,000	376,800	410,000	408,700	458,100	279,500
Tender, wheels, diameter	—	2' 9"	2' 9"	2' 9"	2' 9"	2' 9"
,, water . . . U.S. galls.	9,000	9,000	8,500	9,000	9,600	4,500
,, fuel . . . U.S. tons	14	14	16	17·5	20	8½
,, weight in service . . . lbs.	166,800	146,700	167,700	186,300	206,100	100,800

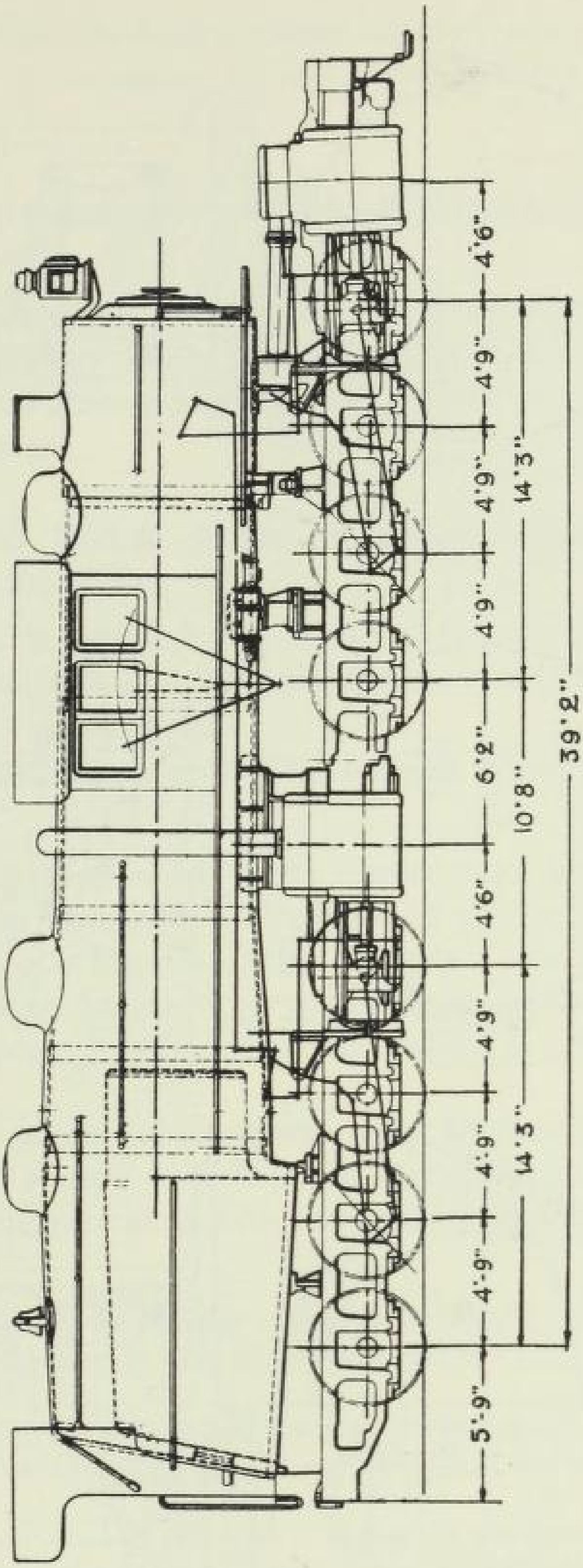


Fig. 158.—0-8 + 8-0 Mallet Locomotive, Erie R.R.
(Standard Gauge.)
Built by the American Locomotive Co.

had been in use some time. They had Wootten fireboxes with combustion chambers 4 ft. (1·22 m.) in length. The total heating surface being thus reduced, it had to be supplemented

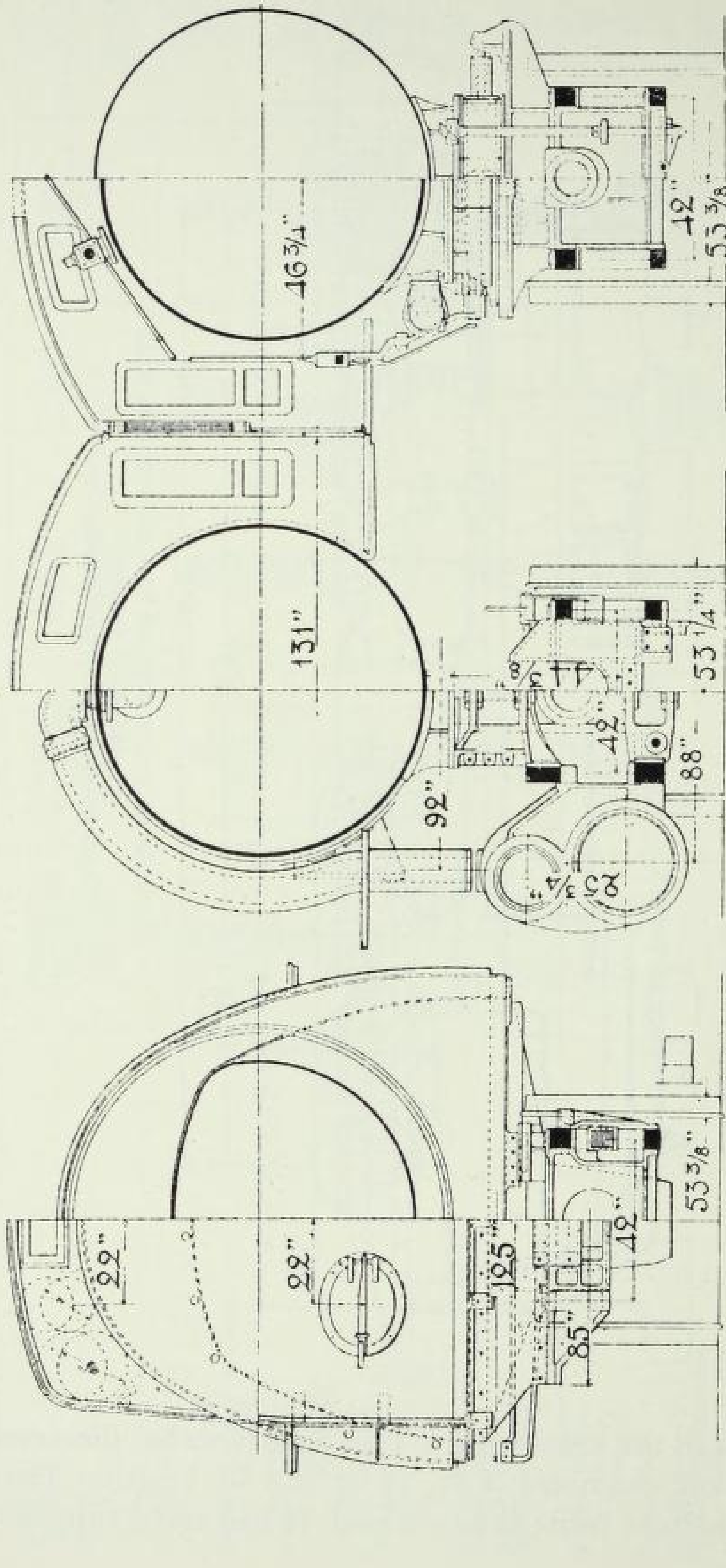


FIG. 159.—Erie R.R. 0-8 + 8-0 Mallet. Cross Sections.

by lengthening the boiler, which entailed an increase of weight. This made it necessary to add a coupled axle to each wheel group.*

0-8 + 8-0 Locomotives of the Central of Brazil Ry.—5 ft. 3 ins. gauge (1m.60).

These locomotives are similar to the Baltimore and Ohio's. The 1911 *Mallets* dealt with trains of 950 tons approximate on the Serra do Mar section.† Their predecessors only handled 500-ton trains.

0-8 + 8-0 Mallets of the Delaware and Hudson R.R.—Standard gauge (Fig. 160).

These each replaced two Consolidations in banking service.‡ They have a 4 ft. (1m.22) combustion chamber.

0-8 + 8-0 Mallets of the Norfolk and Western Ry.—Standard gauge.

The introduction of these locomotives brought about the abolition of double heading on a 2 per cent. incline, where previously one Twelve-wheels and one Consolidation had been used for each train. This resulted in a coal economy of 36 per cent. per ton mile. The load drawn is 1,050 tons approximate.

At the time when they were introduced, these locos. (No. 2,600 *et seq.*) were the most powerful in the world. The boilers were provided with combustion chambers.

* These locomotives were allocated to banking service on the section from Susquehanna to Gulf Summit, where the ruling gradient is 1·3 per cent.

† The difficult section lies between Belem (near Rio) and Barra de Pirahy. The gradients are 1·8 per cent. and the curves 600 ft. radius (181 m.).

‡ They are used on 95 miles (153 km.) of the line from Jefferson City, which carries the mineral traffic from Carbondale (Pa.) to Oneonta (N.Y.). From Carbondale to Forest City, a distance of 6¼ miles (10 km.) the ruling gradient is 1·4 per cent. Thence to the summit level at Ararat, a distance of 14¼ miles (23 km.), it is 8 per cent. The remaining 74½ miles (120 km.) to Oneonta is an almost continuous descent of 1 per cent.

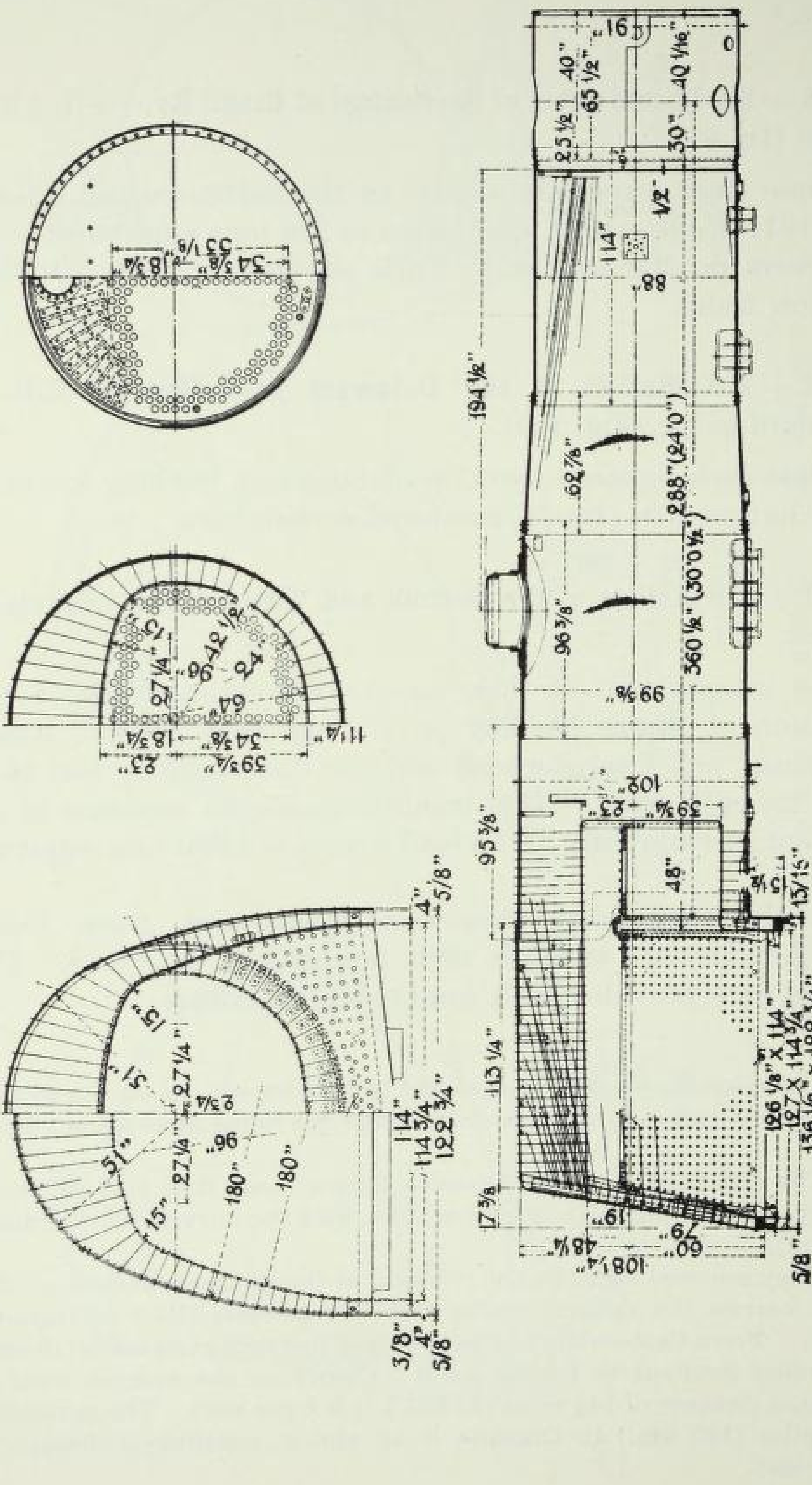


FIG. 160.—0-8 + 8-0 Mallet of the Delaware and Hudson R.R. Cross Sections of Boiler.

0-8 + 8-0 Mallets of the New York Central Lines.—Standard gauge.

These big locos. are employed on heavy shunting service.*

0-8 + 8-0 Mallets of the Birmingham and Garfield Ry.—Standard gauge.

These were introduced in 1912 for banking service. They made on an average four to six round trips per day. On the upward journey they drew a train of empties weighing 1,420 tons approximate in one hour fifty-eight minutes. The load on the downward journey was 2,350 tons and the time one hour forty minutes.

The coal consumption was 5 tons 4 cwt. per round trip, *i.e.*, 209 lbs. per ton-mile (1·065 kg. per tonne-kilometre). The water consumption was 9,000 gallons (34 cub. m.), *i.e.*, 0·138 lbs. per ton-mile (1·043 litres per tonne-kilometre).†

0-8 + 8-0 Mallets of the Pennsylvania R.R.—These locos., which were built in 1913, are excellent examples of this class of *Mallet*, although types with pony trucks are now preferred on this railway.

In Table 85 the chief dimensions are given of the principal types of *Mallets* used by the *Pennsylvania*, namely, the 0-8 + 8-0 compounds, some experimental 2-8 + 8-2 locos. with

* Their chief dimensions are as follows :—

Weight	466,000 lbs. (211·4 tonnes).
Wheels, diameter . .	4 ft. 3 ins. (1m.30).
Boiler pressure . .	220 lbs. (15·5 kg.).
Cylinder, diameter, H.P. .	26 ins. (0·66 m.).
Cylinder, diameter, L.P. .	40 ins. (1·02 m.).
Cylinder, stroke . .	28 ins. (0·71 m.).
Tractive force . .	100,500 lbs. (45·4 tonnes).

† The ruling gradient is $2\frac{1}{2}$ per cent. The line rises from 4,200 ft. (1·280 m.) to 6,250 ft. (1·905 m.) in a distance of 20 miles (32 km.).

The chief dimensions of these locomotives are as follows :—

Cylinders, diameter, H.P.	26 ins. (0·66 m.).
Cylinders, diameter, L.P.	41 ins. (1·05 m.).
Cylinders, stroke . .	28 ins. (0·71 m.).
Boiler pressure . .	220 lbs. (15·5 kg.).
Wheels, diameter . .	4 ft. 3 ins. (1·30 m.).
Weight	457,000 lbs. (207·3 tonnes).
Tractive force . . .	105,500 ,, (47·9 tonnes).

Table 85.—Principal Dimensions of 2-8 + 8-0 Mallet Locomotives

Gauge	3 ft. 6 ins.	3 ft. 6 ins.	Standard	Standard.	Standard.
Railways	Java State Rys.	Java State Rys.	Pennsylvania R.R.	Gt. Northern (U.S.A.) Ry.	B. & O., Utah R.
Builder	American Loco. Co.	Hanover Co.	Railway Workshops.	Baldwin.	Baldwin.
Date	1922	1924.	1919.	1913.	—
Cyl.: Diam., H.P.	17½″	17¾″	30½″*	28″	28″
,, L.P.	26½″	27 9/16″	—	42″	41″
,, Stroke	24″	24″	32″	32″	32″
Boiler:	8′ 0″	8′ 0″	—	—	10′ 1″
Diameter	5′ 4 11/16″	5′ 6¼″	8′ 0″	7′ 6″	7′ 6″
Pressure lbs./sq.in.	200	200	205	210	210
Tubes, number	24–157	24–142	137–284–168	42–232	48–269
,, diameter	5⅜″–2″	5″–2 3/16″	5½″–1⅛″–2¼″	5½″–2¼″	5½″–2¼″
,, length	19′ 0″	19′ 0″	19′ 0″	24′ 0″	24′ 0″
Firebox, width	4′ 11¾″	—	8′ 0″	8′ 0¼″	8′ 0″
,, length	8′ 11¾″	—	14′ 0″	9′ 9¼″	11′ 0¼″
Heating surface:					
Firebox sq. ft.	139	128	531	245	228
Arch tubes ,,	13	—	—	—	35
Comb. chamber ,,	—	—	—	81	113
Tubes ,,	1,549 + 636	1,960	6,125	6,126	5,443
Total ,,	2,337	2,088	6,656	6,446	5,819
Superheater ,,	—	697	3,136	1,366	1,415
Grate area ,,	44·7	44	112	78·4	88·2
Wheels, diameter	2′ 6″	2′ 6⅜″	2′ 9″	2′ 9½″	2′ 9″
,, ,,	3′ 7⅜″	3′ 7⅜″	5′ 2″	5′ 3″	4′ 10″
Wheelbase:					
Rigid	11′ 9″	11′ 9¾″	17′ 1½″	16′ 6″	15′ 6″
Driving	—	31′ 1″	45′ 2½″	45′ 3″	41′ 2″
Total	37′ 11″	38′ 3″	54′ 8½″	52′ 6″	50′ 4″
Loco. and tender	—	—	97′ 3¾″	83′ 1″	87′ 5¼″
Overall, height	12′ 2½″	12′ 1¾″	16′ 0″	—	15′ 6″
,, width	9′ 10″	9′ 9¾″		—	11′ 4″
,, length	69′ 9¼″	68′ 11″	—	—	98′ 0¼″
Tractive force lbs.	40,000	33,500	—	—	95,000
,, ,, ,,	48,000	42,000	135,000	—	—
Weight, adhesive ,,	184,000	195,000	540,000	420,000	459,400
In service ,,	206,500	212,000	575,000	450,000	484,400
Tender:					
Wheels, diameter	2′ 6⅛″	2′ 6⅛″	2′ 9″	3′ 0″	2′ 9″
Water U.S. galls.	4,500	4,900	12,900	8,000	12,000
Fuel . U.S. tons	8	9	13·9	13	20
Wt. in serv. lbs.	96,000	95,800	219,000	150,000	109,600

* These are four-cylinder simple locomotives.

four simple admission cylinders and some 2-8 + 8-0 four-cylinder simple *Mallets* put into service in 1919.

All these locos. have Schmidt superheaters in the tubes, and cylinders with piston valves. The continuous increase in the heating surface is noteworthy.

The first, the 0-8 + 8-0 type, were allocated to shunting service and to banking on some important sections with 2·1 per cent. grades and 16-degree curves. The wheels of the second and third axles have no flanges. But on the latest locos. of this type, destined to work on sections with 5 per cent. gradients, the use of flangeless wheels has been discontinued.

Owing to their large size, the L.P. cylinders are inclined at an angle of 1 in 35 with the horizontal.

It is remarkable to find locomotives capable of exerting a tractive force of 90,450 lbs. (45 tonnes) employed as switchers.

Class K.—2-8 + 8-0 Mallet Locomotives

These are a transitional type. They are, in effect, 0-8 + 8-0 locos. with a leading bissel added. From this it is a natural step to provide a trailing bissel as well. Hence, not many 2-8 + 8-0 *Mallets* have been built.

2-8 + 8-0 Mallets of the Gt. Northern Ry. (U.S.A.).—Standard gauge.

From its first adoption of the *Mallet* loco., this railway has continually increased its power. But, unlike some others, it has effected this increase in gradual steps.

The first series of 2-6 + 6-2 locos. were allocated to banking service.* They were followed in 1907 by another series of the same type, for main line traffic. †

* The "pushers" are used on the ascent from Leavenworth to the Mount Cascade tunnel, a distance of 32¼ miles (52 km.), with 2·2 per cent. grades and curves of 600 ft. (181 m.) radius. The trains weighed 1,070 tons approximately. The train engines used are Consolidations. The share of the load taken by the *Mallets* is 710 tons approximately.

The economy in coal was claimed to reach 46 per cent. per ton-mile.

† The new *Mallets* work on a section from Leavenworth to Spokane, a distance of 197 miles (317 km.). The ruling gradient is 1 per cent. The weight of the trains is 1,290 tons approximately.

The economy in fuel was stated to be 31 per cent. per ton-mile.

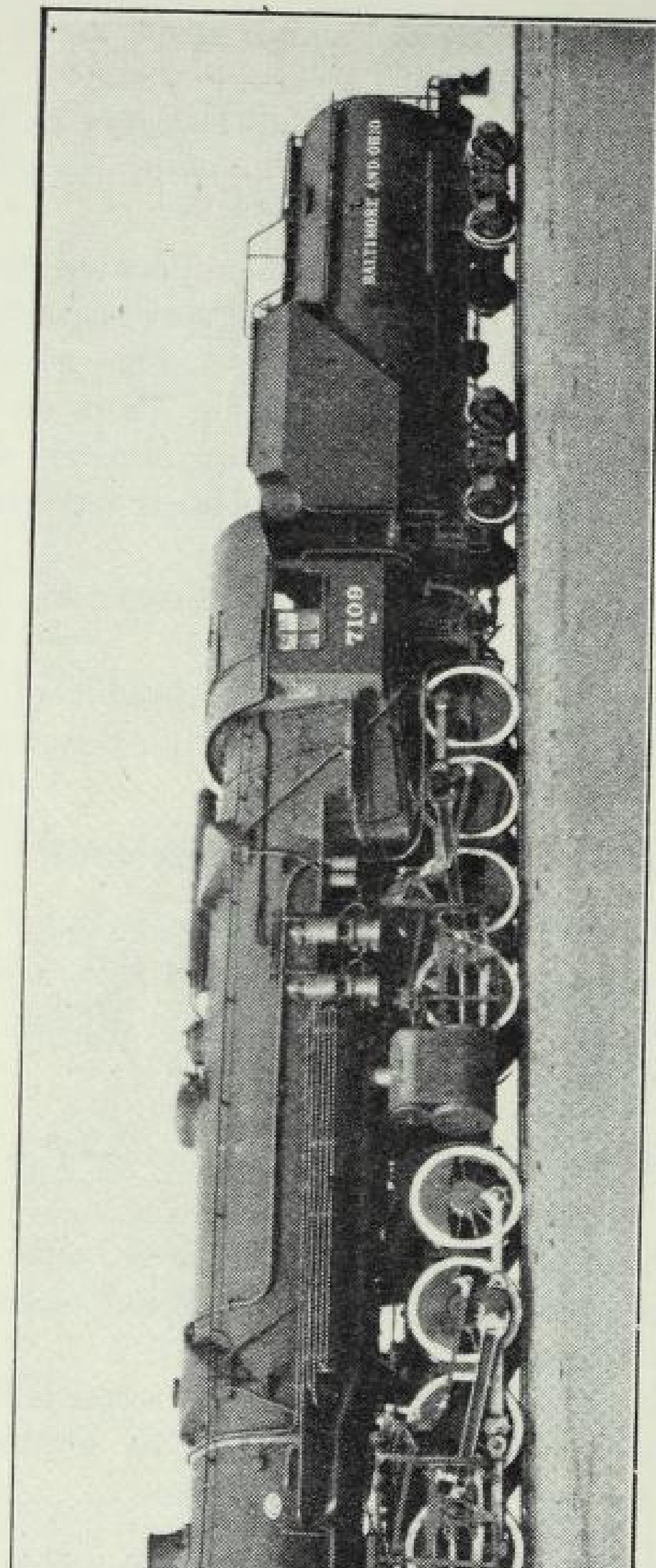


Fig. 161.—2-8 + 8-0 Mallet Locomotive, Baltimore and Ohio R.R.
(Standard Gauge.)
Built by the American Locomotive Co.

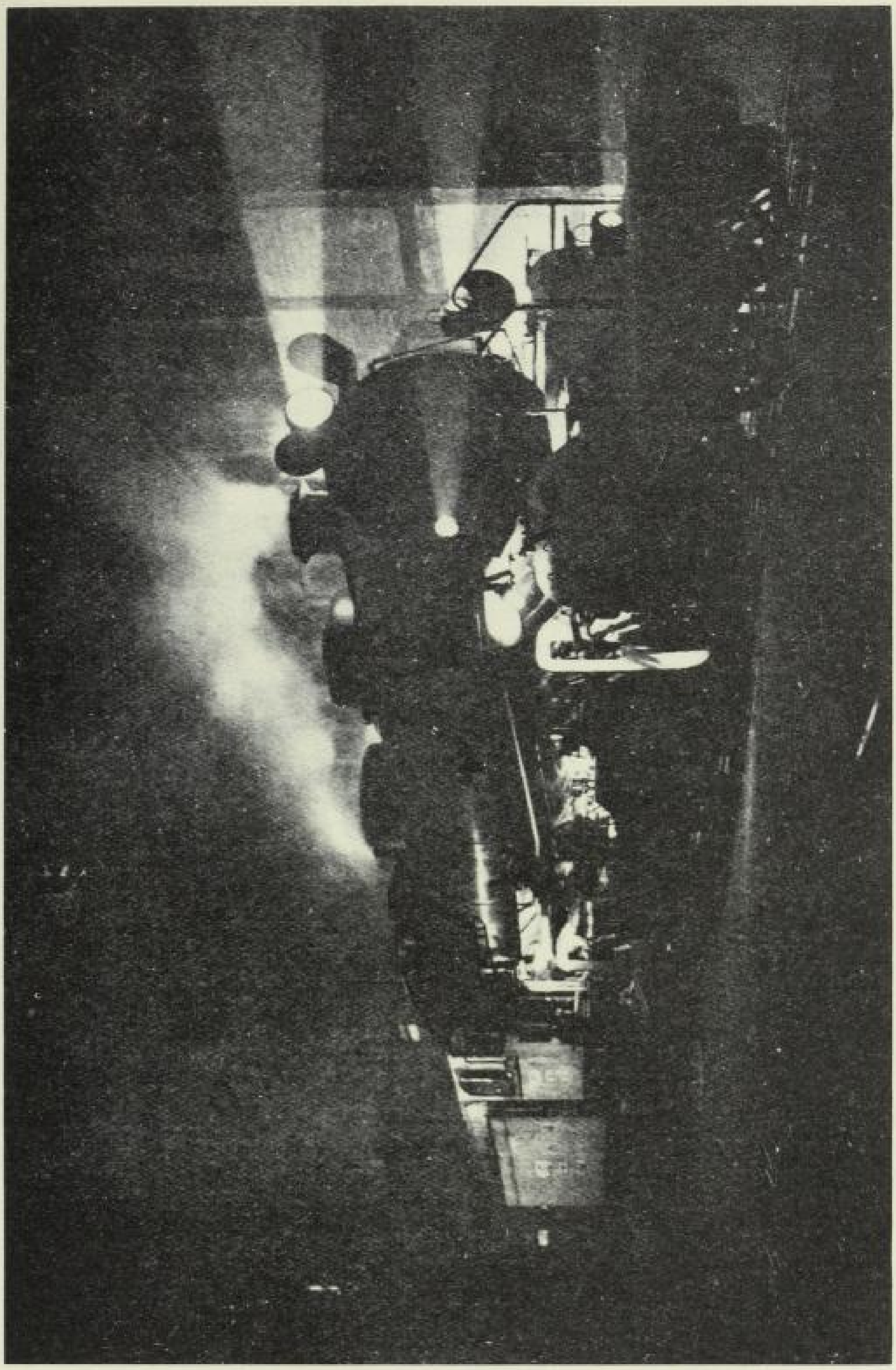


FIG. 162.—2-8 + 8-0 Mallet Locomotive, Java State Rys. (3 ft. 6 ins. Gauge.) Built by the Hanover Locomotive Works.

The next *Mallets* to be introduced were 2-6 + 8-0. They were Consolidations converted by reconstruction into *Mallet* locomotives. Through this stage the 2-8 + 8-0 type, which we are now considering, was reached. The fitting of a leading

TABLE 86.—PRINCIPAL DIMENSIONS OF 2–12–2-T MALLET LOCOMOTIVES, JAVA STATE RYS.

Gauge	3′ 6″	3′ 6″	3′ 6″	2′ 0″	3′ 6″	3′ 6″	3′ 6″
Railway	State.	State.	State.	State.	State.	State.	State.
Builder	Schwarzkopf.	Schwarzkopf.	Hanover.	Henschel.	Winterthur.	American.	Hanover.
Date	—	1908.*	—	1905–09.	1927–28.	1922.	1924.
Type	**0-4 + 4-2-T**	**2-6 + 6-0-T**	**2-12 – 2-T**	**0-4 + 4-0**	**2-6 + 6-0**	**2-8 + 8-0**	**2-8 + 8-0**
Cylinders, diameter	11$\frac{13}{16}$″	13$\frac{3}{8}$″	21$\frac{1}{4}$″	6″	16$\frac{1}{2}$″	17$\frac{1}{2}$″	17$\frac{3}{4}$″
,, diameter	18$\frac{1}{8}$″	20$\frac{1}{2}$″	—	9$\frac{1}{2}$″	25$\frac{5}{8}$″	26$\frac{1}{2}$″	27$\frac{9}{16}$″
,, stroke	20$\frac{1}{8}$″	20$\frac{1}{2}$″	20$\frac{1}{2}$″	11$\frac{13}{16}$″	24″	24″	24″
Boiler, centre line	6′ 3″	7′ 6$\frac{1}{2}$″	8′ 0$\frac{1}{4}$″	4′ 6$\frac{1}{2}$″	8′ 0$\frac{1}{2}$″	8′ 0″	8′ 0″
,, diameter	3′ 11$\frac{5}{8}$″	4′ 2″	—	2′ 5$\frac{1}{4}$″	4′ 11$\frac{3}{4}$″	5′ 4$\frac{11}{16}$″	5′ 6$\frac{1}{4}$″
,, pressure lbs. per sq. in.	171	171	171	171	199	200	200
Tubes, number	224	109	114–18†	62	21–116–21	24 + 157	24–142
,, diameter	1$\frac{7}{16}$″	2$\frac{3}{8}$″	—	1$\frac{5}{16}$″	2$\frac{3}{16}$″–2$\frac{3}{8}$″–5$\frac{5}{16}$″	5$\frac{3}{8}$″–2″	5″–2$\frac{3}{16}$″
,, length	11′ 9$\frac{1}{2}$″	15′ 0″	16′ 2$\frac{7}{8}$″	7′ 5″	17′ 9″	19′ 0″	19′ 0″
Heating surface, firebox sq. ft.	83	100 (102)	—	21	123+17‡	139+13‡	128
,, ,, tubes ,,	1,090	2,000 (1,360)	—	159	1,120+495	1,549+636	1,960
,, ,, total ,,	1,173	2,100 (1,462)	1,415·5	180	1,750	2,337	2,088
,, ,, Superheater ,,	None.	None.	439·2	None.	538	None.	697
Grate area ,,	16	22·5 (21·5)	28·0	4·5	35·5	44·7	44·0
Wheels, diameter	None.	2′ 6$\frac{3}{8}$″	None	None.	2′ 6″	2′ 6″	2′ 6$\frac{3}{8}$″
,, ,,	3′ 7$\frac{5}{16}$″	3′ 7$\frac{3}{8}$″	3′ 7$\frac{3}{8}$″	2′ 0″	3′ 7$\frac{3}{4}$″	3′ 7$\frac{3}{8}$″	3′ 7$\frac{7}{8}$″
,, ,,	2′ 6$\frac{3}{4}$″	None.	None	None.	None.	None.	None.
Wheelbase, rigid	4′ 7$\frac{1}{8}$″	8′ 6″	—	2′ 5$\frac{5}{8}$″	8′ 10$\frac{1}{4}$″	11′ 9″	11′ 9$\frac{3}{8}$″
,, driving	15′ 9″	—	—	8′ 9″	14′ 6$\frac{1}{4}$″	—	31′ 1″
,, total	19′ 8″	30′ 10″	33′ 7$\frac{5}{8}$″	8′ 9″	32′ 11″	37′ 11″	38′ 3″
Overall height	12′ 1$\frac{3}{4}$″	12′ 2″	—	—	12′ 0″	12′ 2$\frac{1}{2}$″	12′ 1$\frac{3}{4}$″
,, width	8′ 10$\frac{1}{2}$″	8′ 7$\frac{1}{2}$″	—	—	9′ 10″	9′ 10″	9′ 9$\frac{3}{4}$″
,, length	35′ 9″	43′ 6″	—	—	43′ 0″	69′ 9$\frac{1}{4}$″	68′ 11″
Weight, adhesive t.	34–2	52–0 (50–14)	56–2	—	65–2	184,500	195,000
,, empty t.	33–17	45–17 (44–17)	58–2	8–17	65–2	—	—
,, in service t.	42–4	58–14 (57–18)	73–16	9–17	72–8	206,500 lbs.	212,000 lbs.
,, tender, in service t.	None.	None.	None.	—	37–9	96,000 lbs.	95,800 lbs.
Tractive force lbs.	13,000 (50%)	13,500	21,100 (60%)	—	25,000	40,000/48,500	33,500/42,000
Water tanks galls.	300 I.g.	1,320 I.g.	1,875 I.g.	400 I.g.	4,000 I.g.	4,500 (U.S.)	4,900 (U.S.)
Fuel bunkers t.	1–8	2–4	3–0	1–0	4–18	16,000 lbs.	18,000 lbs.

* In parentheses dimensions of the locomotives of the same class built by the Chemnitz Works.
† Also three arch tubes.
‡ Arch tubes heating surface.

TABLE 87.—PRINCIPAL DIMENSIONS OF MALLET LOCOMOTIVES OF THE GREAT NORTHERN RY. (U.S.A.) (STANDARD GAUGE)

Type	2-6 + 6-2	2-6 + 6-2	2-6 + 8-0	2-8 + 8-0	2-8 + 8-2
Builder	Baldwin.	Baldwin.	Baldwin.	Baldwin.	Baldwin.
Year	1906.	1906.	1909.	1912.	1925.
Cylinders:					
Diameter, H.P.	20″	21½″	23″	28″	28″
,, L.P.	31″	33″	35″	42″	—
Stroke	30″	32″	32″	32″	32″
Boiler:					
Diameter	6′ 0″	7′ 0″	7′ 0″	7′ 6″	8′ 4″
Pressure lbs./sq. in.	210	200	200	210	210
Tubes, number	301	437	32–275–582	42–232	68–310
,, diameter	2¼″	2¼″	5″–2¼″–2¼″	5½″–2¼″	5½″–2¼″
,, length	21′ 0″	21′ 0″	15′ 0″ feed 5′ 2″	24′ 0″	24′ 0″
Firebox, width	5′ 6¼″	8′ 0″	8′ 0″	8′ 0¼″	9′ 0″
,, length	9′ 8⅛″	9′ 9″	9′ 9″	9′ 9¼″	12′ 0″
Heating surface:					
Firebox sq. ft.	198	225	225	245+81	272+160
Tubes ,,	3,708	5,375	3,038	6,120	6,710
Reheater ,,	—	—	1,777	—	—
Total ,,	3,906	5,600	5,080	6,446	7,142
Superheater ,,	None.	None.	480	1,368	1,896
Grate area ,,	53·4	78	78	78·4	108
Wheels, diameter	2′ 6″	2′ 6″	2′ 6″	2′ 9½″	2′ 9″
,, ,,	4′ 7″	4′ 7″	4′ 7″	5′ 3″	5′ 3″
Wheelbase:					
Rigid	9′ 10″	10′ 0″	15′ 0″	16′ 6″	16′ 6″
Driving	28′ 11″	30′ 0″	35′ 0″	43′ 3″	43′ 7″
Total	43′ 7″	44′ 10″	43′ 11″	52′ 6″	58′ 2″
Loco. and tender	72′ 0¼″	72′ 3¼″	76′ 2½″	83′ 1″	96′ 3½″
Tractive force lbs.	—	71,600C	—	98,500C	127,500
Weight:					
Adhesive ,,	263,350	321,450	359,600	420,000	532,800
In service ,,	302,650	362,150	378,300	450,000	594,940
Tender ,,	147,350	147,850	147,700	150,000	321,560
Tender:					
Wheels, diameter	3′ 0″	3′ 0″	3′ 0½″	3′ 0″	2′ 9″
Water U.S. galls.	8,000	8,000	8,000	8,000	16,800
Fuel U.S. tons	13	13	13	13	—

bissel only is due to the fact that these locomotives are used for main line traffic only and do not therefore have to run any distance in reverse. Thus most of the weight is available for adhesion.

This locomotive represents an increase of power of 36 per cent. over the 2-6 + 8-0 of 1909 and 55 per cent. above the 2-6 + 6-2 of 1906.

The locomotive has a tapered boiler with a Belpaire firebox and a combustion chamber.

Emerson superheaters of exceptionally large size have been fitted. One pair of headers is placed on either side of the smokebox, and the pipes which connect them with the twenty-one superheater elements have ball-joint connections with the headers. The pipes leading to the rear cylinders are on either side of the locomotive and are connected by an equalising pipe prior to reaching the cylinders.

The receiver pipe is 11 ins. bore. The centre line of the ball joint coincides with the centre of the articulated frame connection ; this ball is situated in a cavity of the H.P. cylinder saddle. At its forward end, the pipe has a lip joint just prior to reaching a Y cross connection which leads to the L.P. cylinders.

2-8 + 8-0 Mallets of the Utah Ry.—Standard Gauge.

These are used both for main line and banking service on sections where the ruling gradient is 2·4 per cent. As the curves are often sharp—390 ft. (88 m.) radius (20 degrees)—flange lubrication is provided for the first and last axles of each group.

2-8 + 8-0 Mallets of the Baltimore and Ohio R.R.

The first *Mallets* in U.S.A. were introduced on this line in 1904. Since that date, this railway has put into service a certain number of new types. The dimensions of this company's *Mallets* are given in Table 88.

The boiler of the 2-8 + 8-0 locomotive is not longer than that of the 0-8 + 8-0 type, but its diameter is increased almost to the limit of the loading gauge. The cylinder dimensions and steam pressure are the same in both types, but the 2-8 + 8-0 has a greater heating surface both of boiler and superheater. Furthermore, although the grate area is somewhat smaller, a combustion chamber 5 ft. (1m.52) in length has been added.

It therefore appears that the addition of one pony truck has permitted a design giving a better evaporative efficiency, although the theoretical tractive force remains unchanged.

TABLE 88.—PRINCIPAL DIMENSIONS OF MALLET LOCOMOTIVES OF THE BALTIMORE AND OHIO R.R. (STANDARD GAUGE)

Co.'s Class	—	—	EL4.†	EL5.	EL6.	EL5A.‡ EL5 converted.	EL6A.§ EL6 converted.
Builders	American.	American.	American.	Baldwin.	American.	—	—
Date	1904.	—	1911–1912.	1919–1920.	1917–1918.	—	—
Type	**0-6 + 6-0**	**0-8 + 8-0**	**2-8 + 8-0**	**2-8 + 8-0**	**2-8 + 8-0**	**2-8 + 8-0**	**2-8 + 8-0**
Cylinders, diameter	20″	26″	26″	26″	26½″	24″ §	25″ §
,, ,,	32″	41″	41″	41″	42″	—	—
,, stroke	32″	32″	32″	32″	32″	32″	32″
Boiler, centre line	10′ 0½″	10′ 0¼″	10′ 1″	10′ 1¾″	10′ 5″	10′ 1¾″	10′ 5″
,, diameter	7′ 0″	6′ 10″	90″	91¼″	86¼″	91¼″	86¼″
,, pressure lbs. per sq. in.	235	210	210 then 225	210–225	210–225	210–225	210–225
Tubes, number	436	277	273–40	269–48	259–48	269–48	259–48
,, diameter	2¼″	2¼″	2¼″–5½″	2¼″–5½″	2¼″–5½″	2¼″–5½″	2¼″–5½″
,, length	21′	24′	23′ 10¾″	23′ 10¾″	24′ 10¾″	23′ 10¾″	24′ 10¾″
Firebox, width	96″	—	114″	96″	96¼″	96″	96¼″
,, length	108″	—	126¼″	132¼″	132⅛″	132¼″	132⅛″
Heating surface, firebox sq. ft.	219	322	321·5	341	398	341	398
,, ,, tubes ,,	5,366	5,210	38,43 + 1,377	3,790 + 1,653	3,802 + 1,722	3,790 + 1,653	3,802 + 1,722
,, ,, total ,,	5,585	5,532	5,540·8	5,784	5,922	5,784	5,922
Superheater ,,	None.	1,050	1,002	1,415	1,380	1,415	1,380
Grate area ,,	72	100	100	88·2	88	88·2	88
Wheels, diameter	None.	None.	33″	33″	33″	33″	33″
,, ,,	56″	56″	56″	58″	63″	58″	63″
Wheelbase, rigid	10′ 0″	15′ 8″	15′ 0″	15′ 6″	16′ 6″	15′ 6″	16′ 6″
,, driving	30′ 8″	40′ 9″	40′ 8″	41′ 2″	44′ 0″	41′ 2″	44′ 0″
,, total	30′ 8″	40′ 9″	49′ 8½″	50′ 4″	53′ 4″	50′ 4″	53′ 4″
,, loco. & tender	64′ 10½″	—	86′ 3¼″	91′ 2½″	98′ 3¼″	91′ 2½″	98′ 3¼″
Overall height	—	—	15′ 6″	15′ 6⅜″	15′ 5 9/16″	15′ 6⅜″	15′ 5 9/16″
,, width	—	—	11′ 6″	11′ 4″	11′ 5″	11′ 4″	11′ 5″
,, length, loco. & tender	—	—	95′ 4½″	98′ 6⅝″	102′ 6″	98′ 6⅝″	106′ 4¾″
Factor of adhesion	—	—	4·3–4·0	4·6–4·3	4·7–4·4	—	4·22
Tractive force * lbs.	71·5–90	—	105–112·4	101–108·5	97·8–104·8	118·8	108
Weight, adhesive ,,	354,000	461,000	455,300	466,300	456,700	466,300	456,700
,, in service ,,	354,000	461,000	471,300	491,300	492,000	491,300	492,000
Tender, wheels, diameter	33″	—	33″	33″	39″	33″	33″
,, water galls.	5,800 imp.	—	9,500 U.S.	12,000 U.S.	12,000 U.S.	12,000 U.S.	12,000 U.S.
,, fuel lbs.	30,000	—	16 t. U.S.	17·5 U.S.	18·5 U.S.	17·5 U.S.	20 U.S.
,, weight ,,	—	—	181,500	211,000	219,000	211,000	219,000

* First figure corresponds to 210 lbs. boiler pressure; the second to 225 lbs.
† This *Mallet* was obtained by conversion of LL1 class with front engine truck added at Co.'s shops.
‡ EL5A is former EL5 converted from compound to simple.
§ EL6A is former EL6 converted to simple.

TABLE 89.—PRINCIPAL DIMENSIONS OF 2-8 + 8-2 MALLET LOCOMOTIVES

Gauge Railway Builders Date	Metre. Paulista (Brazil). Baldwin. —	Standard. Atchison, Topeka and Santa Fé. Baldwin. 1909.	Standard. Associated Lines. Baldwin. 1910.	Standard. Philadelphia and Reading. Baldwin. —	Standard. Denver and Rio Grande Western R.R. American. 1923.	Standard. Nashville, Chicago and St. Louis. Baldwin. —	Standard. U.S. Ry. Administration.* Baldwin. —	Standard. Norfolk and Western. Baldwin. 1918.
Cylinders, diameter, H.P.	19"	26"	26"	36"	25"	27"	25"	24½"
,, ,, L.P.	22"	30"	40"	40"	39"	41"	39"	39"
,, stroke	22"	34"	30"	32"	32"	30"	32"	32"
Boiler height of centre line	7' 6"	10' 0"	10' 0"	9' 9"	10' 4"	10' 2"	—	—
,, diameter	5' 4"	7' 0"	7' 0"	7' 6"	8' 2"	7' 4"	8' 2"	8' 2"
,, pressure lbs./sq. in.	200	220	200	210	240	210	240	230
Tubes, number	21–150	387–417 reheater	401–401 reheater	50–277	53–274	43–253	53–274	53–285
,, diameter	5¾"–2¼"	2¼"	2¼"	5½"–2"	5½"–2"	5½"–2¼"	5½"–2¼"	5½"–2¼"
,, length	19' 4"	21' 6⅛"	21' 5"	23' 0"	24' 0"	24' 0"	24' 0"	24' 0"
Firebox, width	5' 2⅞"	6' 6⅞"	6' 6¼"	9' 0¼"	8' 0¼"	8' 1¼"	8' 0¼"	8' 0¼"
,, length	8' 6$\frac{3}{16}$"	10' 9⅝"	10' 6"	12' 0¼"	14' 2⅛"	10' 6"	14' 2⅛"	12' 0½"
Heating surface, firebox sq. ft.	37+47	236	232	264+94	386	228+116	301+85	293+134
,, ,, tubes ,,	2,081	4,768–2,818 reheater	4,945–1,220 reheater	5,389	5,685	5,044	5,685	5,840
,, ,, arch tubes ,,	—	—	—	—	49	45	49	41
,, ,, total ,,	2,265	6,621	6,393	5,747	6,120	5,433	6,120	6,308
Superheater ,,	485	544	625	1,436	1,582	1,262	1,475	1,567
Grate area ,,	44·5	—	68·4	108	96·3	85·5	96·3	—
Wheels, diameter	2' 0¼"	2' 10¼"	2' 6½"	2' 9"	2' 6"	2' 9"	2' 6	2' 6"
,, ,,	3' 6"	5' 3"	4' 9"	4' 7½"	4' 9"	4' 8"	4' 9"	4' 8"
Wheel-base, rigid	11' 3"	16' 6"	15' 0"	15' 0"	15' 9"	15' 0"	14' 9"	15' 6"
,, driving	29' 11"	43' 4"	39' 4"	39' 8"	42' 4"	40' 4"	42' 4"	42' 1"
,, total	43' 4"	59' 10"	56' 7"	55' 10"	58' 0"	55' 8"	58' 0"	57' 4"
,, loco. & tender	67' 9"	98' 5¼"	90' 4"	82' 11½"	94' 9"	85' 7¾"	94' 6"	85' 8"
Overall height	—	—	15' 2½"	15' 0"	15' 8⅝"	15' 6"	—	—
,, width	—	—	11' 1½"	10' 8"	11' 2"	11' 2"	—	—
,, length	—	—	96' 0"	91' 8½"	105' 1⅞"	97' 7"	—	—
Tractive force lbs.	—	—	85,500	98,000	107,350	97,000	—	—
Weight, adhesive ,,	197,700	184 t. 2 cwt.	398,000	435,200	481,000	430,000	478,000	470,500
,, in service ,,	222,400	206 t. 9 cwt.	433,600	478,800	534,000	469,400	531,000	523,600
,, of tender ,,	90,600	104 t. 5 cwt.	179,400	151,000	210,000	165,600	214,000	161,400
Tender, wheels, diameter	2' 4"	—	2' 9"	3' 0"	2' 9"	3' 0"	2' 9"	2' 9"
,, water galls.	4,500 U.S. galls.	12,000 Imp. galls.	10,000 U.S. galls.	8,000 U.S. galls.	12,000 U.S. galls.	8,500 U.S. galls.	12,000 U.S. galls.	9,000 U.S. galls.
,, Fuel	8 U.S. tons.	4,000 imp. galls.	3,200 U.S. galls.	13 U.S. tons.	16 U.S. tons.	14 U.S. tons.	16 U.S. tons.	16 U.S. tons.

* This standard locomotive was allocated to the Carolina, Clinchfield and Ohio R.R.

As in the other cases, the L.P. cylinders, owing to their size, have to be set in an inclined position.

Class L.—2-8 + 8-2 Mallet Locomotives

For some little time this was the most powerful type of *Mallet*, but it was superseded by *Mallets* with two groups of five, making ten coupled axles. Nevertheless, the constituent parts of the 2-8 + 8-2 *Mallets* have been developed and lightened by an extensive use of vanadium alloy steel, with the result that the type has regained its popularity. The recent 2-8 + 8-2 are, indeed, more powerful than the *Mallets* with ten coupled axles which were built before them.

2-8 + 8-2 Mallets of the Atchison, Topeka and Santa Fé Ry.

These were put into service at the same time as the 4-4 + 6-2 locomotives previously described. Like them, they had a separable boiler with H.P. and L.P. superheaters and a feed-water heater. The same type of boiler was also used on the 2-6 + 6-2 *Mallets* of this railway.

The semi-cylindrical tender is carried on two six-wheeled bogies. It weighs more than 98 tons 14 cwt. (100 tonnes) in working order and has a capacity of 16,000 gallons (60 cub. m.) of water and 4,000 gallons (15 cub. m.) of oil fuel.

Although its rigid wheelbase is comparatively long—16 ft. 6 ins. (5m.03)—this locomotive negotiates curves of 1,360 ft. (110 m.) radius satisfactorily.

2-8 + 8-2 Mallets of the St. Louis and San Francisco R.R.

The firebox is arranged like that of the 0-8 + 8-0 type ; being over the driving wheels, it is not deep. It is extended by a combustion chamber.*

2-8 + 8-2 Mallets of the Associated Lines.—Standard Gauge.

The Associated Lines comprised several railway companies with common interests, notably the Southern Pacific R.R., the Union Pacific R.R. and the Oregon R.R. and Navigation Co.

In 1909, two 2-8 + 8-2 *Mallets* were introduced for through

* These locomotives are used for banking on 1½ per cent. grades. The loads are 1,720 tons approximately at 5 miles (8 km.) per hour, and 1,120 tons at 10 miles (16 km.) per hour.

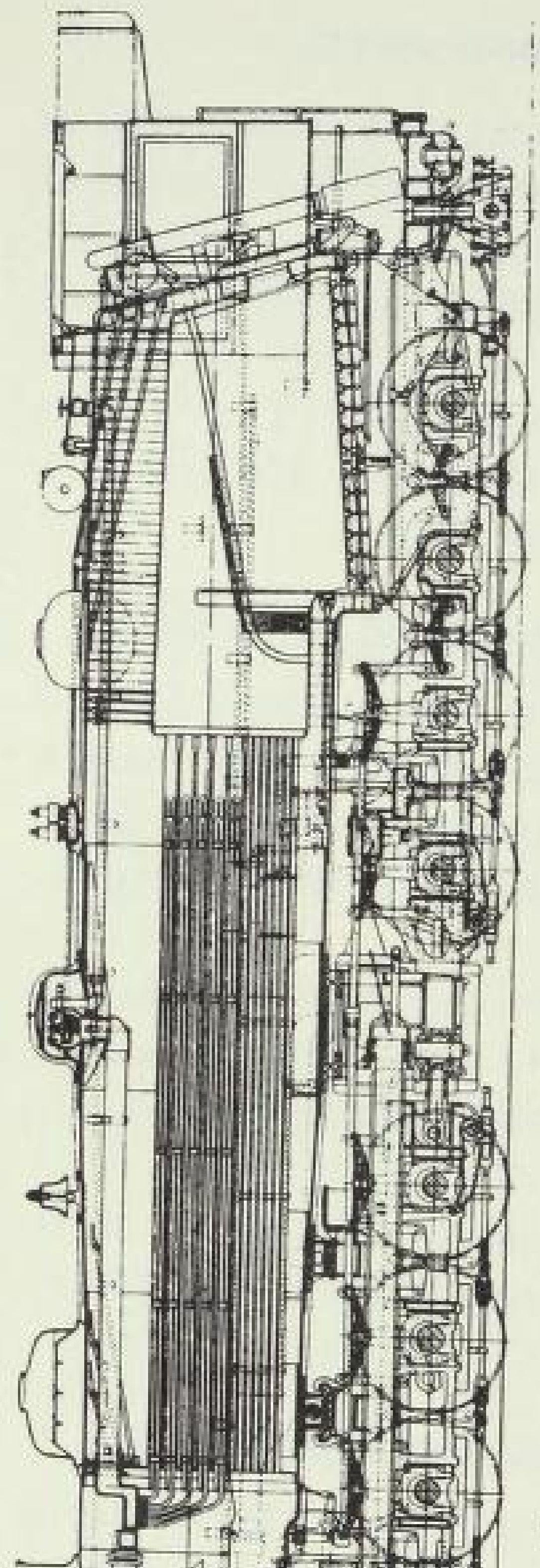


FIG. 163.—2-8 + 8-2 Baldwin Mallet Locomotive.

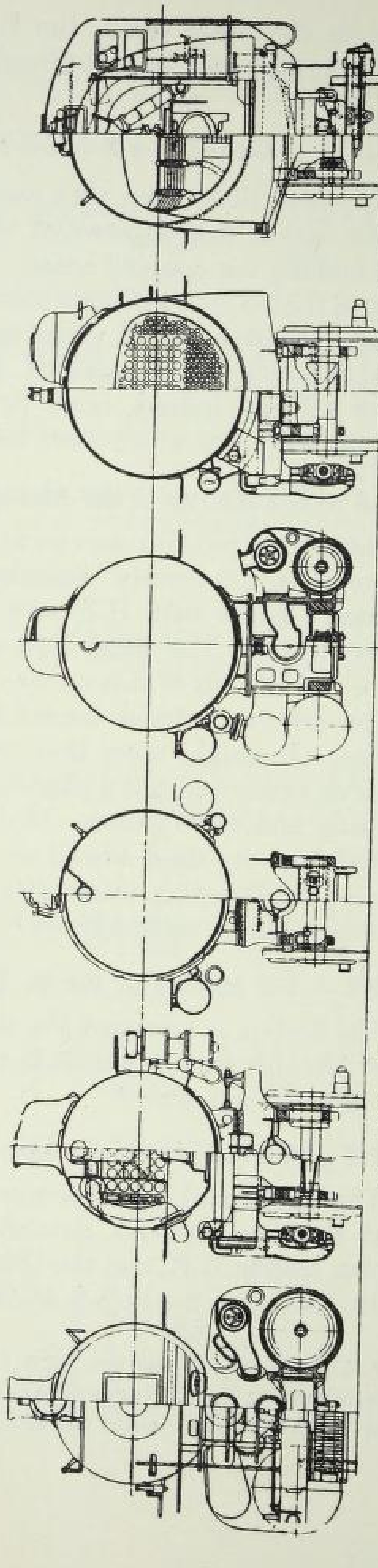


FIG. 164.—Cross-sections of Baldwin's-built 2-8 + 8-2 Mallet Locomotive.

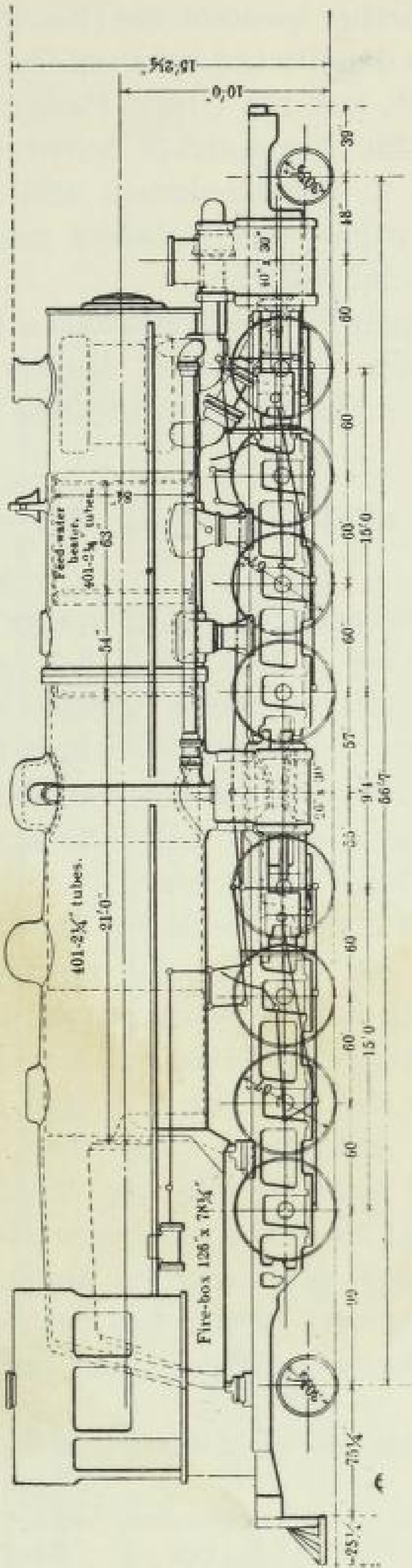


FIG. 165.—2-8 + 8-2 Mallet Locomotive, Southern Pacific R.R.
(Standard Gauge.)
Built by the Baldwin Locomotive Works.

freight service on the trans-continental line.* They were

* The Sacramento division of the Central Pacific Ry. forms a section of the trans-continental trunk line (*viâ* Ogden) on the western

followed in 1910 by further locomotives (No. 2,002 *et seq.*) of the same size, which were distributed between the Southern Pacific R.R., the Oregon R.R. and the Union Pacific R.R.

The Southern Pacific locomotives burnt oil fuel, and the tender was attached to the smokebox end (Fig. 165). The locomotives on the other two railways used coal, so their tenders were in the usual position.

The boilers were separable and contained a feed-water heater and a L.P. superheater. The latest *Mallets* on this railway system are provided with flange lubrication for the first axle of each group.

2-8 + 8-2 Mallets of the Virginian Ry.—Standard gauge (Fig. 166).

This railway has successively put into service four types of *Mallets:* 2-6 + 6-0, 2-8 + 8-0, 2-8 + 8-2, and 2-10 + 10-2, besides a *Triplex* locomotive. Each type has been more powerful than its predecessor. One section where they are specially used is in the Deepwater division between Elmore and Clark's Gap where, in a distance of 14¼ miles (23 km.), there are 11½ miles (18·5 km.) of 2·7 per cent. grade.

The earlier 2-8 + 8-2 type, built by Baldwin in 1910, can negotiate curves of 280 ft. (85 m.) radius. The boiler is separable and contains a feed-water heater and a L.P. superheater consisting of thirty-one tubes of 2 ins. (51 mm.) diameter located in a large flue of 1 ft. 9 ins. (0·533 m.) diameter, which passes through the reheater. The later 2-8 + 8-2 types (Nos. 604, 5, 6 and 7) were built by the American Locomotive Co., and were for some time the most powerful locomotives of this type. In the central portion of the boiler, there is a superheater of the double U type, which has forty-eight elements of 5½ ins. (140 mm.) diameter tubes. The firebox arch is sup-

slope of the Sierra Nevada, the most westerly of the Rocky Mountain chain.

Sacramento is 29½ ft. (9 m.) above sea level. Roseville, mile 18 (km. 29) is at an altitude of 161 ft. (49 m.). The summit level is at + 7,015 ft. (2,139 m.). After Roseville, the ascent is effected first by an incline of 1½ per cent. for 3¾ miles (6 km.) to Rocklin; then follow 32 miles (51 km.) of 2 per cent. average gradient, followed by an easier section to Colefax. This is succeeded by some 51 miles (82 km.) of continuous ascent, the gradient varying from 2·15 per cent. to 2·2 per cent.

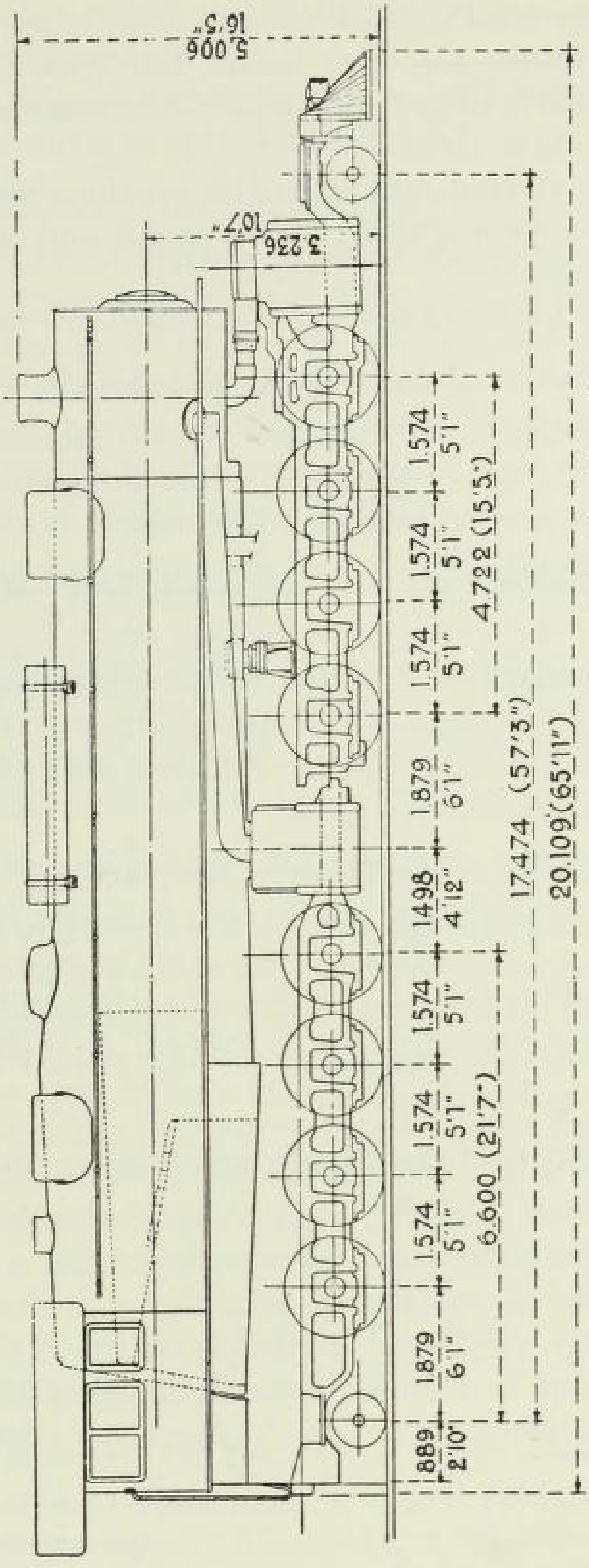


FIG. 166.—2-8 + 8-2 Mallet Locomotive of the Virginian Ry. (Standard Gauge.)

ported by cross-water tubes $3\frac{1}{2}$ ins. (0·089 m.) diameter, which increase the dried heating surface and improve the circulation. Vanadium alloy steel is much used in this design, for example, for the main frame, the cross heads, the tyres and the truck and driving axle springs. Castings of the same alloy steel are used in some other places.

Trains of 3,720 tons are dealt with on the above-mentioned section by a Baldwin *Mallet* as train engine and one of the new *Mallets* as a pusher.

The tractive force of the former is 92,000 lbs. (41·731 kg.).

2-8 + 8-2 Mallets of the Duluth, Missabe and Northern Ry.

These are similar to the Virginian Ry. locomotives. They are used for dealing with empty freight cars between the docks at Duluth and the sorting sidings at Proctor.*

2-8 + 8-2 Mallets of the St. Louis, Iron Mountain and Southern Ry.

As these locomotives are used for shunting, and are therefore frequently starting and stopping, they have automatic starting valves, so that the locomotives always work single expansion when starting.

2-8 + 8-2 Mallets of the Western Maryland Ry.

These locomotives weigh 498 short tons. They were built by the Lima Locomotive Works. We believe that these are the only articulated locomotives which these Works have turned out, apart from their well-known *Shay* geared locomotives, which have been described *ante*.

2-8 + 8-2 Mallets of the Norfolk and Western Ry.

The first *Mallets* of this type introduced on this railway had separable boilers with feed-water heaters, also a L.P. superheater located in the smokebox.

This company continued to improve its *Mallets*, and in 1918 brought out a modified type, embodying the results of ten years' experience. The size of the locomotives has been

* This line, $6\frac{1}{4}$ miles (10 km.) in length, has 2·2 per cent. grades and curves of 952 ft. (290 m.) to 574 ft. (75 m.), compensated. A train-load consists of 55 wagons of 14 tons 7 cwt. (14·6 tonnes) each, with a brake-van weighing 86 tons 17 cwt. (9 tonnes). The speed is $11\frac{3}{4}$ miles (19 km.) per hour.

somewhat reduced owing to the difficulty of accommodating very large L.P. cylinders. On the other hand, the boiler pressure has been raised to 230 lbs. per square inch (16·2 kg. per square centimetre).

All the driving wheels have flanges, although the sharpest curves have a radius of only 300 ft. (98 m.).

2-8 + 8-2 Mallets of the Philadelphia and Reading Ry.

These enormous locomotives were designed for working on sections with 3 per cent. grades. They have a Wootten boiler, and burn a mixture of anthracite and bituminous coal. The firebox is extended by a combustion chamber 4 ft. 11$\frac{5}{8}$ ins. (1m.21) in length with a firebox baffle wall across it. The boiler centre line had to be lowered below the normal, owing to the limitations of the loading gauge.

2-8 + 8-2 Mallets of the Carolina, Clinchfield and Ohio Ry.

The power of these locomotives is comparable with that of the Philadelphia and Reading locomotives above described, but the L.P. cylinders, which are very large, are set too low. The driving wheels are provided with flange lubrication. There is a combustion chamber 5 ft. 5$\frac{3}{4}$ ins. (1·67 m.) in length.

2-8 + 8-2 Mallets of the U.S.A. Railway Administration.

These are a standard type, designed at the same time as the 2-6 + 6-2 *Mallets* of this Administration.

The same dimensions have been retained as far as applicable. Thus, the axle load, the driving wheel diameter and the piston stroke are the same in both types.

In both types, the diameter of the cylinders has been limited, so as to allow these locomotives to run on as many railway systems as possible.

The Gaines firebox is used with a combustion chamber 3 ft. 1 in. (0·94 m.) in length. Both the Carolina, Clinchfield and Ohio Ry. and the Western Pacific Ry. have a certain number of these standard types.

2-8 + 8-2 Mallets of the Pekin-Sunyan Ry. (China).—Standard gauge (Fig. 167).

For use on the ascent to the Nankou Pass on the main line to Kalgan, three different types of articulated locomotives are used. Firstly, *Shay* geared locomotives, secondly, some

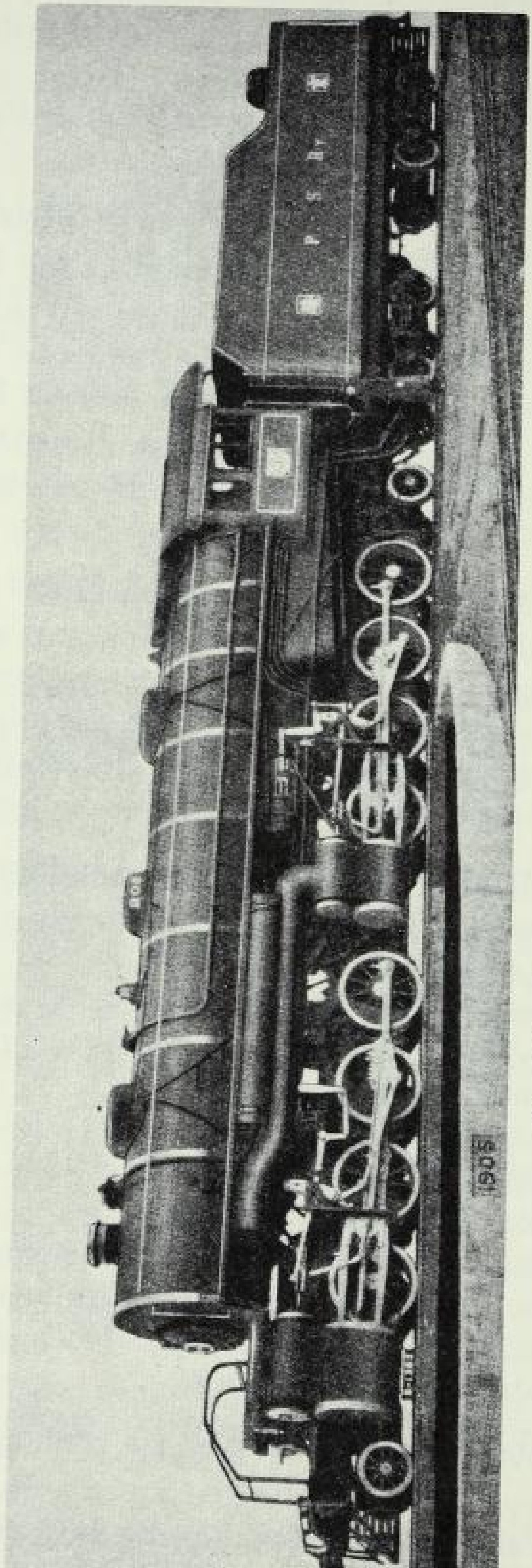


Fig. 167.—2-8 + 8-2 Mallet, Pekin-Sunyan Ry.
(Standard Gauge.)
Built by the American Locomotive Co.

TABLE 90.—PRINCIPAL DIMENSIONS OF MALLET LOCOMOTIVES ON CHINESE RAILWAYS (STANDARD GAUGE)

Type	**0-6 + 6-0**	**2-8 + 8-2**	**2-8 + 8-2**
Railway	Pekin-Kalgan.	Pekin-Kalgan.	Pekin-Sunyan.
Builder	North British.	American Locomotive Co.	
Cylinders :			
Diameter, H.P.	18″	20″	24″
,, L.P.	28¾″	32″	38″
Stroke	28″	26″	28″
Boiler :			
Ht. of centre line	10′ 0″	—	—
Diameter	—	5′ 7¼″	7′8 ¼″ (int.)
Pressure lbs./sq. in.	200	200	220
Tubes, number	253	24–192	48–251
,, diameter	2¼″	5¼″–2¼″	5½″–2¼″
,, length	17′ 0″	20′ 0″	24′ 0″
Firebox, width	—	6′ 3¼″	9′ 0¼″
,, length	—	9′ 6¼″	10′ 6$\frac{1}{16}$″
Heating surface :			
Firebox sq. ft.	166	252	315
Arch tubes ,,	None.	21	37
Tubes ,,	2,425	2,353	3,534+1,652
Total ,,	2,591	2,626	5,538
Superheater ,,	None.	563	1,433
Grate area ,,	45	60	95
Wheels, diameter	4′ 3″	4′ 2″	4′ 2″
Wheelbase, rigid	9′ 8″	13′ 6″	14′ 9″
,, driving	29′ 4″	—	—
,, total	29′ 4″	50′ 1″	53′ 11″
Tractive force lbs.	36,000—(50%)	56,500	93,500
	—	67,800	111,000
Weight, adhesive	96 tons 10 cwt.	106 tons 10 cwt.	388,500 lbs.
,, in service	96 tons 10 cwt.	129 tons 10 cwt.	446,000 lbs.
Tender :			
Water	—	6,000 imp. galls.	10,000 U.S. galls.
Fuel	—	7 tons 0 cwt.	20,000 lbs.
Weight in service	—	55 tons 15 cwt.	192,300 lbs.

European-built 0-6 + 6-0 *Mallets,* and finally some American-built double-Consolidation *Mallets.*

These latter have arch tubes and a combustion chamber 2 ft. 11½ ins. (0·90 m.) in length. They have no outstanding features, but are of interest as an example of the adoption of standard American practice in large *Mallets* to a line where the maximum permissible axle load is only 13 tons 6 cwt. (13·5 tonnes), which is considerably less than the maximum on

American railways. The use of such large locomotives on lines of comparatively light construction where, as in this case, the axle load must be kept down, introduces difficulties in design. In order to obtain the necessary heating surface, the ratio of boiler length to diameter has to be excessive ; also the leading bissel and the first driving axle have to be in front of the smokebox. If, on the other hand, a boiler of better proportions with a larger number of shorter tubes is used, it is difficult to distribute the weight so that the rear truck is not overloaded.

Class M.—2-10 + 10-2 Mallet Locomotives

This is the most powerful type of *Mallet* yet introduced. It was first tried on the Atchison, Topeka and Santa Fé Ry. Its use was not at first extended, because the double-Consolidation *Mallets*, whose power had been increased, were sufficient for present needs. But when fuller power was required the double Santa Fé type was again introduced.

2-10 + 10-2 Mallets of the Atchison, Topeka and Santa Fé Ry.

These were built up from some 2-10-2 rigid locomotives. A new leading truck complete with L.P. cylinders was provided, also an extension to the boiler which contained a feedwater heater and a Buck-Jacobs superheater, for both H.P. and L.P. steam.

Apart from their great size, these locomotives do not differ in principle from the 2-8 + 8-2 locomotives of this railway, which were also obtained by the conversion of ordinary Consolidations.

2-10 + 10-2 Mallets of the Virginian Ry.—Standard gauge (Fig. 168).

The American Locomotive Co. built these locomotives about the year 1919. They are more powerful than the Triplex *Mallets* previously introduced on this railway, and are obviously less complicated. On the other hand, the load per axle is necessarily very high, being no less than 27 tons 11 cwt. (28 tonnes).

As in the case of the Great Northern Ry. and the Baltimore and Ohio R.R., the Virginian only reached the use of these enormous locomotives by stages and owing to the special

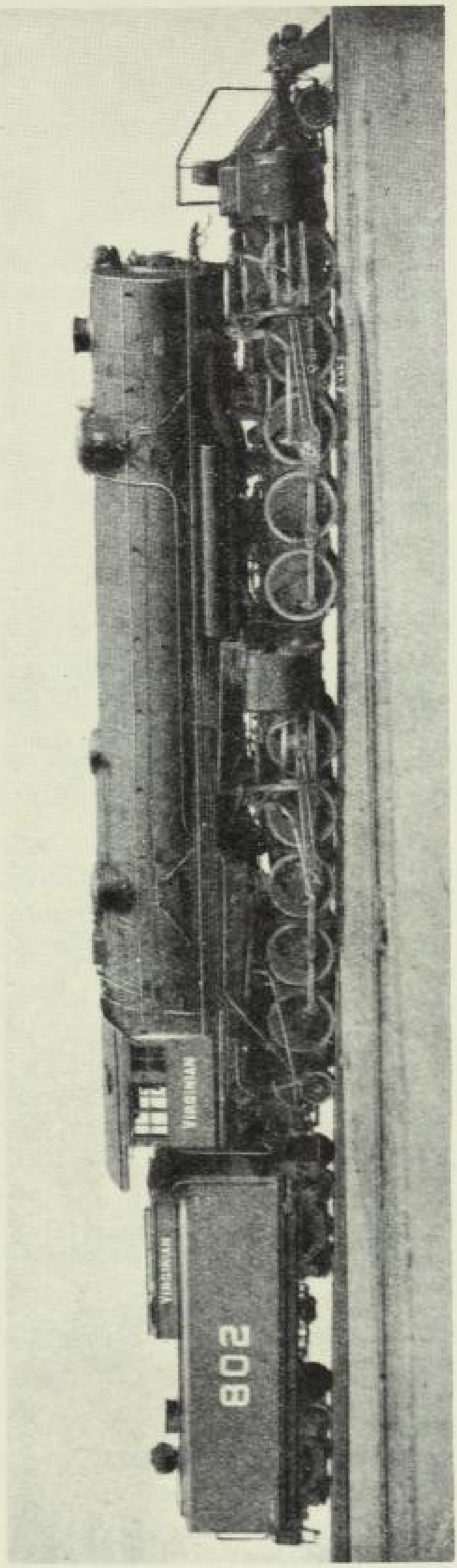


FIG. 168.—2-10 + 10-2 Mallet, Virginian Ry.
(Standard Gauge.)
Built by the American Locomotive Co.

requirements of a certain difficult section of the railway system. A considerable tonnage had to be handled over it,

TABLES 91 AND 92.—PRINCIPAL DIMENSIONS OF MALLET LOCOMOTIVES OF THE VIRGINIAN RY., AND 2-10 + 10-2 LOCOMOTIVES OF THE ATCHISON, TOPEKA AND SANTA FÉ RY. (STANDARD GAUGE)

Railway	Virginian Ry.	Virginian Ry.	Virginian Ry.	Virginian. Ry.	Virginian Ry.	Virginian Ry.	Atchison, Topeka and Santa Fé. (Rebuilt.)
Builder	Baldwin.	Baldwin.	Baldwin.	American	American.	—	
Date	—	1912	1912	1913	1918	—	—
Type	**2-6 + 6-0**	**2-8 + 8-2**	**2-8 + 8-2**	**2-8 + 8-2**	**2-10 + 10-2**	**2-10 + 10-2**	**2-10 + 10-2**
Cylinders, diameter, H.P.	24"	26"	28"	28"	30"	28"	27 9/16"
,, ,, L.P.	36"	40"	44"	44"	48"	50"	37¾"
,, stroke	32"	32"	32"	32"	32"	32"	32"
Boiler, height of centre line							
,, diameter	7' 0"	7' 2"	8' 4" (ext.)	8' 4" (ext.)	8' 7⅛" (int.)	—	—
,, pressure . lbs./sq. in.	210	210	200	200	215	200	145
Tubes, number	437	401	65–365	48–334	70–381	65 + 365	377
,, diameter	2¼"	2¼"	5½"–2¼"	5½"–2¼"	5½"–2¼"	5 7/16–2¼"	—
,, length	21' 0"	21' 0"	25' 0"	24' 0"	25' 0"	25' 0"	16' 4¾"
Firebox, width	8' 0"	8' 0"	9' 0¼"	9' 0¼"	9' 0¼"	11' 10"	9' 6"
,, length	9' 9"	10' 6 1/16"	15' 8"	14' 7 1/16"	15' 1 1/16"	15' 7"	12' 5"
Heating surface, firebox sq. ft.	234	250	359	380	437·5	357	295
,, ,, arch tubes ,,	30	48	71	67	78·5	93·6	—
,, ,, tubes ,,	5,377	4,934	7,689	6,462	2,510	7,700	3,600
,, ,, feed heater ,,	—	1,694	—	—	5,580	—	—
,, ,, total ,,	5,641	6,926	8,120	6,909	8,606	—	—
Superheater ,,	742	—	2,059	1,311	2,120	2,050	2,270
Grate area ,,	78	84	108·2	99·2	108·7	108	82
Wheels, diameter	2' 4"	2' 4" and 3' 0"	2' 6"	2' 6"	2' 6"	2' 6"	2' 10¼"
,, ,,	4' 8"	4' 8"	4' 8"	4' 8"	4' 8"	4' 8"	4' 8"
Wheelbase, rigid	10' 8"	15' 0"	15' 3"	15' 6"	19' 10"	15' 3"	22' 7"
,, driving	31' 2"	39' 10"	41' 5"	42' 1"	58' 9"	41' 5"	48' 6"
,, total	40' 4"	58' 2"	50' 6"	57' 4"	64' 3"	50' 9"	85' 3"
,, loco. and tender	74' 8¼"	89' 2¼"	90' 11"	91' 5 3/16"	97' 0"	90' 6"	108' 0"
Overall height	—	—	14' 3"	16' 5¼"	16' 7½"	—	—
,, width	—	—	10' 1¼"	11' 8½"	12' 0"	—	—
,, length	—	—	65' 11¼"	99' 9⅝" (loco. and tender)	73' 3"	—	—
Tractive force . lbs.	—	100,800	115,000	115,000 138,000	147,200 176,000	116,000	110,000
Weight, adhesive	356,800	405,400	487,400	475,000	617,000	490,000	555,000
,, in service	385,300	448,750	526,190	540,000	684,000	530,000	623,000
Tender, wheels, diameter	2' 9"	2' 9"	2' 9"	2' 9"	2' 9"	2' 9¼"	2' 10¼"
,, water . U.S. galls.	9,500	9,500	13,000	12,000	13,000	—	—
,, fuel . U.S. tons	15	16	12	16	12	—	—
,, weight in service . lbs.	181,700	176,250	235,000	212,000	214,300	—	—

while it was undesirable to split up the freight trains in order to negotiate this section with locomotives of ordinary power.*

The various types of *Mallets* which have been successively introduced on this railway are as follows :—

Firstly.—Two varieties of the 2-6 + 6-0 type, having a tractive force of 70,800 lbs. (32,800 kg.), and 90,000 lbs. (41,000 kg.) respectively ; eight of this latter type were built.

Secondly.—Two successive productions of the 2-8 + 8-2 type, having a tractive force of 100,800 lbs. (45,700 kg.) or 115,000 lbs. (51,200 kg.) respectively. Six of the former type were built.

Thirdly.—A Triplex *Mallet* with motor tender.

Fourthly.—The latest 2-10 + 10-2 *Mallets*, which have a tractive force of 151,700 lbs. (68,800 kg.).

The above figures of tractive force are calculated for compound working.

The trains on this section consist of sixty wagons of 15 short tons (gross) making a total train load of 4,500 short tons. They were handled by three locomotives. The train engine was a 2-6 + 6-0, and the two pushers were 2-8 + 8-2. The total tractive force available was, therefore, 320,000 lbs. (145,150 kg.).

The introduction of the double-Decapod (2-10 + 10-2) allowed the train load to be increased still further. With a 2-8 + 8-0 as train engine and two 2-10 + 10-2 as pushers, trains of seventy-eight of the same wagons, an aggregate of 5·850 (short) tons, were handled. The available tractive force was 409,400 lbs. (185.900 kg.).

These double-Decapods do not present any novel features, so it will suffice to give some of their leading dimensions.

The journals of the axles are very liberally designed, being 12 ins. (0·31 m.) diameter for the driving axles and 11 ins. (0·28 m.) for the pony axles. The length of the journals is 15 ins. (0·38 m.) and 13 ins. (0·33 m.) respectively. The ratio of the cylinder capacities is 2·56. The centres of the cylinders

* The section in question is the one from Elmore to Clark's Gap, 14 miles (22·5 km.) in length. The gradient for the first 3 miles (5 km.) is only 0·5 per cent. The remainder of the section is 2 per cent. with 12-degree curves, *i.e.*, 485 ft. (148 m.) radius (compensated). This single line section has five tunnels, and, for operating reasons, it was desirable to use the longest possible trains, generally with one train engine and two pushers.

are 7 ft. 6 ins. (2·29 m.) apart and the overall width 11 ft. $11\frac{1}{2}$ ins. (3·65 m.). This is little more than two and a half times the rail gauge. As this figure exceeded the clearance on many other railway systems, it was necessary to send these locomotives from the works to their destination by a devious route.

Piston valves with internal admission are used for the H.P. cylinders. The L.P. cylinders have flat slide valves with external admission.

The firebox arch rests on cross water tubes. The firebox is extended by a combustion chamber.

The following ratios (English measures) are of interest :—

$$\frac{\text{Adhesive weight}}{\text{Tractive force}} = \begin{cases} 3{\cdot}2 \text{ (simple),} \\ 4{\cdot}2 \text{ (compound).} \end{cases}$$

$$\frac{\text{Total weight}}{\text{Tractive force (compound)}} = 4{\cdot}6.$$

$$\frac{\text{Tractive force (compound)} \times \text{D}}{\text{Equivalent heating surface}} = 699{\cdot}4.$$

$$\frac{\text{Equivalent heating surface}}{\text{Grate area}} = 108{\cdot}4.$$

$$\frac{\text{Heating surface of firebox}}{\text{Equivalent heating surface}} = 4{\cdot}4 \text{ per cent.}$$

$$\frac{\text{Adhesive weight}}{\text{Equivalent heating surface}} = 52{\cdot}4.$$

$$\frac{\text{Total weight}}{\text{Equivalent heating surface}} = 58{\cdot}0.$$

$$\text{Volume equivalent simple cylinders} = 41 \text{ ft.}^3$$

$$\frac{\text{Equivalent heating surface}}{\text{Volume of cylinders}} = 287{\cdot}4.$$

$$\frac{\text{Grate area}}{\text{Volume of cylinders}} = 2{\cdot}7.$$

With live steam admitted to all four cylinders, as in starting, the tractive force was the greatest hitherto attained in any type of locomotive.

The principal dimensions of recent locomotives on the Virginian Ry. are given in Table 91, and show the gradual development in power.

We have added for comparison the dimensions of the 2-10 + 10-2 *Mallets* of the Atchison, Topeka and Santa Fé Ry., which are the only other double-Decapods yet built.

GROUP III.—MODIFIED MALLET LOCOMOTIVES

Besides various modifications of detail which do not affect the *Mallet* principle, some locomotives have been designed which introduce fundamental alterations. They may be classified thus :—

Sub-Group IIIa.—Altered *Mallets*, with ordinary cylinder arrangements.

Type 1.—*Mallet* locomotives with articulated boilers. (The separable boiler is not a fundamental modification.)

Type 2.—*Mallet* locomotives having driving wheels of two different diameters. This has not got beyond the experimental stage on the South African Rys., where it was tried.

Type 3.—*Mallet* locomotives for combined service on simple adhesion and rack railways. Designs only have been prepared.

Type 4.—*Triplex* locomotives, having three motor groups. This is an extension of the *Mallet* principle.

Sub-Group IIIb.—Next come the locomotives where the alterations bear on the cylinders.

Type 1.—Locomotives with four simple admission instead of compound cylinders. This tendency is making good headway.

Type 2.—Locomotives with the cylinders grouped at the centre, which changes many of Mallet's principles. Tried on the Canadian Pacific only.

Type 3.—Locomotives with the cylinders at the extreme ends. Tried on the New Zealand Government Rys.

These alterations to the cylinders are analogous to what has taken place in connection with the *Meyer* type of articulated locomotives. It also entails radical modifications of the original locomotive, but, with the exception of substituting the use of H.P. steam to compounding, which brings the least change, have met with no success, nor are they likely to.

SUB-GROUP III A.—ALTERED MALLETS, WITH ORDINARY CYLINDER ARRANGEMENTS

Type 1.—Mallet Locomotives with Articulated Boilers

In the *Mallet* design the rear end of the boiler and the rear truck are rigidly connected. Hence, the front of the boiler moves outwards when the locomotive is running through curves and the longer the boiler, the greater is this outward displacement. This has two disadvantages. Firstly, the

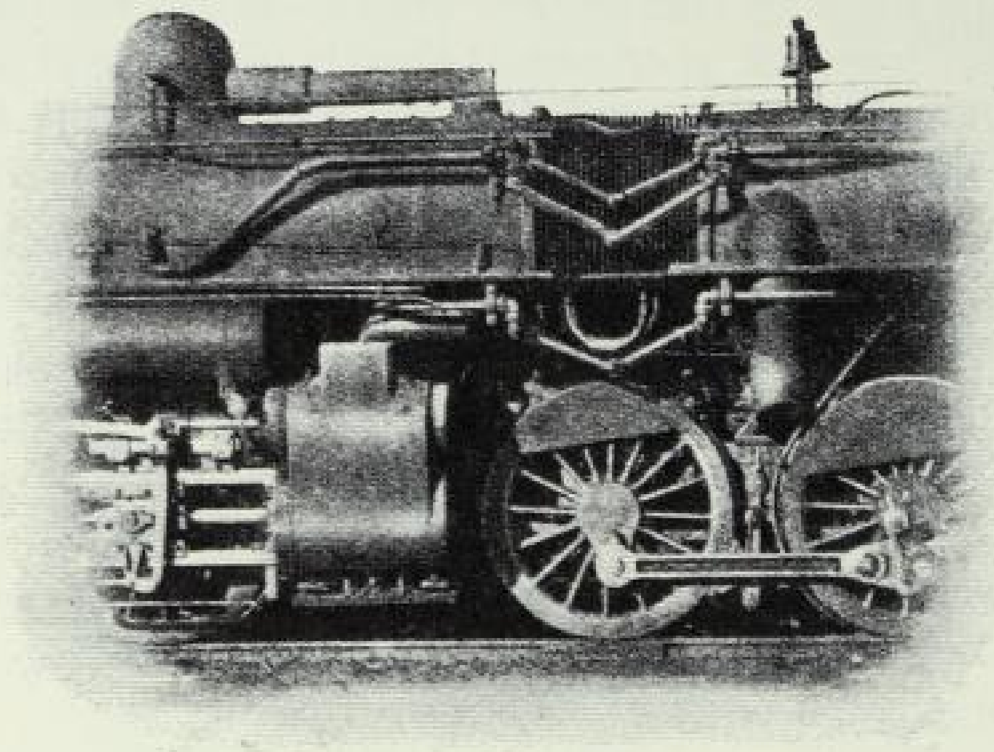


Fig. 169.—Articulated Boiler, Mallet Locomotive.

centre of gravity of the locomotive is displaced outwardly. Secondly, the projection of the forward end of the boiler may infringe on the loading gauge.

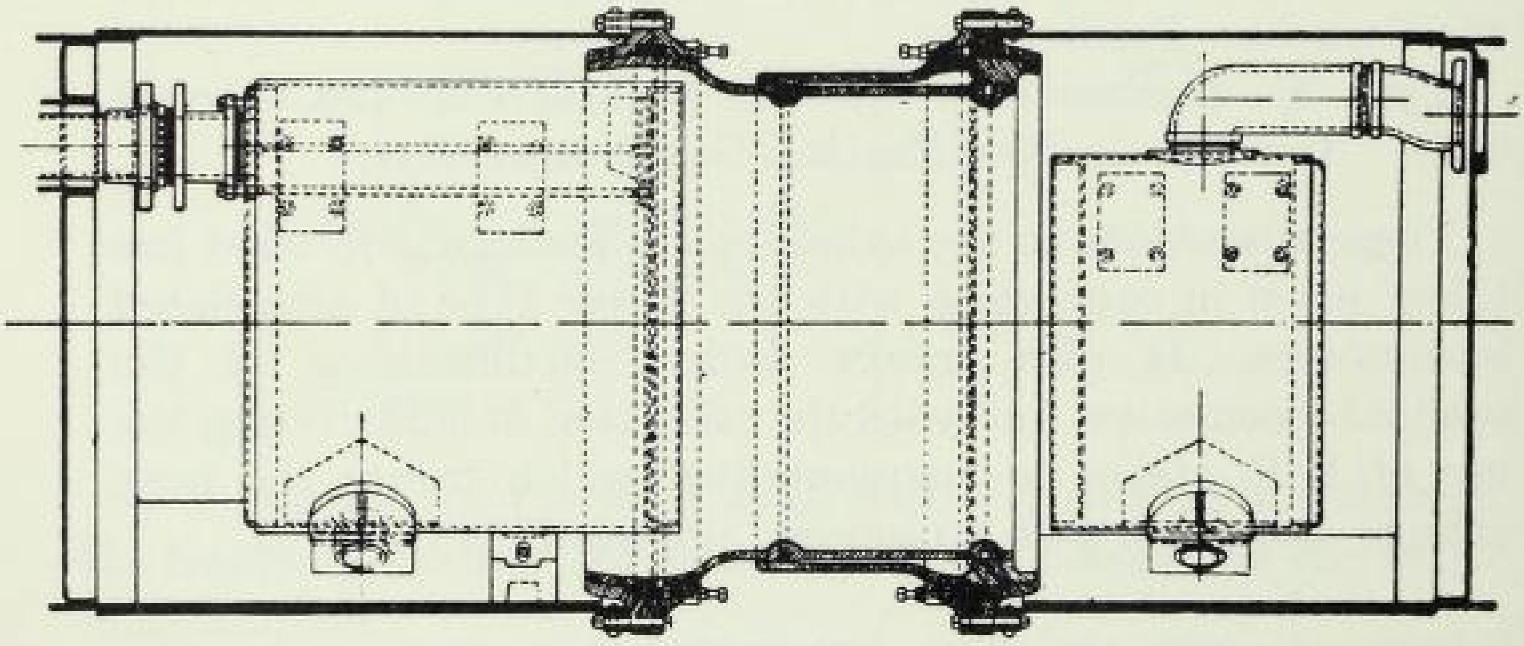


Fig. 170.—Articulated Boiler, Baldwin Mallet Locomotive

The articulated boiler was tentatively introduced to obviate these disadvantages. The articulation between the two portions of the boiler has been effected in two ways.

The first type is shown in Fig. 170.

In the second type (Figs. 169, 171) the two portions of the boiler are united by a bellows-piece.

In both types, the joint is made a little in front of the hinge joint of the frame above the H.P. cylinders. In order to reduce the number of flexible steam pipes, the pipes supplying the H.P. cylinders run through the rear boiler section only. The H.P. superheater must therefore be located in this section. The only steam pipes which cross the articulation of the boiler are those which lead the steam from the H.P. to the L.P. cylinders. Besides these steam pipes, flexible connections

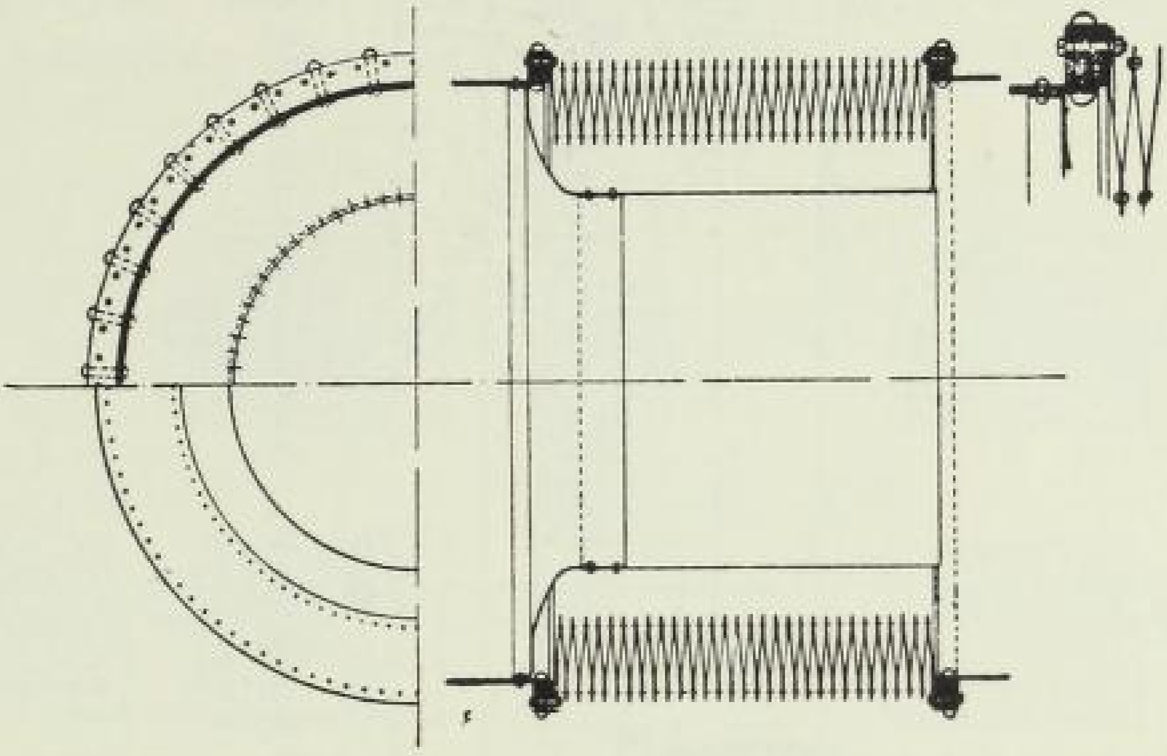


FIG. 171.—Flexible Joint, Baldwin Articulated Boiler.

have to be provided for the injector pipe, and the pipe from the feed-water heater to the rear part of the boiler.

In the Baldwin design, the flexible joint consists of fifty rings of high carbon steel, which are 10 ins. wide, and formed with a slight set so that when placed adjacent to one another they form a series of V-shaped joints. The rings have an outside diameter of 6 ft. $3\frac{1}{2}$ ins.; they are riveted together at their inner and outer edges and form a bellows-piece, which is 3 ft. $8\frac{3}{4}$ ins. in length. This is bolted into place between the front and rear boiler sections. An internal flue 3 ft. 8 ins. in diameter traverses the flexible connection and is flared out at the back to fit in the rear boiler section. This flue prevents ashes and cinders from lodging in the flexible joints.

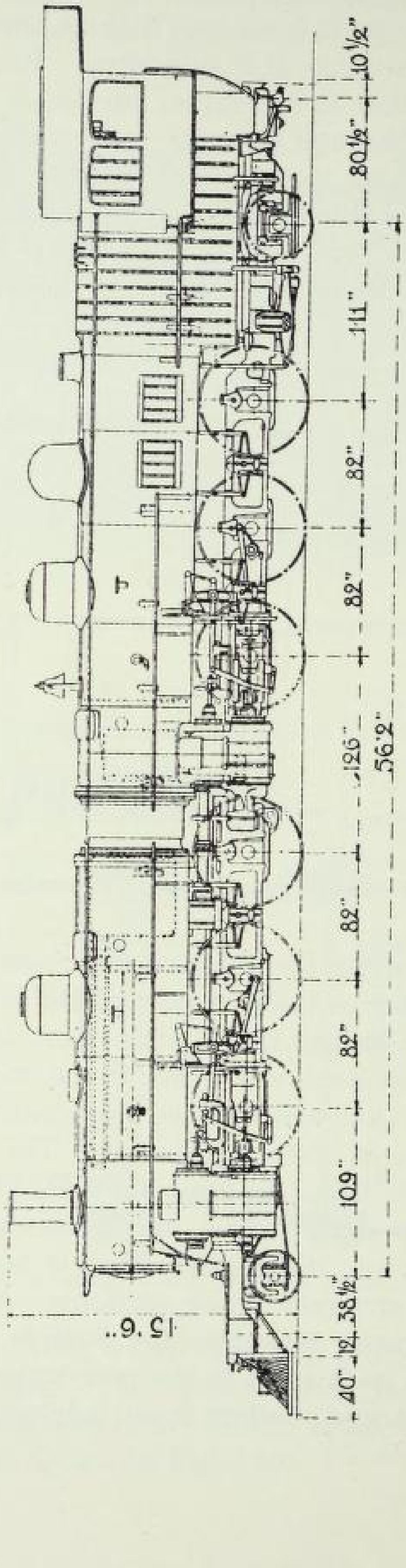


Fig. 172.—Atchison, Topeka and Santa Fé Ry. Mallet Locomotive with Articulated Boiler.

Locomotives with Articulated Boilers of the Atchison, Topeka and Santa Fé Ry.—Standard gauge (Fig. 172).

In 1910, this railway ordered from Messrs. Baldwin forty 2-6 + 6-2 *Mallets*, two of which had articulated boilers. Apart from this feature, the only differences between these two locomotives and the others was that the H.P. superheater (which is separate from the L.P. superheater) was brought back into the rear section of the boiler, and that the steam pipes were internal. Four similar locomotives were built in 1911.

The front section of the boiler is longer than the rear one. It is fixed in front, in the same way as in rigid locomotives, to the L.P. cylinder saddle above the casting which contains the steam passages. The rear end of the boiler rests on the intermediate cross member and can move longitudinally on the frames as it expands.

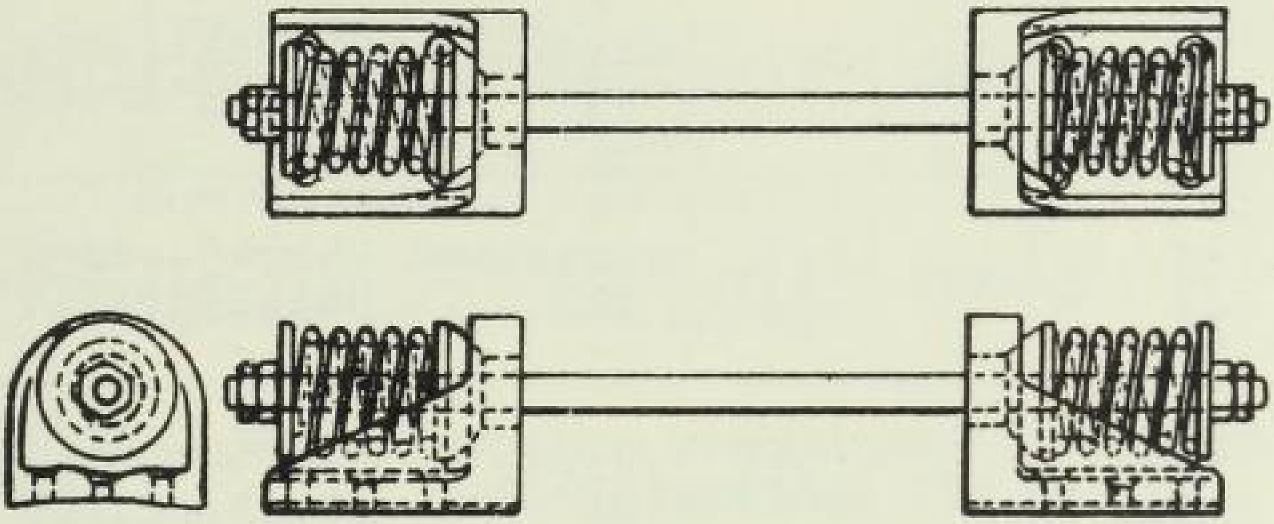


Fig. 173.—Centring Device, Baldwin Articulated Boiler.

The centring device shown in Fig. 173 ensures the alignment of the two parts of the boiler.

Some of the steam pipes are internal ; those which take the steam from the dome and those which lead from the H.P. superheater to the L.P. cylinders. Thence, the steam passes through horizontal pipes, which terminate in the intermediate box casting which supports the boiler and serves as a cross member for the front frames. As these pipes traverse the flexible section of the locomotive they are provided with universal joints.

After passing through the L.P. superheater, the steam reaches the L.P. cylinders by a pipe enclosed in a larger one at the top of the feed-water heater.

TABLE 93.—PRINCIPAL DIMENSIONS OF MALLET LOCOMOTIVES OF THE SOUTH AFRICAN RYS., 3 FT. 6 INS. GAUGE LINES

Type	2-6 + 6-0	2-6 + 6-0	2-6 + 6-0	2-6 + 6-0	2-6 + 6-2	2-6 + 6-2	2-6 + 6-2	2-6 + 6-2	2-6 + 6-2
Builder	American.	N. British.	N. British; Montreal.	Maffei.	N. British. —	N. British.	—	N. British.	American.
Date	1909	—	1916	—	—	—	—	1916	—
Former Company, if any	Natal Gov.	—	—	—	ME	—	MG	—	Cent. S.A.
Series	MA	MCI	MJ	MJI	4 Cyl. H.P.	MF	2 diam. drivers.	MH	—
Cylinders, diameter	28"	28½"	26"	26"	15"	28½"	28½" | —	31½"	18"
,, ,,	17½"	18"	16½"	16½"	15"	18"	— | 28"	20"	25½"
,, stroke	26"	26"	24"	24"	23"	26"	28" | 26"	26"	26"
Boiler, centre line	7' 4"	7' 6"	7' 9"	7' 9"	7' 9"	7' 9"	7' 11½"	7' 10½"	—
,, diameter	5' 4"	5' 8"	5' 1"	5' 2¾"	4' 1¾"	6' 0¼"	6' 0¼"	5' 10"	6' 1½"
,, pressure lbs. per sq. in.	200	200	200	200	170	200	200	200	200
Tubes, number	230	27–152	18–150	22–148	14–90	25–151	269	25–168	271
,, diameter	2¼"	5⅜"	5⅜"	5⅜"	5¼"	5⅜"	2¼"	5¼"	2¼"
,, ,,	—	2¼"	2"	2"	2¼"	2¼"		2¼"	—
,, length	17' 10½"	16' 2¾"	17' 0"	17' 0¼"	18' 6¼"	19' 10¼"	20' 4¼"	22'	20'
Heating surface, firebox . sq. ft.	125	154	133	136	115	156	160·5	250	157
,, ,, tubes ,,	2,422	2,060	1,780	1,906	1,340	695–1,765	3,223·0	2,961	3,168
,, ,, total ,,	2,547	2,214	1,913	2,042	1,455	2,616	3,383·5	3,211	3,325
Superheater ,,	None	580	462	556	346	738	None	618	None
Grate area ,,	40	42·5	40	39·8	32	49·5	49·5	53	49·5
Wheels, diameter	2' 4½"	2' 4½"	2' 4½"	2' 4½"	2' 6"	2' 4½"	2' 4½"	2' 4½"	2' 4½"
,, ,,	3' 9½"	3' 9½"	3' 6½"	3' 6½"	3' 6½"	3' 10"	4' 3" | 3' 10"	4' 0"	3' 10"
Wheelbase, rigid	8' 4"	8' 4"	8' 4"	8' 4"	8' 6"	8' 4"	8' 10" | 8' 4"	8' 8"	8' 4"
,, driving	25' 9"	25' 7"	25' 5"	25' 5"	25' 0"	25' 11"	26' 9"	26' 7"	25' 11"
,, total	33' 2"	23' 5"	32' 8"	32' 8"	38' 3"	40' 3"	41' 6"	43' 7"	40' 3"
,, loco. and tender	60' 2¾"	60' 0"	58' 11¼"	60' 8¼"	58' 5¼"	65' 8"	66' 9"	70' 10¼"	65' 5"
Overall height	68' 2¾"	68' 5¼"	67' 5¼"	68' 7¼"	66' 7¾"	73' 7¼"	74' 10¼"	75' 5"	—
,, length	12' 5¼"	12' 5 3/16"	12' 6"	12' 6"	12' 10"	12' 10⅜"	12' 10⅜"	12' 10"	—
Tractive efforts (75%) lbs.	44,810	47,000	38,170	38,170	31,230	45,900	45,200	53,750	48,100
Weight, maximum axle load	13–16	16–4	13–15	14–2	9–18	15–4	18–4	18–4	—
,, adhesive t.-cwt.	79–14	88–19	76–3	81–0	59–8	87–9	88–8	101–13	94–14
,, in service t.-cwt.	86–12	97–18	84–0	88–10	72–2	102–13	103–2	128–5	110–14
,, tender t.-cwt.	42–17	50–18	50–18	50–18	37–12	50–16	50–17	51–7	62–10
Tender, wheels	2' 6"	2' 9½"	2' 9½"	2' 9½"	2' 9½"	2' 9½"	2' 9½"	2' 9½"	—
,, water galls.	4,000	4,250	4,250	4,250	3,000	4,000	4,000	4,250	5,000
,, coal t.	10	10	10	6	10	10	—	10	10

Type MB is similar to MC, from which it does not differ much.
Type MD is similar to type MF, but has no superheater.

These locomotives, which are now obsolete, had the following ratios :—

$$\frac{\text{Adhesive weight}}{\text{Maximum tractive effort}} = 5{\cdot}16.$$

$$\frac{\text{Total weight}}{\text{Maximum tractive effort}} = 6{\cdot}39.$$

$$\frac{\text{Tractive effort} \times \text{Diameters, drivers}}{\text{Total heating surface}} = 1{,}175.$$

$$\frac{\text{Total heating surface}}{\text{Grate area}} = 69{\cdot}0.$$

$$\frac{\text{Direct heating surface}}{\text{Total heating surface}} = 6{\cdot}48 \text{ per cent.}$$

$$\frac{\text{Adhesive weight}}{\text{Total heating surface}} = 88{\cdot}0.$$

$$\frac{\text{Total weight}}{\text{Total heating surface}} = 108{\cdot}2.$$

$$\text{Volume equivalent simple cylinders} = 20{\cdot}6 \text{ cub. ft.}$$

$$\frac{\text{Total heating surface}}{\text{Equivalent volume simple cylinders}} = 175{\cdot}00.$$

$$\frac{\text{Grate area}}{\text{Equivalent volume simple cylinders}} = 2{\cdot}54.$$

Type 2.—Mallet Locomotives with Driving Wheels of Two Different Diameters

Shortly before the Great War, the South African Rys. put into service a *Mallet* in which the two sets of driving wheels had different diameters. Although, at first sight, this may seem a surprising innovation, yet there is really no fundamental objection to it. But is there any good reason for making the diameters different ? If we take the ordinary formula $\frac{pd^2s}{D}$, it is clear that whatever constant is used, the diameter of the driving wheels affects the results. Decreasing the diameter of the rear driving wheels, *i.e.*, those driven by the H.P. cylinders, obviously increases the developed tractive force of the rear truck.

On the other hand, there seems to be no difficulty in designing a locomotive with all driving wheels of the same diameter to give the same tractive force.

The experimental locomotive which we are now considering was built in America. It was fitted with a Street mechanical stoker, this being the first application of mechanical stoking on a narrow gauge railway.

The principal dimensions of *Mallet* locomotives on the South African Rys. are given in Table 93. The dimensions of this locomotive can therefore be readily compared with those of the other *Mallets* with all driving wheels of the same diameter. A comparison with the 2-6+6-2 *Mallet* supplied to the Central South African Ry. is of special interest.

Type 3.—Combined Rack and Adhesion Mallet Locomotives

It is possible to adapt the *Mallet* locomotive for use on rack railways, but this has not got beyond the design stage so far.

Messrs. Baldwin have kindly supplied us with some information concerning two of Mr. Henderson's designs for combined locomotives of the kind, the second of which, comprising a steam tender, is dealt with hereafter.

The first type (Fig. 174) is a tank locomotive which is, in effect, a rack-rail locomotive in which two pairs of wheels of each group can be driven by simple adhesion on those sections of the line where there is no rack.

The only articulated combined rack and adhesion locomotives that have hitherto been employed are the *Meyer-Kitson* and the *Esslingen* locomotives of the Transandine Ry.

Type 4.—The Triplex Locomotives

In the year 1912, George Henderson, then chief mechanical engineer of the Baldwin Locomotive Works, took out a patent for a steam-tender *Mallet*, in which the tender frame was joined to the locomotive main frame by a vertical hinge, in the same way that the main frame is joined to the frame of the leading truck.

The locomotive carriage was thus constantly attached to its pseudo-tender, without any gear or coupling apparatus, and the appellation *Triplex* was given to it, as there were three groups of driving wheels.

But as the tender is not detachable and forms part of the locomotive proper, it is more rational to consider the *Triplex* in the nature of a locomotive derived from the original *Mallet* than as a *Mallet* with a steam tender.

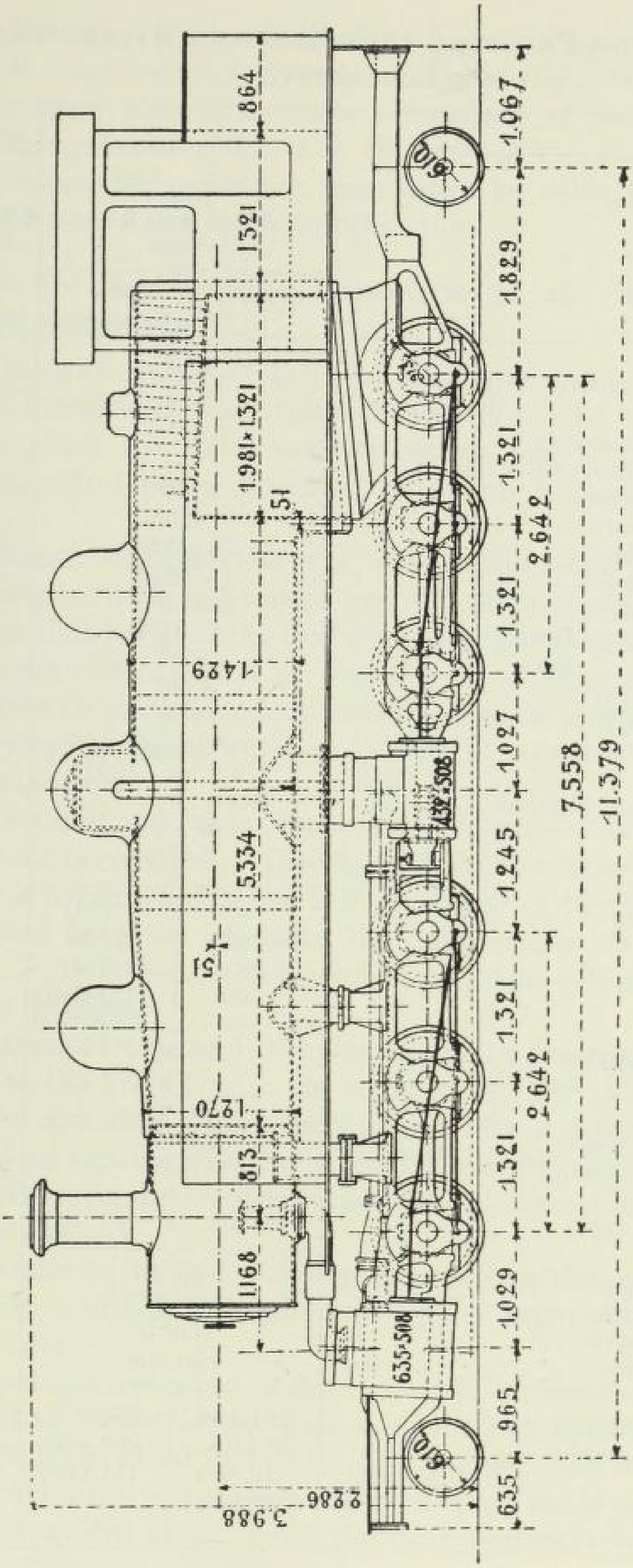


FIG. 174.—Henderson design for Mallet Combined Rack and Adhesion Locomotive.

TABLE 94.—PRINCIPAL DIMENSIONS OF MALLET TRIPLEX LOCOMOTIVES

Railway	Erie R.R.		Virginian Ry.
Locomotive No.	5104.		700.
Type	**2-8 + 8 + 8-2**		**2-8 + 8 + 8-4**
Builder	Baldwin.		Baldwin.
Date	1914	1916 (alterations).	1916.
Cylinders, diameter, H.P. (2) .	36″		34″
,, ,, L.P. (4) .	36″		34″
,, stroke (6)	32″		32″
Boiler, height of centre line . .	—		10′ 9″
,, diameter	7′ 10″		8′ 4″
,, pressure . . lbs./sq. in.	210		215
Tubes, number	53 + 326		65 + 325
,, diameter	5½″–2¼″		5½″–2¼″
,, length	24′ 0″		25′ 0″
Firebox, height, front . . .	7′ 3¼″		8′ 7⅝″
,, ,, back	5′ 8″		7′ 3⅞″
,, width	9′ 0″		9′ 0¼″
,, length	13′ 6″		15′ 8″
Heating surface :			
Firebox . . . . sq. ft.	272	(251)	359
Combustion chamber . ,,	108	—	—
Tubes . . . . . ,,	6,418		7,689
Arch tubes . . . . ,,	88	(74)	72
Total . . . . . ,,	6,886	(6,851	8,120
Superheater . . . . ,,	1,584	(1,584)	2,059
Grate area . . . . . ,,	90	(121·5)	108·2
Wheels, diameter	2′ 9½″		2′ 6″
,, ,, ...	5′ 3″		4′ 8″
,, ,, ...	3′ 6″		2′ 6″
Wheelbase, rigid	16′ 6″		15′ 3″
,, driving	7′ 6″		67′ 7″
,, total	90′ 0″	(91′ 0″)	91′ 3″
Overall, height	16′ 4″		16′ 10″
,, width	11′ 3″		12′ 0″
,, length	106′ 0″		—
Tractive force . . . . lbs.	160,000		146,000
Weight, adhesive . . . ,,	761,000	(766,300)	726,000
,, in service . . . ,,	853,050	(860,400)	844,000
Water . . . . U.S. galls.	10,600	(11,600)	13,000
Fuel . . . . . . lbs.	32,000	—	24,000

The Baldwin Works built 2-8 + 8 + 8-2 *Triplexes* for the Erie R.R., and others followed. A second line, the *Virginian*, adopted them also, with slight alterations of details and of wheel arrangement, which is in this case 2-8 + 8 + 8-4. But in both cases their place has been taken by other locomotives of greater power and lesser complication.

2-8 + 8 + 8-2 Triplex Locomotives of the Erie R.R.—Standard gauge (Fig. 175).

This railway had already in service some 0-8+8-0 *Mallets* when it introduced the triplex *Mallets* (2-8+8+8-2). These were in effect 2-8+8-0 locomotives to which were added 0-8+2 pseudo-tenders provided with two L.P. cylinders in front.

The frames are of the bar type, of vanadium alloy steel. The connection between the tender and the central wheel group is similar to that between the two wheel groups of the locomotive, but the drawbar, instead of working on a circular spigot, is fixed direct to the frame as in ordinary *Mallet* locomotives.

The cylinders, all of which are identical, are cast separately from their saddles.

The two H.P. cylinders are, as usual, located near the centre of the locomotive itself. The steam from the right-hand H.P. cylinder is led forward to the L.P. cylinders of the front-wheel group, that from the left-hand H.P. cylinder is led backward to the L.P. cylinders of the tender. All the cylinders are of the same diameter.

The exhaust from the L.P. cylinders of the front-wheel group is taken to the blast pipe in the usual way. The exhaust from the tender cylinders passes through a feed-water heater in the tender to an auxiliary funnel at the back of the tender.

The arrangement of the pipework in these locomotives should be noticed.

The header is divided. Steam passes from the superheater to the H.P. cylinders through outside pipes fitted with ball and sliding joints.

Two passages are cored in the H.P. cylinder saddle : the one on the left towards the rear ones, both through flexible receiver pipes having the usual ball and sliding joints. The steam from the front cylinders exhausts in the usual way, the pipe having a flexible joint ; the steam from the back cylinders traverses a

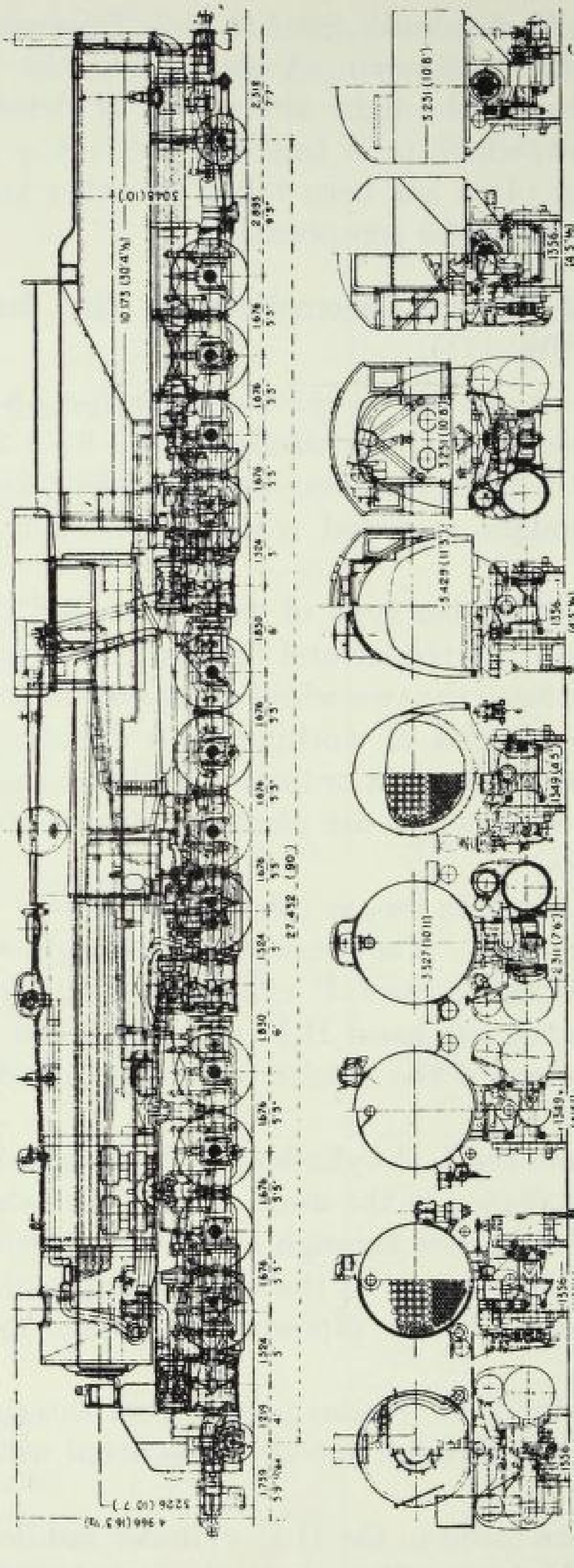


FIG. 175.—2-8-0 + 0-8-0 + 0-8-2 Triplex Mallet of the Erie R.R. (Standard Gauge.) Built by the Baldwin Locomotive Co.

feed-water heater before exhausting into a vertical 20-in. pipe situated at the rear of the tender. This feed-water heater consists of a longitudinal drum running along the lower portion of the tank. It contains thirty-one 20-in. tubes, $2\frac{1}{4}$ ins. in diameter.

The firebox is of the Gaines type. The brick arch is supported by six cross water tubes. Although the dimensions of the firebox are very great, it is prolonged by a combustion chamber. A Street mechanical stoker is fitted.

There is a fifty-three-elements Schmidt superheater in the tubes. Baker valve gear and Ragonnet steam reversing gear are fitted.

The driving wheels of locomotive and tender are all of the same diameter and have flanges ; the only bissels are situated at the front of the locomotive and at the rear of the tender and are alike.

Of course, the adhesive weight of the tender is variable, but the locomotives in question are used for banking service, where there are opportunities for frequent watering and fuelling. Hence, under full load almost 90 per cent. of the total weight is available for adhesion.

Apart from the features already noted, this locomotive does not comprise any novel elements. It is, rather, a case of the application, for a different purpose, of well-tried elements. This also applies to the tender, where the mechanism is similar to that of the locomotive. Many of the components are interchangeable with those of the Mikado locomotives of the same railway.

The principal ratios are as under :—

$$\frac{\text{Adhesive weight}}{\text{Tractive effort}} = 4{\cdot}76.$$

$$\frac{\text{Total weight}}{\text{Tractive effort}} = 5{\cdot}33.$$

$$\frac{\text{Adhesive weight}}{\text{Weight in service}} = 0{\cdot}89.$$

$$\frac{\text{Tractive effort} \times \text{diameter drivers}}{\text{Total equivalent heating surface}} = 1{,}088{\cdot}32.$$

$$\frac{\text{Total equivalent heating surface}}{\text{Grate area}} = 102{\cdot}9.$$

$$\text{Volume equivalent simple cylinders} = 51{\cdot}3 \text{ cub. ft.}$$

$$\frac{\text{Total equivalent heating surface}}{\text{Volume equivalent simple cylinders}} = 180{\cdot}48.$$

It is interesting to compare this locomotive with the Virginian Ry. 2-10+10-2 *Mallets*, which are the most powerful built so far. It will be noticed that the Erie's *Triplex* is only 1 ton heavier.

In trials made on the Susquehanna section, this locomotive drew a train of 250 loaded wagons. The total weight, exclusive of the locomotive, was 16,025 tons (16,300 metric tons), and the speed 13½ miles (22 km.) per hour.

The drawbar pull as measured by the dynamometer was 130,000 lbs. (59,000 kg.). Pushers were used at starting in order to avoid excessive stress on the drawgear.

In regular service, these locomotives were used for banking on the Susquehanna incline (1½ per cent.). Each took the place of three ordinary locomotives previously used as pushers.

In two later examples delivered in 1916, various modifications were made as the result of experience.

The Gaines brick wall was omitted and the grate extended to 13 ft. 6 ins. (4·11 m.), thus occupying the full length of the furnace and giving an area of 121·5 sq. ft. (11·2 sq. m.). The firebox has a 54-in. combustion chamber, with arch tubes from the bottom to the back sheet of the firebox, and a vertical wall across the throat of the combustion chamber.

The capacity of the tanks has been increased by 1,600 gallons, thus reaching 11,600 U.S. gallons, and necessitating the moving backwards of the rear truck by a distance of 1 ft. (30 cm.), bringing the total to 91 ft. (27·74 m.).

The sand boxes, previously placed on the forward cylinder saddle, are now situated on either side of the top of the boiler.

2-8 + 8 + 8-4 Triplex Locomotives of the Virginian Ry.— Standard gauge.

When describing the double-Decapod *Mallets* (2-10+10-2) of this railway, we referred to the great difficulties experienced in the working of the 14-mile section from Elmore to Clark's Gap. It was for use on this section that some Triplex *Mallets* were ordered. They were similar to those of the Erie R.R., except that there was a four-wheeled bogie at the rear of the tender instead of a bissel.* Furthermore, several details were modi-

* A test train of thirty-four 42-ft. wagons, weighing 2,310 tons (2,350 tonnes), with a 2-6 + 6-2 *Mallet* in front and the Triplex behind, climbed this section, 14 miles (22·5 km.) in length, in two hours. The Triplex used 6 tons 14 cwt. (6·8 tonnes) of coal, and 12,000 U.S. gallons of water.

fied in the light of experience. Notably, the evaporation was improved. Vanadium alloy steel was extensively used, for example, for all connecting rods, for the driving wheel axles, for the tyres, the springs, the cross-heads, the frames, and even the cylinders.

The most interesting ratios of this locomotive are :—

$$\frac{\text{Adhesive weight}}{\text{Tractive effort}} = 4{\cdot}4.$$

$$\frac{\text{Total weight}}{\text{Tractive effort}} = 5{\cdot}1.$$

$$\frac{\text{Tractive effort} \times \text{diameter of driving wheels}}{\text{Equivalent heating surface}} = 829{\cdot}3$$

$$\frac{\text{Equivalent heating surface}}{\text{Grate area}} = 103{\cdot}6.$$

$$\frac{\text{Firebox heating surface}}{\text{Equivalent heating service}} = 3{\cdot}2 \text{ per cent.}$$

$$\frac{\text{Equivalent heating service}}{\text{Adhesive weight}} = 64{\cdot}8.$$

$$\frac{\text{Total weight}}{\text{Equivalent heating service}} = 75{\cdot}3.$$

$$\frac{\text{Equivalent heating service}}{\text{Volume of cylinders}} = 241{\cdot}1$$

SUB-GROUP III. B.—MALLET LOCOMOTIVES WITH ALTERED CYLINDER ARRANGEMENTS.

The Mallet locomotive has four cylinders working compound, the H.P. cylinders acting on the rear rigid set of wheels, and the L.P. ones on the fore truck. This is an integral part of the system.

In spite of this, other arrangements have been tried, and for the sake of clearness we have grouped them here :—

Type 1.—Four single-expansion cylinders in the usual position.

Type 2.—The four cylinders, either simple or compound, are located at the centre of the locomotive.

Type 3.—The four cylinders are placed at the outer ends of the two sets of wheels.

After difficult beginnings, the first type has been entirely successful; not so the two latter, neither of which has got

TABLE 95.—PRINCIPAL DIMENSIONS OF FOUR-CYLINDER SINGLE-EXPANSION ARTICULATED LOCOMOTIVES

Gauge / Railway	3' Uintah Ry.	3' 6" South African Rys.	Standard. Pennsylvania Lines.		Standard. Great Northern Ry.	Standard. Chesapeake and Ohio R.R.		Standard. Denver Rio Gde. Western R.R.	Standard. Baltimore and Ohio R.R.	
Builder	Baldwin.	N, British.	Co.'s Works.	Amer. Loc.	Baldwin.	Amer. Loc.	Am. Loc. Co.	Am. Loc. Co.	Am. Loc. Co	Am. Loc. Co.
Date	1926.	1912.	1919.	1912.	1925.	1918–1927.	1924.	1927.	1918–1927.	1919–1926.
Type	**2-6 + 6-2**	**2-6 + 6-2**	**2-8 + 8-0**	**2-8 + 8-2**	**2-8 + 8-2**	**2-6 + 6-2**	**2-8 + 8-2**	**2-8 + 8-2**	**2-8 + 8-0**	**2-8 + 8-0**
Cylinders, diameter	15"	15"	20½"	27"	28"	20"	23"	26"	25"	24"
,, stroke	22"	23"	32"	28"	32"	32"	32"	32"	32"	32"
Boiler, centre line	—	7' 9"	—	—	—	9' 9⅛"	10' 0"	10' 7"	10' 5"	10' 1¾"
,, diameter	5' 4"	4' 1¾"	8' 0"	7' 3⅜"	9' 1"	8' 0"	7' 8"	8' 4 15/16"	7' 2⅛"	7' 7½"
,, pressure lbs. per sq. in.	210	170	205	160	210	210	205	240	200–225	210–225
Tubes, number	24–146	14–90	137–168	45–282	68–310	38–195	60–278	74–284	48–259	48–269
,, diameter	5⅜"–2"	5¼"–2¼"	5¼"–2¼"	5½"–2¼"	5½"–2¼"	5½"–2¼"	5½"–2"	5½"–2"	5½"–2¼"	5½"–2¼"
,, ,,	—	—	1¼"	1½"	—	—	—	—	—	—
,, length	18' 0"	18' 6½"	19' 0"	24' 8⅞"	24' 0"	24' 0"	24' 0"	24' 0"	24' 10¾"	23' 10¾"
Firebox, width	5' 6¼"	—	8' 0"	8' 0¼"	9' 0"	8' 0"	8' 0⅛"	9' 0"	8' 0¼"	8' 0"
,, length	8' 10⅛"	—	14' 0"	12' 0⅛"	12' 0"	9' 0"	17' 0⅛"	18' 2"	11' 0⅛"	11' 0¼"
Heating surface, firebox sq. ft.	—	115	531	405	432	344 + 24 *	467	560	398	341
,, ,, tubes ,,	—	1,340	6,125	5,712	6,710	4,806	3912 + 6,550	45+110 + 2,064	3,802 + 1,722	3,790 + 1,653
,, ,, total ,,	2,100	1,455	6,656	6,117	7,142	7,351	6,443	7,265	5,922	5,784
Superheater ,,	505	346	3,136	1,319	1,896	2,176	1,885	2,295	1,380	1,415
Grate area ,,	37·4	32	112	96·3	108	72·2	112·9	136·5	88	88·2
Wheels, diameter	—	2' 6"	2' 9"	2' 6"	2' 9"	2' 6"–3' 9"	2' 9"–3' 6"	2' 9"–3' 6"	2' 6"	2' 9"
,, ,,	42"	3' 6¼"	5' 2"	4' 8"	5' 3"	4' 8¼"	4' 9"	5' 3"	5' 3"	4' 10"
Wheelbase, rigid	7' 8"	8' 6"	17' 1½"	15' 6"	16' 3"	12' 0"	15' 9"	16' 9"	16' 6"	15' 6"
,, driving	—	25' 0"	45' 2½"	41' 10"	43' 7"	30, 6"	42' 0"	33' 6"	44' 0"	41' 2"
,, total	38' 3"	38' 3"	54' 8½"	57' 5"	58' 2"	48' 10"	58' 1"	62' 10"	53" 4'	50' 4"
,, loco. and tender	—	58' 5½"	97' 3¾"	88' 2"	96' 3½"	86' 11⅜"	99' 9½"	108' 0"	98' 3¼"	91' 2½"
Overall height	14' 2½"	12' 0"	16' 0"	15' 3¾"	—	15' 0"	15' 0"	16' 0½"	16' 0"	15' 6⅜"
,, width	10' 1"	—	—	—	—	—	10' 6"	11' 1½"	10' 1"	11' 4"
,, length	—	66' 7⅜"	—	—	—	68' 7"	70' 3¾"	74' 6⅛"	66' 4½"	—
,, loco. and tender	—	—	—	98' 3¾"	—	94' 7½"	109' 3⅜"	—	106' 4¾"	98' 6⅝"
Tractive force lbs.	42,100	31,230	135,000	99,144	127,500	81,240 (65%)	103,500	131,800 (70%)	108,000	118,800
Weight, adhesive lbs. or t.-cwt.	194,000	59–8	515,000	437,500	532,800	379,000	491,800	559,500	456,700	466,300
,, total ,, ,,	236,300	72–2	540,000	482,000	595,000	450,000	565,000	649,000	492,000	494,300
Tender, wheels, diameter	—	2' 9½"	2' 9"	2' 9"	—	2' 9"	2' 9"	2' 9"	2' 9"	2' 9"
,, water galls.	2,800 U.S.	3,000 Imp.	12,900 U.S.	9,000 U.S.	16,800	12,000	12,000	18,000	12,000	12,000
,, fuel lbs. or t.-cwt.	9,000 lbs.	6–0 U.S.	27·7 U.S.	30 U.S.	5,500 galls. U.S.	15 t. U.S.	15 U.S.	30 U.S.	20 U.S.	17·5
Weight in service lbs. or t.-cwt.	—	36 t. 12 cwt.	21,900	186,000	321,560	208,000	210,200	343,500	219,000	211,000

* Arch tubes, 3 ins. diameter; superheater tubes, 1 3/16 ins.

beyond the experimental stage, where their promoters have left them.

Type 1.—Single-expansion Articulated so-called Mallet Locomotives

From the first introduction of the *Mallet* type of locomotives endeavours were made to adapt it to simple working by the use of four H.P. cylinders.

M. Mallet himself always protested against this innovation, as it violated one of the essential principles of his design.

The *primâ facie* objection to the arrangement is that steam at full boiler pressure has to be taken through articulated pipe-work to the cylinders on the (mobile) truck. This was, indeed, a very great objection in earlier days. Various devices were utilised to get over it, but it was clear that some more drastic remedy would have to be sought for. Besides this, there was still another difficulty to be overcome: that of providing sufficient evaporative capacity for the supply of H.P. steam simultaneously to four cylinders. Larger fireboxes and superheating were provided, and experimental locomotives were tried on the Trans-Siberian, the South African and the Uintah Rys.; others are now in regular service on a number of other lines, such as the Great Northern Ry. (U.S.A.), the Chesapeake and Ohio R.R., the Baltimore and Ohio R.R., the Denver and Rio Grande Western, the Pennsylvania Lines, the Southern Pacific and the Northern Pacific, and include locomotives with the largest boilers in the world.

After the original abortive attempts, a definite step forward was accomplished by the Pennsylvania Lines when they built their 2-8 + 8-0 simple-admission locomotive in 1912. The War put a stop to further research, but as early as 1919 the Pennsylvania put into service a single-expansion *Mallet* with 50 per cent. limited cut-off. Steam consumption was not excessive, and the temperature was sufficient in the cylinders. Between times, articulated joints had been made steam-tight, so 200 lbs. boiler pressure was reinstated.

On the other hand, about this time, American practice ceased to favour compounding and reverted to two- and three-cylinder superheated locomotives. Rigid locomotives of greater power were turned out, and as they were necessarily more simple than articulated locomotives, they were better adapted to the general conditions to be met with on most roads. Besides which, they were, in many cases, more powerful than the *Mallets* which were used previously, and which they advantageously displaced.

But, on the other hand, the American railway companies were obliged to economise and could not afford to scrap their old *Mallets*. Some of them, such as the Chesapeake and Ohio R.R. and the Baltimore and Ohio R.R., rebuilt such old units as seemed worth the expense, and applied modern ideas concerning compounding. Results justified this policy, and since this time the problem of the single-expansion *Mallet* was solved.

We will therefore briefly examine their constructive particularities and give some information concerning the most noteworthy examples which have been put into service.

General Characteristics of Single-expansion "Mallets" (so-called)

Cylinders.—Owing to the great variation of pressure on the piston, due to the fact that steam admission takes place early in the cycle, all valve-gear bearing surfaces are ample. Auxiliary ports allow the introduction of small quantities of steam in the cylinders, whatever the position of the eccentric.

The diameter of the cylinders of recent single-expansion articulated locomotives varies from 23 to 26 ins., whereas the piston stroke has been standardised at 32 ins.

The following table gives the principal dimensions of the cylinders which have been substituted for former high and low pressure cylinders of compound *Mallets* converted to simple :—

Railway.	Type.	Diameter (Original).	Diameter (Converted).	Stroke.
Baltimore and Ohio .	2-8 + 8-0	26″ and 41″	24″	32″
,, ,, .	2-8 + 8-0	26½″ and 42″	25″	32″
Chesapeake and Ohio .	2-6 + 6-2	22″ and 35″	20″	32″
Great Northern . .	2-8 + 8-0	—	—	32″

Steam Piping.—This varies considerably even in such a limited field as that provided by recent single-expansion *Mallets*.

On the Chesapeake and Ohio and on the Southern Pacific two steam pipes are run back along the boiler, one on either side above the driving wheels to the rear cylinder steam chests. The exhaust steam is carried through other pipes alongside of them, so as to reach the smokebox.

A second system is in use on the Great Northern, where the exhaust steam flows into a Y-piece provided in the rear cylinder casting and is then carried forwards through a single flue placed on the axis of the locomotive. As a corollary, the exhaust takes place through two concentric openings instead of through tandem chimneys as in the former case.

Still another system is in use on the Denver and Rio Grande Western, where the header has two branch pipes. The right one is carried below the running board and joins a cross-over pipe which supplies steam to both the rear cylinders' steam chests. The left branch pipe supplies live steam to both front steam chests. The rear exhaust follows the running board along the left side of the locomotive. whereas the front exhaust follows piping generally similar to the live steam pipe. As the steam is at high temperature, the right-hand pipe has a socket joint immediately beyond the point where it curves rearwards. The front cylinders' steam pipe has a ball joint followed by an S-shaped portion ; the exhaust is similarly treated.

FIREBOX.—This has no special feature apart from its unusual size. In most cases it is from 8 to 9 ft. wide,* and its length reaches 16 ft. 4⅛ ins. on the Southern Pacific, 17 ft. on the Chesapeake and Ohio, and 22 ft. 2⅛ ins. on the Northern Pacific.

The length of the combustion chamber reaches 6 ft. 2½ ins. on the Denver and Rio Grande Western. When solid fuel is provided, as on the latter, a Gaines wall with 3 ins. arch tubes is used. Nicholson syphons are also applied.

BOILER pressures are higher than formerly. Thus the pressure of the B. and O.'s locomotives has been increased from 200 or 210 to 225 lbs. ; the Denver and Rio Grande Western's is 240 and the Northern Pacific's 250 lbs. per square inch.

The Chesapeake and Ohio's boiler is the longest constructed by the American Locomotive Co., and it fills the generous

* 9 ft. 6¼ ins. on the Northern Pacific.

loading gauge to such an extent that it has been found impossible to place the cylinders and accessory apparatus in their usual position. The Northern Pacific's is larger still, but this locomotive is still in the experimental stage.

It should be borne in mind that the size of the tubes has been standardised in America. They all are 24 ft. long, the diameter being $2\frac{1}{4}$ ins. for the fire tubes, $1\frac{1}{8}$ ins. for the superheater, and $5\frac{1}{2}$ ins. for the flues.

Indirect heating surface reaches 6,700 sq. ft. on the Denver and Rio Grande Western, and 6,800 sq. ft. on the Northern Pacific. The firebox and combustion chamber contribute another 560 and 610 sq. ft. respectively, and the superheater 2,295 and 3,219 sq. ft. The maximum grate area is 136 sq. ft. on the Denver and Rio Grande Western and 182 sq. ft. on the Northern Pacific.*

Wheels.—As these locomotives are never used for fast trains, the diameter of the driving wheels is kept between 4 ft. 9 ins. and 5 ft. 3 ins.

The front truck wheels are 2 ft. 6 ins. or 2 ft. 9 ins. diameter, with journals $6\frac{1}{2}$ or 7 ins. diameter, and 12 or 14 ins. in length. The rear truck wheels are 3 ft. 6 ins. or 3 ft. 9 ins., with journals $7\frac{1}{2}$ ins. maximum diameter.

The wheelbase is in direct relation with these figures.

In one case only has a booster been fitted to the locomotive, and in this case the journals are 9 ins. diameter.

As with rigid locomotives, trailing four-wheel trucks have appeared in the most recent single-expansion locomotives.

The Weight per axle follows the same progression as with rigid locomotives. The average weight on drivers is 50,000 lbs. on the Denver and Rio Grande Western, and 70,000 on the Northern Pacific.

The front truck axle bears as much as 52,000 lbs. (Southern Pacific), and the rear four-wheel truck 115,000 lbs. (Northern Pacific) with 60,000 lbs. on the booster axle.

The total weight of the Denver and Rio Grande Western's double-Consolidations is 649,000 lbs. in service and of the Northern Pacific's 715,000 lbs.—truly a stupendous amount.

All this allows these locomotives to exert up to 131,800 lbs. tractive force at 70 per cent. boiler pressure.

* The maximum on the Pennsylvania's rigid locomotives is 531 sq. ft.

TENDERS carry up to 16,800 U.S. galls. of water and 60,000 lbs. of fuel. Weight in service reaches 401,000 lbs. on the Northern Pacific. They run on four- or six-wheel bogies, with wheels 2 ft. 9 ins. in diameter. It is not surprising, under these conditions, that they should be fitted with tender-boosters or Bethlehem auxiliary engines.

Four-cylinder Single-expansion Articulated Locomotives of the Trans-Siberian Ry.—Gauge, 5 ft. (1·52 m.).

These locomotives, built in 1902, were the first four-cylinder simple *Mallets*. They were of the 2-4 + 4-0 type. *Mallet* locomotives were introduced on this system owing to the low limit of axle load necessitated by the light track. Unfortunately, the results obtained with these locomotives did not answer to expectations. This was due chiefly to the difficulties which, at that time, were experienced in keeping the articulated pipe system tight against steam at full boiler pressure.

2-6 + 6-2 Four-cylinder Single-expansion Articulated Locomotive of the South African Rys.—Gauge, 3 ft. 6 ins. (1·067 m.).

This locomotive had a superheater. Although, in earlier days, it was not practicable to take H.P. superheated steam through an articulated pipe system, it became possible to do so and to maintain steam tightness. Furthermore, superheating compensates, to some extent, for the loss of heat energy due to the length of the path which the steam has to travel.

This locomotive went through a series of comparative trials with similar *Mallets* of the ordinary compound type, but has not been duplicated.

2-6 + 6-2 Four-cylinder Single-expansion Articulated Tank Locomotive, Uintah Ry.—3 ft. gauge (Fig. 176).

When describing articulated geared locomotives, we have had occasion to quote this interesting mountain railway, which is situated in Western Colorado and Eastern Utah. It has constant gradients, one of which, 4 miles in length, is a continuous climb at the rate of 7·5 per cent. and numerous curves, the sharpest of which are 66 degrees, where the rails are spread $\frac{7}{8}$ inch.

In spite of these unusual conditions, the Baldwin Locomotive Works, drawing on the experience gained by them with articu-

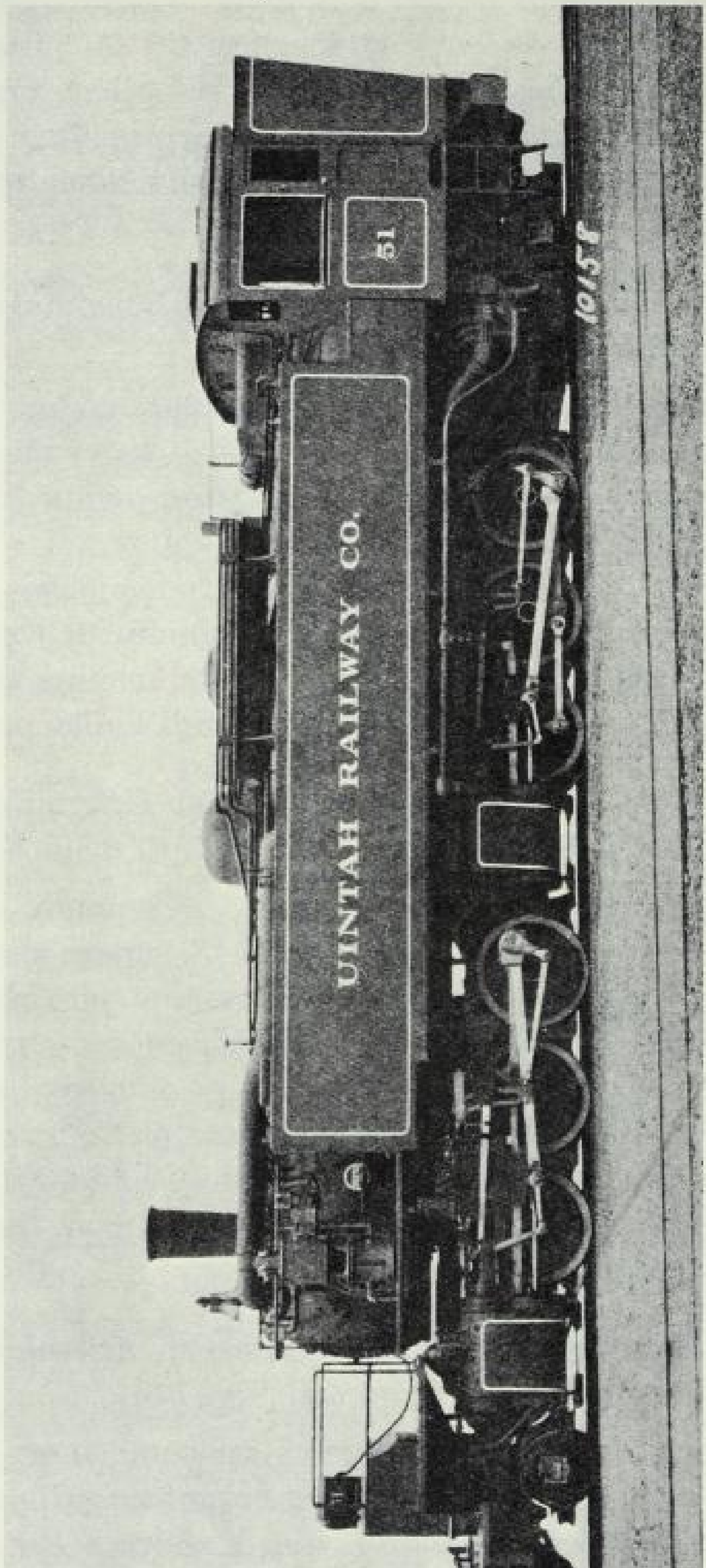


FIG. 176.—Single-expansion Tank Articulated Locomotive, Uintah Ry.
(3 ft. Gauge.)
Built by the Baldwin Locomotive Works.

lated locomotives used in logging service, supplied in the year 1926 an articulated *Mallet* engine, which has since been repeated, and which presented an able advance on the locomotive power previously used on the railway. Its principal dimensions are as follows :—

TABLE 96.—UINTAH RAILWAY ARTICULATED TANK LOCOMOTIVE

Cylinders (4) :		Tubes, number .	24+146
Diameter . .	15″	,, diameter .	$5\frac{3}{8}$″–2″
Stroke . .	22″	Wheels, diameter .	2′ 6″ and 3′ 6″
Boiler. diameter .	64″	Wheelbase, rigid .	7′ 8″
,, pressure .	210 lbs.	,, total .	38′ 3″
Firebox, width .	$66\frac{1}{4}$″	Tank capacity .	2,800 U.S. galls.
,, length .	$106\frac{1}{16}$″	Fuel capacity .	9,000 lbs.
Water heating surface . . .	2,100 sq. ft.	Tractive force .	42,100 lbs.
		Weight, adhesive .	194,500 lbs.
Superheating surface	505 sq. ft.	,, total .	236,300 lbs.
Grate area . .	37·4 sq. ft.	Ratio of adhesion .	4·62

Apart from the unusual employment of four H.P. cylinders on tank *Mallets*, the special arrangements applied, owing to the stringent conditions of operation, are of particular interest.

The radius bar joining the frames is connected to the front frame by the usual horizontal pin and to the back one by a ball-jointed connection with a vertical pin, which is seated in the back cylinder saddle, thus providing vertical and horizontal flexibility. The leading truck is of the constant resistance type and can swing $6\frac{3}{4}$ ins. on each side ; it is equalised with the driving wheels of the front unit. The back truck (bissel) is equalised with the rear group of drivers. The middle pairs of driving wheels have no flanges.

Live steam is conveyed from the header to the near cylinders through two external pipes which pass out through the top of the smokebox and are heavily lagged. These pipes branch just above the steam chest, and these branches are united in a single flexible pipe placed on the centre line, and which carries live steam to the cylinders of the front unit. The exhaust from the front cylinders passes through a flexible pipe, which is placed on the centre line ; that from the rear cylinders, through external rigid pipes. These exhaust in two semi-circular rings which surround the central circular tip of the front cylinder exhausts.

Provision has been made for eventual conversion of this tank locomotive into a locomotive with separate tender, should it be found desirable to do so.

In practice, the *Mallet* hauls, on the 5 per cent. grades, twice the tonnage previously hauled by the geared locomotives, and in little more than half the time, which represents an important reduction in cost per train-mile and an increase in track capacity. Tonnage rating is as follows :—

Section.	Maximum Grade.	Tonnage.
Rack to Atchee	2·9 per cent.	525
Atchee to Baxter Pass	7·5 ,, ,,	145
Watson to Dragon	1·1 ,, ,,	1,150
Dragon to Wendella	3·34 ,, ,,	525
Wendella to Baxter Pass	5·0 ,, ,,	240

2-8 + 8-2 Four-cylinder Single-expansion Articulated Locomotives of the Pennsylvania R.R.—Standard gauge.

In this experimental locomotive, built in 1912, the boiler pressure was only 160 lbs. per square inch (11·25 kg. per square centimetre), the object being to render it easier to keep the articulations of the pipe work steamtight. The output of the boiler was increased by the provision of a Schmidt superheater in the tubes.

A wagon-top boiler of unusual dimensions was needed in order to maintain the steam supply to the four H.P. cylinders. The firebox had arch tubes in accordance with the usual practice of the builders, the American Locomotive Co. These brought the total heating surface up to 6,114 sq. ft. (568 sq. m.) exclusive of the superheater surface, which was 1,257 sq. ft. (116·8 sq. m.).

The chief dimensions of the firebox, in which bituminous coal is used, are as follows :—

Length	3·661 m.	14′ 0″
Width	2·38 m.	8′ 0″
Thickness of plates, crown	11 mm.	$\frac{7}{16}$″
,, ,, sides	11 mm.	$\frac{7}{16}$″
,, ,, rear	11 mm.	$\frac{7}{16}$″
,, ,, tube plate	12·5 mm.	$\frac{1}{2}$″
Water space, front	140 mm.	$5\frac{1}{2}$″
,, ,, sides and rear	127 mm.	5″

Radial stay bolts are used. Rocking grates are fitted and the exhaust pipe is duplicated.

The following are the chief dimensions of the wheels and axles :—

Wheels.	Driving.	Trucks.	Tender.
Diameter on tread	4′ 8″	2′ 6″	2′ 9″
,, of centres . . .	4′ 2″	—	—
Journals	12″ × 16″	6½″ × 12″	6½″ × 12″

The diameter of the piston rods is 4 ins. (0·108 m.). Piston valves are used.

The tender is carried on 13 ins. (0·330 m.) frames. The usual American U-shape water tanks are provided. The floor of the coal bunker is inclined to facilitate firing.

2-8 + 8-0 Four-cylinder Single-expansion Articulated Locomotive of the Pennsylvania R.R.

Although the first trials of the four-cylinder simple *Mallet* on this line were not satisfactory, further trials were made with the object both of simplifying the *Mallet* locomotive and of avoiding the necessity for very large cylinders on the front truck, for the development of the compound *Mallet* is necessarily limited by the great size of the L.P. cylinders.

This locomotive is a natural development of the 2-8+8-0 *Mallet* of the same railway. It was ordered by the U.S.A. Railway Administration, in 1919, from designs prepared by the Company under the supervision of the above administration. It follows standard modern practice, so there is no need to dwell on construction details, except to state that the cut-off is limited to a maximum of 50 per cent. Large cylinders do not, therefore, make undue demands on the boiler, the steam is reasonably expanded before exhaustion, and the temperature in the cylinders remains high.

All bearing surfaces of the motion are ample, as there is a large fluctuation in pressures on the piston when cut-off takes place early in the working cycle.

Auxiliary ports, which communicate with the main ports, are cut through the bushing of the valve chamber to enable a small amount of steam to pass into the cylinder at any position of

TABLE 97.—PRINCIPAL DIMENSIONS OF MALLET LOCOMOTIVES OF THE PENNSYLVANIA R.R.

Co.'s class	CC 1 s.	CC 2 s.	HC 1 s.	HH 1 s.
Builder	Baldwin.	Baldwin.	Co.'s Shops.	American.
Date	1913.	—	1919.	1912.
Type	**0-8 + 8-0**	**0-8 + 8-0**	**2-8 + 8-0**	**2-8 + 8-2**
Cylinders, diameter	23″	26″	4 H.P. cyl.	4 H.P. cyl.
,, ,,	39″	40″	$30\frac{1}{2}$″	27″
,, stroke	30″	28″	32″	28″
Boiler, centre line	10′ 6″	—	—	—
,, diameter	6′ $10\frac{1}{4}$″	7′ $2\frac{1}{8}$″	8′ 0″	7′ $3\frac{1}{8}$″
,, pressure	205	225	205	160
Tubes, number	36+259 +144	52+209 +208	137+168 +284	45+282 +180
,, diameter	$5\frac{1}{2}$″–$2\frac{1}{4}$″	$5\frac{1}{2}$″–$2\frac{1}{4}$″	$5\frac{1}{2}$″–$2\frac{1}{4}$″	$5\frac{1}{2}$″–$2\frac{1}{4}$″
,, ,,	$1\frac{1}{2}$″	$1\frac{1}{2}$″	$1\frac{1}{2}$″	$1\frac{1}{2}$″
,, length	22′ 11″	21′ 10″	19′ 0″	24′ $8\frac{7}{8}$″
Firebox, width	8′ 0″	8′ 0″	8′ 0″	8′ $0\frac{1}{4}$″
,, length	9′ 9″	12′ 0″	14′ 0″	12′ $0\frac{1}{8}$″
H.S. Firebox . sq. ft.	237	378	531	404
Arch tubes ,,	32	—	—	—
Tubes ,,	4,684	4,635	6,125	5,712
Total ,,	4,953	5,013	6,656	6,116
Superheater ,,	988	1,379	3,136	1,319
Grate area ,,	78	96	112	963
Wheels, diameter	None.	None.	2′ 9″	2′ 6″
,, ,,	4′ 8″	4′ 3″	5′ 2″	4′ 8″
,, ,,	None.	None.	None.	2′ 6″
Wheelbase, rigid	15′ 0″	14′ 9″	17′ $1\frac{1}{2}$″	15′ 6″
,, driving	39′ 6″	40′ $1\frac{1}{2}$″	45′ $2\frac{1}{2}$″	41′ 10″
,, total	39′ 6″	40′ $1\frac{1}{2}$″	54′ $8\frac{1}{2}$″	57′ 5″
,, loco. & ten.	71′ $10\frac{1}{4}$″	78′ $8\frac{3}{4}$″	97′ $3\frac{3}{4}$″	88′ 2″
Overall height	15′ 3″	—	—	—
,, width	10′ 8″	—	—	—
,, length	87′ $6\frac{3}{4}$″	—	—	98′ $3\frac{3}{4}$″
Tractive force . lbs.	82,200*	99,792*	135,000†	99,150‡
Weight, empty ,,	349,100	410,000	—	425,700
,, adhesive ,,	408,700	458,150	515,000	437,500
,, in service ,,	408,700	458,150	540,000	482,500
Tender :				
Wheels, diameter	2′ 9″	2′ 9″	2′ 9″	2′ 9″
Water . U.S. galls.	9,000	9,600	12,900	9,000
Fuel . lbs.	28,000	39,300	27,700	30,000
Weight, empty ,,	83,400	86,800	83,800	81,400
,, in service ,,	186,300	206,100	219,900	186,000

* $\frac{1.7\ Pc^2S}{\left(\frac{c^2}{C^2}+1\right)D}$ † $\frac{1.5\ PC^2S}{D}$ ‡ $\frac{1.7\ PC^2S}{D}$

the crank. This enables the engine to move even when the main ports are blind owing to the position of the cranks.

The following ratios are of interest :—

$$\frac{\text{Adhesive weight}}{\text{Tractive force}} = 4.$$

$$\frac{\text{Total weight}}{\text{Tractive force}} = 4{\cdot}26.$$

$$\frac{\text{Equivalent heating surface}}{\text{Grate area}} = 101{\cdot}43.$$

$$\frac{\text{Diameter, drivers} \times \text{tractive effort}}{\text{Equivalent heating surface}} = 736{\cdot}8.$$

$$\frac{\text{Firebox heating surface}}{\text{Equivalent heating surface}} = 4{\cdot}67 \text{ per cent.}$$

$$\frac{\text{Adhesive weight}}{\text{Equivalent heating surface}} = 232.$$

$$\frac{\text{Total weight}}{\text{Equivalent heating surface}} = 246.$$

$$\frac{\text{Equivalent heating surface}}{\text{Volume equivalent cylinders}} = 854.$$

$$\frac{\text{Grate area}}{\text{Volume equivalent cylinders}} = 8{\cdot}4.$$

Principal dimensions, together with those of this railway's other *Simple Mallets*, are given in Table 97.

2-8 + 8-2 Four-cylinder Single-expansion Articulated Locomotives of the Chesapeake and Ohio R.R.—Standard gauge (Figs. 177 and 178).

In the Alleghanys, one of the important sections of this railway includes a tunnel in which the loading gauge is reduced below that of the rest of the system. The largest compound *Mallet* which could operate through it was a 2-6+6-2 *Mallet*. The train loads were therefore limited to the capacity of this type. However, there was a demand for heavier train loads and higher speed. Unfortunately, the maximum width which the loading gauge of the tunnel permitted severely restricted the diameter of the L.P. cylinders. A design with four H.P. cylinders and an increased boiler pressure had therefore to be adopted.

As the loading gauge limited the diameter of the boiler, the heating surface needed had to be obtained by increasing its

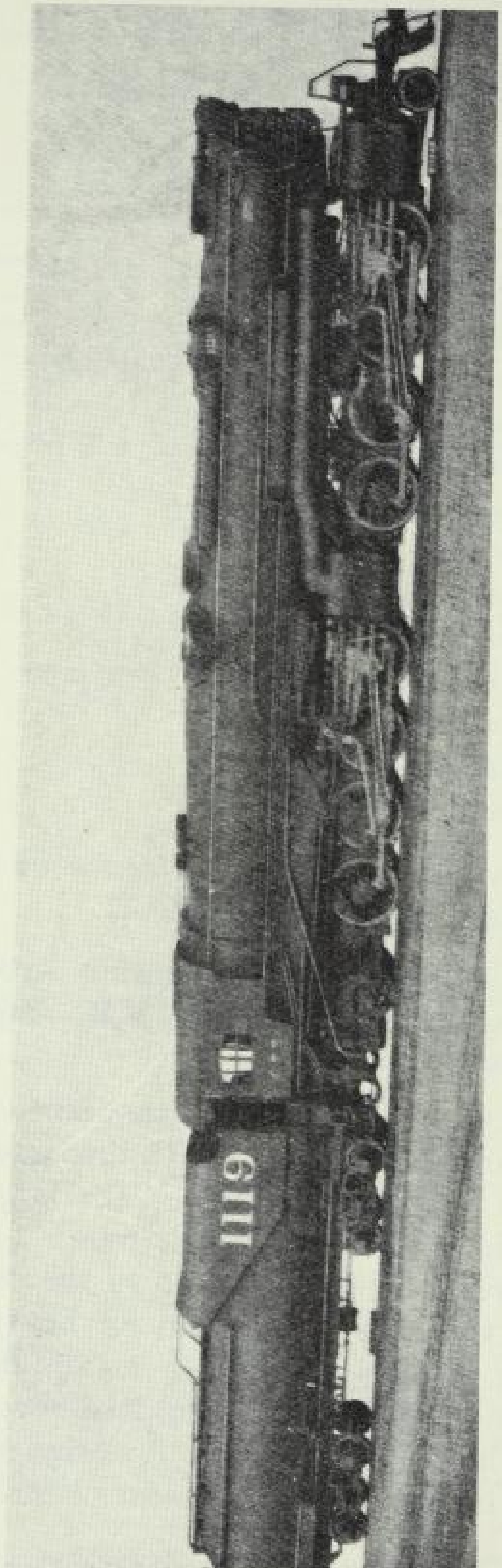


FIG. 177.—2-8 + 8-2 Single-expansion Articulated Locomotive, Chesapeake and Ohio R.R. (Standard Gauge.)

length. Indeed, the boilers of these locomotives are the longest so far built by the American Locomotive Co. They have no less than five courses exclusive of the firebox.

The locomotive so completely fills the loading gauge that various contrivances have had to be adopted in order to accommodate the accessories. Thus, the brake cylinders are located in front of the smokebox. The dome only projects 5½ ins. (0·140 m.), and the funnel 11½ ins. (0·293 m.) above the top of the boiler. In actual fact there are two funnels, one behind the other, each taking the exhaust from one pair of cylinders.

According to the Coles formula, the combined horse-power of the cylinders is 3·902 (3·954 French) and the horse-power of the boiler is 3,767 (3,726 French), *i.e.*, 94·2 per cent., but to the latter figure must be added the effect of two Elesco feedwater heaters.

These locomotives are fitted with Duplex mechanical stokers which can fire 12·682 lbs. (5·753 kilos) per hour, being 3¼ lbs. per rated horse-power-hour (1·46 kilos per French horse-power-hour). This is equivalent to 112·3 lbs. of coal per hour per square foot of grate area (584 kilos per square metre).

Owing to the lack of space, it was not possible to set the cylinders symmetrically with the centre line of the locomotive, for, in order to accommodate the receiver pipe, one of the castings is 1 ft. (0·205 m.) wider than the other.

The path of the steam is as follows : after leaving the superheater, the steam passes through two pipes in the smokebox into two other pipes of 9⅝ ins. (0·244 m.) diameter, which run outside the boiler above the driving wheels of the leading truck until they reach the cylinders of the trailing truck. Thence the steam leaves by a Y pipe forming part of the cylinder casting, and thus reaches the front cylinders. This pipe has universal joints at both ends and runs along the centre line of the locomotive, immediately above the coupled axles. The steam reaches the piston valves by another Y conduit formed in the casting of the front cylinders, similar to that in the rear cylinders. All these pipes have universal or telescopic joints, and are fully lagged.

The exhaust pipes from the rear cylinders run parallel to the steam pipes and have universal joints.

The tender is of the Vanderbilt type.

In view of the novel design and the exceptional arrangements

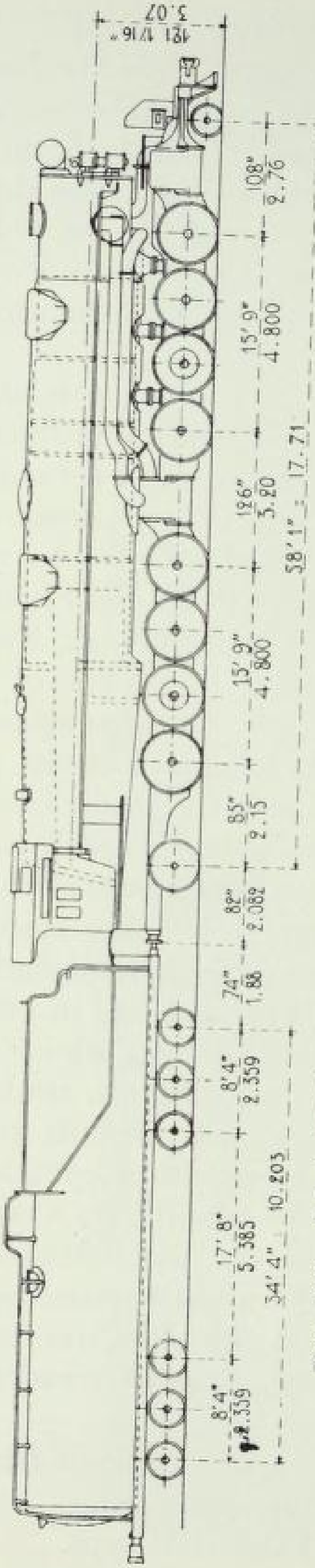


FIG. 178.—2-8 + 8-2 Single-expansion Articulated Locomotive, Chesapeake and Ohio R.R. (Standard Gauge.)

of these locomotives, the following ratios will be of interest (metrical dimensions):

$$\frac{\text{Adhesive weight}}{\text{Total weight}} = 86{\cdot}9 \text{ per cent.}$$

$$\frac{\text{Adhesive weight}}{\text{Tractive force}} = 4{\cdot}91.$$

$$\frac{\text{Total weight}}{\text{Heating surface (including superheater)}} = 330.$$

$$\frac{\text{Total weight}}{\text{Horse-power of cylinders}} = 147{\cdot}1.$$

$$\frac{\text{Firebox heating surface}}{\text{Grate area}} = 4{\cdot}40.$$

$$\frac{\text{Firebox heating surface}}{\text{Heating surface (excluding superheater)}} = 7{\cdot}72 \text{ per cent.}$$

$$\frac{\text{Superheater heating surface}}{\text{Heating surface (excluding superheater)}} = 29{\cdot}25 \text{ per cent.}$$

Further locomotives of this type have been supplied by the Baldwin Locomotive Works. They differ from those we have just described in details only.

They operate on 20-degree curves and on 1·5 per cent. grades.

2-6 + 6-2 Single-expansion Articulated Locomotives of the Chesapeake and Ohio R.R.—Standard gauge.

Owing to the successful results obtained in service by their double-Consolidation simple *Mallets*, the Chesapeake and Ohio R.R. has converted a number of compound *Mallets* to simple locomotives (in 1927).

The locomotives concerned had been built by the American Locomotive Co. in 1918, and had cylinders 22 ins. and 35 ins. by 32 ins., and a tractive force of 94,000 lbs. simple and 74,200 lbs. compound.

As simple locomotives with four H.P. cylinders 20 ins. by 32 ins., the tractive force is 81,240 lbs. The boiler pressure has been reduced from 210 to 200 lbs. At the same time, the old boilers have been provided with superheaters and the heating surface increased, which has necessitated the use of tenders with a larger water capacity (this has been increased from 9 to 12,000 U.S. gallons). In spite of these alterations, the weight of the locomotive is lesser than formerly, and the piping is simplified.

Table 98.—Simple and Compound Mallets of the Chesapeake and Ohio R.R.

Co.'s class	H.4.	H.4a.	H.6.	H.7a.
Builder	American.	American.	American.	Baldwin.
Date	1918.	1918/1927.	1923.	1926.
Type	**2-6 + 6-2** Compound.	**2-6 + 6-2** Experi-mental.	**2-6 + 6-2** Compound.	**2-8 + 8-2** Simple.
Cylinders, diameter	22″	20″	22″	22″
,, ,,	35″	—	35″	—
,, stroke	37″	32″	32″	32″
Tubes, number	234–36	195–38	234–36	276–60
,, diameter	2¼″–5½″	2¼″–3½″	2¼″–5½″	2¼″–5½″
,, length	24′ 0″	24′ 0″	24′ 0″	24′ 0″
,, sup. tubes	$1\frac{7}{16}$″	$1\frac{3}{16}$″	$1\frac{7}{16}$″	—
,, arch tubes	4 of 3″	4 of 3″	4 of 3″	None.
Firebox, width	96″	96″	96″	96¼″
,, length	108″	108″	108″	204⅛″
Boiler, centre line	9′ 9″	9′ 0⅛″	9′ 9⅛″	12′ $1\frac{1}{16}$″
,, diameter	89¼″ front	87¼″	89¼″	92″
,, pressure, lbs. per sq. in.	200	210	210	205
Heating surface:				
Firebox . sq. ft.	345	344·4	345	467
Tubes ,,	4,532	4,806·6	4,532	5,976
Arch tubes ,,	24	24·0	24·0	—
Comb. chamber ,,	None.	None.	None.	Incl. fireb.
Total ,,	4,901	7,351·3	4,901	6,443
Superheater ,,	—	2,176·3	—	1,885
Grate area ,,	72·2	72·2	72·2	112·9
Wheels, diameter	30″	30″	30″	30″
,, ,,	51¼″	56¼″	56¼″	57″
,, ,,	45″	45″	45″	42″
Wheelbase:				
Rigid	10′	10′	10′	10′ 9″
Driving	30′ 6″	30′ 6″	30′ 6″	42′ 0″
Total	48′ 10″	48′ 10″	48′ 10″	58′ 1″
Locomotive & tender	82′ 5¾″	88′ 11¾″	87′ 10⅜″	105′ 5″
Overall Height	15′ 0⅛″	15′ 0⅛″	15′ 0⅛″	15′
,, Length, loco.	61′ 1½″	—	60′ 9½″	—
,, ,, Loco. & tender	87′ 7¼″	94′ 7½″	96′ 7⅞″	118′ 1⅛″
Tractive force, Simple lbs.	94,000	81,240	98,700	103,500
,, ,, Compound lbs.	74,200	None.	77,910	None.
Weight, adhesive ,,	367,000	379,000	378,500	491,800
,, total ,,	437,000	450,000	449,000	569,800
,, tender ,,	176,900	208,000	209,800	300,000
Tender:				
Wheels, diameter	30″	30″	33″	33″
Water . U.S. galls.	9,000	12,000	12,000	16,000
Coal . U.S. tons	15		15	20

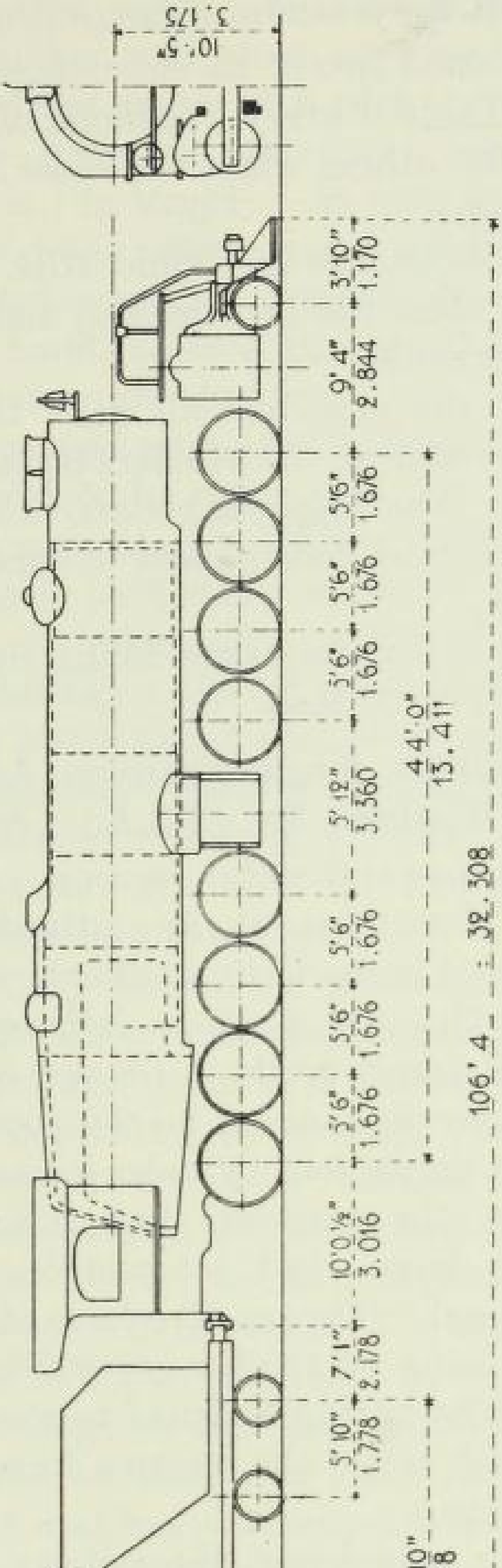


Fig. 179.—2-8 + 8-2 Simple Admission Articulated Locomotive, Baltimore and Ohio R.R. (Standard Gauge.)

2-8 + 8-0 Single-expansion Articulated Locomotives of the Baltimore and Ohio R.R.—Standard gauge (Fig. 179).

This line has converted two of its older classes of compound to simple *Mallets*. There is every likelihood of similar conversions taking place for others when the older locomotives are worth the expenditure.

In this case, the Baltimore and Ohio R.R. has thus dealt with its EL–5 1917 class (58 ins. drivers) and with its EL–6 1918 class (63 ins. drivers).

In the first type, the cylinders all have the same stroke (32 ins.), but the diameter of all cylinders is 24 ins. instead of 26 ins. and 41 ins. The original boilers, which had superheaters, have been retained, but the new standard double-draft chimney is provided.

In the second type all cylinders are 25 ins. by 32 ins. instead of 26½ ins. and 42 ins. by 32 ins.

2-8 + 8-2 Four-cylinder Single-expansion Articulated Locomotives of the Great Northern Ry. (U.S.A.).—Standard gauge.

The important trans-continental section of this railway crosses the Rocky Mountains at an altitude of 5·213 ft. (1·588 m.). The ascent is made by gradients which, although not excessive, are sufficiently steep to impose limitations on train loads. The maximum grade is 1·8 per cent.* In 1912, this railway put into service some 2-8+8-0 compound *Mallets*, which it converted to simple four-cylinder locomotives in 1924.

In the meanwhile, the road-bed had been strengthened, which allowed some large rigid locomotives of the 2-10-2 Santa Fé type to be used. The tractive force of these exceeded that of the *Mallets*, being 87,100 lbs. (39,500 kgs.). This was still further increased by fitting boosters to the latest locomotives of this type, which raised the tractive force at starting to 100,000 lbs. (43,350 kgs.).

As a result of their experience, the railway administration decided that locomotives with a big axle load were admissible, and also that large four-cylinder simple *Mallets* were desirable

* The new *Mallets* are used on the section from Cut Bank to Whitefish (Montana), 128 miles (206 km.) in length. The ruling gradient is 1 per cent. westwards and 0·8 per cent. eastwards, except for a section 13·8 miles (22·2 km.) in length, where it is 1·8 per cent., and where banking engines are used. The smallest curve is 10 degrees (178 m.) radius.

if boilers of sufficient steaming capacity could be provided. These conclusions led to the construction of the *Mallets* which we are now describing, and whose tractive force is 47 per cent. more than that of the Santa Fé 2-10-2 locomotives.

These *Mallets* have an enormous combustion chamber, 6 ft. 0 in. (1·72 m.) in length. As they are oil-fired, no brick arch is necessary, but as they may eventually be converted to coal-firing, arch tubes and a brick arch are actually installed.

On the other hand, a brick flash wall is placed across the throat of the combustion chamber.

An internal dry pipe connects the throttle valve of the main dome (on the third boiler ring) with the superheater header. A steam pipe connects this header with another, which is situated at the lower part of the smokebox and from which outside pipes lead, on either side, to the rear cylinders. Their exhaust passes through a pipe placed outside the left-hand side of the boiler and which terminates in an annular opening which surrounds the exhaust of the front cylinders.

The front cylinders receive live steam from the smokebox lower header by means of a centrally located pipe having three slip and ball grease-lubricated joints.

The vertical hinge pin of the articulated frame connection is held rigid in the rear cylinder saddle, and is 6 ins. in diameter; it is case-hardened, and works in a bushed seating in the saddle.

The boiler is supported by a single bearing with a liberal bearing area which allows a rocking movement of the frames. The complicated centring device formerly employed has been dispensed with, as its complication was not compensated by the services it rendered. Indeed, its advantages are more theoretical than practical.

The upper castings of the rear cylinder saddle and of the bearer are riveted to the boiler; the liners are outside the shell. The front unit has a three-point suspension.

The tender is semi-elliptical and contains oil fuel, though a stoker conveyor has been fitted in view of subsequent conversion of these locomotives to coal-firing.

These locomotives are used to haul 4,000 short ton trains up 0·8 grades. With a 2-8+8-0 helper, they handle the same load up 1·8 per cent. grades.*

* In winter the load is reduced to 3,800-tons, which is, at that time, the capacity of the helper to Walton.

Principal ratios are :—

$$\frac{\text{Adhesive weight}}{\text{Total weight}} = 89{\cdot}5 \text{ per cent.} \qquad \frac{\text{Firebox heating surface}}{\text{Grate area}} = 4{\cdot}00.$$

$$\frac{\text{Adhesive weight}}{\text{Tractive force}} = 4{\cdot}09. \qquad \frac{\text{Firebox heating surface}}{\text{Tubes heating surface}} = 6{\cdot}04.$$

$$\frac{\text{Total weight}}{\text{Combined heating surface}} = 6{\cdot}57. \qquad \frac{\text{Superheating surface}}{\text{Tubes heating surface}} = 26{\cdot}5.$$

$$\frac{\text{Tractive force}}{\text{Combined heating surface}} = 14{\cdot}1.$$

2-8 + 8-2 Four-cylinder Single-expansion Articulated Locomotives of the Denver and Rio Grande Western Ry.*

During the last two or three years American railways have been introducing new locomotive designs in which there are possibilities of increased efficiency. New types such as 2-8-4 and 2-10-4 locomotives have been created to this end, and certain of the new rigid locomotives are more powerful than earlier articulated locomotives which they have displaced, as it is always preferable to employ a rigid locomotive instead of an articulated locomotive whenever it is possible to do so.

Furthermore, compounding is rapidly losing favour in America, preference being given to two- or three-cylinder simple locomotives having a restricted full gear cut-off, provided with superheaters, reheaters, thermic syphons, and other accessories for economical working. The appearance on this railway of a new type of large *Mallet* was therefore a notable event.

This locomotive was required to draw trains of 3,000 (short) tons eastward from Grand Junction (Col.) at a speed which varied from 15 miles (24 km.) to 25 miles (40 km.) per hour according to the grades.†

* The Denver and Rio Grande Western's 780-mile main line from Denver, Col., to Ogden, Utah, crosses two high mountain ranges, the Rockies at an altitude of 10,239 ft. and the Wasatch at 7,444 ft.

† Going east from Ogden, the first section of the main line extends from Grand Junction to Glenwood Springs, 89 miles (143 km.). The next to Minturn, 58 miles (93 km.). The third section, which crosses the Tennessee Pass, is the heaviest. It is 20½ miles (33 km.) long from Minturn to the Divide, with a ruling gradient of 3½ per cent. and 16-degree curves. On the other side of the Pass the *Mallets* take the trains on to Pueblo, 66 miles (106 km.) or Salida, 162 miles (261 km.). On

The loading gauge and the strength of the road-bed permit the use of locomotives of the remarkable size of the examples which we are now considering. The use of four H.P. cylinders was possible because there was space to accommodate a boiler of sufficient size to furnish an ample supply of steam. Furthermore, the strength of the road-bed has permitted the load per axle to be raised to 70,000 lbs. (31·7 tonnes) with a factor of adhesion of 4·2.

The firebox is probably the largest yet made. It has a combustion chamber 6 ft. 0½ in. (1·84 m.) in length. There is a Gaines arch in the front of the firebox and two Nicholson siphons.

The steam piping is arranged on a simple plan. The steam passes directly from the dome to the superheater header, the pipes running down the inside of the smokebox on both sides. The right-hand pipe leaves the smokebox at its lower portion and runs to the rear cylinders. An expansion joint is provided at the bend, in view of the very high pressure of the steam. This pipe terminates in a transverse pipe which runs right and left to the rear cylinders.

Special care has been devoted to the piping which leads from the left-hand pipe in the smokebox to the cylinders of the front truck. There is a ball joint followed by an S pipe which is connected by a slip joint to the transverse pipe which feeds the front cylinders.

The exhaust from the rear cylinders is led to the smokebox through a pipe which runs along the left-hand side of the locomotive parallel to the steam pipe on the right-hand side.

the return journey from Salida the trainload is also 3,000 (short) tons, and the speed 16 to 17 miles (26 to 27 km.) per hour. Grand Junction is at mile 332 (km. 534) from Ogden. Its altitude is 4,583 ft. (1,397 m.).

The Tennessee Pass is at mile 50 (km. 806). Its altitude is 10,239 ft. (3,121 m.). At this point the line leaves the watershed of the Grand River and enters that of the Arkansas River, which follows the wonderful Royal Gorge on its way to Pueblo, where the thalweg is reached at an altitude of 4,568 ft. (2,393 m.) and milepost 622 (km. 1,065). After having crossed a secondary ridge, the line reaches Denver City, altitude 5,198 ft. (1,584 m.) at mile 782 (km. 1,258).

On the easier sections, the *Mallet* handles a 3,000 ton train unaided, at a speed of 29 miles an hour. On the 3⅓ per cent. grades two lighter *Mallets* are used as banking engines, and the speed falls to 15 miles an hour.

TABLE 99.—PRINCIPAL DIMENSIONS OF SINGLE-EXPANSION ARTICULATED LOCOMOTIVES WITH TRAILING FOUR-WHEELED TRUCK

Gauge	Standard.	Standard.
Railway	Southern Pacific.	Northern Pacific.
Builder	Baldwin.	American.
Date	1928.	1929.
Types	**2-8 + 8-4** (Cabin end Foremost).	**2-8 + 8-4** (With Booster).
Cylinders, diameter	24″	26″
,, stroke	32″	32″
Boiler, height of centre line	10′ 8″	10′ 7″
,, diameter inside first ring	7′ 8″	8′ 7¼″
,, length over tube sheets	22′	22′
,, pressure . . . lbs./sq. in.	235	250
Tubes, number	91–240	92–280
,, diameter	2¼″–3½″	2¼″–3½″
Firebox, width	8′ 6¼″	9′ 6¼″
,, length	16′ 4½″	22′ 2⅛″
Combustion chamber, length	5′ 8″	6′ 0½″
Heating surface, firebox and syphons . sq. ft.	513	610
,, ,, combustion chamber ,,	—	262
,, ,, tubes and flues ,,	5,992	6,801
,, ,, total evaporative ,,	6,505	7,673
,, ,, superheating ,,	2,988	3,219
,, ,, combined evaporative and superheater ,,	9,493	10,892
Grate Area	—	—
Wheels, diameter	2′ 9″	2′ 9″
,, drivers	5′ 3½″	5′ 3″
,, trailers	3′	3′ and 3′ 6″
Journals, front truck, diameter	7″	7″
,, drivers, diameter	12″ and 11″	12½″ and 11½″
,, trailers ,,	8″	7″ and 9″
,, all wheels, length	14″	14″
Wheelbase, driving	44′ 7″	44′ 6″
,, rigid	11′ 4″	16′ 9″
,, total, locomotive	66′ 11″	66′ 8″
,, ,, ,, and tender	106′ 5¼″	99′ 8″
Overall dimensions, height	16′ 4″	16′ 4″
,, ,, width	11′ 0″	11′ 0″
,, ,, length	over beams 74′ 7″	overall 80′ 5½″
Weight, adhesive . . . lbs.	475,200	554,000
,, booster axle ,,	None	60,500
,, total locomotive ,,	614,600	715,000
,, tender in service ,,	292,300	401,000
Tender, water capacity . . U.S. galls.	16,152	21,200
,, fuel capacity ,,	4,860	None
,, oil ,, . . . lbs.	None	54,000

The exhaust from the front cylinders passes through an S pipe provided with the usual articulations.

As is now usual, the boiler is carried on the front truck by a single bearing.

Though the trailing truck wheels are larger than those of the leading truck, no booster is provided.

The principal ratios of this interesting locomotive are as under (English measures) :—

$$\frac{\text{Adhesive weight}}{\text{Total weight}} = 86{\cdot}25 \text{ per cent.}$$

$$\frac{\text{Adhesive weight}}{\text{Tractive force}} = 4{\cdot}27.$$

$$\frac{\text{Total weight}}{\text{Combined heating surface}} = 67{\cdot}8.$$

$$\frac{\text{Tractive force}}{\text{Combined heating surface}} = 13{\cdot}8.$$

$$\frac{\text{Tractive force} \times \text{diameter driving wheels}}{\text{Combined heating surface}} = 8{\cdot}68.$$

$$\frac{\text{Firebox heating surface}}{\text{Grate area}} = 4{\cdot}1.$$

Firebox heating surface per cent. of evaporative heating surface = 7·7.

Superheating surface per cent. of evaporative surface = 31·6.

2-8 + 8-4 Four-cylinder Single-expansion Articulated Locomotives of the Southern Pacific Ry.—Standard gauge (Fig. 180).

For some time past the importance of the rear carrying axle has been appreciated, and since the appearance of the booster American engineers have retained it as the best way of providing adequate fireboxes. From the single trailing axle to the rear four-wheeled truck is but a step, and when large evaporative surfaces are necessary, it is becoming customary to use the trailing truck for rigid locomotives.

The last few months have witnessed their appearance in "simple *Mallets*," and instances have occurred on the Southern and on the Northern Pacific railways.

According to recent practice, the Southern Pacific's locomotives run firebox end foremost, and the cab is situated at what is, to all practical purposes, the front end of the locomotive. In spite of this, we have retained the usual wheel designation, though several contemporaries have—erroneously in our opinion—reversed it. Whyte's notation consists of three figures, the first of which designates the number of carrying axles at the smokebox end, and the last

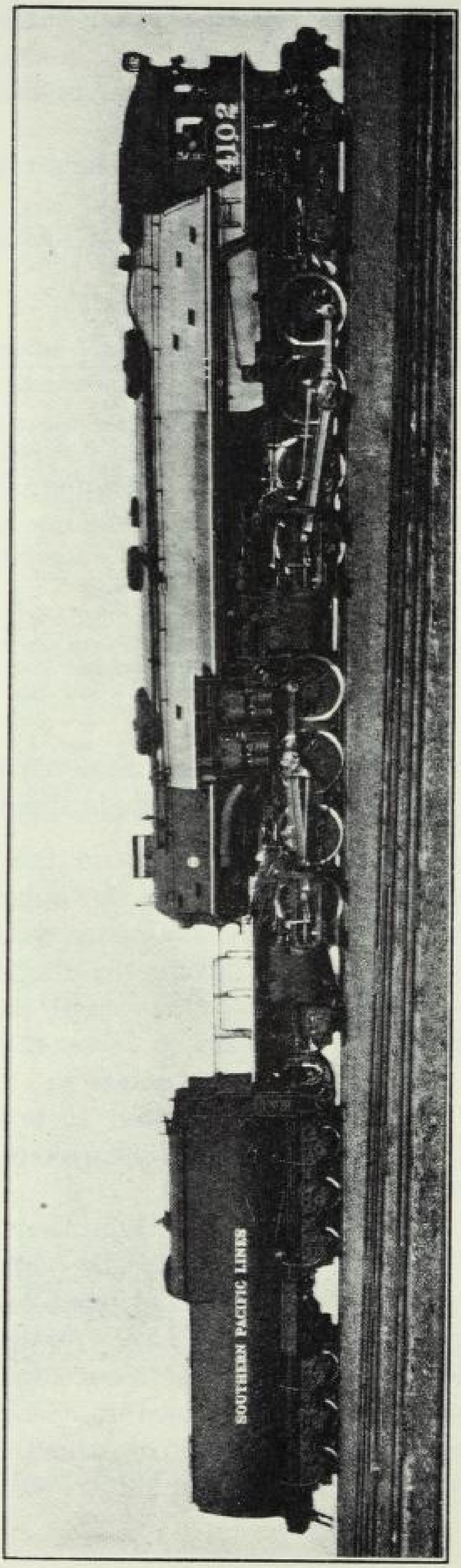


FIG. 180.—2-8 + 8-4 Single-expansion Articulated Locomotive Southern Pacific Lines.
(Standard Gauge)
Baldwin Locomotive Works

of them, the number of trailing axles at the firebox end, and *not* the number of axles in relation to the end of the locomotive which happens to be running first. For in this case it would become necessary to alter locomotive designations were the railway company to run its locomotives occasionally one way, and occasionally the other, which is unreasonable. This is why we have deemed it indispensable to call attention to this fact, so as to prevent confusion.

We have previously quoted the main characteristics of the line over which these locomotives operate.* The first batch supplied by the Baldwin Locomotive Works in 1928 consisted of ten locomotives for mixed traffic.

The frame hinge is not in the usual position nearer the front set of wheels. It has been moved away from the steam truck, being 67 ins. from the latter's rear axle and 62 ins. from the first axle of the rigid set of wheels. This is in accordance with the fact that the locomotive runs rigid set of wheels first.

2-8 + 8-4 Single-expansion Articulated Locomotive of the Northern Pacific Ry.—Standard Gauge.

This experimental locomotive is the outcome of a combination of circumstances which explain the remarkable features that are embodied in it.

The 216-mile section (344 km.) from Mandan (N. Dak.) to Glendive (Mont.) has a number of 1·1 per cent. gradients which are to be met with at points situated along the entire course. The 4,000 (short) ton trains are severed at Glendive, as the booster-fitted Mikados, with 63,000 lbs. tractive power, are unable to haul more than 2,225 short tons over this section.

Relocation was out of the question, owing to prohibitive cost. It therefore became imperative to design a locomotive able to

* See p. 143 under the heading "2-8 + 8-2 *Mallets* of the Associated Lines."

There are, on this section, a number of tunnels and of snow sheds, aggregating a considerable mileage. The smoke nuisance is, therefore, a considerable one, and has to be obviated; hence the necessity for running these locomotives cabin-end foremost. The semi-cylindrical tenders are attached behind the smoke-box, and, of course, liquid fuel is used.

haul the trains arriving at Glendive without splitting them as had been done so far. On the other hand, the Company owns, in the state of Montana, sub-bituminous coal-mines where the coal can be quarried out. Though this coal has no more heat units than good lignite,* it was decided to make use of it and the new locomotives had to be designed, on the one hand, with sufficient power to deal with heavy loads on the Montana division and, on the other hand, to use for the purpose what is really inadequate fuel. This was seeking difficulties, as there are no data stating how extra large fire-boxes would stand everyday practice. Hence, this locomotive is an experimental one—and a most interesting one at that.

The superheater is of unusual dimensions; in spite of this, the ratio of direct to indirect heating surface is not abnormal. Steam for the reheater is collected from the front cylinders' exhaust. The steam piping has nothing unusual.

The most interesting feature is therefore the firebox. This is 22 ft. $2\frac{1}{8}$ ins. long inside and 9 ft. $6\frac{1}{4}$ ins. wide; the water space is 6 ins. on the sides, and 7 ins. in front. The combustion chamber which follows is 6 ft. $0\frac{1}{2}$ ins. long. There are five thermic syphons, three of which are located in the firebox and two in the combustion chamber.

The wagon-top boiler weighs 165,000 lbs. and carries a pressure of 250 lbs. per square inch. A mechanical stoker is able to feed 40,000 lbs. of fuel per hour into the firebox, which has three sliding plate supports on each side. Owing to its great length, two extra doors have been provided to enable the grate to be raked at 16 ft. from the rear of the firebox.

The smokebox has been hollowed out so as to find room for the Coffin feedwater heater, whose pumps have a capacity of 100,000 lbs. of water per hour. The boiler can evaporate up to 120,000 lbs. of water during the same space of time.

The piping deserves a passing mention, as it has some unusual features. Thus the socket joints of the rear cylinder live steam pipes have been dispensed with, but the pipes have been

* Upon coming out of the mine, this fuel contains 24·6 to 30 per cent. of moisture, 12 to 14 per cent. ash, with a heat value of 6,200 to 7,000 B.Th.U. But when dried its heat value is increased to 10,000 B.Th.U., which is practically the same as the Pernik lignite which is used with success on the Bulgarian State Rys.

curved so as to allow for expansion. The pipes are laid alongside the boiler barrel, where they are carried by brackets which are maintained in position by forged steel straps which pass over the boiler barrel.

Finally, we would add that the trailing truck is fitted with a booster with constant 50 per cent. cut-off and a ratio of adhesion of 4·52.

This is the latest of the so-called "simple *Mallets*" and shows the trend of modern—and future—practice.

Conclusion

(1) On the general question of the simple *Mallet*, we may conclude that if provision can be made for an adequate supply of steam, then there is no longer any reason why the evolution of the *Mallet* with four or even six H.P. cylinders should not proceed on parallel lines to the development of the rigid locomotives.

(2) There is no longer any theoretical or practical reason why four-cylinder single-expansion articulated locomotives of this type should not be used instead of compounds.

(3) Where locomotives of exceptionally great power are needed for dealing with heavy freight trains on light or heavy gradients, it is sound practice to use "simple *Mallets*" when rigid locomotives cannot furnish sufficient tractive power.

(4) "Simple *Mallets*" are less complicated than compound ones. There are no longer any drawbacks to the use of high-pressure steam in articulated joints.

(5) In some instances the employment of "simple *Mallets*" enable railways to keep old articulated locomotives of less power than newer rigid ones on the active list. When they are still good enough they bear reconstruction according to these principles.

(6) The performance of single-expansion articulated locomotives on steep gradient railways, such as the Uintah Ry., should be followed closely, for, should they be successful—which is still an open question—they would advantageously replace rack engines on mixed rack and adhesion lines.

(7) We append a comparative table of the principal ratios of recent locomotives of this class :—

Principal Ratios of Single-expansion Articulated Locomotives

Railway / Type		Chesapeake and Ohio. 2-8 + 8-2	Great Northern. 2-8 + 8-2	Denver and Rio Grande Western. 2-8 + 8-2	Southern Pacific. 2-8 + 8-4	Northern Pacific. 2-8 + 8-4
Tractive force, main engine	lbs.	103·500	127·500	131·800	112·760	139·900 +
Booster engine	,,	none	none	none	none	13·400
Adhesive weight / Total weight in service		83·0	89·5	86·4	77·3	77·4
Adhesive weight / Tractive force		4·74	4·18	4·24	4·21	3·94
Total weight in service / Combined heating surface		67·8	65·8	67·9	64·7	65·8
Tractive force × diameter drivers / Combined heating surface		759	885	871	754	742
Combined heating surface / Grate area		73·6	83·6	70·0	68·3	60·0
Firebox heating surface per cent. / Evaporative heating surface		7·25	6·05	9·84	7·89	7·95
Superheating surface per cent. evaporative surface		29·3	26·5	31·6	45·9	41·9

Type 2.—"Mallet" Locomotives with Cylinders Grouped at the Centre

This arrangement has the obvious advantage of reducing the length of the steam piping between the H.P. and L.P. cylinders. On the other hand, the two wheel groups are necessarily further apart, the rear group being entirely under the firebox and the cab, and the first axle of the front group under the smokebox.

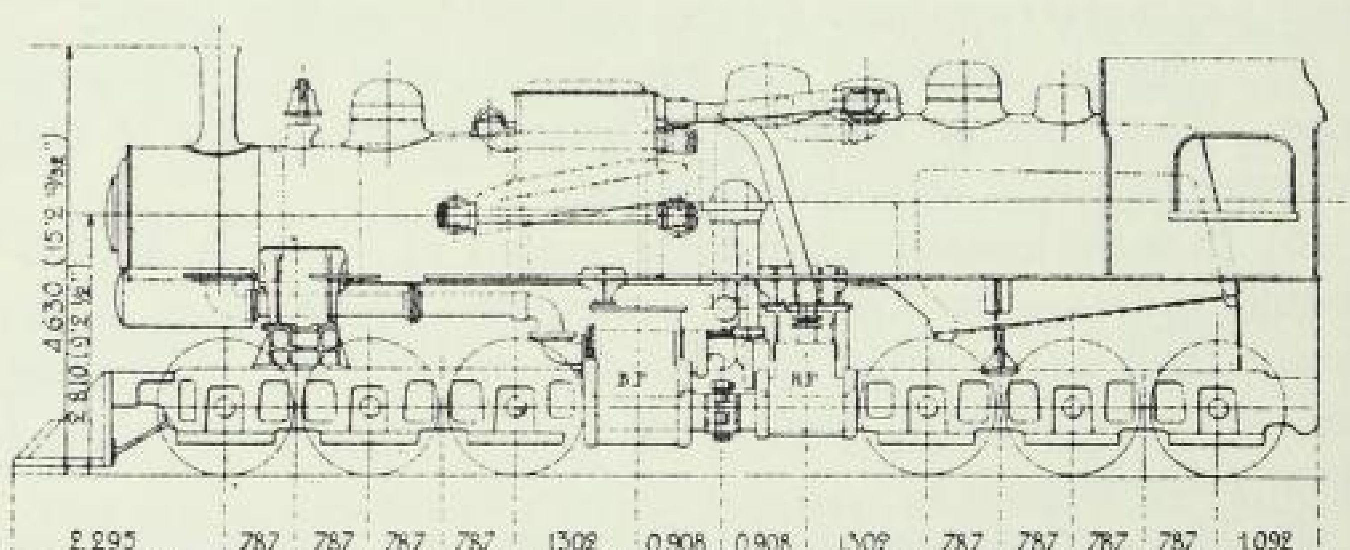


Fig. 181.—Compound Modified *Mallet*, Canadian Pacific Ry. (Standard Gauge.)

0-6 + 6-0 Compound Locomotives of the Canadian Pacific Ry.— Standard Gauge (Figs. 181 and 182).

In this locomotive it has not been thought necessary to

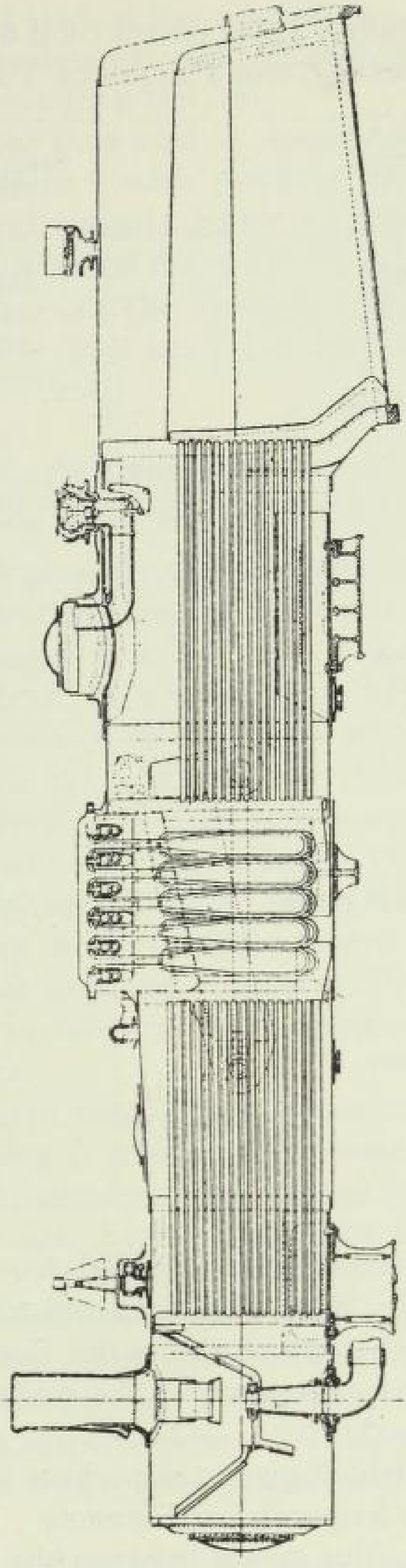


FIG. 182.—Boiler of Modified *Mallet*, Canadian Pacific Ry.

support the overhang of the four centrally located cylinders by pony trucks, as was done on the *du Bousquet* locomotives of the Northern Ry. of France.

TABLE 100.—PRINCIPAL DIMENSIONS OF **0-6+6-0** "MALLET" LOCOMOTIVES OF THE CANADIAN PACIFIC RY.

Gauge	Standard.	Standard.
Date	1909.	1911.
Cylinders, diameter, H.P.	$23\frac{1}{4}''$	$20''$ (4)
,, ,, L.P.	$34''$	—
,, stroke	$26''$	$26''$
Boiler, height of centre line	$9'\ 7\frac{9}{16}''$	
,, diameter	$5'\ 5\frac{1}{4}''-6'\ 2\frac{1}{2}''$	
,, pressure . . . lbs./sq. in.	200	
Tubes, number	167–22+18 sup.	
,, diameter	$2\frac{1}{4}''-5\frac{1}{4}''-2''$	
,, length	$20'\ 0\frac{3}{8}''$	
Firebox, width	$5'\ 10\frac{7}{8}''$	
,, length	$10'\ 0''$	
Heating, surface, firebox . sq. ft.	185	
,, ,, tubes . . ,,	2,765	
,, ,, total . . ,,	2,950	
Superheater . . ,,	548	
Grate area . . ,,	59	
Wheels, diameter	$4'\ 10''$	
Wheelbase, rigid	$10'\ 4''$	
,, total	$35'\ 2''$	
,, locomotive & tender	$60'\ 9\frac{1}{2}''$	
Overall height	$15'\ 3\frac{3}{8}''$	
,, length	$46'\ 7\frac{1}{4}''$	
Tractive force . . lbs.	57,500	
Weight . . ,,	262,000	
Tender, wheels, diameter	$3'\ 0\frac{1}{4}''$	
,, water . . galls.	5,900	
,, coal . . tons-cwt.	12–0	
,, weight in service . . lbs.	133,000	

In the front of the boiler there is a feed-water heater, followed by a superheater (Fig. 182). The feed-water heater has a tube assemblage similar to that of the boiler itself, with which it communicates by two pipes, one at the centre and one at the top; both are external.

The superheater (which gives a superheat of 83° C.) consists of sixty-nine double-loop vertical elements. They are located across the path of the flue gasses between the boiler proper and the feed-water heater. The length of the section of the boiler barrel occupied by the superheater is 5 ft. $3\frac{1}{4}$ ins. (1·605 m.).

The adhesive weight of the leading truck exceeds by 3 tons

19 cwt. (4 tonnes) that of the rear truck. The object of this is to reduce the tendency to slip, which is always greater with the front wheel group than the rear.

These locomotives were used on the new section which crosses the Rocky Mountains * with gradient of 2·2 per cent., and includes two spiral tunnels 2,910 ft. (887 m.) and 3,215 ft. (980 m.) in length, with curves of 574 ft. (175 m.) radius. This new alignment increases the distance from Montreal to Vancouver by $4\frac{1}{4}$ miles (6·8 km.), the total distance now being 2,920 miles (4,676·7 km.).

0-6 + 6-0 Four-cylinder Simple Articulated Locomotives of the Canadian Pacific Ry.—Standard gauge.

These are analogous to the compound locomotives above described. The introduction of simple working has, however, led to certain changes.

The tractive force of a compound locomotive diminishes rapidly with increase of speed. This was one of the reasons why, since the year 1911, this railway has substituted simple for compound working. For this purpose more powerful boilers were needed. But the bridges on the line only allowed a maximum weight of 262,000 lbs. (118,800 kgs.). It was therefore necessary to save weight where possible in order to increase the boiler capacity. Thus 6,000 lbs. was saved by using cast-steel cylinders with cast-iron liners instead of ordinary cast-iron cylinders.

By such savings in weight, it was possible to provide a boiler capable of steaming four H.P. cylinders, 20 × 26 ins. The cylinders of the corresponding compound locomotive were $23\frac{1}{4}$ ins. and 34 ins. by 26 ins. (0·59 m. and 0·56 m. by 0·66 m.).

In all *Mallet* locomotives there is an outwards displacement of the vertical hinge pivot when running through curves. The greater the distance between the pivot and the adjacent axles, the greater is this displacement. When, as in this locomotive, the four cylinders are grouped at the centre, the adjacent axles

* It was not until 1908 that the temporary line descending the western slopes by Kicking Horse Pass with $4\frac{1}{2}$ per cent. grades, which had been in use for twenty-four years, was replaced by the present alignment.

of the two wheel groups are necessarily more widely separated. Hence the lateral displacement of the pivot is increased, which causes excessive wear of the wheel flanges of the two adjacent axles.

This trouble has been neatly overcome by the provision of a longitudinal tie bar between the two portions of the frame, the fixing pivots of which, axially located, are much nearer the two axles ; the portions of the two frames in contact are rounded off like the faces of some spring buffers.

The boiler rests on the front truck by means of a single support. Castings are bolted both to the underpart of the boiler and to the frames, and the upper casting is free to move sideways when the locomotive enters a curve.

The boiler is of the wagon-top type and contains a five-tube style superheater with separate saturated and superheated steam headers.

Steam is carried to the back cylinders through a $4\frac{7}{8}$-in. diameter pipe (0·124 m.), rigidly fixed to the lower portion of the boiler on the left-hand side.

A similar pipe is fixed to the right-hand side for the delivery of steam to the front cylinders, but in this case there is a packed joint bolted over each steam chest. There is a swivelling movement reaching 5 degrees, but the sliding movement is negligible.

The exhaust pipes from the four cylinders lead into a cast-steel header bolted to the boiler barrel. The exhausts from both sets of cylinders are carried forward through a 10-in. wrought-iron pipe, having a vertical dividing wall up to a point just below the conical exhaust nozzle, where the exhausts finally combine.

This arrangement necessitates an articulated connection along the exhaust pipe from the front engine ; this consists in spring-loaded ball rings arranged both for swivelling and sliding.

There are thus altogether but three articulated tubes, whereas there are five in the usual type of *Mallet* locomotive.

The Company soon put into service rigid locomotives of greater power, which did away with the necessity of continuing tests with this or other types of articulated locomotives.

Type 3.—Modified "Mallet" Locomotives with Cylinders at the Outer Ends of the Groups of Wheels

2-6 + 6-0 Eight Cylinder Compound Articulated Tank Locomotive, New Zealand Government Rys.—3 ft. 6 ins. gauge (Fig. 183).

The Rimutaka incline, which contains the famous Raumiru spiral, was established on the *Fell* centre rail system, with a 3-mile grade of 1 in 15 with numerous 5-chain radius curves.

An experimental tank engine was designed in New Zealand by G. A. Pearson, somewhat on the same lines as the *Mallet* locomotives, with a view to working the incline by ordinary adhesion only, the central rail to be retained for grip brake purposes only.

The rear set of wheels was rigid, the front set constituting a

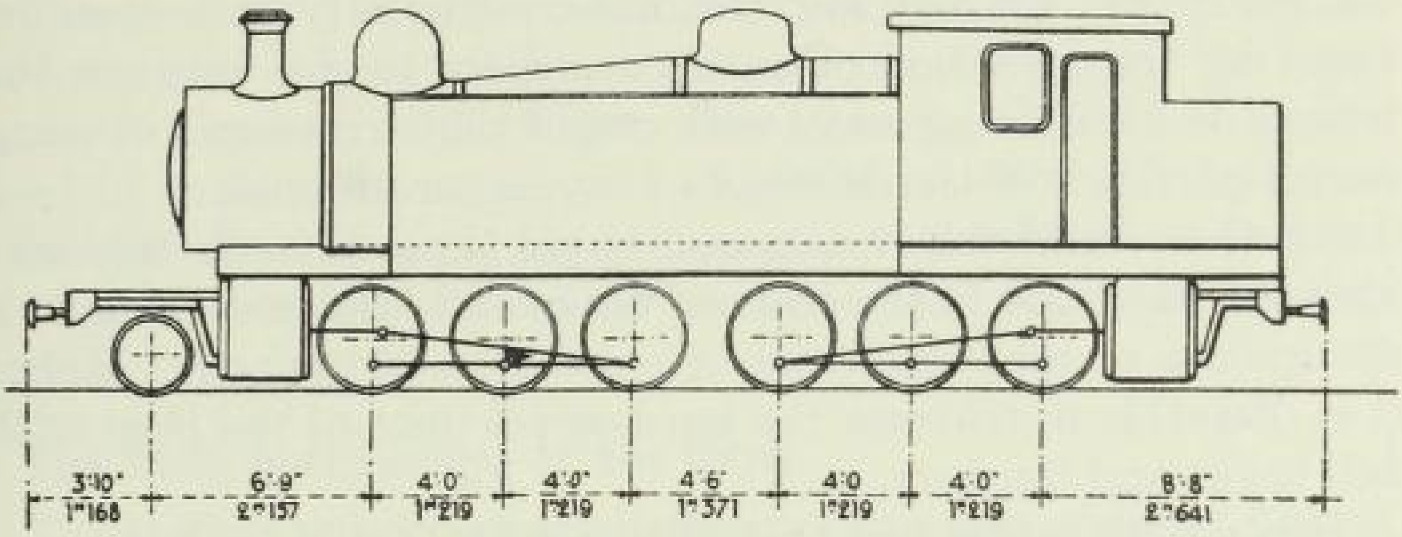


Fig. 183.—2-6 + 6-2 Tank Articulated Locomotive, New Zealand Government Rys.
(3 ft. 6 in. Gauge.)

truck, which was coupled to the other by a suitable knuckle-joint. The principal novelty lay in the cylinders, which were Vauclain compound. Each set of wheels had two H.P. and two L.P. cylinders (in each case, the L.P. being above the H.P.); the cylinders of the (front) truck were under the smokebox, and those of the back set of wheels overhung at the back of the locomotives and were directly under the cab, which made the latter very hot, especially in the tunnels. It had not been possible to place them in the usual position, owing to the existing smokebox saddles on the cylinder castings.

The boiler is of the Vanderbilt type, with corrugated iron firebox.

This locomotive only hauled 66 tons up the incline, which was little more than the lighter *Fell* locomotives could do, so it was removed to Wellington, where it was used as a banking engine and finally withdrawn.

SECTION II. C.—TWIN OR DUPLEX LOCOMOTIVES

The idea of coupling two locomotives back to back and of working them as a single unit, with one or sometimes with two locomotive crews, is an old one, and pairs of locomotives have been variously called "twin locomotives" or "duplex locomotives," though this latter designation has been often misapplied. But looseness in designation is a general characteristic of everything pertaining to articulated locomotives.

An advantage claimed for the "duplex" system is that should one unit require repairs it can be easily uncoupled—certainly more easily than in any other type of articulated locomotive. The principal drawback is that the amount of water and coal carried is very limited, and this has occasionally been counteracted by the provision of an intermediate tender between the two units, thus doing away with one of the advantages of using one duplex locomotive instead of two separate ones.

Another drawback is common to all types of tank engines; that the variation in the state of tanks and bunkers results in a diminution of adhesion which often reaches 20 per cent. Hence it is desirable to traverse the hardest portions of the lines with full tanks and bunkers.

It is a remarkable fact that although the use of twin locomotives has always been condemned, they have reappeared periodically all through railway history, and new patents in connection with them have even been taken out quite recently. We cannot therefore omit to notice them; we shall also give brief particulars of the principal instances in which they have been used.

To sum up, we may conclude that the use of twin locomotives is more in the nature of a temporary expedient for dealing with traffic under special circumstances than a system proper.

Utilisation of Twin Locomotives

We shall subdivide our examination into two groups as under :—

Group I.—Two locomotives coupled together.

Type 1.—Simple twin locomotives.
Type 2.—Compound twin locomotives.
Type 3.—The Weidknecht patent twin locomotives.

Type 4.—The Lange and Livesey patent twin locomotives.
Type 5.—Stephenson's patent twin locomotives.

Group II.—One locomotive is carried on two carriages, one for the boiler, the other for the engine.

GROUP I.—TWO LOCOMOTIVES COUPLED TOGETHER

Type 1.—Simple Twin Locomotives

Practically all the locomotives we have grouped under this heading differ in details from each other, and the reader would have no difficulty in thinking out other or similar cases.

Heusinger von Waldegg states that he presented a design for a duplex locomotive at the Semmering Competition in 1851.* The two units swivelled about a pin which was carried by an intermediate bogie. This supported the footplate, the coal and two firemen. The engine driver was placed on a higher level to enable him to see over the boilers. Each of the latter consisted of two barrels superimposed, one of which was a kind of superheater, and the whole providing 235 sq. m. of heating surface.

The Twin Locomotives of the Giovi.

The earliest important application of this arrangement was on the Italian line of the Giovi, where the gradients reached $3\frac{1}{2}$ per cent. and the adhesion was bad.† Patents were taken out for this type of locomotive by three Italian engineers, G. Sommeiller, G. Grandes, and D. Ruva. Six locomotives were made to their designs, three by the Société John Cockerill, at Seraing (Belgium), and three by Robert Stephenson & Co., at Darlington. The latter firm expressed the opinion that duplex locomotives were likely to cause a good deal of trouble.‡ These locomotives each had two sets of two coupled axles. They had a central

* For further information, see "Handbuch für spezialle Eisenbahn Technik," Vol. III., p. 256.

† The line from Turin reached Novi on January 1st, 1851, and Genoa on December 18th, 1853. At that time, the crossing of the Giovi Pass was more difficult than it now is, and during eighteen months wagons were drawn up by animal power and let down by gravity.

An improved alignment was considered in 1852. It had an inclined plane between Busalla and Pontedecimo.

‡ This information is chiefly taken from a work by the Italian engineer, Nicholas Pavia.

Table 101.—Principal Dimensions of Duplex or Twin Locomotives

Gauge	Standard.			Standard.	1·52 m.	Standard.	1·067 m.	1·67 m.	Standard.	Standard.	0·60 m.	0m.90.	0m.615.
Railway	Turin to Genoa.			Victor Emmanuel.	Trans-caucasian.	Cornwall Minerals Ry.	Cape Rys.	North Western (India).	McCloud River R.R.	Belgian State Rys.	Military Rys.	Factory Lines.	Mayumbé (Congo).
Builder	Stephenson.	Cockerill	Cockerill	Cockerill	Yorkshire.	Neilson.	Kitson.	Neilson.	Baldwin.	Various.	Various.	Hanomag.	St. Léonard.
Date	1854.	1853.	1856.	1856.	1869/70.	1873/74.	1875.	1890.	1901	1905.	—	—	—
Type	**4 + 4**	**4 + 4**	**6 + 6**	**4 + 4**	**2·4 + 4·2**	**6 + 6**	**2·6 + 6·2**	**6 + 6**	**6 + 6**	**6 + 6**	**6 + 6**	**4 + 4**	**4 — 4**
Cylinders, diameter	0m.33	0m.34	0m.41	0m.42	0m.42	0m.41	0m.30	0m.48	0m.29 0m.48	0m.50	0m.18	0m.31	0m.20
,, stroke	0m.56	0m.56	0m.56	0m.60	0m.56	0m.51	0m.52	0m.66	0m.5	0m.60	0m.24	0m.44	0m.30
Boiler pressure . . kg./sq. cm.	8	7·5	8·0	8	—	9·8	—	10	14·1	10	15	12	14
Heating surface, firebox . sq. m.	—	—	—	—	—	7·4	—	—	13·7	—	—	—	—
,, ,, total ,,	72·4	71·5	100·5	72·5	96·6	76·5	—	128·5	181·3	120·7	14·3	36·8	19·6
Grate area ,,	1·0	—	—	1·0	1·4	1·0	—	2·04	2·4	5·14	1·29	0·80	0·52
Wheels, diameter	0m.99	1m.08	1m.22	1m.20	1m.60	1m.07	1m.98	1m.27	1m.02	1m.30	0m.58	0m.82	0m.60
,, diameter	None	None.	None.	None.	0m.84	None.	0m.60	None.	None.	None.	None.	None.	None.
Wheelbase, rigid	2m.40	2m.45	—	2m.00	—	—	2m.36	2m.99	2m.97	4m.20	1m.30	1m.80	1m.60
,, total	10m.08	—	—	—	6m.17	—	3m.45	—	11m.68	13m.20	5m.30	—	—
Weight, locomotive . . t.	28 t.	29 t.	33 t.	27·7	—	31·3	—	44·0	36·6	46·4	8·19	18·7	13·0
,, tender ,,	None.	None.	None.	None.	None.	None.	None.	41·5	None.	None.	11·2	None.	None.
,, total ,,	56	58 t.	66 t.	55·4	—	62·6	—	129·5	73·2	93·0	27·6	37·4	26·0
Tractive force ,,	5·55	6·30	7·96	9·10	*	†	‡	—	§	7·74	1·19	8·27	1·89

* Water tanks, 15 cub. m.; oil tanks, 4·5 cub. m.
† Overall length, 3m.33.
‡ Boiler centre line, 1m.60 above rail level.
§ Boiler diameter 1m.17; 136 tubes, 0m.051 diameter and 3m.89 long; water tanks, 9,084 litres.

TABLE 101A.—PRINCIPAL DIMENSIONS OF DUPLEX OR TWIN LOCOMOTIVES

Gauge	Standard.			Standard.	5′	Standard.	3′ 6″	5′ 6″	Standard.	Standard.	1′ $11\frac{1}{2}$″	2′ $11\frac{5}{8}$″	2′
Railway	Turin to Genoa.			Victor Emmanuel.	Transcaucasian.	Cornwall Minerals. Ry.	Cape Rys.	North Western (India).	McCloud River R. R.	Belgian State Rys.	Military Rys.	Factory Lines.	Maymbé (Congo).
Builder	Stephenson.	Cockerill	Cockerill	Cockerill	Yorkshire.	Neilson.	Kitson.	Neilson.	Baldwin.	Various.	Various.	Hanomag.	St. Leonard.
Date	1854.	1853.	1856.	1856.	1869/70.	1873/74.	1875.	1890.	1901.	1903.	—	—	—
Type	**4 + 4**	**4 + 4**	**6 + 6**	**4 + 4**	**2-4 + 4-2**	**6 + 6**	**2-6 + 6-2**	**6 + 6**	**6 + 6**	**6 + 6**	**6 + 6**	**4 + 4**	**4 + 4**
Cylinders, diameter	13″	$13\frac{1}{2}$″	16″	$16\frac{1}{2}$″	$16\frac{1}{2}$″	$16\frac{1}{4}$″	12″	19″	$11\frac{1}{2}$″ + 19″	$19\frac{5}{8}$″	7″	$12\frac{3}{16}$″	$7\frac{7}{8}$″
,, stroke	22″	22″	22″	$23\frac{5}{8}$″	22″	20″	20″	26″	20″	$23\frac{5}{8}$″	$9\frac{1}{16}$″	$17\frac{6}{16}$″	$11\frac{3}{4}$″
Boiler pressure . . . lbs.	114	111	114	114	—	140	—	140	200	142	216	171	198
Heating surface, firebox . sq. ft.	—	—	—	—	—	70	—	—	148	—	—	—	—
,, ,, total . ,,	779·3	769·6	1,081·8	780·4	1,040	823·3	—	1,384	1,952	1,299·2	153·9	396·2	210·9
Grate area . ,,	11·2	—	—	10·8	15·8	10·8	—	22·0	26·0	55·3	13·9	8·6	5·6.
Wheels, diameter	3′ 3″	3′ $6\frac{1}{2}$″	4′ 0″	3′ $11\frac{1}{4}$″	2′ 9″	3′ 6″	3′ 3″	4′ 2″	3′ 4″	4′ $3\frac{1}{8}$″	1′ $10\frac{13}{16}$″	2′ $8\frac{1}{4}$″	1′ $11\frac{5}{8}$″
,, diameter	None.	None.	None.	None.	5′ 3″	None.	2′ 0″	None.	None.	None.	None.	None.	None.
Wheelbase, rigid	7′ 10″$\frac{1}{2}$	8′ 6″	—	6′ $6\frac{3}{4}$″	—	—	7′ 9″	9′ $9\frac{3}{4}$″	9′ 9″	13′ $9\frac{3}{8}$″	4′ $3\frac{1}{8}$″	5′ $10\frac{7}{8}$″	5′ 3″
,, total	33′ $0\frac{3}{4}$″	—	—	—	20′ 3″	—	11′ 4″	—	38′ 4″	43′ $3\frac{3}{4}$″	17′ $4\frac{5}{8}$″	—	—
Weight, locomotive . t.-cwt.	27–10	28–8	32–8	27–4	—	30–16	—	43–6	72–2	45–16	8–0	18–8	12–16
,, tender . ,,	None.	None.	None.	None.	None.	None.	None.	40–16	None.	None.	11–0	None.	None.
,, total . ,,	55–2	570	64–18	54–10	—	61–12	—	127–8	72–2	91–10	27–2	36–16	25–12
Tractive force . . lbs.	12,200	13,900	17,500	20,000	*	†	‡	—	§	17,000	2,600	18,200	4,160

* Water, 3,960 galls. ; oil fuel, 1,190 galls.
† Overall length, 10′ $11\frac{1}{4}$″.
‡ Boiler centre line, 5′ 3″ above rail level.
§ Boiler dimension, 46″ ; 136 2-in. tubes, 12′ 9″long. Tanks hold 2,400 U.S. galls.

joint and one driver served both locomotives. They were put into service on December 18th, 1853.

Contrary to the prognostications of Messrs. Stephenson, these locomotives gave such satisfaction that this railway similarly coupled up some *Mastodon* type (0-6-0) engines * which had previously been built for the Dusino Ry. and which remained in service until the year 1861. They have been replaced by locomotives with four coupled and finally with five coupled axles.

Twin Locomotives of the Victor-Emmanuel Ry.—Standard gauge.

These were built to the designs of E. Mayer by the Société Cockerill, of Seraing.

Like the earlier ones, they had outside cylinders, but they were provided with saddle tanks which reached down to the frames.

The rigid wheelbase was short and, as the firebox was unsupported, special devices were adopted in coupling the locomotives back to back. Extra "tenons" were inserted and provided with short vertical buffers, but these gave trouble, as they prevented sufficient vertical play, and were subsequently removed.

Twin Locomotives of the Chemin de fer du Pecq à Saint-Germain.—Standard gauge.

The last section of this Parisian suburban line consists of a short sharp gradient up to the terminus which has always been a cause of trouble. Many different attempts were made to cope with it before the line was converted to electric traction. One method tried was the provision of duplex locomotives similar to those just described,† which were ordered by M. Mayer

* This designation is now applied to the 4-10-0 type. The early *Mastodons* were tank engines of 34 tons approximately, having driving wheels 3 ft. 11¼ ins. (1·20 m.) diameter. They were put into service on the Dusino section on August 14th, 1851, and were in service till 1858.

The locomotives with two coupled axles drew 95-ton trains, and those with three coupled axles 120-ton trains, the speed being 9½ miles (15 km.) per hour.

† *Crampton's duplex locomotive* was patented on August 25th, 1856. Coal was carried on the frames and water in a tender coupled to one of the units.

when he became chief of the former Chemin de fer de l'Ouest's locomotive department.

Great Indian Peninsula 0-4-0 Twin Locomotives.—5 ft. 6 in. gauge (1m.67).

This company's main line runs from Bombay to Kalyan, where it reaches the Western Ghaut, which it scales by inclined planes, having maximum gradients of 2·7 per cent. It splits into two lines, so as to follow the Bhore Ghaut in the direction of Madras and the Thul Ghaut in the direction of Calcutta.*

E. B. Wilson's duplex Ghaut locomotives were similar to Stephenson's. They were supplied in 1856, and put into service in 1858.†

Twin 0-4-4 Locomotives, Transcaucasian Ry.—5 ft. gauge.

This line runs parallel to the Baku pipe line.

For some forty years this railway used old tank locomotives, built by the Yorkshire Engine Co. in 1869–1870, and coupled so as to form *twin* locomotives.

Twin 0-6-0 Locomotives, Cornwall Minerals Ry.—Standard gauge.

F. Trevethick designed these locomotives, nine pairs of which were supplied by Sharp, Stewart & Co. in 1873–1874.

Twin 2-6-0 Locomotives, Cape Government Rys.—3 ft. 6 in. gauge.

In 1875, Kitson built a number of locomotives for South Africa. The regulator and reversing gear were duplicated.

Messrs. Barclay built similar locomotives for a timber firm.

Twin 0-6-0 Locomotives, Belgian State Rys.—Standard gauge.

These are of interest because they were designed as a temporary expedient to meet sudden traffic requirements. In 1905, traffic having unexpectedly increased owing to the Liège Exhibition, there were not enough banking engines to deal with the trains up the Liège-Ans incline. So some ordinary goods

* The first section of the G.I.P. Ry., which was also the first to be operated in India, was opened from Bombay to Thana on April 16th, 1856.

† This delay was due to the slowness of ship transit. The locomotives had cylinders 15 ins. by 22 ins. (0m.38 by 0m.56) and wheels 4 ft. in diameter (1m.22).

engines were coupled back to back and provided with necessary mechanism for temporary service as duplex locomotives.

Twin Locomotives of the Mayumbé Ry. Co. (Belgian Congo).* —Gauge, 61 cm. (2 ft.) (Fig. 184).

In its earliest days, this railway used 0-4-0 engines, weighing 12 tons in working order. When traffic increased the company tried coupling two locomotives together, inserting a platform for the driver, so that double engine power could be obtained without an increase of *personnel*. These locomotives were used for some time, but have since been replaced by *Garratts*.

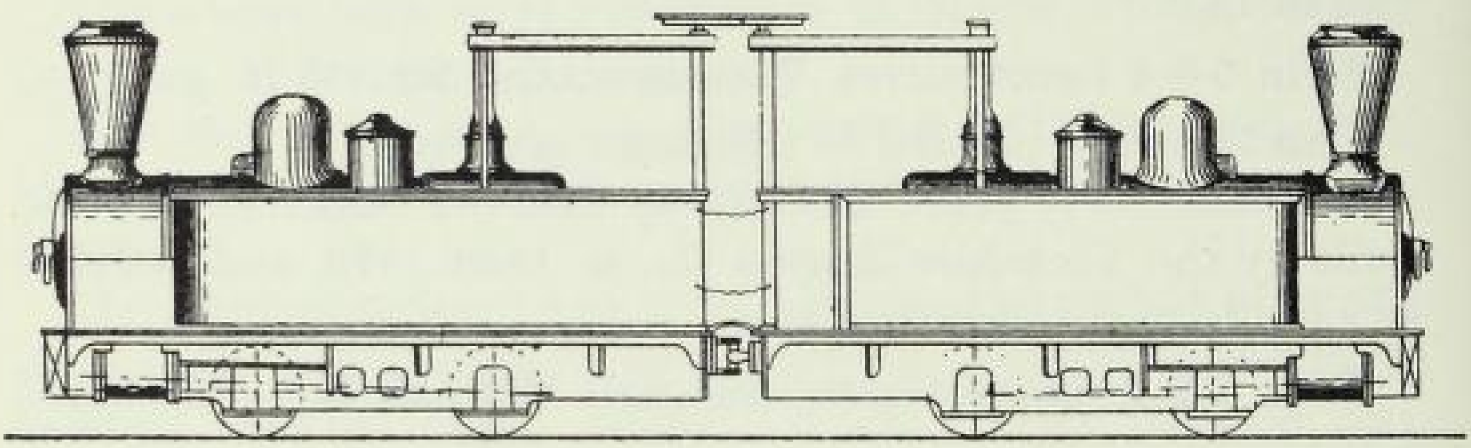


FIG. 184.—Mayumbé Ry. (Belgian Congo) Twin Locomotives. (2 ft. Gauge.)

Twin Locomotives for Military Railways.—Gauge, 0m.60 (1 ft. 11½ ins.) (Fig. 185).

An interesting type of twin locomotive has been used on military railways in Germany and Japan.

Though they have side tanks, a two-bogie tender was sometimes added, which could be attached to either end of the twin engine.† The capacity of the tanks is thus remarkable for so

* This railway is 138 km. (85¾ miles) in length between Boma, on the navigable portion of the River Congo, and Tchela. It has some 4 per cent. gradients and curves of 30 m. (100 ft. approximately) radius. The gauge is being narrowed to 0·60 m. (approximately 1 ft. 11½ ins.).

† The leading dimensions of these tenders were as follows :—

Diameter of wheels .	0·450 m. ...	1 ft. 5¾ ins.
Wheelbase of bogies .	0·700 m. ...	2 ft. 3½ ins.
Distance between centres	2·900 m. ...	9 ft. 6 ins.
Frame . . .	Outside ...	Outside.
Water capacity . .	5 cub. m. ...	176·6 cub. ft.
Weight in working order	11·3 met. tons	11 tons 2 cwt.
Coal capacity . .	1·8 met. tons ...	1 ton 15 cwt.
Weight empty . .	4·3 met. tons ...	4 tons 5 cwt.

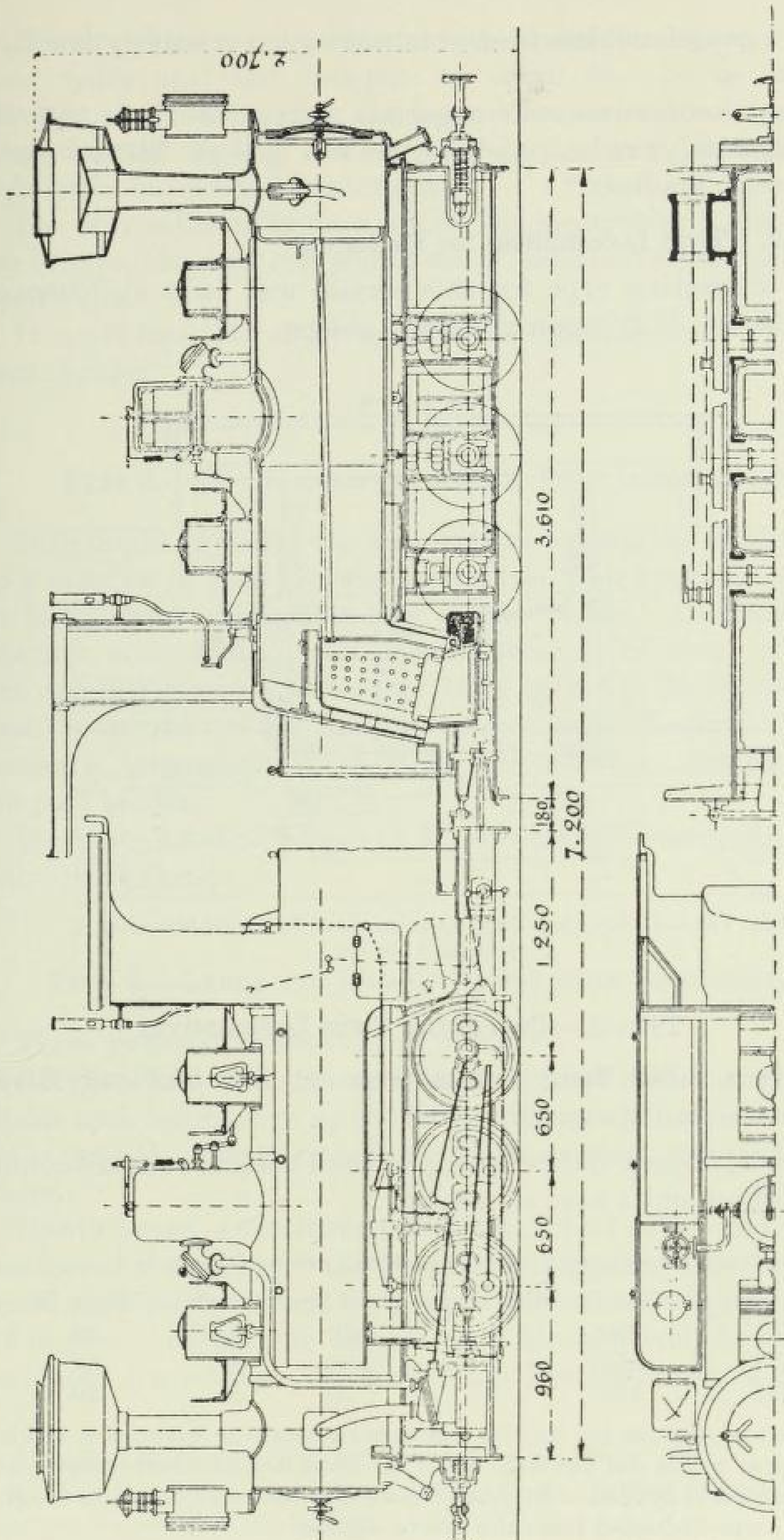


Fig. 185.—Twin Locomotives for German Military Railways. (Approximately 2 ft. Gauge.)

small a gauge, and has been obtained with a relatively low tare weight.

These locomotives can negotiate curves of 20 m. (66 ft. approximately) radius, and can draw a load of 32 tons up a 4 per cent. gradient.*

0-4-0. Twin Locomotives for Factories.

An interesting type for this service was built at Hanover for a 90 cm. (3 ft. approximately) gauge.

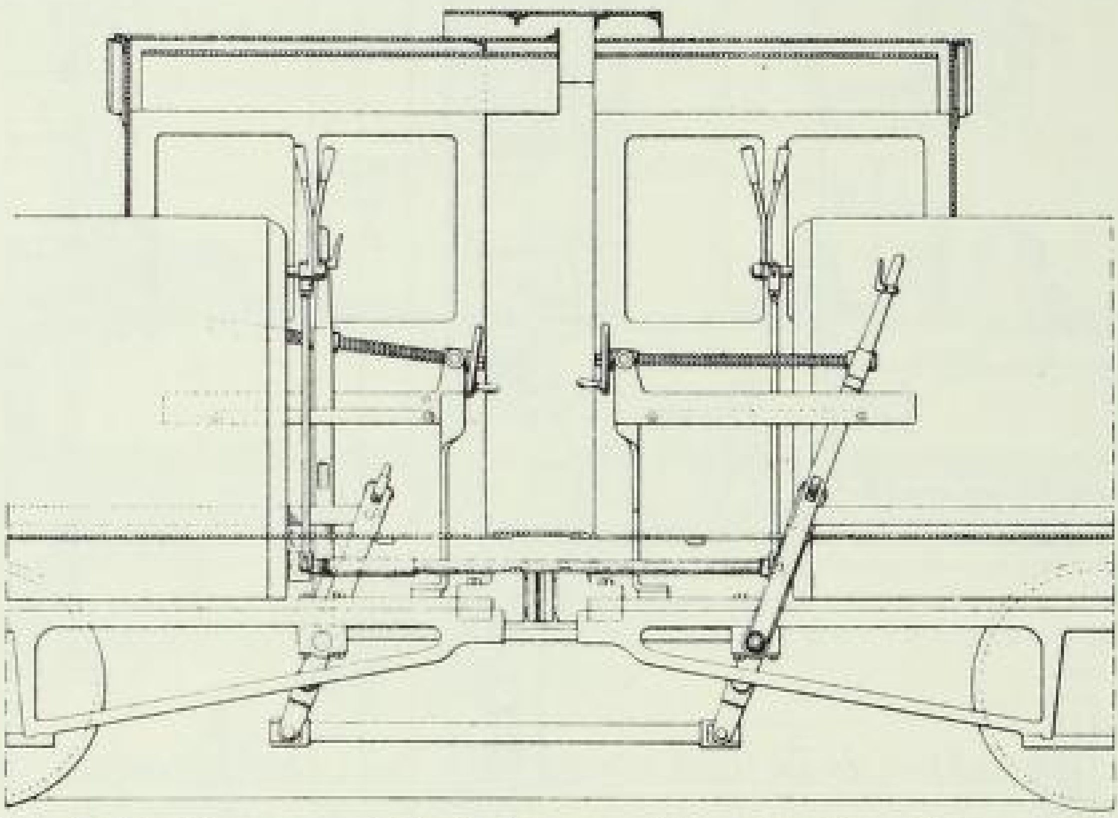


Fig. 186.—Compound Twin Locomotives, McCloud River R.R. (Standard Gauge.)

Type 2.—Compound Twin Locomotives

Baldwin 0-6-0 Twin Locomotives of the McCloud River R.R.—Standard gauge (Fig. 186).

In 1901, Messrs. Baldwin supplied and designed these locomotives, whose units were separable.

* The loads drawn up various gradients are as follows :—

Per cent.	Tons Fr.	Per cent.	Tons Fr.	Per cent.	Tons Fr.
0·1	380	1	120	3·33	40
0·2	250	1·66	84	4	32
0·5	180	2	70	5	20

The above figures are for the locomotives working without a tender on services which did not take them far from depots where they could be watered and fuelled. In cases where a tender was used, its weight (loaded) was deducted from the above figures

The drawbars are of great strength, and the holes have clearance space next the drawpins to admit the strains to pass through the buffers when the locomotive is used as a pusher. The throttle rigging and reverse levers were arranged in duplicate, but could be interlocked.

The only noteworthy item about this locomotive is that it is, we believe, the only compound twin locomotive that has ever been built.

It could haul 125 short tons (113·5 metrical tons) up 7 per cent. grades.

Type 3.—The Weidknecht Patent Twin Locomotives

1889 might be called the year of the articulated locomotive, as a number of new systems then made their appearance or—in lucky cases—their first bow to the public. Of these, two patents concerned duplex locomotives. The first one was granted in France on September 26th, 1889,* to M. *Weidknecht*, and the second was applied for and granted in England. Each concerns locomotives both with or without an intermediate coupled tender.

We have not had access to M. *Weidknecht's* designs, so can only quote them.

Type 4.—Lange and Livesey Patent Twin Locomotives

These patents covered many points :—

Locomotives Connection.—A continuous drawbar extended under each locomotive up to the footplates, where the drawbars were jointed. Convex surface buffing castings were provided there.

Regulators and Reversing Gear.†—Levers and a rod connected the former ; the two reversing gears were made to work together by means of a cross shaft at an angle of about 45 degrees beneath the footplates. At each end, bevel gears produced the rotation of this shaft. The horizontal wheels of

* French Patent No. 200,978.

† This description is taken from Ahrons, "The British Steam Railway Locomotive from 1825 to 1925."

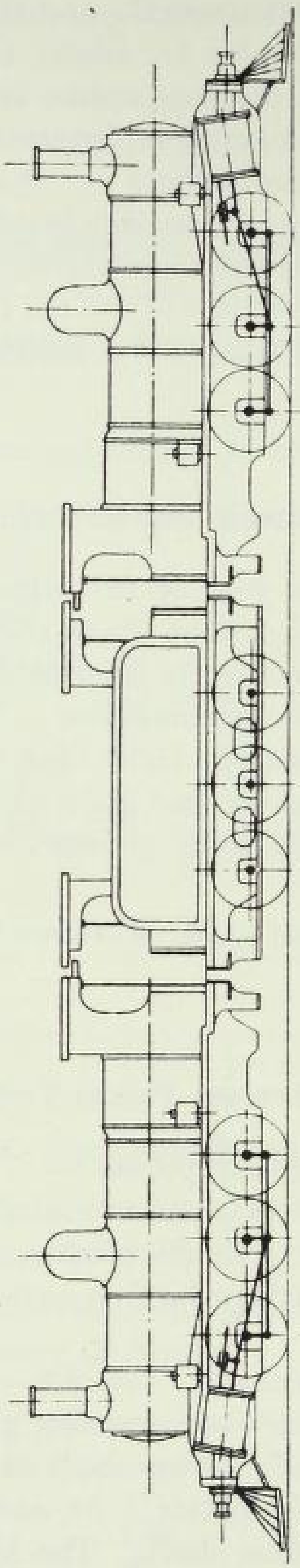


Fig. 187.—0-6-0 Twin Locomotives, North Western Ry. (India). (5 ft. 6 ins. Gauge.)

the bevel gears were keyed to vertical shafts (one to each foot-plate), each of which had a handle at the top which enabled the driver to reverse both engines.

Twin 2-6-0 Locomotives, Interoceanic Railway of Mexico.—3 ft. gauge.

The first locomotives of this type were supplied by Messrs. Beyer, Peacock and Co. in 1889.

Twin 0-6-0 Locomotives, North Western Ry. (India).—5 ft. 6 ins. gauge (Fig. 187).

Twenty pairs of these locomotives were built in 1890 by Messrs. Neilson & Co. They differ from the former in the provision of a great deal more space for water and fuel which was obtained by the insertion of a tender between the twin locomotives. This had an extra advantage ; the weight on the drivers remained constant, so the available tractive force did not vary with the state of the tanks.

These locomotives are the most powerful twin locomotives ever built and were used on the Sindh-Pishin line running through the Bolan Pass.*

Type 5.—Stephenson Patent Twin Locomotives

The most recent development of twin locomotives is described in a patent taken out in the year 1914 by Messrs. Robert Stephenson & Co., of Darlington. Its most notable feature is the arrangement by which the movement is transmitted from one unit to the other.

Each unit pivots around the centre of its rigid base. A frame is supported on each of the engine frames by means of pivots located at their centres. This frame supports the cab and the water tanks and coal bunkers, which are arranged symmetrically.

The tractive stresses are therefore transmitted through the pivots and the frame, as in the case of the *Fairlie* locomotives.

The weight of the frame itself and the equipment which it supports is not, however, carried by the pivots, but is sustained by side and end brackets. The link motion for all four cylinders is operated by a single control.

* This section has gradients of 4 per cent. At first they were provided with racks, but with racks the gradients could have been far steeper in order to compensate for the inconvenience they caused.

When this was recognised the racks were removed and ordinary locomotives substituted. At first *Consolidations* were used—two, three, or even four to each train. Later, *Mallet* and *Garratt* engines have been employed.

We understand that, so far, no locomotives have been actually built to this design, but it should be easy to convert existing engines in accordance therewith.

GROUP II.—TWO-CARRIAGE LOCOMOTIVES

The Harrison Locomotives

We must refer to a singular arrangement devised by T. E. Harrison in the early days of railway construction, with the object of facilitating repairs.

With this end in view, he placed the engine on one carriage, the boiler on another and the tender beyond, thus closing the procession. It would therefore be possible to couple up either a spare engine carriage or a spare boiler one when repairs became necessary.

Whilst these were but early freaks, they should be noticed, because at least one type of turbine locomotive has—barring the tender, which is combined with the engine—a somewhat similar arrangement.

In 1838, Messrs. R. and W. Hawthorn supplied two of these locomotives to the old broad gauge Great Western Ry. They were called the *Hurricane* and the *Thunderer*, and differed in principle from each other. We believe (though we cannot vouch for it) that a third locomotive embodying the same ideas was supplied to the Stanhope and Tyne Ry.

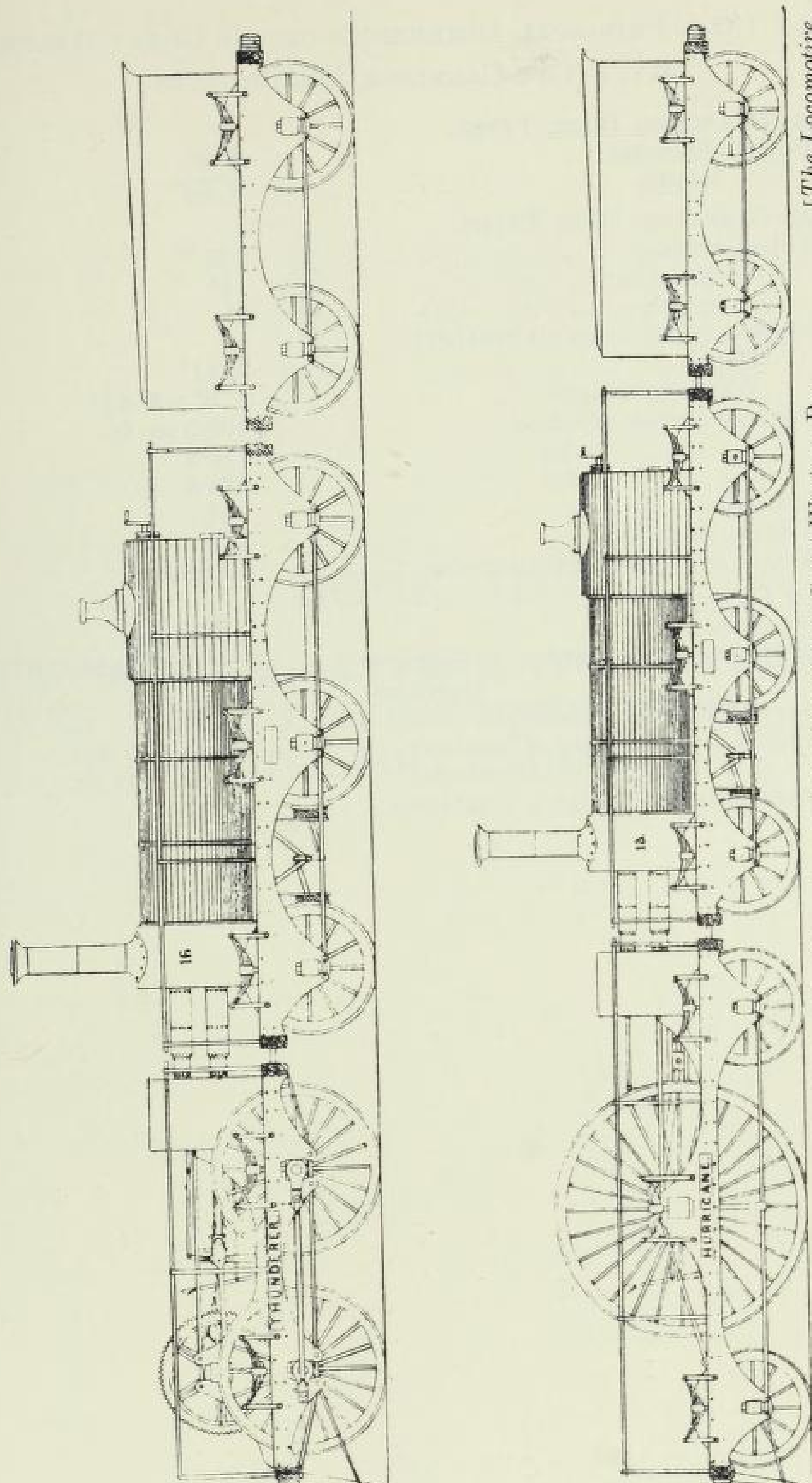
The *Hurricane* had a single pair of driving wheels, 10 ft. in diameter, and is stated to have attained a speed of 84 miles per hour. In spite of this it was scrapped after a couple of years.

The *Thunderer* had coupled wheels 6 ft. in diameter. But the pistons drove a large fly wheel, which was provided with wooden teeth, which meshed with a pinion carried by one of the axles. The ratio of this gearing being 27 to 10, the effect was the same as if the drivers had been 14 ft. in diameter.

The supply and exhaust steam passed from the boiler to the engine carriage by means of flexible steam pipes.

Needless to say, these freaks never gave satisfactory service.

The principal dimensions of these curious locomotives are given (subject to correction) on p. 520.



[*The Locomotive.*

Fig. 188.—The *Thunderer* and the *Hurricane*, Great Western Ry.
(7 ft. Gauge.)

Table 102.—Principal Dimensions of the Great Western Ry.'s Two-Carriage Locomotives

Boiler Carriage, Both Types.	
Boiler, diameter	3′ 9″
,, length	8′ 8½″
Boiler Carriage, Both Types.	
Tubes, number	135
,, diameter	1⅝″
,, length	9′
Firebox (with water midfeather):	
Depth	3′ 11″
Width by length	2′ 5″ × 3′ 8½″
Heating surface, firebox	108·3 sq. ft.
,, ,, tubes	515·2 ,,
,, ,, total	623·4 ,,
Grate area	17·2 ,,
Wheels, diameter	4′ 6″
Weight in service, approximate	12 tons
Engine Carriage	
Cylinders	16″ × 20″
Driving wheels, diameter, *Thunderer*	4′ 6″ (equivalent to 14′)
,, ,, ,, *Hurricane*	10′
Carrying wheels, *Hurricane*	4′ 6″
Weight, approximate, *Thunderer*	12 tons 10 cwt.
,, ,, *Hurricane*	11 tons 10 cwt.
Total adhesive weight, *Hurricane*	6 tons

BOOK III

TEMPORARILY ARTICULATED LOCOMOTIVES OR LOCOMOTIVES WITH AN AUXILIARY ENGINE

BOOK III

TEMPORARILY ARTICULATED LOCOMOTIVES OR LOCOMOTIVES WITH AN AUXILIARY ENGINE.

General Observations

THE proportion of its rated tractive effort which a locomotive can utilise depends on two factors, the steam supply and the adhesion between wheel and rail.

The adhesion is increased by arranging that the largest practicable proportion of the total weight of the locomotive be borne by the driving wheels.

But it would be obviously convenient if the normal adhesion of the locomotive could be temporarily increased at will, at starting or on other occasions when an abnormal draw-bar pull is called for. Several devices have been evolved to meet this, of which the most noteworthy is the traction increaser.*

The results obtained were not, however, of much interest.

Attempts have also been made to increase adhesion by electro-magnets, but they have led to no practical result.

* Traction increasers have been in use in America for a considerable time to facilitate starting or to increase the adhesion temporarily. The desired result was obtained by modifying the distribution of the load between the pony truck and the driving axles by means of small cylinders which acted on the springs at the bissel axles, or on the spring compensators. As this transfer of weight was only carried out at low speeds, no damage was done to the rails.

Thus, locomotive No. 5000, built by Messrs. Baldwin in 1880, had normally a total adhesive weight of 15 tons 15 cwt. (16 tonnes). This could be raised to 19 tons 13 cwt. (20 tonnes) by a transference of load from the rear truck. This locomotive ran between Philadelphia and New York.

Three types of traction increasers have been used.

The Player type of the Atchison, Topeka and Santa Fé Ry., in which the springs of the axle to be unloaded were acted upon.

In Henderson's and the American Locomotive Co.'s (New York Central lines) types the spring compensators were acted upon.

All such arrangements are but palliatives and cannot give results of much value.

The use of auxiliary steam cylinders, acting on those axles which normally are not driven, is, however, a much more practical proposition, the auxiliary drive being only brought into use at starting, or when there is a specially great demand for power. Thus an increased draw-bar pull can be obtained at low speeds, but on the other hand, certain complications are introduced.

Until quite recently auxiliary apparatus of this type was seldom used in Europe, though it originated here. It is otherwise in America. For here the load carried by the rear trailing axle is seldom less than 10 and reaches up to 20 tons. It is obvious than an increase of adhesion of this order is worth considering. It may amount to as much, or more, than 10 per cent. of the total adhesion.

Furthermore, as the systems now in use are thoroughly satisfactory, they are likely to have a definite influence on future locomotive design. It has become necessary to use fireboxes of considerable depth. The provision of a rear trailing axle renders the design of such fireboxes easier, and as the load on this axle can be used when required for adhesion, the objection to such axles ceases to have much force, as no diminution in the loads drawn is occasioned thereby.

GROUP I.—AUXILIARY ENGINE ACTING ON THE FRONT CARRYING AXLE OR AXLES

Type 1.—The Krauss System of Auxiliary Engine

Krauss seems to have been the first to try to temporarily utilise for adhesion, when it was needed, the weight normally borne by the front truck. The means by which he threw the auxiliary engine in or out of action is the most noteworthy feature of the system.*

With this end in view, he added a special carrying axle to the front bogie, which was normally out of action, the wheels being maintained at a height of 3 cm. (a little more than an inch) above the rails. This axle could be, at will, pressed into service,

* German Patent No. D.R.P. 71,722. See *Zeitschrift des Verein Deutsche Ingenieur*, January 6th, 1894. p. 28.

TABLE 103.—PRINCIPAL DIMENSIONS OF KRAUSS LOCOMOTIVES WITH AUXILIARY AXLE, THE BAVARIAN STATE RYS.

		Metric Measures.		English Measures.	
Gauge		1.435 m.		Standard.	
Type / Builder / Date		**4-2-2** Krauss. 1895.	**4-4-2** Krauss. 1900.	**4-2-2** Krauss. 1895.	**4-4-2** Krauss. 1900.
Cylinders, diameter, H.P.	m.	0·385–0·26	0·44–0·26	15¼"–10¼"	17½"–10¼"
,, ,, L.P.	,,	0·61	0·65	24"	25⅝"
,, ,, stroke	,,	0·61–0·46	0·66–0·46	25⅝"–18⅛"	26"–18⅛"
Boiler, height of centre line	,,	2·25	2·64	7' 4½"	8' 5¾"
,, diameter	,,	1·39	1·46	4' 6¾"	4' 9⅜"
,, pressure	kg./sq. cm.	13	14	185 lbs./sq. in.	199 lbs./sq. in.
Tubes, number		226	238	226	238
,, diameter	mm.	41–46	47–52	1 19/32"–1 13/16"	1 27/32"–2 1/16"
,, length	m.	3·78	5·10	12' 4½"	16' 7"
Heating surface, firebox	sq. m.	9·5	11·81	105 sq. ft.	127 sq. ft.
,, ,, tubes	,,	112·8	179·2	1,225 sq. ft.	1,930 sq. ft.
,, ,, total	,,	122·3	191	1,330 sq. ft.	2,057 sq. ft.
Grate area	,,	—	2·9	—	31·2 sq. ft.
Wheels, diameter, pony and trailing	m.	0·995	1·0	3' 3 5/16"	3' 3⅜"
,, ,, auxiliary	,,	1·0	1·0	3' 3⅜"	3' 3⅜"
,, ,, driving	,,	1·86	1·87	6' 1½"	6' 1⅞"
Wheelbase, rigid	,,	—	1·94	—	6' 6"
,, ,, with auxiliary driver	,,	—	4·68	—	15' 4"
,, total	,,	7·40	8·94	24' 2"	39' 1½"
Overall, height	,,	4·25	4·23	13' 11"	13' 10¼"
,, width	,,	3·00	2·75	9' 9¾"	9' 0¾"
,, length	,,	10·05	11·65	32' 9¾"	29' 1"
Tractive force, driving	t.	—	7·177	—	15,900 lbs.
,, ,, auxiliary	,,	—	3·730	—	8,300 lbs.
,, ,, total	,,	—	11·947	—	26,500 lbs.
Weight, adhesive	,,	14·7	28·2	14 tons 4 cwt.	27 tons 15 cwt.
,, ,, auxiliary	,,	13·3	13·4	13 tons 2 cwt.	13 tons 4 cwt.
,, ,, total	,,	28·0	41·6	27 tons 11 cwt.	40 tons 18 cwt.
Tender, weight in service	,,	34·3	43·9	33 tons 15 cwt.	43 tons 4 cwt.
,, water	cub. m.	14·0	18·0	2,860 galls.	3,960 galls.
,, fuel	t.	5·0	6·0	4 tons 18 cwt.	5 tons 18 cwt.
,, wheels, diameter	m.	0·996	1·00	3' 3 5/16"	3' 3⅜"

when a special auxiliary engine drove it. Two locomotives have been so equipped, the second one being an improvement upon the original one.

4-(2)-2-2 Krauss Auxiliary Locomotive of the Palatinate Rys.—Standard gauge.

This locomotive, which was exhibited in Nurnberg in 1896, had an auxiliary pair of drivers back of the leading bogie. The cylinders of this auxiliary engine were placed on the locomotive's main frame, above the engine's ordinary cylinders. When needed, the auxiliary drivers were pressed on to the rail by small cylinders.

Experience gathered from actual practice encouraged the

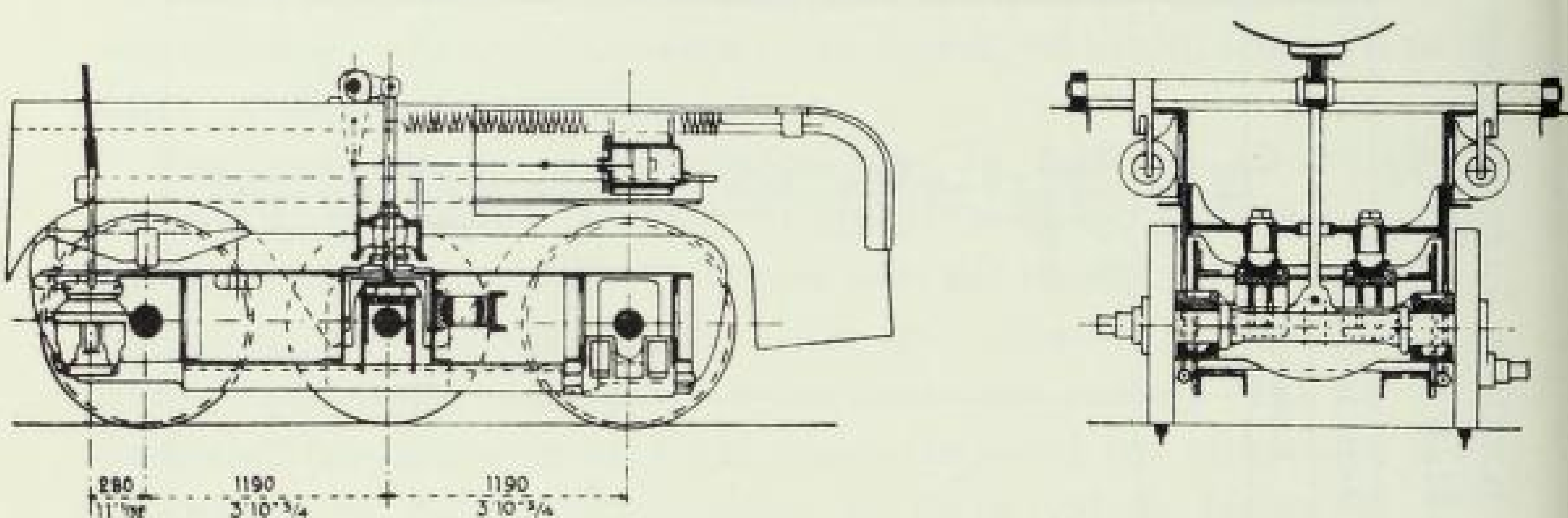


FIG. 189.—Leading Bogie of the Bavarian State Rys. $\frac{4}{(2)}$-2-2 Locomotive. (Standard Gauge.)
Built by the Krauss Locomotive Works.

firm of builders to embody a number of improvements in another locomotive.

$\frac{4}{(2)}$-4-2 Krauss Auxiliary Locomotive of the Bavarian State Rys.—Standard gauge (Fig. 189).

This locomotive was exhibited at the Vincennes Annexe of the Paris Exhibition of 1900. In this case, the auxiliary axle was placed between the bogie's axles, which was more reasonable. Adhesion could be increased by 47 per cent. in this case, as against 90 per cent. in the previous type.

The details of this early design are of interest, in view of the subsequent considerable use of the auxiliary booster engine.

The main pin of the bogie was set 15 ins. (0·38 m.) in front of the centre of the bogie itself. The load rested on the bogie at three points, one in front and two behind. By means of a spring tending to raise the rear axle, the two axles were unevenly loaded, the front axle having a load of 14·8 tonnes, the rear one, 10·9 tonnes.

The auxiliary axle was independent of the bogie and was set exactly in its centre line.

It was carried in the frames, so that when it was put into service it transformed a 4-4-2 locomotive into a $\frac{4}{(2)}$ + 4-2 non-articulated locomotive. The auxiliary wheels had no flanges.

The most interesting feature of the design is the method by which the auxiliary axle is depressed on to the rails, so as to give the desired adhesion. There are two small cylinders located above the leading axle of the bogie. The pistons of these cylinders actuated two small levers at right angles, thus forming a square, the upper angle of which is fixed to a cross shaft which runs under the boiler. The free end of this arrangement is connected to a vertical link, the other end of which is connected to the axles. When the lever ceases to act, under the pressure of the steam, the axle is returned to its normal position by spiral springs fixed to the frames under the running plate.

The weight of this axle is 1 ton 15 cwt. (1,750 kg.), and its adhesive weight (deducting a weight of 3 tons 15 cwt., or 3,800 kg., for the counter pressure of the springs) is 13 tons (13,197 kg.). The two axles of the bogie are equally relieved of this weight.

The alterations of the load are as follows :—

	Auxiliary Axle.		Auxiliary Axle.	
	Out of Action.	In Action.	Out of Action.	In Action.
Leading axle of bogie .	14,800 kg.	8,200 kg.	14 t. 11 cwt.	8 t. 1 cwt.
Auxiliary axle . .	0	13,400 kg.	0	13 t. 4 cwt.
Trailing axle of bogie .	10,900 kg.	4,300 kg.	10 t. 15 cwt.	4 t. 5 cwt.

It is, of course, far more simple to obtain additional temporary adhesion by a booster fitted to the rear trailing axle than by the above-described arrangement.

Type 2.—The Esslingen Combined Rack and Adhesion Locomotive

The Maschinenfabrik Esslingen has long specialised in rack locomotives, and has endeavoured to increase their efficiency.

In one of their attempts, which took place in 1913, they carried out the idea of utilising the coupled wheels for adhesion and fitting an auxiliary rack engine to the leading bogie. Such a locomotive enters into the group under notice, as it is provided with two engines, the rear one of which works a rigid train of wheels, and the fore one a leading truck, articulated to the main engine and which provides extra power when it is needed on the rack sections.

The leading truck has Walschaert's valve gear with the link behind the crank. The latter, as the coupling rods, are situated outside the frames. The second axle takes the drive.

0-4 + 10-0 Rack and Adhesion Locomotives of the Arica and La Paz Ry. (Chile and Bolivia).—Metre gauge.

This important line, which was built in compliance with the stipulations of the Treaty of Ancon, gives La Paz a direct ocean outlet. From Arica, up the slopes of the Cordilleras, the rise is so steep that it was necessary to build an Abt rack section which is, in effect, the longest one in the world.

Central (km. 70, mile 43) is at an altitude of 1,491 m. (4,892 ft.); then comes the 42 km. (26 miles) rack section with a gradient of 1 in 12 which carries the railway up to Putquios (km. 112·2, mile 70—altitude 3,728 m., 12,231 ft.). The next section as far as La Cumbre (km. 183, mile 114—altitude 4,257 m., 13,067 ft.) is easier, and from here to the terminus at La Paz (km. 439, mile 273—altitude 4,083 m., 13,345 ft.), the line follows the Bolivian plateau.

The original locomotives were 2-8-2 mixed rack and adhesion ones.* They were followed in 1913 by those under notice, which are remarkable not only in having a front rack truck, but also in being ten-coupled mixed locomotives. The following Table (104) quotes comparative dimensions of both types.

* The rack-wheels are arranged in the usual fashion in a sub-frame situated between the coupled running wheels, which have outside bearings. These locomotives haul 166 metric tons over the rack section at an average speed of 9½ miles an hour.

TABLE 104.

Railway	Arica to La Paz.			
Gauge	Metre.			
Date	1913.		1913.	
Type	**2-8-2**	**0-4 + 10-0**	**2-8-2**	**0-4 + 10-0**
Cylinders (adhesion), diameter	0m.50	0m.50	1′ 7 5/8″	1′ 7 5/8″
„ „ stroke	0m.50	0m.50	1′ 7 5/8″	1′ 7 5/8″
Cylinders (rack), diameter	0m.45	0m.48	1′ 5 6/32″	1′ 6 7/8″
„ „ stroke	0m.45	0m.48	1′ 5 6/32″	1′ 6 7/8″
Wheels, diameter, adhesive	0m.94	0m.95	3′ 1″	3′ 1 3/8″
„ „ rack	0m.69	0m.88	2′ 3 1/8″	2′ 10 5/8″
Wheelbase, total	—	8m.87	—	29′ 1 1/4″
Boiler, pressure	14 atm.	15 atm.	199 lbs.	213 lbs.
Heating surface	184·2 sq. m.	189·0 sq. m.	1,989 sq. ft.	2,034 sq. ft.
Grate area	2·6 „	3·2 „	28·0 „	34·4 „
Weight, empty	55·5 t.	75·5 t.	54–14 t.-cwt.	74–8 t.-cwt.
„ in service	73·3 t.	92·0 t.	72–3 „	90–12 „
„ adhesive	51·9 t.	65·6 t.	51–0 „	65–12 „

GROUP II.—LOCOMOTIVES WITH AN INTERMEDIATE MOTOR AXLE

After the introduction of the *Krauss* system, a trial was made in Canada of a Mogul locomotive fitted with two pairs of small wheels located between the driving wheels. Either the small or the large wheels could be used to move the locomotive, the drawbar pull being in reverse ratio to the diameter of the wheels.

We have referred to these locomotives here only for the sake of completeness. They are not articulated locomotives at all, since their driving axles always remain parallel.

GROUP III.—LOCOMOTIVES WITH AN AUXILIARY ENGINE ACTING ON THE REAR PONY AXLE

Type 1.—The Booster *

GENERAL CHARACTERISTICS

The hauling capacity of a locomotive is a function of the ratio between the tractive force and the resistance of the load drawn. The greater the difference between these quantities the more rapid will be the acceleration. But as the speed increases the drawbar pull diminishes until there is a balance between the two quantities.

* These auxiliary engines are built by the Franklin Supply Co., New York.

It was in the light of these facts that Mr. Ingersoll, of the New York Central Ry., designed his booster in 1919 (Fig. 190).

The booster consists of a horizontal two-cylinder engine, cylinders 10 ins. × 12 ins. (0·25 m. × 0·30 m.), arranged to drive the rear trailing axle at times when a temporary increase of tractive effort is required. Each cylinder has its own steam chest and the usual plug piston valve, piston rods, cranks and crankshafts. The trailing axle bears a tooth wheel hydraulically pressed on to it.

The cast-steel bed plate has a three-point suspension: one

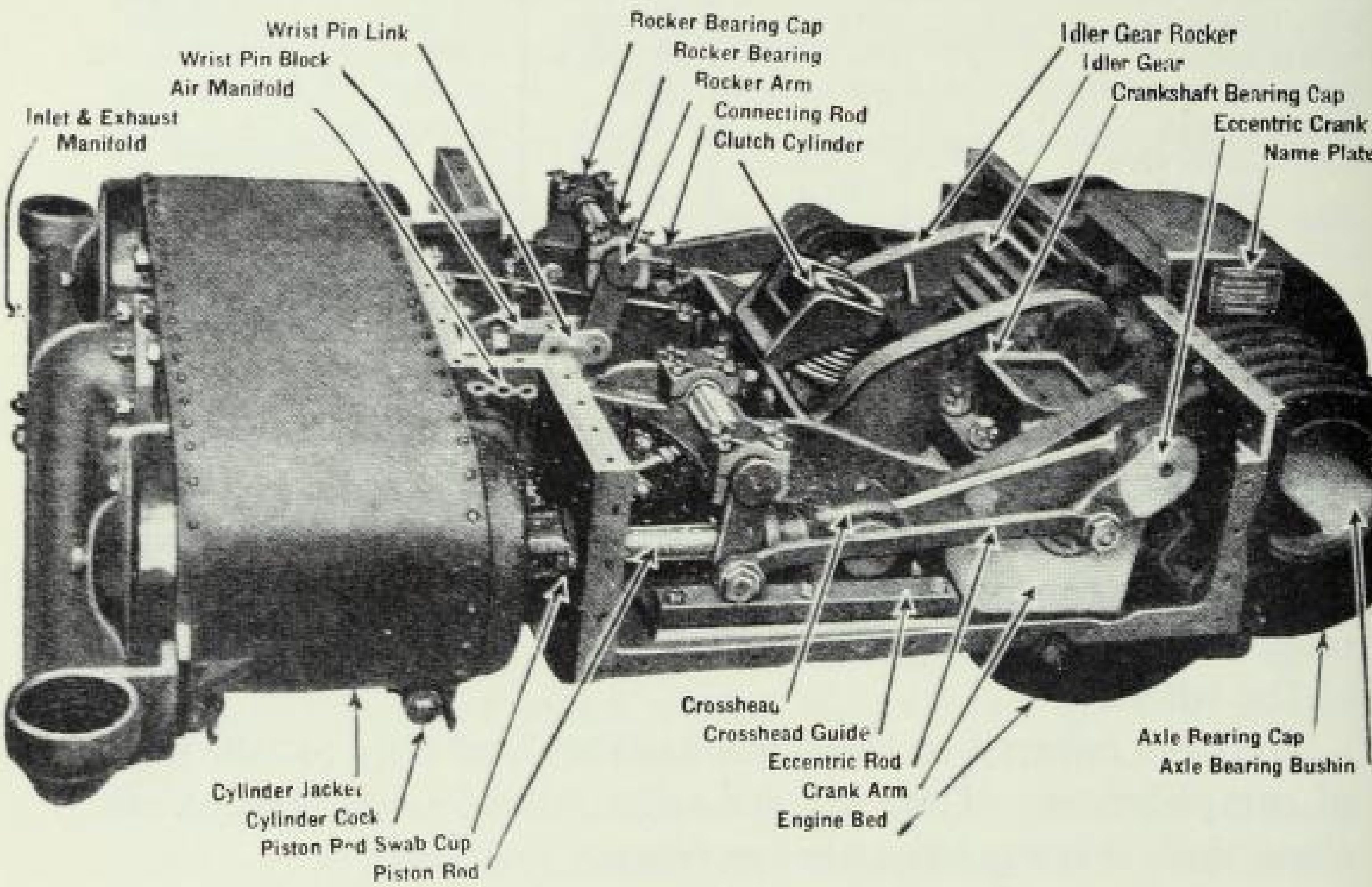


Fig. 190.—The Booster.
Franklin Supply Co.

point on the spherical seat at the centre of the rear cross member of the truck-frame, and two points on the trailing axle's bearings. The booster can be put into action when desired by means of a transmission shaft, which engages with the axle by a system of gears, spur wheels being fixed to the transmission shaft and the axles, both of which can be slid into or out of gear. The pinion is disengaged automatically when a predetermined speed is reached, generally 10 miles (16 km.) per hour. The original booster could only be worked when the locomotive was running forward.

The cut-off in the booster cylinders is fixed at 75 per cent. The steam supply is taken direct from the dome or steam chest. Its admission is controlled automatically. The exhaust is led to the blast pipe through flexible connections.

It seems advisable that the booster should cut in, on freight service, when speed has a tendency to fall below 10 miles an hour and should not be cut out, in passenger service, below 15 to 20 miles an hour, so as to get the utmost advantage from the rapid acceleration it allows, and which enables the locomotive to reach its road speed in about half the time it would otherwise take.

The increase of tractive effort obtained by the booster depends on the type of locomotive on which it is used. On

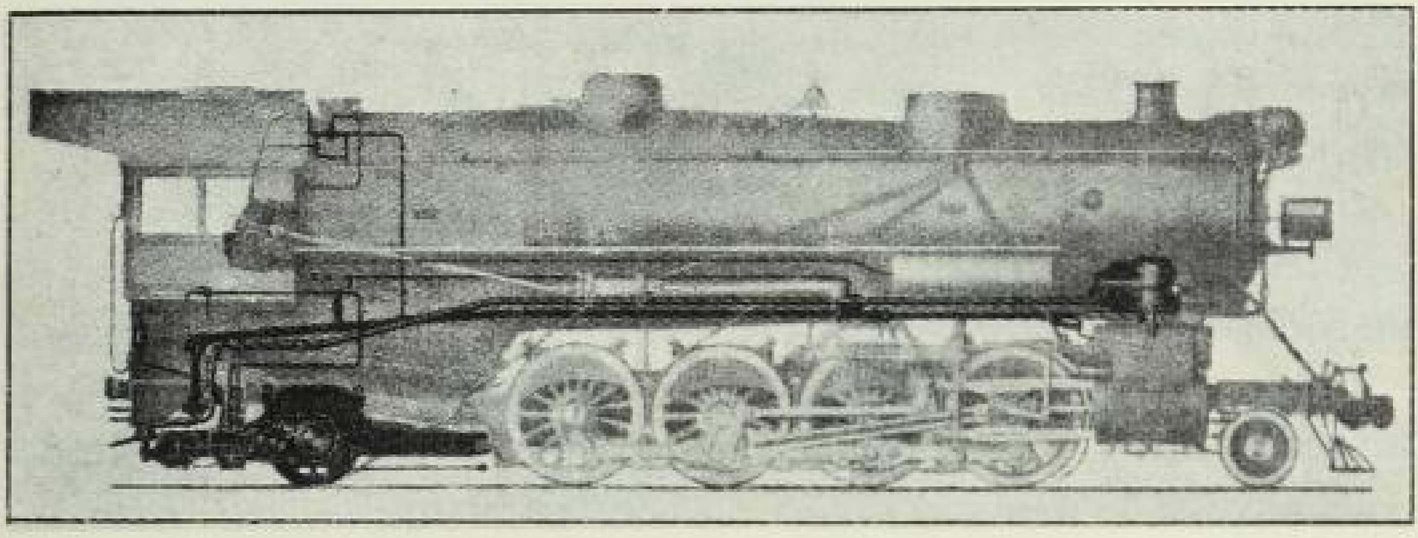


FIG. 191.—Adaptation of a Booster to a 2-8-2 Locomotive, which becomes a 2-8-0 (+ 2) Locomotive.

American locomotives it is about 30 per cent. for the Atlantic, 27 per cent. for the Pacific, 23 per cent. for the Mikado, and 10 per cent. for the Santa Fé types.

The advantages of the booster are that quicker acceleration and increased speed up gradients are obtained. It is thereby an aid to the general working of the line since, by its means, it is often possible to dispense with a banking engine.

Furthermore, on a section which is mostly easy, but has a few heavy gradients, it is possible to use a locomotive type suitable for service over most of the section instead of a type with an additional coupled axle, the extra adherence of which is needed only on the gradients. Alternatively, a more powerful locomotive of the better type can be used.*

* The addition of a booster to a 2-10-2 Santa Fé locomotive weighing

Utilisation of the Booster

The first booster was applied to an Atlantic locomotive of the New York Central Ry. It increased the drawbar pull at starting by 36 per cent. and was cut out automatically at a speed of 22 miles (35 km.) an hour.

Another booster fitted to a Pacific locomotive of the same railway increased the drawbar pull at starting by 23 per cent.

Such satisfactory results have led to wide diffusion of the booster, so much so that by September, 1924, no less than 1,450 of them were in service on American railways, and by July, 1928, over 4,000 were in use, of which 1,500 were applied to the single Mikado type, whose power was thus increased by about one-sixth.

As for the other types, the Atlantic locomotive has acquired a new lease of life, with increased tractive effort of from 30 to 40 per cent., and the same applies to all other locomotives with trailers.*

The present type of booster (Fig. 190) weighs 2 tons 5 cwt. (235 kg.), and has a gear ratio of 14 to 36. It is claimed that its mechanical efficiency is as high as 94 per cent.

In several cases, the boosters are supplemented by reversible boosters under the tender bogies. Boosters are now used under a variety of types and occur on the following :—

4-4-2	...	2-8-2	...	2-10-2
2-6-2	...	4-8-2	...	4-10-2
4-6-2	...	2-8-4	...	2-10-4
4-6-4	...	4-8-4	...	4-12-2

Trailer applications with side rods occur on the following :— †

2-8-4 ... 2-10-4

It will be seen that the booster is an adjunct of real practical

172 tons 18 cwt. (175 tonnes) raised the tractive effort from 33 tons 9 cwt. to 36 tons 8 cwt. (34 to 37 metric tons). The weight of a Santa Fé capable of developing this tractive effort without a booster was 186 tons 17 cwt. (190 metric tons).

* The tractive force of a Pacific locomotive with 190 lbs. steam pressure has been increased by 11,000 lbs., which brings the total up to 54,000 lbs.

A more modern Mikado (200 lbs. pressure and 67,000 lbs. tractive force) has had 11,500 lbs. added to its tractive force.

† Modern 4-6-4 locomotives (225 lbs. steam pressure and 42,300 lbs. tractive force) have had this increased by 25 per cent. (10,900 lbs.), bringing it up to 53,200 lbs.

Four-wheel Commonwealth trailers have no side rods.

value. That value lies not only in the fact that it can be adapted to existing types of locomotive to increase their power, but also because it will be welcome to the designer of new types of locomotive since the trailing pony axle will no longer be

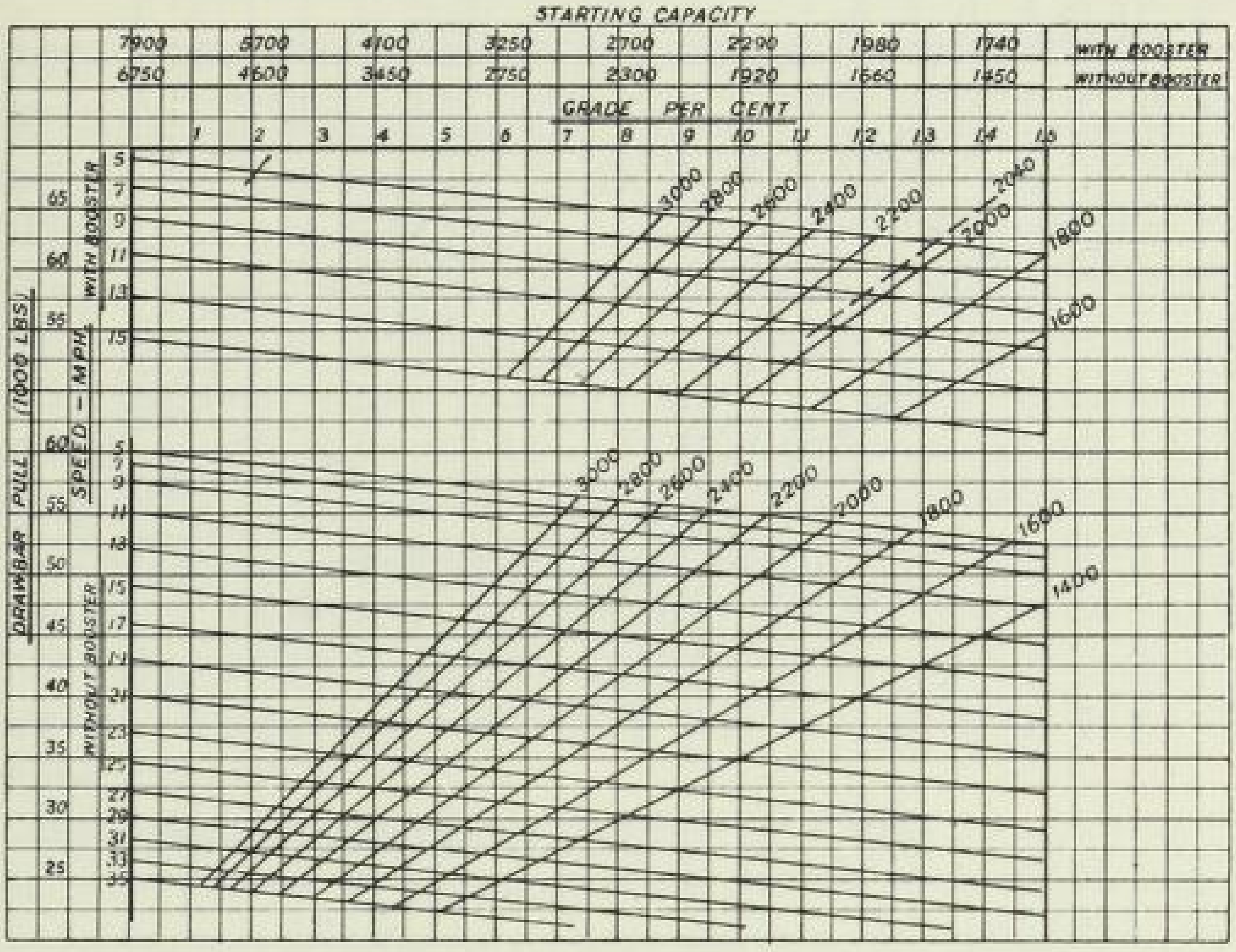


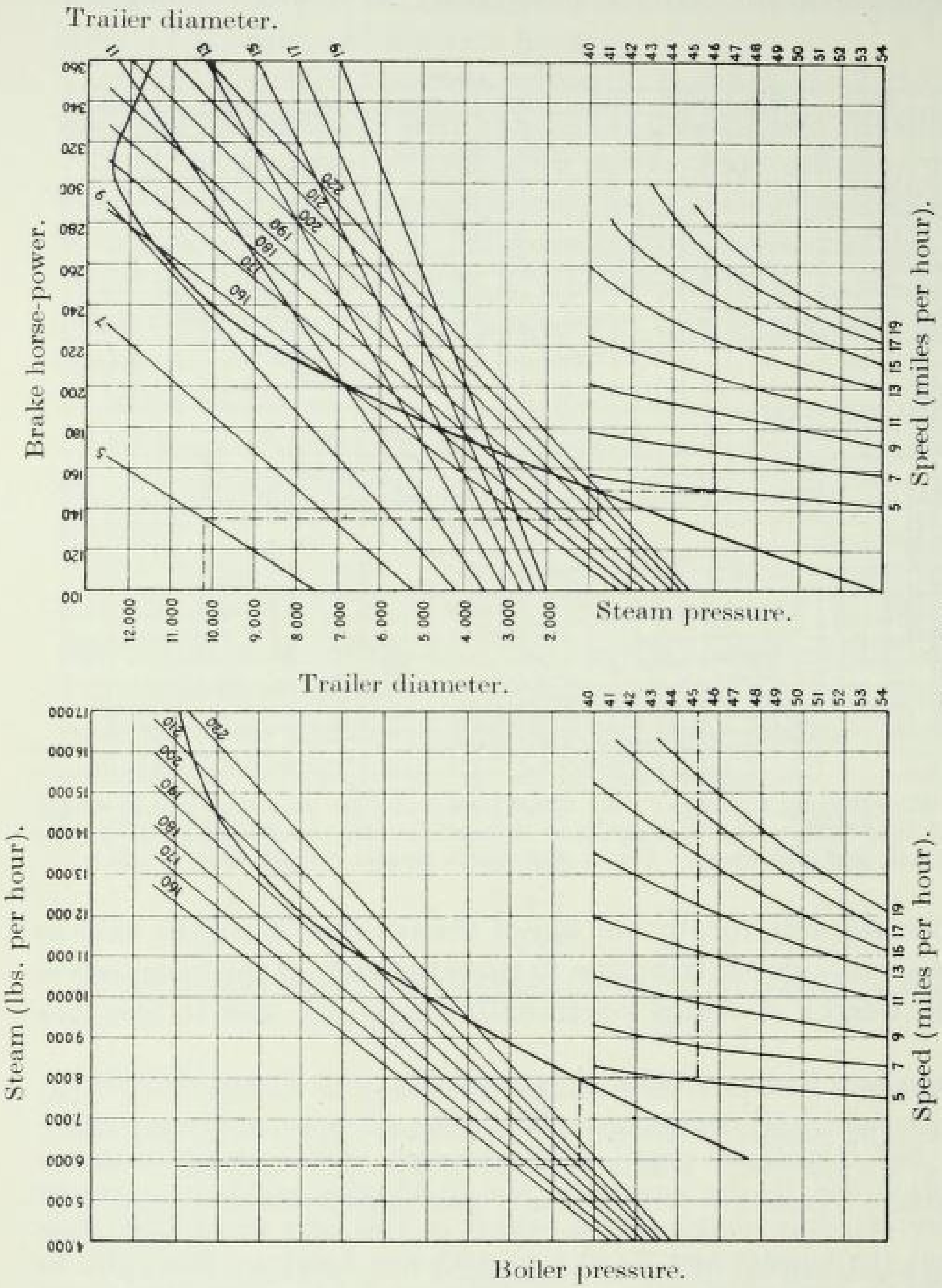
FIG. 192.—Booster tonnage rating chart based on cars whose weight averages 45 tons each. The tonnage may be read for any combination of grade, speed, and curvature. One degree curve equals ·04 per cent. grade.*

a necessary evil, for, by the aid of the booster, it will be able to make a valuable contribution to the adherence of the locomotive.

The weight of trains continually increases, and it becomes

* Example: To find the tonnage which may be handled on a 1 per cent. grade with $2\frac{1}{2}$-degree curve at 12 miles per hour, at the top of the sheet find the virtual grade of 1·1 per cent., follow down vertically on dotted line to the horizontal line of 12 miles per hour. At the intersection, draw diagonal line, which in this case gives 1,800 tons without the booster and 2,040 tons with the booster. Similarly, to find the tonnage which may be started on a 1·1 per cent. grade, and the speed at which may be handled: At the top of sheet under starting capacities, it is found that 2,135 tons may be started with the booster and 1,790 tons without the booster. Follow down vertically on the 1·1 per cent. grade line, and it will be observed that 1,790 tons may be handled at 12 miles per hour without the booster and at 15 miles per hour with the booster.

more and more difficult to design boilers of ample evaporative capacity. Large fireboxes have become a necessity. These need the support of a trailing axle, which, up to the present,



Booster chart for drawbar pull.

Fig. 193.

Booster chart for determining steam consumption.

has been of no use from the adhesion point of view. But the booster has changed the situation. We may, therefore, anticipate considerable development of locomotive types with a trailing pony axle actuated by a booster.

On the other hand, the booster should be used with discretion. The use of an auxiliary engine is always somewhat of a complication, and when a locomotive can be designed with sufficient tractive effort without it, the booster should be dispensed with.

Class A.—Trailing Axle Booster

London and North Eastern Ry. Booster Locomotive.

So far the only European applications of the booster have been made by the London and North Eastern Ry.

The first occurred in 1925, when boosters were applied to two Mikados provided for dealing with trains of 100 coal wagons (approximately 1,600 tons) between London and Peterborough.

The diameter of the trailing wheels, to which the booster is applied, is 3 ft. 8 ins. (1·11 m.); its two cylinders are 10 ins. diameter by 12 ins. stroke (0·25 m. × 0·30 m.), and its tractive effort 8,500 lbs. (3·850 kg.), which, added to the engine's tractive effort 38,500 lbs. (17,460 kg.), brings the total up to 47,000 lbs. (21,300 kg.). The weight on the booster is 18 tons 4 cwt. (18·5 tonnes), giving a ratio of 4·79 as against 4·16 for the engine proper.*

The London and North Eastern Ry. also experimentally applied a booster to an Atlantic locomotive and, after exhaustive trials, several alterations were made in the standard booster to make it more suitable to British locomotive conditions.†

The gear ratio was reduced to $1\frac{1}{2}:1$, the booster's crankshaft then making 262 r.p.m. at a train speed of 25 miles per hour. This enables the booster to be cut in at higher speeds than it otherwise could, and enables the locomotives of express trains to accelerate rapidly after a signal check. Indeed, the rate of acceleration seems to be increased from 0·3 to 0·4 and even 0·5 miles per hour per second. This improved accelera-

* These locomotives, which are, with the exception of the *Garratts*, the most powerful in Great Britain, weigh 100 tons, with 106 cwt. on the leading pair of wheels and 71·10 cwt. on the coupled wheels.

Total heating surface	2·930 sq. ft.	...	272·2 sq. m.
Superheater .	. 525·19 sq. ft.	...	48·8 sq. m.
Grate area .	. 47·3 sq. ft.	...	3·8 sq. m.
Three cylinders	. 20 ins. × 26 ins.	...	0·51 m. × 0·66 m.

† The tests were carried out with an eighteen-coach train weighing 535 tons. The locomotive behind the tender was able to start the train from a dead stop on a 1 in 96 gradient combined with a curve; the drawbar pull thus developed was 25·840 lbs.

tion is a most important factor, as it increases the track capacity and it offsets the decrease of calculated tractive effort of the booster which, in the example we quote, falls from 8,500 to 4,970 lbs. But another advantage becomes apparent in this case, in that there is less back pressure with increasing speed.

Other alterations comprise the combination of booster and engine exhausts in a single blast pipe ; an improved suspension of the booster ; steam instead of air operation of the gear, etc., resulting in the time consumed in putting the booster in or out of gear being reduced to five seconds.

4-8-2 Booster Locomotives of the Nigerian Rys.—3 ft. 6 ins. gauge.

In 1929, two locomotives of a batch supplied by Messrs. Armstrong, Whitworth and Co. were provided with booster furnished by Stone and Co.*

Their performances will be of great interest as these are, we believe, the first occurrences of boosters on narrow gauge lines.

The section on which these locomotives will work have a number of short steep gradients. Of course, a locomotive with five coupled axles could have dealt with the loads, but such a locomotive would have had too great a reserve of unutilised adhesive weight on a large part of the line. As the demand for greater tractive force occurs only at the start and on certain sections, an eight-coupled locomotive was sufficient for the purpose, on condition that an increase of 25 per cent. tractive force should be available when needed ; hence the booster.

The total weight of the locomotive is little affected thereby, but the weight distribution is necessarily altered to a consider-

* Principal dimensions of these locomotives are :—

Cylinders, 19 ins. by 24 ins. Boiler barrel, 5 ft. 3¾ ins. diameter ; length, 18 ft. 10¾ ins. ; pressure, 180 lbs. ; 125 tubes, 2 ins. diameter ; 21 flues, 5½ ins. diameter ; length, 17 ft. ; 21 superheater elements, 1½ ins. diameter outside. Heating surface : firebox, 180, fire tubes, 1,627, total, 2,122 sq. ft. ; superheater, 315 sq. ft. ; grate area, 38 sq. ft. Wheels, diameter : 2 ft. 4½ ins. ; 3 ft. 9 ins. ; 2 ft. 6 ins. Wheels, diameter, trailing booster wheels, 2 ft. 9½ ins. Wheelbase : rigid, 12 ft. 9 ins. ; total, 30 ft. 9 ins. Tender coal capacity, 7½ tons. Weight of tender, 18 tons 12 cwt., empty ; 44 tons 9 cwt., in service.

able extent and, as a matter of fact, improved inasmuch as it is more equally distributed.

Weight per axle.	Non-booster Locomotive.		Booster Locomotive.	
	Empty. Tons-cwt.	In Service. Tons-cwt.	Empty. Tons-cwt.	In Service. Tons-cwt.
Leading bogie . .	9–14	10–16	9–6	9–16
1st coupled axle .	10–9	12–6	10–15	12–11
2nd ,, ,, .	11–8	12–12	11–1	12–11
3rd ,, ,, .	11–3	12–19	11–6	12–18
4th ,, ,, .	11–8	13–1	11–0	12–17
Trailing axle . .	8–9	9–10	11–16	12–19
Total, locomotive .	62–11	71–4	65–4	73–12

2-8-2 Booster Locomotive, Victoria Rys.—Standard gauge.

These locomotives were delivered in the course of the years 1928 and 1929 and rebuilt in the Railway's shops at Newport. The latest units were fitted with boosters, with wheels 3 ft. 7 ins. in diameter. Tractive force, which is 39,360 lbs. (at 85 per cent. boiler pressure) without booster, is raised to 48,360 lbs. when the latter is in action.

It is a curious fact that boosters should make their appearance in a number of British Colonies and that they should not be much used in Great Britain. The reason for this seeming discrepancy is probably twofold. In the first instance, it is always a slow process to have a new idea taken up ; in the second, the quality and cost of the coal reacts both on the firebox and on the utility of the booster itself.

Class B.—Locomotives with a Trailing Bogie Fitted with a Booster

The necessity for continually increasing the evaporative capacity of very powerful locomotives has obliged designers to provide very large fireboxes, which need the support of a four-

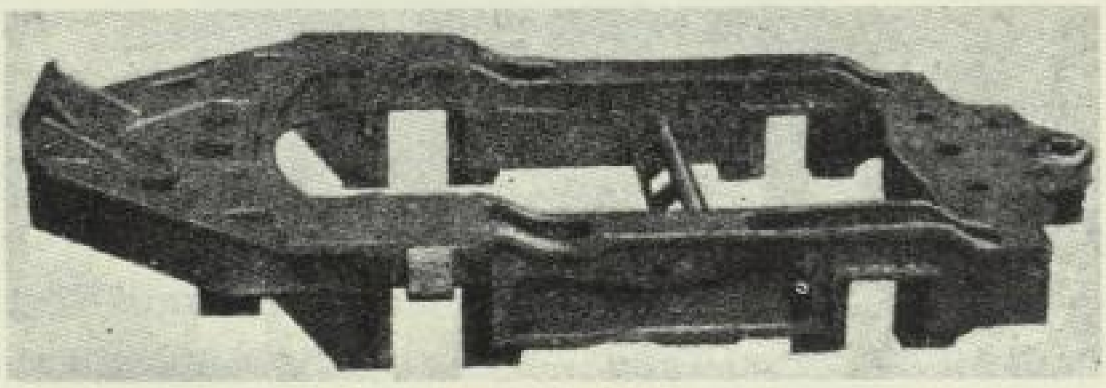


Fig. 194.—The Articulated Trailing Frame Casting.

wheeled bogie. In most designs the wheels of this bogie are of different diameters, and one of the axles is driven by a booster, but later types have coupled wheels. The following brief

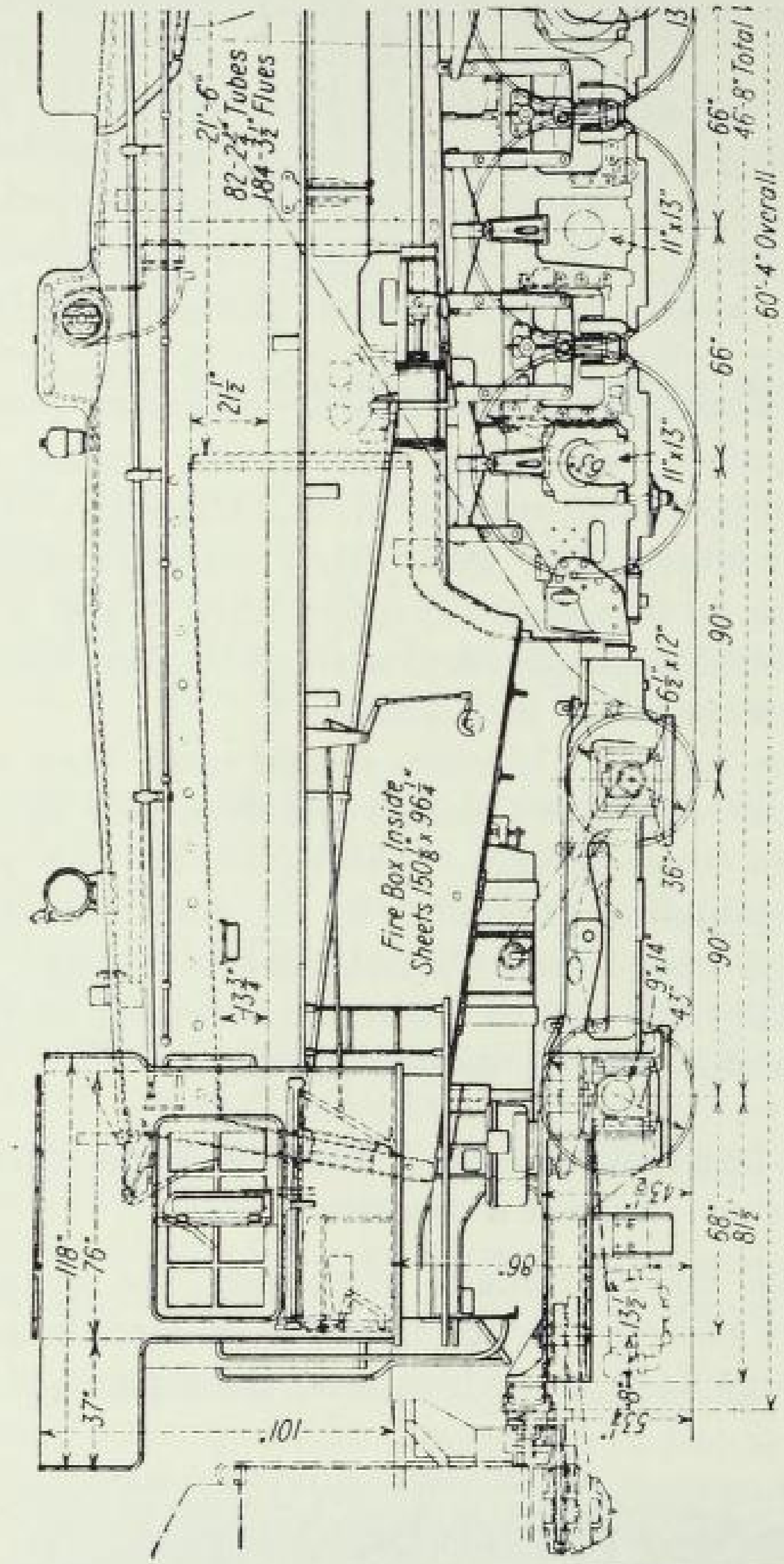
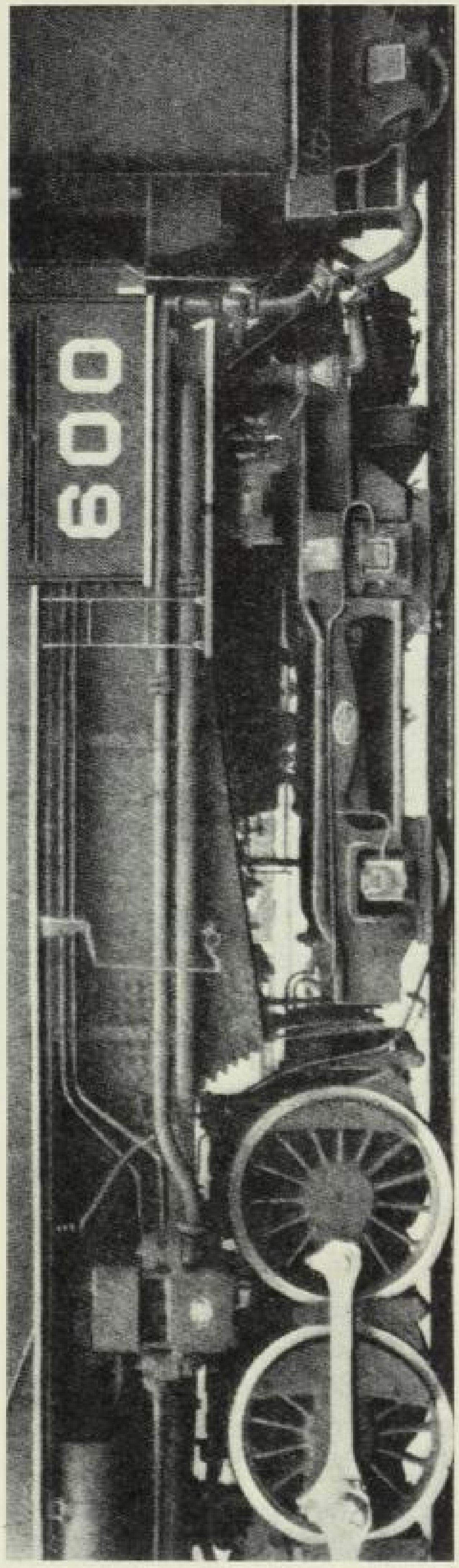


Fig. 195.—Rear Portion of Texas and Pacific 2-10-4 Locomotive, Built by the Lima Locomotive Works. [*The Railway Age.*

tabulation of the results reached for a determined total locomotive weight will be of interest..

Boston and Albany 2-8-4 (Berkshire) Type and Texas and Pacific Ry. 2-10-4 (Texas) Type.—Built by the Lima Locomotive Works in 1925 (Figs. 194, 195 and 196).



[*The Railway Age.*

FIG. 196.—Texas and Pacific Locomotive. The Relation of the Articulated Trailing Truck and the Firebox.

Railway . .	Boston and Albany.		Texas and Pacific.	
Type . . .	2-8-4		2-10-4	
Heating surface :				
Firebox . .	sq. ft. 337	sq. m. 31·4	sq. ft. 473	sq. m. 44·0
Tubes . .	,, 4,773	,, 443·4	,, 4,640	,, 431·0
Total . .	,, 5,110	,, 474·8	,, 5,113	,, 475·0
Superheater .	,, 2,111	,, 196·1	,, 2,110	,, 196·0
Grate area .	,, 100	,, 9·3	,, 100	,, 9·0
Weight, adhesive	lbs. 101,300	t. 46·0	lbs. 106,200	t. 45·7
,, total .	,, 248,000	t. 112·5	,, 300,000	t. 136·1
Tractive force :				
Engine . .	,, 69,400	t. 31·5	,, 83,000	t. 37·6
Engine and booster .	,, 82,600	t. 37·5	,, 96,000	t. 43·5

These figures speak for themselves. We would add that in the latter locomotives, the diameters of the rear bogie wheels are 36 ins. and 43 ins. respectively (0·91 m. and 1·09 m.), with a wheelbase of 93 ins. (2·37 m.).

4-8-4 Locomotive of the Canadian National Rys. (Northern Type).—Standard gauge.

This locomotive, including the booster, was built by the Canadian Locomotive Co. The rear bogie has trailing wheels of 2 ft. 10¼ ins. diameter and drivers of 4 ft. A few locomotives of the same type have no booster, and this is how the two classes compare :—

		With Booster.	Without Booster.
Weight on engine drivers . .	tons	113¾	102¾
,, leading bogie . .	,,	29	29
,, trailing bogie . .	,,	40½	37
,, total in working order .	,,	173¼	168¾
Tractive force	lbs.	67,000	56,800

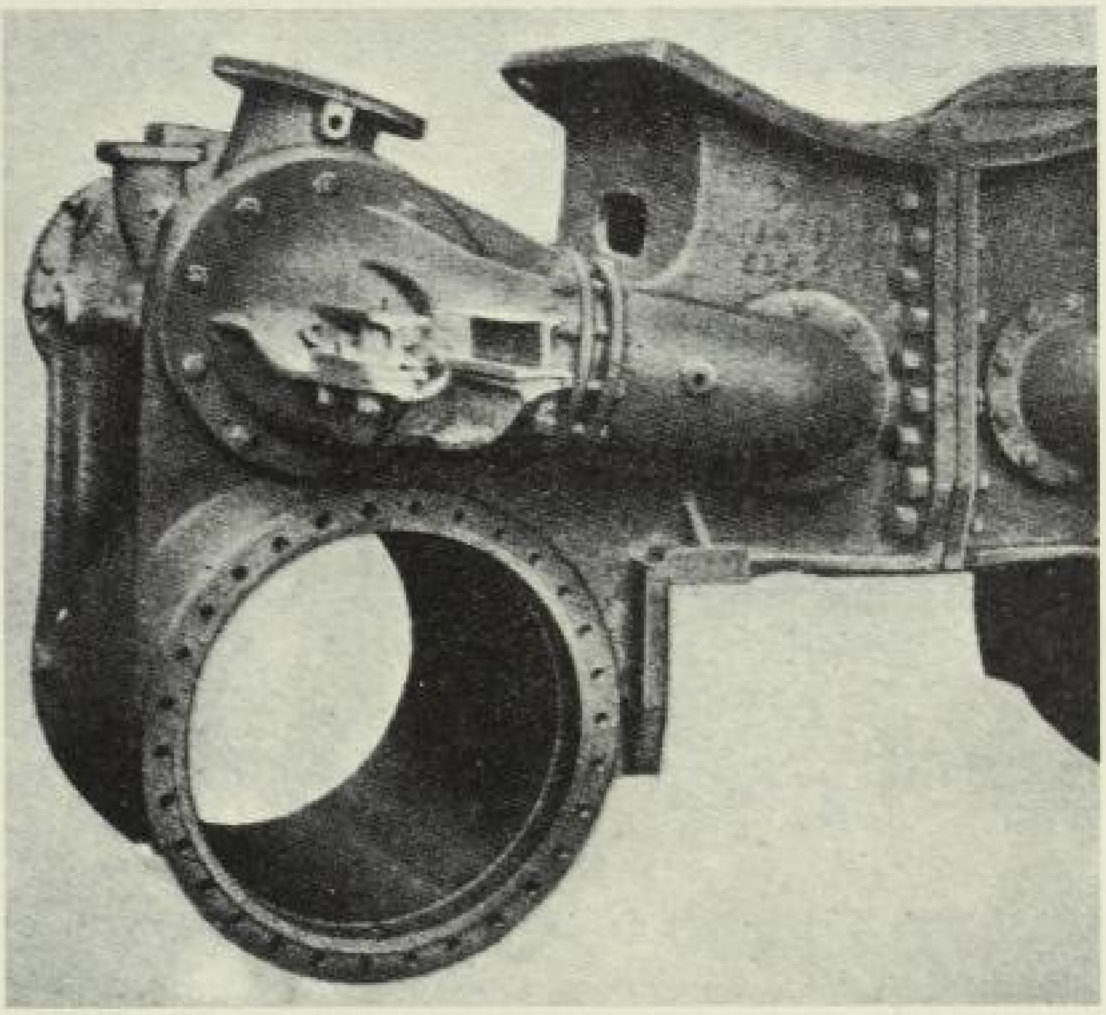
The rear bogie allows the adoption of an 84·4 sq. ft. grate (7·8 sq. m.).

The heating surface consists of 315 sq. ft. (29·2 sq. m.) provided by the firebox, 3,814 sq. ft. (354·3 sq. m.) by the tubes, and 117·1 sq. ft. (10·9 sq. m.) by the arch tubes, a total of 4,246 sq. ft.

4-6-4 Locomotive of the New York Central Lines.—Standard gauge.

This type, then called the Baltic, was first used in France, on the Ch. de fer du Nord, but was abandoned because too much weight was unavailable for adhesion. The booster has done away with this drawback, and the Americans have resuscitated the Baltic under the name of the Hudson. These locomotives reappeared in 1927.

They operate express trains at 50 to 60 miles an hour. In



[*The Railway Age.*

Fig. 197.—The Cast-steel Cylinders, showing one of the Outside Exhaust Passages.

this case, the booster was adopted for a somewhat different reason to the one that is usually put forward in its favour.

The track imposed limitations on the axle load, and it would not have been possible to obtain sufficient adhesion had not the adhesive weight of the rear truck been called upon to supplement that contributed by the main coupled wheels.

With a weight on the rear bogie of 53,500 lbs. (24·2 tonnes) on the trailing axle, and 42,000 (19·1 tonnes) on the leading axle, the tractive force is increased from 42,300 lbs. without to

53,200 lbs. with booster, the adhesion factor being 4·3 for the main drivers and 4·9 for the others.

The firebox is of generous proportions.*

Type 2.—Reversible Boosters

The original booster had been used to help the locomotive to start a heavy train or to help it over a difficult piece of line. It was therefore made to work in one direction only. But it became advisable to use it when the locomotive backed its train into a siding and particularly for switching service, so it was found indispensable to provide a reversible booster.

Thus, if a Mikado brought a train-load into a yard, a three-

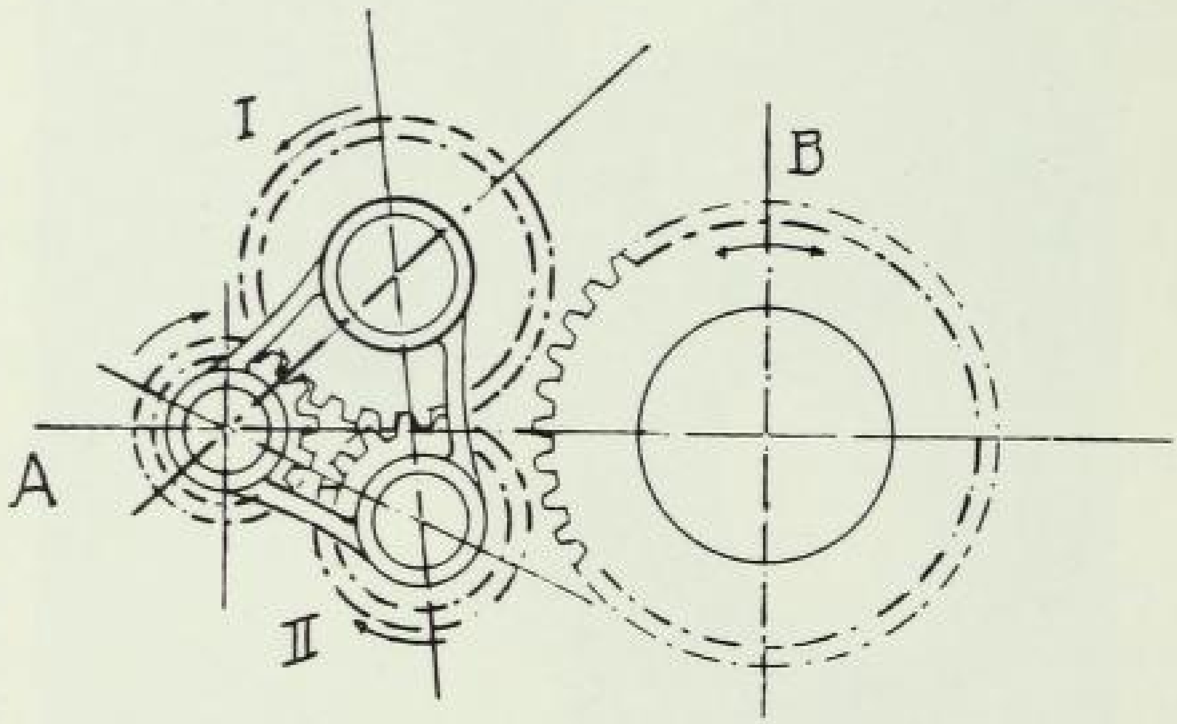


FIG. 198.—Gear Train of Reversible Booster.

coupled switcher, with reversible booster on the trailer, could handle the same weight when shunting.

The Franklin Supply Co. introduced reversible boosters in 1928, and this was obtained by the introduction of additional gearing. The booster itself always moves in the same direction, but its driving shaft can be thrown into mesh with the gear wheel of the driving axle through an idler wheel, and the

* Length, 10 ft. 10 ins. (3·30 m.); width, 7 ft. 6¼ ins. (2·29 m.).

Firebox heating surface, 244 sq. ft. (22·7 sq. m.); the tubes add 4·203 sq. ft. (390·5 sq. m.), and the superheater another 1·951 sq. ft. (181·2 sq. m.). The grate area is 81·5 sq. ft. (8 sq. m.). Yet the weight on each of the drivers is only 30,000 lbs. (13·7 tonnes).

The trailing truck was supplied by the Commonwealth Steel Co., and is of the Franklin C.2 locomotive booster type.

geared axle can move in either direction, but proper control prevents its moving in the opposite direction to that of the locomotive.

An appropriate pilot valve operates the clutch cylinder, and the mechanism is self-acting.

Reversible boosters are applied either to the trailing axle or to one or both of the tender's bogies—in some instances both to the locomotive's trailer and to one of the tender bogies.

BOOK IV

UTILISATION OF THE TENDER'S WEIGHT FOR PROPULSION

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UTILISATION OF THE TENDER'S WEIGHT FOR PROPULSION

THE weight of the tender and its contents is a dead load unavailable for adhesion. If this was found objectionable half a century ago, much more does the objection apply to-day, when, in order to avoid service stops for watering and fuelling, the tenders have to be very large, so that their weight is often a considerable proportion of that of the locomotive.

For example, the tenders of the large American Consolidations weigh almost 75 per cent. of the total adhesive weight of the locomotive itself. The tenders of the Mikados weigh 77 per cent., and those of the Santa Fé type 66 per cent.*

It is therefore natural that attempts should have been made to utilise the weight of the tender for adhesion. This has been done in various ways.

The first attempt was made many years ago, while the latest (and successful) method uses an auxiliary engine or tender booster. This has even been applied to articulated *Mallet* locomotives. Two objections have been advanced —and rightly—against the advisability of employing the tender's weight for extra adhesion : (*a*) that such weight is variable according to the consumption of fuel and water, and (*b*) that if the locomotive boiler have sufficient steam capacity to enable it to supply steam to the tender engine, why not simply use a more powerful locomotive ?

The first argument has been raised against tank engines, and the situation is identical. Yet they have found their sphere of activity and are likely to retain it. One way of deal-

* In the case of the Western Maryland's Decapod, the proportion is greater still.

Whereas the tender weighs 135,920 lbs. empty, with its 22,000 U.S. gallons of water and its 68,000 lbs. of fuel, it weighs 415,920 lbs. in service. The locomotive's total weight is but 419,280 lbs. The tender's weight therefore represents 99·2 per cent. of the total.

ing with the matter is to use only part of the tender's weight for adhesion, and in this case it can be kept sufficiently constant.

As to the second objection, it may be remarked that the boiler of a locomotive is designed to furnish the necessary steam at maximum train speeds. At low speeds, there is always a certain margin of evaporation, which is available for the tender's engine.

This auxiliary engine contributes a valuable addition to the drawbar pull without any material increase in expense.

A number of methods have been devised for solving the problem which we are now considering. They may be grouped as follows :—

Part I.—No engine to the tender.

Section I. A.—The transference of a portion of the weight of the tender to the locomotive, in order to increase adhesion.

Section I. B.—Coupling of the tender to the locomotive axles by chains or other means.

Part II.—The tender is provided with its own engine and cylinder.

Section II. A.—The tender's engine works permanently, in the same way as the locomotive's.

Section II. B.—The tender is equipped with an auxiliary engine, which is cut in or out as occasion demands.

PART I

NO ENGINE TO THE TENDER

SECTION I. A.—UTILISATION OF THE WEIGHT OF THE TENDER TO INCREASE THE ADHESION OF THE LOCOMOTIVE

Several designs have been evolved for transferring a portion of the weight of the tender to the locomotive in order to increase its adhesive weight. True, this does not constitute an articulated locomotive proper, but there are some connections which justify a passing reference.

It is generally thought that *Engerth* was the first to suggest this system. We have, however, found that he was anticipated by at least two persons. One was an American, by name *Miller*, the other a Frenchman, *Thouvenot*.

Engerth first utilised the system for his geared locomotives of which it was an essential feature. When the use of gearing was abandoned, this feature remained as the sole peculiarity of the transformed *Engerth* locomotive. Incidentally, it is interesting to note how often an old idea is re-invented ; for neither *Thouvenot* nor *Engerth* knew that the idea for which they applied for and received patents had been anticipated.

This is a case in point, which shows the desirability of recording briefly the early history of locomotive articulation. For a knowledge of early attempts in this direction will often avoid the repetition of old mistakes, or save valuable time and labour, if some early proposal is capable of practical use under present-day conditions.

In the case now under consideration brief treatment will be enough.

Since the time of *Engerth*, the idea has been revived on several occasions, notably in the locomotives designed by *Beugniot* and, later, by *Stutz*.

Type 1.—E. R. Miller's System

The earliest locomotives built in America were generally of the 2-2-0 type, though in 1834 Baldwin produced some 4-2-0 locomotives, using his flexible beam truck.

In the early locomotives, the firebox was placed between the axles, but in the Baldwin locomotives it generally overhung at the rear.

In June 1834, E. R. Miller took out a patent for a means of transferring a portion of the weight of the tender to the rear of the locomotive. Baldwin applied Miller's system to the eleventh locomotive which he built, and which was put in service on the Philadelphia and Trenton R.R. This was the first outside-connected locomotive built by Baldwin.

Mr. Baldwin paid a royalty of 100 dollars for each engine to which he applied the device, until May 6th, 1839, when he bought it outright for 9,000 dollars. This enabled him to furnish engines as powerful as those of his competitors, where the driving axle was situated in front of the firebox and thus bore more adhesive weight. His locomotives weighed at that time from 20,000 to 26,000 lbs. in working order.

Type 2.—Thouvenot's System

In 1842, this fertile inventor patented a system for the transference of weight similar to the above.

Type 3.—The Modified Engerth Locomotive

The original *Engerth* geared locomotives dealt with earlier in this book underwent a series of modifications.

(*a*) The gearing was abolished while the transference of weight from tender to engine was retained. These are the modified locomotives which we now refer to.

(*b*) The Creusot Works further modified the design by sundry improvements. These locomotives are dealt with in the following paragraphs under the title of " Engerth-Creusot " locomotives.

(*c*) Finally, the tender was entirely separated from the locomotive, but it then ceased to be an *Engerth* locomotive at all.

0-8-4 Modified Engerth Locomotives of the Northern and of the Eastern Rys. of France.—Standard gauge.

These were built at the Creusot Works in 1854 and in subsequent years. They had a trailing bissel with two axles, which carried part of the weight of the pseudo-tender ; the balance was transferred to the locomotive.

TABLE 105.—PRINCIPAL DIMENSIONS OF MODIFIED ENGERTH LOCOMOTIVES ON FRENCH AND BELGIAN RAILWAYS

Gauge	Standard.	Standard.	Standard.
Railway	Eastern (France); Northern (France).	Northern (France); Northern (Belgium).	Northern (Belgium).
Builder	Creusot.	Grafen-staden.	Cockerill.
Date	1854, etc.	1857-58.	1856.
Type	**0-8-4**	**0-8-4**	**0-6 + 2-4** subsequently **0-8-4**
Cylinders, diameter		$19\frac{11}{16}''$	
,, stroke		26″	
Boiler, diameter		4′ $11\frac{1}{4}''$	
,, pressure . . lbs./sq. in.	115	115	100
Tubes, number	219	234	234
,, diameter	$1\frac{15}{16}''$	$1\frac{15}{16}''$	$1\frac{15}{16}''$
,, length	16′ $5\frac{1}{8}''$	16′ $5\frac{1}{8}''$	16′ $6\frac{1}{2}''$
Heating surface, firebox sq. ft.	104·5	96·9	96·8
,, ,, tubes ,,	1962·3	1987·1	1995·2
,, ,, total ,,	2066·8	2084	2092
Grate area ,,	20·9	20·5	20·4
Wheels, diameter		4′ $1\frac{1}{2}''$	
,, ,,		3′ $5\frac{3}{4}''$	
Wheelbase, total	27′ 11″	28′ $6\frac{3}{4}''$	27′ 8″
Overall length	43′ $5\frac{3}{4}''$	—	42′ $2\frac{3}{4}''$
Water . . galls.	1,760	1,820	1,630
Coal . . tons-cwt.	5–0	3–0	4–10
Weight, empty ,,	44–18	50–0	51–4
,, adhesive ,,	38–8	42–6	42–16
,, in service ,,	61–0	66–0	67–10

The pivot of the articulation was behind the firebox. The latter was located between the two groups of wheels.

Twenty-five locomotives were supplied to the French Eastern Ry. and thirty to the Northern. Ten more were built by the newly-opened Grafenstaden Works.

Modified Engerth Locomotives of the Belgian Northern Ry. Chemin de fer du Nord Belge).—Standard gauge.

We believe that this was the first railway to recognise that the inconveniences of the *Engerth* system (though now lessened)

TABLE 106.—PRINCIPAL DIMENSIONS OF ENGERTH-CREUSOT LOCOMOTIVES (STANDARD GAUGE)

Type Railway Builder Date	**0-6-2, 4** P.L.M. Creusot. 1855.	**0-6-2, 2** Dauphiné. Creusot. 1857.	**0-6-2, 2** Midi. Esslingen; also Gouin. 1855–8.	**0-4-2, 4** Nord. Esslingen; also Cavé. 1856.	**0-4-2, 2** Dauphiné. Esslingen; also Grafenstaden and Cavé. 1857–8.
Cylinders, diameter	19″	18½″	19″	17½″	$17\frac{5}{16}''$
,, stroke	25¼″	25¼″	$23\frac{3}{16}''$	22″	22″
Boiler, diameter	4′ 10″ (int.)	4′ 3¼″	—	—	4′ 2½″
,, pressure . lbs./sq. in.	120	115	106	106	110
Tubes, number	203	197	—	166	180
,, diameter	2″	2″	—	2″	2″
,, length	15′ 7″	15′ 7″	—	14′ 7½″	14′ 7½″
Heating surface, firebox . sq. ft.	108·2	93·1	—	82	88·9
,, ,, tubes ,,	1,500	1,455·6	—	1,151	1,368
,, ,, total ,,	1,608·2	1,548·7	1,629	1,233	1,456·9
Grate area ,,	19·3	16·3	19·4	14·5	13·4
Wheels, diameter	4′ 3″	4′ 4¾″	4′ 3⅜″	5′ 8½″	5′ 9¾″
,, ,,	3′ 3½″	3′ 5¾″	3′ 4″	3′ 5¾″	3′ 7″
Wheelbase, rigid	—	—	9′ 3½″	8′ 10¼″	8′ 10¼″
,, total	26′ 5¾″	27′ 4¼″	23′ 1½″	26′ 3″	14′ 3½″
Overall length	41′ 7⅛″	37′ 7¼″	37′ 5″	38′ 6″	36′ 0¾″
Water tanks . galls.	1,250	1,350	—	1,000	1,000
Coal bunkers . tons-cwt.	5–0	4–0	—	1–10	1–10
Weight, empty ,,	45–6	40–8	—	36–10	35–0
,, adhesive ,,	31–0	37–8	35–10	22–10	22–0
,, in service ,,	60–0	53–16	58–0	47–0	45–0

NOTES.—When the Dauphiné Ry. was absorbed by the P.L.M. its locomotives were used on the latter system.
The locomotives of the Midi Ry.—about fifty in number—were chiefly used on the lines in the neighbourhood of the Pyrenees.
On the Nord Ry. some thirty Engerth locomotives were used for express passenger service between Calais and Paris. A number of these locos. were rebuilt as ordinary locomotives with separate tenders between the years 1873 and 1878.

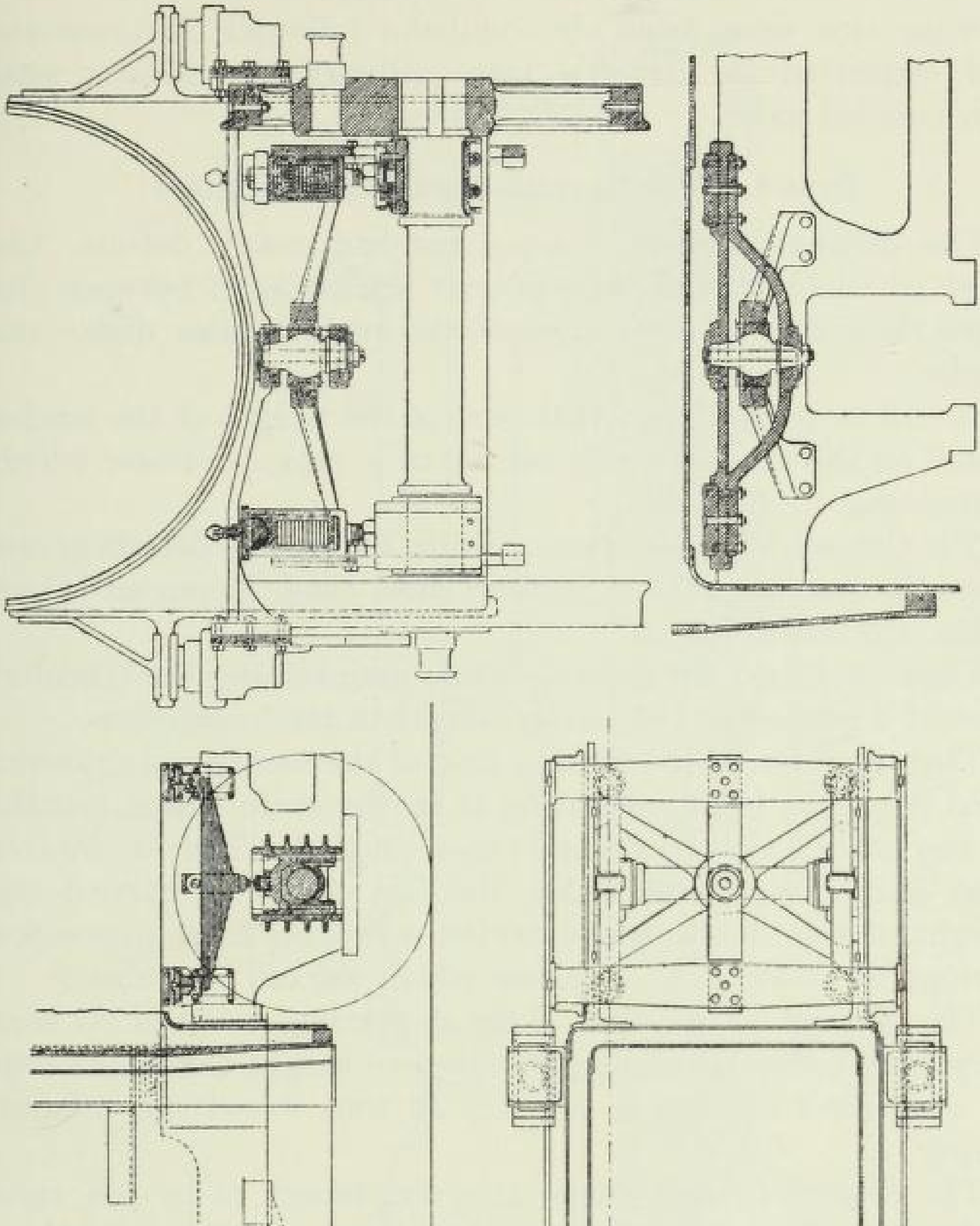


FIG. 199.—Engerth-Creusot Locomotive (Sections).

outweighed its advantages. Between 1858 and 1859, ten of them were converted into ordinary tender locomotives.

Some two years later the Sudbahn followed this example and converted its *Engerths* into ordinary locomotives with four-coupled axles.

Type 4.—The Engerth-Creusot Locomotives

The original *Engerth* locomotives had many defects, the chief of which was the use of gear transmission between the third rigid axle and the first of the mobile axles under the tender.

It will be remembered that part of the weight of the tender rested on the locomotive by means of a movable frame which surrounded its firebox.

The Creusot Works endeavoured to reduce the defects of the *Engerth* system but in actual fact they increased them (Figs. 199 and 200).

They abolished the gearing while maintaining the transference of a portion of the tender weight to the locomotive.

They transferred the leading axle of the mobile group to the rigid group in front, mounting it in the main frame parallel to the other axles, to which it was coupled. The locomotive then had four-coupled axles, the last of which carried the weight of the mobile frame, which rested on fixed suspension springs by means of cross pieces which worked on slides.

The *Engerth* locomotive, without gearing, weighed 55 tons 1 cwt. (56 tonnes), and had an adhesive weight of only 38 tons 11 cwt. (39·2 tonnes) in service, 32 tons 9 cwt. (33 tonnes) empty.

The *Engerth-Creusot* locomotive was found to be too rigid and was liable to derailment at points and crossings. Furthermore, the rear of the boiler rested on the side members of the tender, which threw a part of the weight on the fourth axle of the locomotive.

Measurements made in 1859 showed that all these complications only resulted in a 3 per cent. increase of the load on that axle. Although a large number of these locomotives were introduced on the Northern, on the Eastern, and on the Dauphiné Rys. of France, as also on the Belgian Northern Ry. (Ch. de fer du Nord-Belge), they were soon modified, as will be described later.

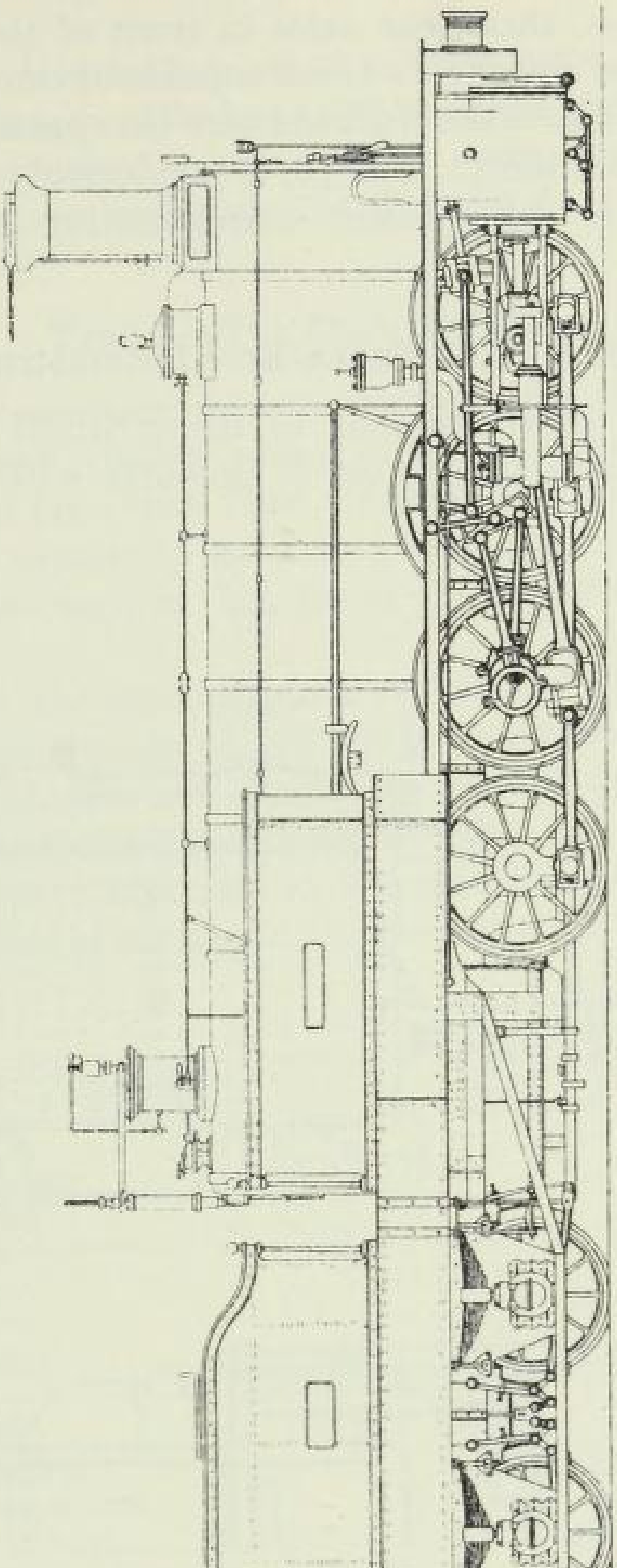


Fig. 200.—Engerth-Creusot Locomotive. (Standard Gauge.)

The locomotives whose dimensions are given in Table 106 had, in all cases, their rear axles in front of the firebox, and one or two axles united in a truck capable of convergent movement lay behind it. We shall indicate this particular arrangement by the notation (2, 2) or (2, 4) respectively, instead of (4) or (6), which is the notation corresponding to the normal arrangements.

Type 5.—The Behne-Kool Locomotives

This system is very similar to the modified *Engerth.* Its object was to facilitate the use of fireboxes with a large grate

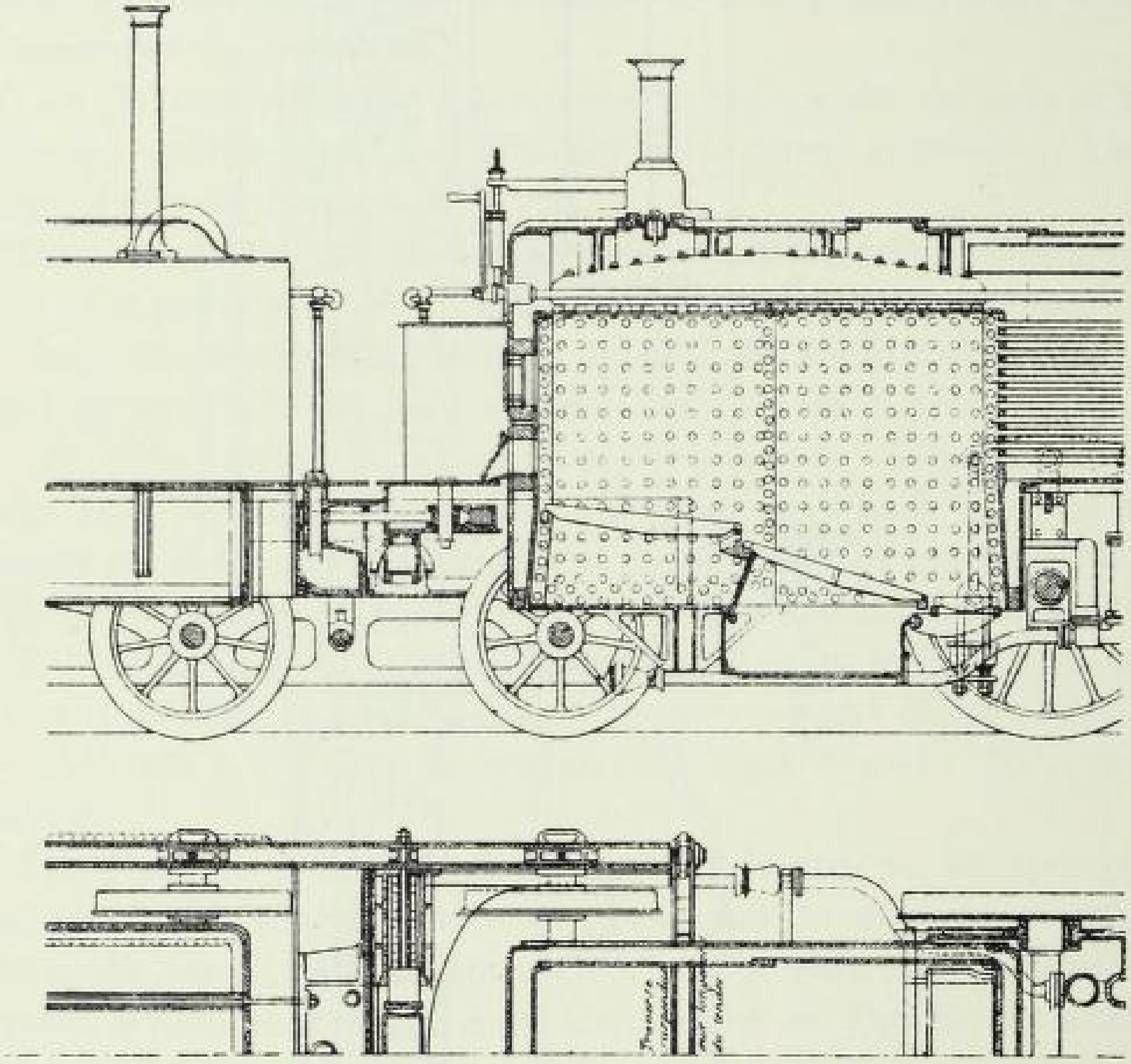


Fig. 201.—The Behne-Kool System.

area for burning inferior coal (Fig. 201). The firebox was placed behind the coupled axles (two in number) but its weight, as well as that of the coal bunker and water tank behind it, was supported by a truck with three axles, the frame of which embraced the firebox. The latter was fixed to a beam, the two ends of which were supported by jointed suspension rods.

The trailing truck had outside frames, the main frames being inside.

The earliest locomotives of this type seem to have been built by the Hanover Works in 1863 for the Brunswick Local Ry. and to standard gauge. They were curiously named "tank locomotives with separate framing."

Type 6.—The Stutz System

This is but another instance where a defunct system has regained renewed vitality owing to special circumstances, and it is curious to note that after all that has been written—and perhaps more especially left unwritten—concerning the modified *Engerth* locomotive, Mr. Stutz should have been able to revive it.

In this case, the pseudo-tender swivels around a pivot which is situated immediately behind the rear coupled axle. Besides this, and so as to increase flexibility, it rests on a bogie instead of on an axle or axles fixed to its frame.

Special interest attaches to the spring gearing and to the arrangement of the spring on the trailing axle.

TABLE 107.—PRINCIPAL DIMENSIONS OF STUTZ LOCOMOTIVE

Cylinders, diameter	$15\frac{3}{4}''$	0·40 m.
,, stroke	$23\frac{3}{8}''$	0·58 m.
Boiler pressure	171 lbs. per sq. in.	12 kg. per sq. cm.
Heating surface	1,172 sq. ft.	1,088 sq. m.
Grate area	18·8 sq. ft.	1·7 sq. m.
Wheels, diameter	$2'\ 0\frac{3}{8}''$	0·62 m.
,, ,,	$4'\ 3\frac{3}{16}''$	1·30 m.
,, ,,	$2'\ 0\frac{3}{8}''$	0·62 m.
Wheelbase, driving	9′ 2″	2·79 m.
,, locomotive	$13'\ 5\frac{3}{16}''$	4·35 m.
,, rear bogie	4′ 11″	1·50 m.
,, total	$31'\ 5\frac{3}{4}''$	9·60 m.
Total length	$42'\ 5\frac{11}{16}''$	12·95 m.
Water	1,320 galls.	6 cub. m.
Coal	3 tons 19 cwt.	4 tonnes
Weight, empty	37 tons 6 cwt.	37 ,,
,, in service	40 tons 0 cwt.	40·6 ,,
,, adhesive	33 tons 10 cwt.	34·2 ,,
Weight of tender, empty	9 tons 9 cwt.	9·6 ,,
,, ,, in service	19 tons 0 cwt.	19·5 ,,

2-8-4 Stutz Locomotive of the Pamplona-Larate Ry. (Spain).— Metre gauge.

It was necessary to provide a locomotive of sufficient power (hence the three-coupled axles) and of great flexibility, owing to local conditions.

Messrs. Maffei, who built these locomotives, therefore provided the shortest possible rigid wheelbase. Besides the special rear arrangement, they adopted, so as further to reduce the rigid wheelbase, a *Krauss-Helmholtz* truck at the front of the locomotive, thus reducing the rigid wheelbase to 9 ft. 2 ins. (2·79 m.) only.

Type 7.—The Beugniot Locomotive *

This design is only referred to because the arrangement is the reverse of that found in the modified *Engerth*.

In short, so as to lighten the rear portion of the locomotive, with its overhanging firebox, part of its weight is transferred to the tender. But, as in the case of the *Engerth*, this transference of weight did not give satisfaction, and it was eventually appreciated that the advantages of the arrangement were imaginary rather than real.

Type 8.—4 + 4 + 4 American Geared Locomotives

American geared locomotives have two bogies, and a shaft carried either alongside or placed on the centre line of the locomotive communicates its action to these bogies by gearing.

When the supply of fuel and of water is insufficient, a tender is added, supported, as the case may be, by one or by two

* In one of his interesting papers, Mallet states that Edouard Beugniot was chief engineer at the works of André Koechlin & Co., Mulhouse. In 1859, he built two 0-8-0 locomotives named "La Rampe" and "La Courbe," in which the axles were connected in pairs by Baldwin compensators, which allowed them a lateral movement. These locomotives were in service on the Paris, Lyons and Mediterranean and on the Central Swiss Rys. Similar locomotives, but of greater power, were supplied to the Bologna-Pistoia Ry. for working the section over the Apennine which had 2½ per cent. grades and curves of 984 ft. (300 m.) radius. While on this work, it was found that the removal of the Baldwin compensators and of the transfer of the weight to the rear did not make this locomotive any less satisfactory.

bogies similar to those of the locomotive, and which add to the available adhesion.

Where a single tender bogie is used, the pseudo-tender's weight is partially transmitted to the locomotive at the connection between them. But as in every respect these 4+4+4 locomotives are otherwise quite similar to the 4+4 geared locomotives, we have not separated them and refer our readers *ante*.

SECTION I. B.—TWO CYLINDERS TO THE LOCOMOTIVE; AND TENDER WITH DRIVING AXLES BUT NO CYLINDERS

This complicated fashion of transmitting the cylinders' action to the tender's driving wheels has met with scant success.

We shall, however, quote a few instances when it was tried, and classify the systems according to the method used for the transmission of the cylinders' action—by chains, by gearing, by means of a countershaft or by connecting rods.

GROUP I.—TRANSMISSION BY CHAINS

The "Bavaria" Locomotive

The "Bavaria" locomotive, which was entered by Maffei at the Semmering Competition, had three wheel groups—two under the locomotive and one under the tender. Each of the two outer groups was connected to the centre group by chains. This arrangement failed in practice and was done away with.

Other attempts have been made to couple the tender with the locomotive wheels, by various more or less ingenious devices, none of which has given satisfaction under working conditions. A few of them may be briefly mentioned.

GROUP II.—TRANSMISSION BY GEARING

American 4 + 4 + 4 + 4 Geared Locomotives

In the larger geared locomotives of the *Shay* and other types a pseudo-tender running on one or two bogies is provided. These bogies are driven by gearing in the same way as are those of the locomotive proper; it is therefore unnecessary to examine them separately from the double bogie-classes.

Their description will, therefore, be found *ante*, but it is necessary, for the sake of completeness, to quote them again here.

GROUP III.—TRANSMISSION BY COUNTERSHAFT

Type 1

Maffei submitted a design at the Semmering Competition in which the connection between the axles was made by a central bell-crank, and a connection to the axles by inclined coupling bar.

Type 2

Dredge and Stein employed a similar system.

GROUP IV.—TRANSMISSION BY CONNECTING RODS

The De Bergues System

De Bergues proposed * to connect the locomotive and tender axles by two mechanisms located very near the centre line of the locomotive and acting on cranks at right angles, as Maffei had done in the case of the two wheel groups of the locomotive. The connection of the axles was effected by vertical oscillating levers, which drove the coupling rods and cranks of the axles. Horizontal coupling rods connected the bottom ends and the vertical levers of the locomotive and tender.

* *Engineering*, July 16th, 1869, p. 48.

PART II

STEAM TENDERS

AFTER having been in use very occasionally during a great number of years, steam tenders have now acquired a new lease of life under a modified form.

All the former types—and they are many—coupled up a tender which was complete with its own cylinders and its engine, and which worked in the same fashion as the locomotive, from which it simply drew such steam as it consumed.

The more recent types have auxiliary engines which only work when called upon to do so. Besides this, part of the tender's weight only is used for adhesion, which is more constant. This does away with one of the main objections to the provision of steam tenders.

Such appliances, therefore, easily fall into two groups, and we shall examine them accordingly.

SECTION II. A.—LOCOMOTIVES WITH PERMANENT STEAM TENDERS

We class in this group the designs which provide the tender with a complete engine and in which the entire weight of the tender is constantly used for this engine's adhesion.

It will be understood that articulated steam joints must be provided between the locomotive and the tender, and that the exhaust from the tender cylinders must either be led back to the chimney or an auxiliary chimney must be provided on the tender.

The prevention of leakage at the articulated steam joints was somewhat of a problem when such steam tenders were first put into service, but this difficulty has long since been overcome.

The provision of a boiler sufficiently powerful to furnish steam to both locomotive and tender cylinders also had to be

TABLE 108.—PRINCIPAL DIMENSIONS OF LOCOMOTIVES WITH STEAM TENDERS

Gauge		Standard.	Standard.	Standard.	Standard.	Standard.	5′ 6″	Monorail.	Standard.	15″
Railway		St. Etienne to Lyons.	St. Etienne to Lyons.	Great Northern Ry.	Est and Gd. Luxembourg.	Gd. Central Belge.	Belmez, Cordoba.	Listowel and Ballybunion.	Southern Ry. (U.S.A.).	Ravenglass and Eskdale.
Builder		—	—	—	Grafenst.	Louvain.	Neilson.	—	Co.'s Shops.	—
Date		1843.	1845.	1863.	1866.	1866.	1872.	1886.	1916.	1928.
System		Verpilleux.	Verpilleux	Sturrock.	Sturrock.	Urban.	Sturrock.	Lartigue.	—	Poultney.
Locomotive type		**0-4-0**	**0-4-0**	**0-6-0**	**0-6-0**	**0-6-0**	**0-6-0**	**0-3-0**	**2-8-2**	**2-8-2**
Cylinders, diameter	m.	0·22	0·28	0·41	0·42	0·46	0·40	0·18	0·66	0·15
,, stroke	,,	0·75	0·74	0·61	0·60	0·60	0·60	0·31	0·76	0·22
Boiler pressure	kg. per sq. cm.	3·5	3·5	10·5	9·0	9·0	—	—	13·4	11·2
Tubes, number		—	117	—	276	367	218	—	—	—
,, diameter	mm.	—	50	—	40	44	45	—	—	—
,, length	m.	—	2·00	—	3·00	3·50	4·25	—	—	—
Heating surface, firebox	sq. m.	—	—	—	11·5	9·7	8·79	—	—	—
,, ,, tubes	,,	—	—	—	117·5	169·5	133·9	—	—	—
,, ,, total	,,	41·6	62·0	129–105	139·0	179·2	142·6	14	—	11·8 – 1·0 (Superh.)
Grate area	,,	1·1	0·34	2·4	2·4	2·4	1·6	0·5	—	0·4
Wheels, diameter	m.	1·24	1·22	1·53–1·62	1·20	1·22	1·05	0·60	1·60	0·30 : 0·43
Wheelbase	m.	—	1·60	—	3·55	3·50	—	—	—	6·24
Weight in service	t.	10·0	17·0	35–34	35	36	35·5	6·8	122·0	—
,, adhesive	t.	10·0	17·0	35–34	35	36	35·5	6·8	97·0	3·3
Tender Type		**0-4-0**	**0-4-0**	**0-6-0**	**0-6-0**	**0-6-0**	**0-6-0**	**0-3-0**	**2-8-0**	**0-8-0**
Cylinders, diameter	m.	0·22	0·28	0·31	0·38	0·35	0·34	0·13	0·46	0·10
,, stroke	m.	0·75	0·74	0·38–0·41	0·42	0·40	0·50	0·18	0·51	0·22
Wheels, diameter	m.	1·24	1·22	1·37–1·22	1·20	1·22	1·05	0·60	1·27	0·44
Wheelbase	m.	—	1·60	—	315	3·20	—	—	—	—
Water capacity	t.	—	—	—	7·5	8·1	—	—	30·0	1·4
Coal capacity	t.	—	—	—	3·5	4·0	—	—	11·0	2·5
Weight, empty	t.	—	—	—	—	15·0	17·0	4·5	—	—
,, in service	t.	7	14	25–30	28	26·9	30	11·5	77·0	—

TABLE 108A.—PRINCIPAL DIMENSIONS OF LOCOMOTIVES WITH STEAM TENDERS

Gauge	Standard.	Standard.	Standard.	Standard.	Standard.	5′ 6″	Monorail.	Standard.	15″
Railway	St. Etienne to Lyons.	St. Etienne to Lyons.	Great Northern Ry.	Grand Luxembourg.	Belgian and Grand Central.	Cordoba, Belmez	Listowel and Ballybunion.	Southern Ry. (U.S.A.).	Ravenglass and Eskdale.
Builder	—	—	—	Grafenstaden.	Louvain.	Neilson.	—	Co.'s Shops.	—
Date	1843.	1845.	1863.	1866.	1866.	1872.	1886.	1916.	1928
System	Verpilleux	Verpilleux	Sturrock.	Sturrock.	Urban.	Sturrock.	Lartigue.	—	Poultney.
Locomotive type	**0-4-0**	**0-4-0**	**0-6-0**	**0-6-0**	**0-6-0**	**0-6-0**	**0-3-0**	**2-8-2**	**2-8-2**
Cylinders, diameter	8¾″	11″	12″	16¼″	18⅛″	15¾″	7″	26″	5½″
,, stroke	29½″	29″	17″–24″	23¼″	23⅝″	23⅝″	12″	30″	8½″
Boiler pressure . . . lbs. per sq. in.	50	50	149	128	128	—	—	190	160
Tubes, number	—	117	—	276	367	218	—	—	—
,, diameter	—	2″	—	1 9/16″	1¾″	1 1/16″	—	—	—
,, length	—	6′ 6¾″	—	9′ 10⅝″	11′ 4¾″	13′ 11″	—	—	—
Heating surface, firebox . . . sq. ft.	—	—	—	123·8	104·4	94	—	—	—
,, ,, tubes ,,	—	—	—	1,264·7	1,821·0	1,446·8	—	—	—
,, ,, total ,,	447·7	667·4	1,082–1,130	1,388·5	1,925·4	1,535·4	150·7	—	127 – 11 (Superh.)
Grate area ,,	11·8	3·7	25·8	25·8	25·8	16·8	5·4	—	4·7
Wheels, diameter	4′ 0¾″	4′ 0″	5′ 0″–5′ 3″	3′ 11¼″	4′ 0″	3′ 5⅜″	2′ 0″	5′ 3″	12″ : 1′ 5″
Wheelbase	—	5′ 3″	—	11′ 6⅞″	11′ 4⅞″	—	—	—	20′ 5½″
Weight in service . . . t.-cwt.	9–17	16–15	34–8	34–8	35–8	34–18	6–14	120–0	—
,, adhesive . . . t.-cwt.	9–17	16–15	34–8	34–8	35–8	34–8	6–14	95–8	3–5
Tender Type	**0-4-0**	**0-4-0**	**0-6-0**	**0-6-0**	**0-6-0**	**0-6-0**	**0-3-0**	**2-8-0**	**0-8-0**
Cylinders, diameter	8¾″	11″	12″	15″	13¾″	13⅜″	5″	18¼″	3½″
,, stroke	29½″	29″	17″	16½″	15¾″	19¾″	7″	20⅛″	8½″
Wheels, diameter	4′ 0¾″	4′ 0″	4′ 5⅞″–4′ 0″	3′ 11¼″	4′ 0″	3′ 5⅜″	2′	4′ 2″	1′ 5½″
Wheelbase	—	5′ 3″	—	10′ 4″	10′ 6″	—	—	—	—
Water capacity . . . galls.	—	—	—	1,650	1,780	—	—	6,600	300
Coal capacity . . . t.-cwt.	—	—	—	3–10	4–0	—	—	10–16	2–10
Weight, empty . . . t.-cwt.	—	—	—	—	14–16	16–14	4–8	—	—
,, in service . . . t.-cwt.	6–18	13–18	24–12	27–12	26–10	29–10	11–2	75–15	—

considered, and this practically restricted the use of steam tenders to slow speeds only.

Finally, at a very early stage, the exhaust steam from the tender cylinders passed through feed heaters placed in the water tanks before passing to the atmosphere.

The invention of steam tenders is commonly attributed to Mr. Sturrock, former chief mechanical engineer of the Great Northern Ry. (England). Though he certainly was the first to use them on a large scale, Verpilleux anticipated him by a number of years.

Since that time steam tenders have reappeared periodically, without being definitely adopted or definitely condemned. It is only since it was appreciated that the tender engine was essentially a device for temporary use only—in starting or when an abnormal drawbar pull was required for a short time—that it has found its proper place in sound locomotive practice.

The principal types which were tried were *Verpilleux's*, *Sturrock's*, and *Maurice Urban's*.

Then came a long period when they lost all favour, and they seem only to have been referred to in connection with combined rack and adhesion locomotives which were designed but never built (Lartigue's and Henderson's types).

A few years back, some *Mallet* locomotives were provided with them. The latest development is, however, of more general use and is due to *Poultney*.

We shall now proceed to take these various types in proper order.

Type 1.—Verpilleux's Steam Tender

The brothers Verpilleux, of Rive-de-Gier, were the first to design a steam tender, and they took out a patent for it (Fig. 202), No. 9,069, September 26th, 1842. The original application of their system was to some locomotives working on the railway from Saint-Etienne to Lyons. On this line there was an incline of 1½ per cent. where the presence of coal dust, which collected on the rails, interfered with adhesion. The locomotives then used weighed 9 tons 17 cwt. (10 tonnes) and drew a load of only 14 tons 15 cwt. (15 tonnes) exclusive of the weight of the four-wheeled tender, which was 6 tons 18 cwt. (7 tonnes). Verpilleux fitted the tender with a pair of cylinders, which received their steam supply through an articulated pipe.

The locomotive was allotted 22 and the tender 14, making a total of 36 tonnes, which could be drawn by the locomotive and its steam tender.

Type 2.—The Baldeyrou and Verpilleux System

This was patented on November 30th, 1857. Though it was never applied in practice, its importance is considerable. It is curious that it should have lapsed so completely into oblivion, because it concerns the use of steam in compound cylinders and the propulsion of the tender by means of larger L.P.

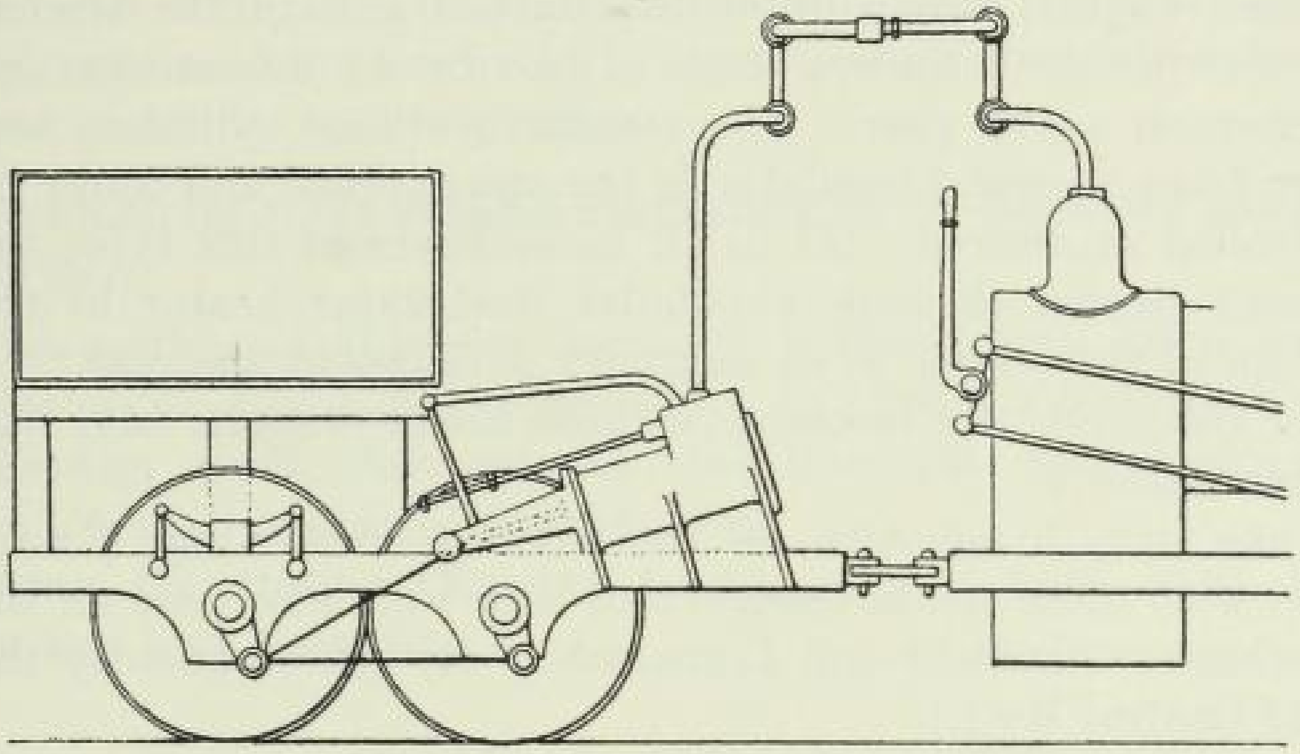


FIG. 202.—Verpilleux Motor Tender Patent (1842).

cylinders after expansion of the steam exhausted from the locomotive's H.P. cylinders.

The L.P. exhaust was led to the locomotive's chimney to increase the blast.

The wording of the patent even states that it is clear that the efforts due to the cylinders of the locomotive and to those of the tender are perfectly equilibrated, and hence the locomotive wheels cannot slip without the tender wheels doing the same immediately.

The steam connections between locomotive and tender had ball and socket joints.

Owing to recent controversies concerning the inventor of compounding for locomotives, the above information has a special interest.

Type 3.—The Sturrock Steam Tenders

These were the first locomotives fitted with steam tenders which gave satisfactory results and, after having been introduced on several British railways, were also utilised abroad, in Spain, in France, and in Germany.

Steam Tender Locomotives of the Great Northern Ry. and of the Manchester, Sheffield and Lincolnshire.—Standard gauge.

Archibald Sturrock brought out his steam tender in 1863. It was so designed that it could be attached to any locomotive of his day. It was a six-wheeled tender with a complete two-cylinder engine, which drove the central axle of the tender. The two inside cylinders were 12 ins. by 17 ins. stroke and Stephenson valve gear. The steam for these cylinders was taken from a second regulator in the steam dome and could be controlled as desired. As in all locomotives of this type, the exhaust passed through a tubular feed-water heater in the bottom of the tender to an auxiliary chimney at the rear.*

On the level, the locomotive drew thirty wagons and the tender fifteen.†

Some sixty locomotives of the Great Northern Ry. ‡ were fitted with these steam tenders and they were also used on the Manchester, Sheffield and Lincolnshire Ry. (subsequently the Great Central Ry.).‡

Unfortunately, the trains which these locomotives could draw were too long for the brake power then available. Furthermore, two drivers on the footplate were needed in some cases.

Sturrock's locomotives were able to haul forty to fifty loaded coal wagons on the 1 in 200 gradients which occurred on the main line from London to Peterborough, and sixty wagons on the level in the Lincolnshire division. Locomotives without steam tenders hauled only thirty and thirty-five wagons respectively.

Mr. Bulleid stated that in tests carried out in 1866 steam tender locomotives burnt 62·7 lbs. of coal per mile when hauling

* The length of the feed-water heater was 13 ft. 1½ ins. (4 m.).

† The tractive effort of the locomotive was 11.264 lbs. (5,000 kg.); that of the tender was 5,600 lbs. (2,500 kg.).

‡ Both these railways now form part of the London and North Eastern Ry.

an average of 30·9 wagons per trip, as against 49·3 lbs. of coal per mile and 30·2 wagons per trip for the locomotives with ordinary tenders. The latter therefore used 29 per cent. less coal when hauling 15 per cent. less load.

Stirling, who had succeeded to Sturrock in 1866, scrapped the steam tenders and provided the locomotives with larger cylinders so as to use the extra steam supplied by their relatively powerful boilers.

Locomotives of the F. C. de Cordova a Belmez.—Gauge, 1m.67 (6 ft. 6 ins.).

Two locomotives with steam tenders similar to the above * were built in England for this Spanish railway in the year 1869. They were used for service on a 3 per cent. incline, which had curves of 656 ft. (200 m.) radius.

Locomotives of the Grand-Luxembourg Ry.†—Standard gauge (Fig. 204).

The section of this line between Brussels and Arlon has numerous gradients of 1·6 per cent. In 1866 the Eastern Ry. of France, which then operated the line, put into service a 0-6-0 locomotive with a steam tender.

Other locomotives similar to the above were used in Germany and elsewhere.

Type 4.—The Maurice Urban Steam Tender

This differs in details only from Sturrock's. It was designed for the locomotives of the Ch. de fer du Grand-Central Belge, † (Fig. 203), which worked the 1·8 per cent. Lodelinsart incline, near Charleroi. The load drawn was 250 to 300 tons and the speed 12½ miles (20 km.) an hour.

Type 5.—American Mallet Locomotives with Steam Tenders

As the dimensions of *Mallet* locomotives increase, so does the size of their tenders. Hence endeavours have been made to use some or all of the weight of the tender—otherwise pure dead load—for adhesion.

In a 2-8+8-2 *Mallet*, a third of the total weight (locomotive

* All four cylinders had Gooch's external valve gear.

† Now incorporated in the system of the Belgian National Rys.

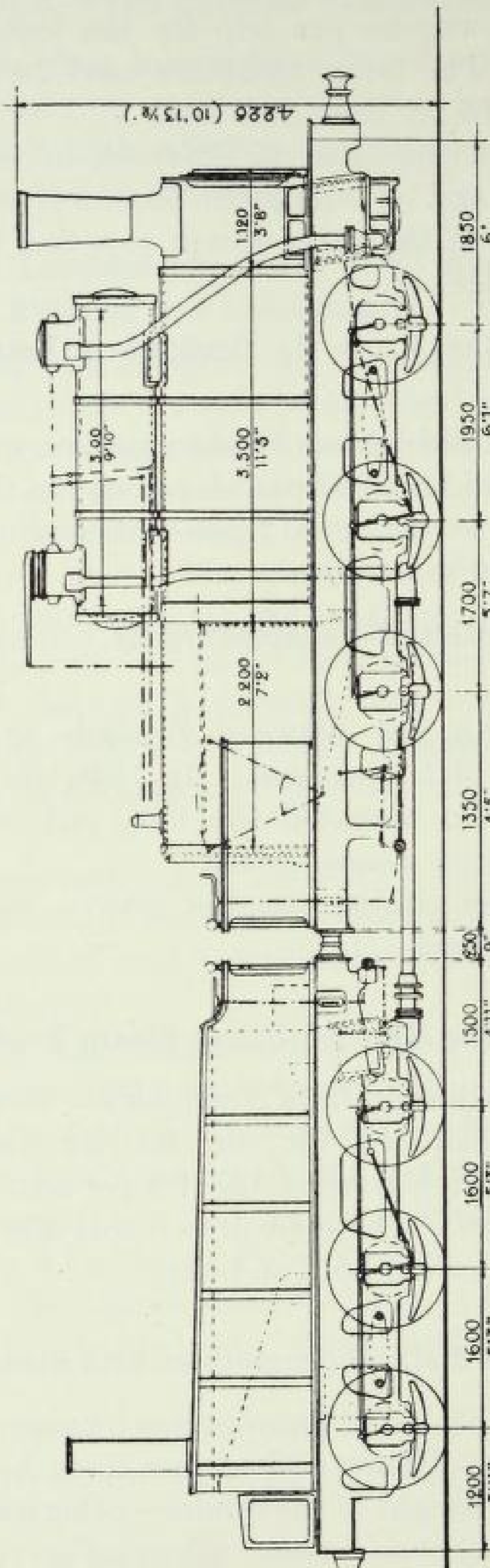


FIG. 203.—Chemin de fer du Grand Central Belge Tender Locomotive. (Standard Gauge.)

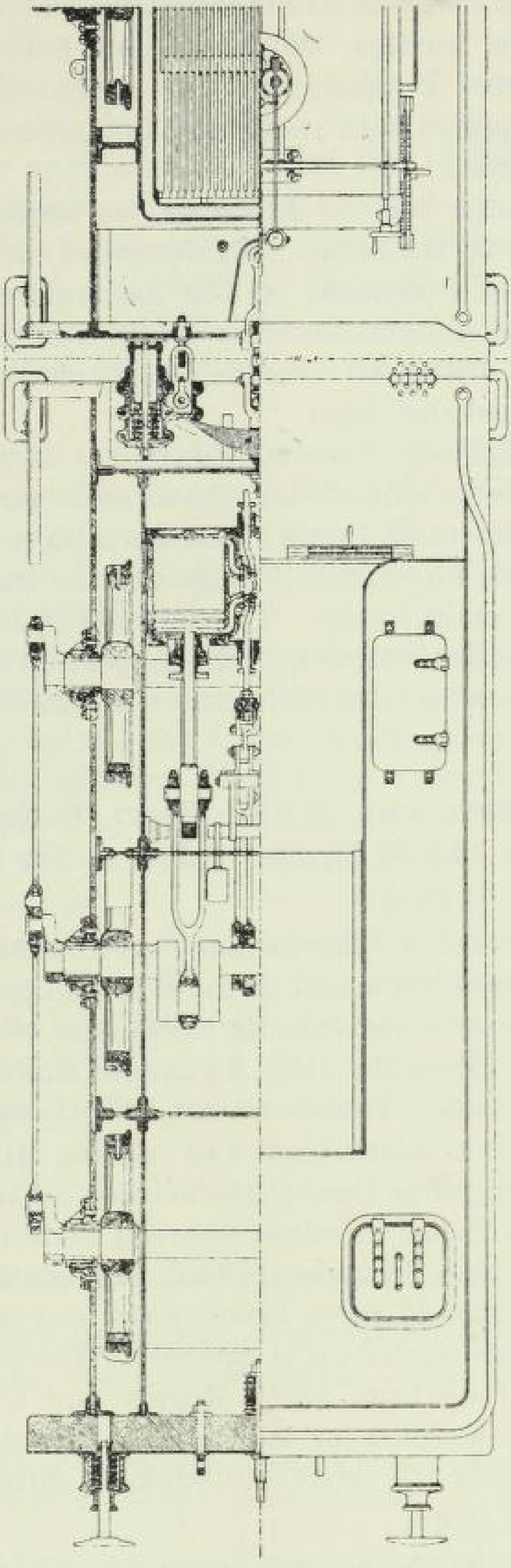


FIG. 204.—Horizontal Section, Steam Tender of the Chemin de fer du Grand-Luxembourg. (Standard Gauge.)

+ tender) is not available for adhesion. It is therefore well worth while to endeavour to obtain additional adhesion from the weight of the tenders, which are now heavier than they ever were before. Furthermore, the cylinders driving the tender can be supplied with steam at a low pressure, which has certain advantages.

The steam tender can be uncoupled as occasion demands, which is useful from the maintenance point of view.

In other cases, it is fixed to the locomotive frame by a vertical pivot, and constitutes what we have called a " pseudo-tender " which, being an integral part of the locomotive proper, is examined elsewhere.

Finally, the Baldwin Locomotive Works have hinged the tender frame of large *Mallets* they have built for the Erie and the Virginian to the main frame of the locomotive proper, in the same way that the fore truck is hinged to the front portion of the locomotive's main frame. This is the *Triplex* design, but here again, the tender is an undetachable portion of the locomotive ; we have therefore described it in the section dealing with semi-articulated locomotives.

2-8-0 Locomotives with (2-6-0) Steam Tenders and 2-8-2 Locomotives with (2-8-0) Steam Tenders of the Southern Ry. (U.S.A.).—Standard gauge.

The construction of *Triplex* locomotives as a development of the *Mallet* type drew attention to the desirability of using the weight of the tender to increase the adhesion.

In 1916, the Southern Ry. (U.S.A.) carried this out on a number of its locomotives. They were not, strictly speaking, new, for the motor tenders were adapted to existing Mikado locomotives in order to improve their performances on the line which united North and South Carolina between Ashville (N.C.) and Hayne (S.C.), which is 70 miles (113 km.) in length.

The reconstruction of these locomotives was carried out in the Company's own workshop at Spencer. The motor tenders were largely built up from early Moguls and Consolidations which had been scheduled for scrapping. The old locomotive frames were used and the tanks and bunkers, suitably adapted, were mounted on them.

The ordinary coupling between locomotive and tender in the Mikado was modified. As the boiler had now to furnish steam to four cylinders instead of two, the firebox was provided with a brick arch, and the exhaust from the tender cylinders was taken through a feed-water heater before passing to an escape pipe at the rear. The drop in boiler pressure was about 1 atmosphere, but the tractive force on a 1 per cent. grade was increased by approximately 9,920 lbs. (4,500 kg.).

As the adhesion of the tender would have been insufficient to utilise the power of the original Consolidation cylinders, which were 20½ ins. (0·51 m.) diameter, these cylinders were fitted with liners, which reduced their diameter to $18\frac{3}{16}$ ins. (0·46 m.). The original stroke, 20½ ins. (0·51 m.), was left unaltered.

The steam for the tender cylinders was taken from the upper part of the superheater, immediately behind its funnel. It was led through a pipe, 3 ins. (76 mm.) diameter, to a flexible pipe which connected with the cylinders. This was obviously a weak point in the design.

Alternatively, the tender cylinders could be supplied with saturated steam by a connection on the top of the boiler barrel, immediately behind the dome.

An interesting point about these motor tenders is that they are independent of the locomotive to which they are applied. This rather fortuitous arrangement has now been superseded by tender boosters.

The Mikado locomotives to which these tenders were applied had cylinders originally 34¼ ins. diameter reduced to 26 ins. diameter, and with the original stroke 30 ins.

The tractive force of the locomotive was 48,100 lbs. (21·8 tonnes). The tender added another 28,660 lbs. (13 tonnes).*

Type 6.—Mallet Locomotive with Rack Steam Tender

Mr. George Henderson designed an articulated locomotive answering to these requirements. The pinions which mesh

* Before their conversion, these Mikados drew about 1,000 tons on an incline 21¾ miles (35 km.) in length with 1·7 per cent. ruling gradient, and about 50 tons more on 1·5 per cent. grades. With Mogul or Consolidation motor tenders, they drew 27 to 30 per cent. more with only a small increase in the coal consumption.

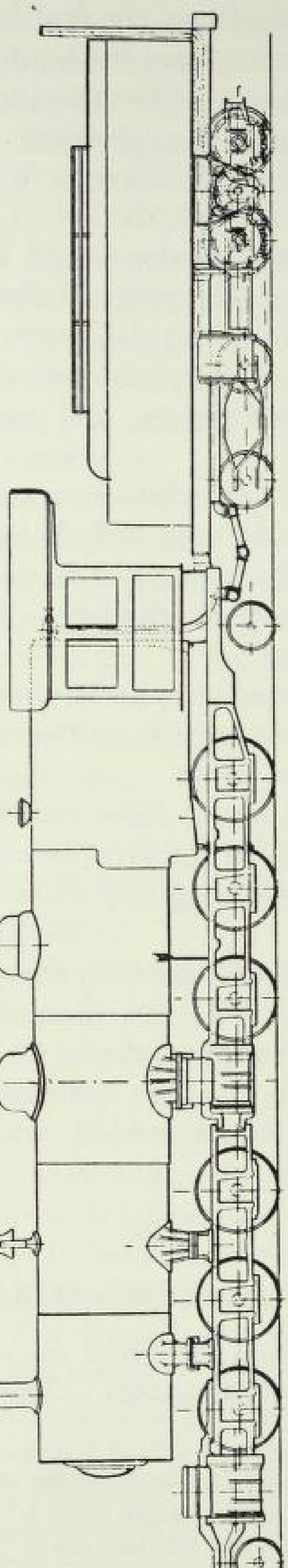


FIG. 205.—Henderson's Design for Mixed Rack and Adhesion Tender Locomotive with Rack Steam Tender.

with the rack are driven by an auxiliary engine and pair of cylinders fixed to the tender. The exhaust from these cylinders is discharged through a chimney fixed to the rear of the tender (Figs. 205 and 206).

An objection to this design would seem to be the use of a

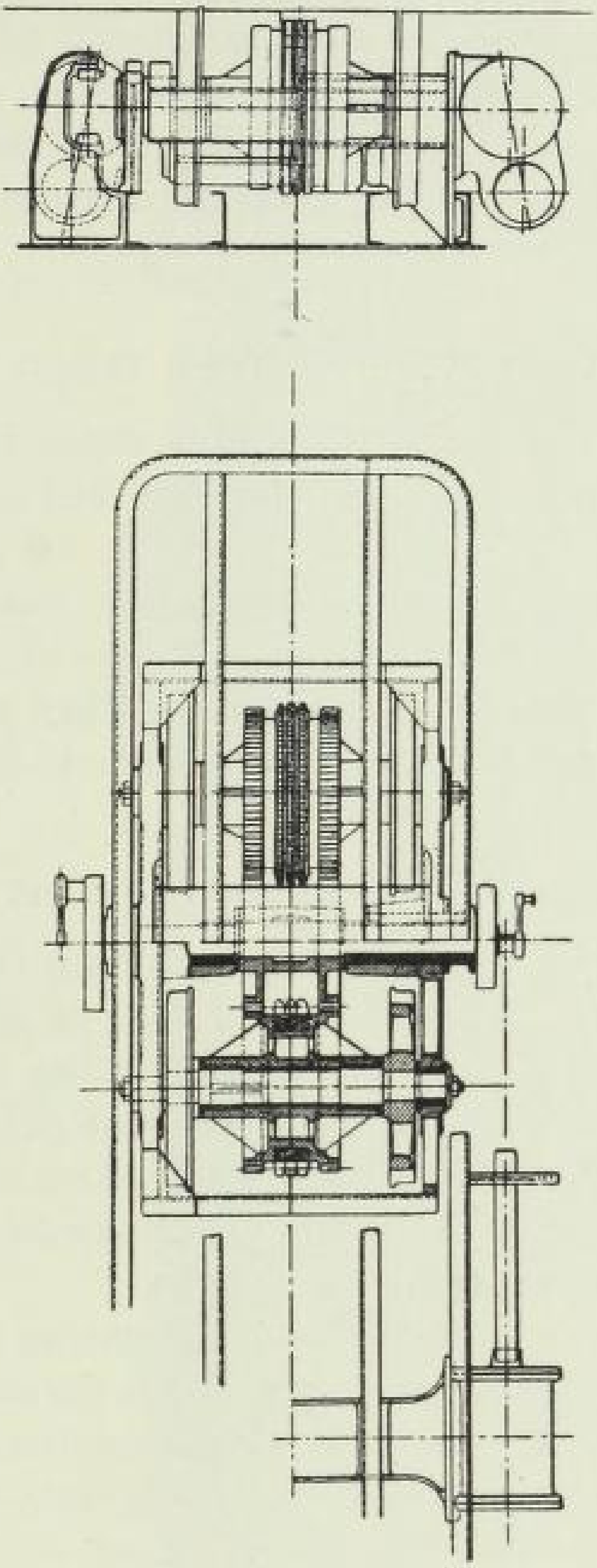


FIG. 206.—Tender's Rack Engine, Henderson Mixed Rack and Adhesion Tender Locomotive.

separate tender on a rack railway. The nett load which can be drawn up such railways is in itself so small that it seems most undesirable to reduce it still further by adding the dead weight of a separate tender. Furthermore, locomotives with total adhesion or, at most, with one pony axle, would seem more suitable for a rack railway.

Type 7.—Lartigue Monorail Rack and Adhesion Locomotive

This locomotive was designed by Anatole Mallet for experimental purposes, and ran, in 1886, on a temporary Lartigue line laid in London, which had gradients up to 1 per cent.

To the locomotive proper (which had two coupled wheels) was added a sort of platform bearing a steam cylinder which drove a cog-wheel gearing in a rack rail fixed under the supporting rail.

Type 8.—Lartigue Monorail Steam Tender Locomotive

The Hunslet Locomotive Co. built three locomotives provided with steam tenders for the Listowel and Ballybunion Ry.

These had two cylinders whose action was transmitted to the tender's wheels by gearing in the ratio of 1 to 1·35. This gearing could be thrown out of action when required, so that there should be no extra resistances due to the piston when out of work.

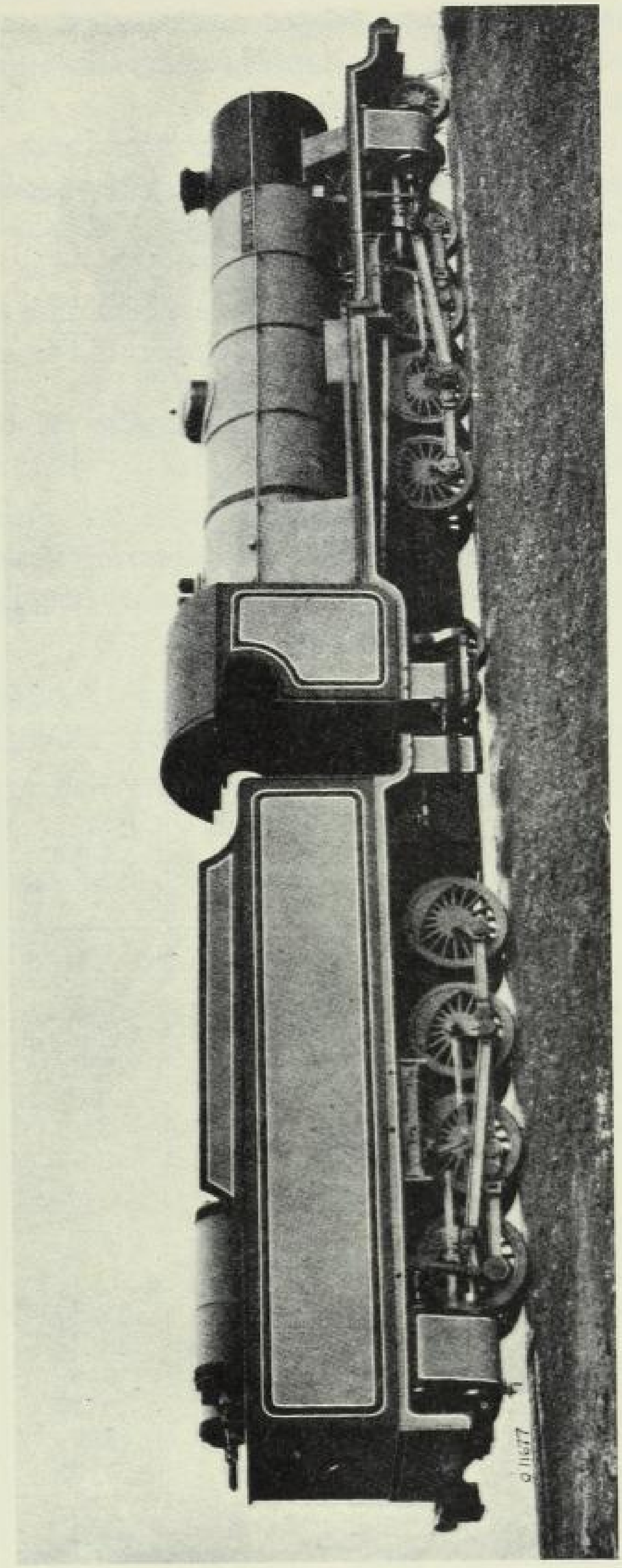
Type 9.—The Poultney System

Mr. Poultney has endeavoured to obviate the drawbacks of most steam tenders, in which the amount of steam provided is generally insufficient, without providing the locomotive with a very large boiler, which unduly loads the driving wheels.

He therefore limits his cut-off so that the maximum admission takes place at 50 per cent. of the piston stroke, the steam consumption thus being minimum.

By utilising larger cylinders and calculating the locomotive's elements so that the maximum power is furnished with a cut-off of 50 per cent., he saves the difference between this steam consumption and the one which corresponds to the usual 80 or 90 per cent. cut-off, though he must subtract from this economy the extra steam used owing to the increase in the size of the cylinders. He can then use the balance of steam which is available for the cylinders with which he provides the tender.

The only other difference between a Poultney locomotive and any other is that it is necessary to provide the valves



with slot ports to enable the locomotive to start. An auxiliary port gives the equivalent of 50 per cent. cut-off and, being of small dimensions, its effect is rapidly neutralised as the locomotive gathers speed.

The exhaust steam is deflected in the usual way, that from the main engine up the chimney, that from the tender's engine into a feed-water heater.

The patent rights have been secured by the Yorkshire Engine Co., and the first locomotive to which this system has been applied has been turned out in 1928 for a 15-in. gauge line.

2-8-2 + 0-8-0 Tender Poultney Locomotive of the Ravenglass and Eskdale Ry.—Gauge, 15 ins. (0m.38) (Fig. 207).

We have previously, when dealing with the *Fairlie* group, alluded to the reconstruction of this interesting little railway's motive power in 1928. As it was necessary to increase the

TABLE 109.—PRINCIPAL DIMENSIONS OF RECONSTRUCTED LOCOMOTIVES OF THE RAVENGLASS AND ESKDALE RY.

Loco. type Name	**0-8-2** River Irt	**2-8-2 + 0-8-0** River Esk	**4-6-0 + 0-6-4** River Mite
Cylinders, diameter, locomotive	5½″	5⅞″	4½″
,, ,, tender	—	3⅞″	4½″
,, stroke, all	8″	8½″	6¾″
Boiler, diameter	1′ 8½″	1′ 9″	1′ 9″
,, pressure lbs. per sq. in.	180	180	180
Heating surface . sq. ft.	95	127	97
Fire-grate area . ,,	3·1	4·7	4
Superheater ,,	—	11	—
Wheels, bogie, diameter	10″	12″	10″
,, loco. drivers	1′ 5½″	1′ 5½″	1′ 8½″
,, tender drivers	—	1′ 5½″	1′ 8½″
Total wheelbase	16′ 6″	20′ 5⅜″	19′ 10″
Overall length	22′ 6″	25′ 1¼″	24′ 0″
Weight, adhesive t.-cwt.	3–15	3–5	3–5
,, total t.-cwt.	6–5	6–18	5–15
Water galls.	320	300	260
Coke cwt.	4	2½	2
Water, per mile galls.	11	11	12
Coke, per mile lbs.	8	8	6
Evaporation per lb. of coke galls.	1·37	1·37	2
Maximum load hauled tons	38	50	32

hauling capacity of the locomotives, a 2-8-2 unit, with Lentz poppet valves, was also overhauled. In practice these valves did not come up to expectation, owing probably to the exiguity of the gauge, and it was decided to entirely rebuild the locomotive (called the River Esk).

It is too early to quote results obtained in practice, but this trial on so narrow a gauge is most noteworthy.

SECTION II B.—LOCOMOTIVES WITH TEMPORARY STEAM TENDERS

Only since it was realised that the tender's adhesion should only be called upon intermittently, when extra tractive force was temporarily needed has the steam tender proved a practical success.

The first type was innovated by the Bethlehem Works.

A second type is an adaptation of the locomotive booster to the tender.

Both are successful.

These tender auxiliary engines can be used for road service, but they have recently been successfully applied to switching locomotives, and this has opened up a new field for them. This has come about through the fact that the provision of these tender boosters gives the locomotive reserve power which enables it to develop the same tractive power as a locomotive of higher class having an extra coupled axle.

It may seem curious at first sight that such a locomotive be not provided instead of the weaker one with tender auxiliary engine, but track limitations or excessive stand-by losses may account for this. Thus a 0-6-0 locomotive, in a yard where the number of coupled axles cannot be increased owing to wheel-base limitations and where the axle load is limited by the track, may yet be able to deal with, thanks to a tender booster, full train loads brought in by Mikado locomotives.

The inclusion of the booster in the design and the employment of limited cut-off, which produces one horse-power for 30 per cent. less steam, increase the locomotive's efficiency, diminish the dead load of the tender, and by increased speed at starting and greater acceleration enhance the capacity of the yard.

Type 1.—The Bethlehem Auxiliary Engine *

The extended use of boosters applied to the trailing pony axles of large locomotives led the Delaware and Hudson Ry. to replace the trailing bogie on some of their tenders by a steam-driven truck. As in the case of the booster, the auxiliary

* These are built by the Bethlehem Steel Co., of Bethlehem, Pa.

engine was only used at starting, and at times when an exceptional drawbar pull was required or for hauling trains up short banks (Figs. 208, 209, 210 and 211).

These auxiliary engines enable the line to be better utilised

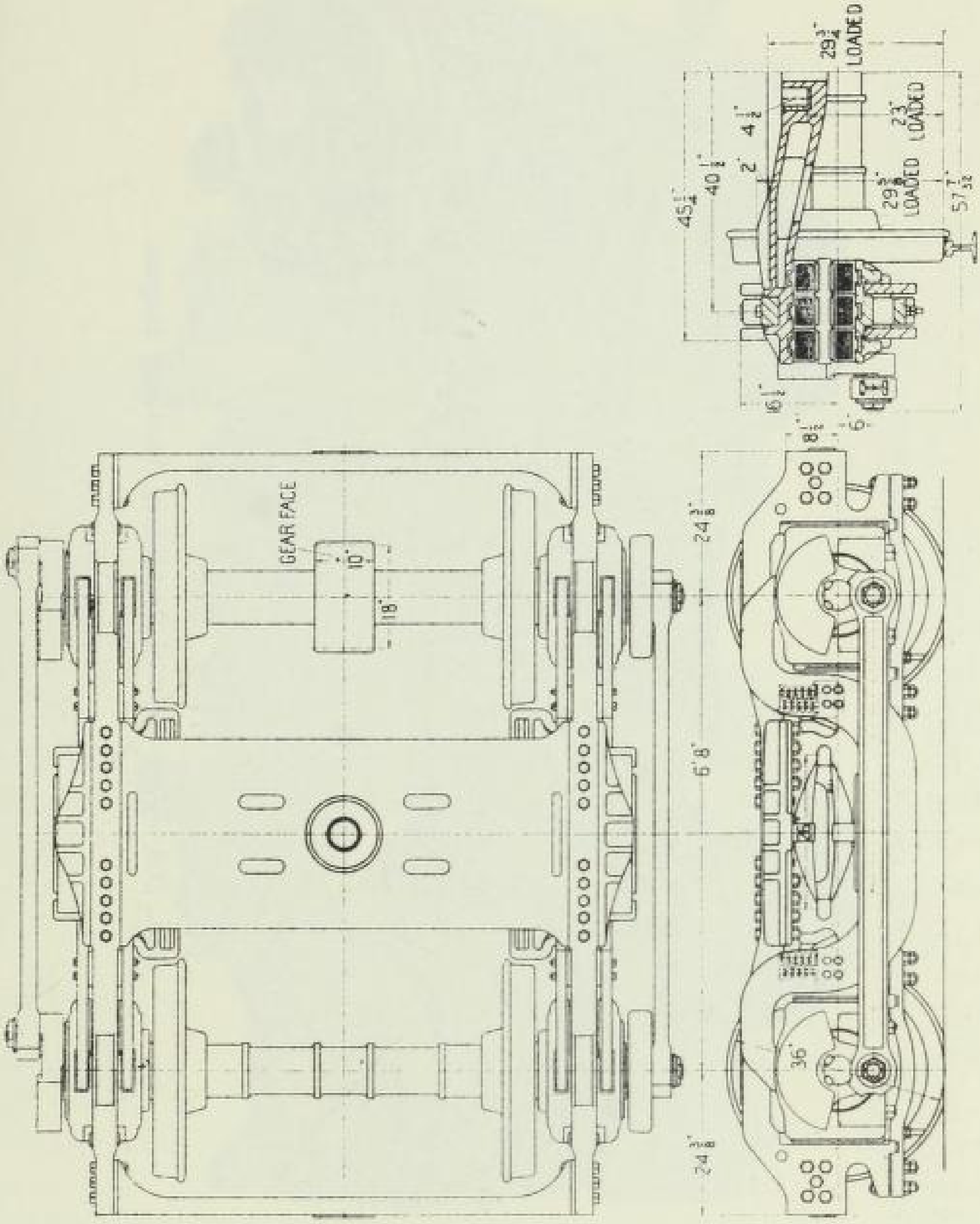


Fig. 208.—Truck Assemblage of Bethlehem Auxiliary Engine.

by accelerating the service all round. They also promote uniformity in the train speeds and a more uniform output from the boiler. Like the booster, the tender engine is put into, or out of, gear by a simple sliding pinion which meshes with spur wheels on the engine crankshaft and the driving axle. The gear ratio is $2\frac{1}{4}:1$. The intermediate pinion automatically comes out of mesh at a predetermined speed in the case of the locomotives we are now considering. By the employment of this auxiliary engine an increase of 20 to 35 per cent. in drawbar pull can be obtained without a material increase in fuel consumption.

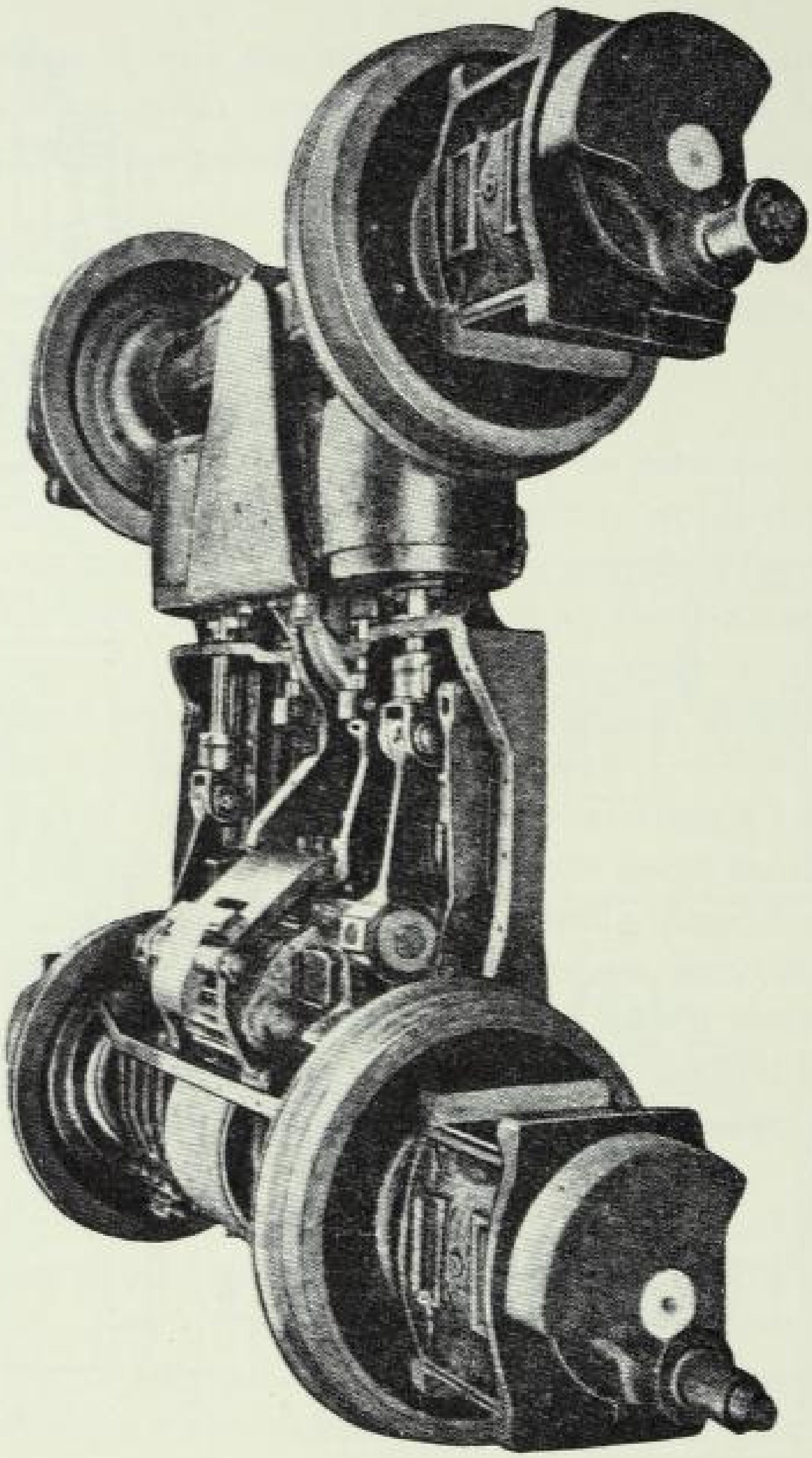


Fig. 209.—Side View of Bethlehem Auxiliary Engine.

The truck is a modification of the side equaliser type using a combination of elliptical and helical springs. The truck bolster is designed to carry 100,000 lbs.

It is easy to instal the auxiliary locomotive as a complete power unit instead of the ordinary tender truck. To attain this, all that need be done is to provide a body centre plate, control valves and adequate piping for using superheated steam.

The 1922 design was altered in 1925, after the Bethlehem Co. had taken over the manufacture of this booster. Principal dimensions of both types are as under :—

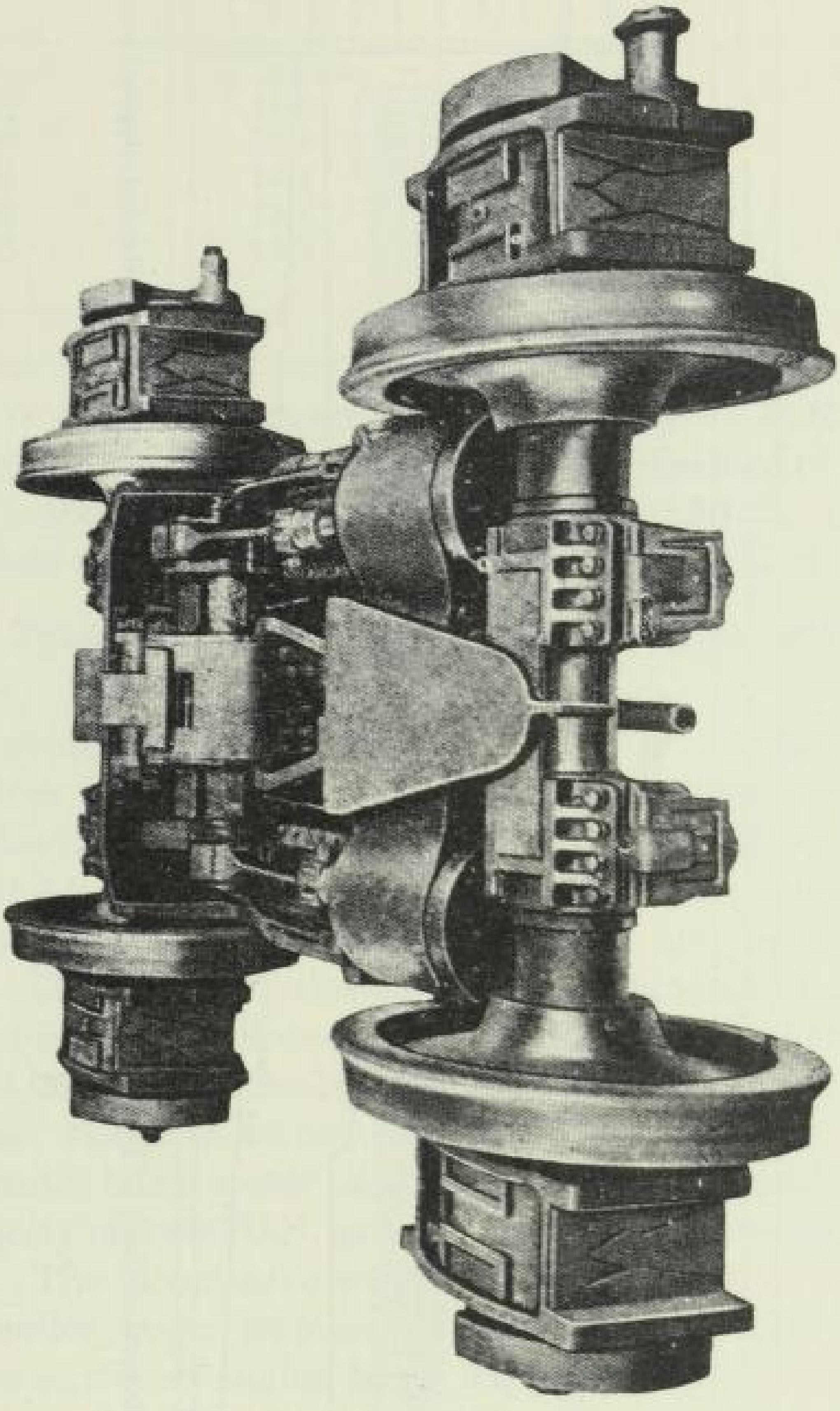


FIG. 210.—Rear View of Bethlehem Auxiliary Engine with Cover Removed.

	1922.		1925.	
Wheels, diameter .	33″	0·84 m.	36″	0·91 m.
Cylinders, diameter .	10″	0·25 m.	10″	0·25 m.
,, stroke .	10″	0·25 m.	12″	0·30 m.
Gear ratio, 1 to .	4·25		2·25	
Steam pressure . .	250 lbs.	16·6 kg.	250 lbs.	17·6 kg.
Weight	—	—	31,000 lbs.	14·1 t.

The cylinders are equipped with piston valves, the motion being connected to the main pin.

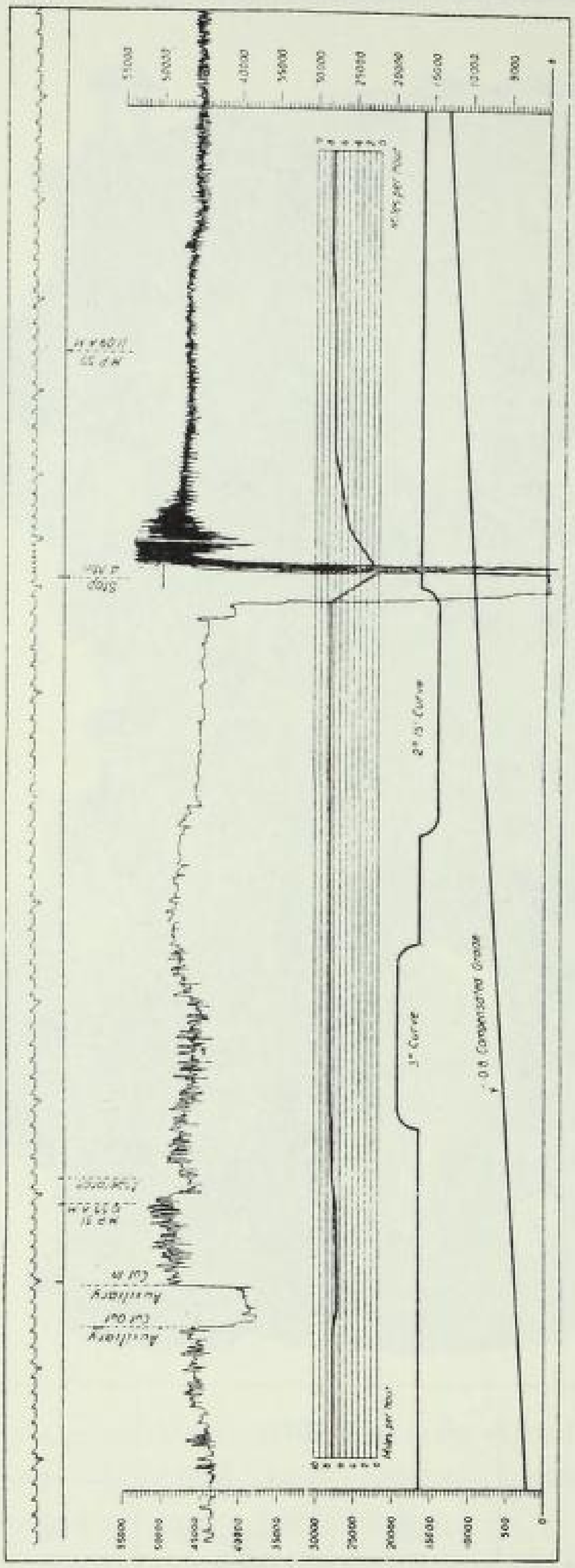


Fig. 211.—Record of Test of Bethlehem Auxiliary Engine with a Dynamometer Car on the Schoharie Grade.

All moving parts work in oil.

The nett increase of weight caused by the auxiliary engine is only about 10 tons.

The following table gives the tractive force developed at 7 miles (11 km.) per hour :—

Boiler pressure.		Tractive force.	
lbs./sq. in.	kg./sq. cm.	lbs.	tonnes.
188	12·8	13,300	6
200	14·1	14,400	6·6
210	14·8	15,100	6·9
200	15·5	15,850	7·2
250	17·8	18,000	8·2

The first machine of this type was applied to a Consolidation locomotive on the Delaware and Hudson Ry. in 1925. In the earliest model, the wheels were 3 ft. (0·91 m.) instead of 2 ft. 9 ins. (0·84 m.), the piston stroke was $11\frac{3}{4}$ ins. (0·30 m.) instead of 10 ins. (0·25 m.), and the gear ratio 1 to $4\frac{1}{4}$ instead of 1 to $2\frac{1}{4}$.

0-8-0 Texas and Pacific R.R. Locomotives with Tender Engines.

The application of the booster to the tender of switching locomotives is of recent date. The first of them was supplied by the Baldwin Locomotive Works in 1926. These consisted in two 0-8-0 locomotives for use in yard or pusher service, where they operated on 22-degree curves and up 3 per cent. grades. The length of these gradients, where the locomotives were used as pushers, reached two to four miles, and the booster added 15,000 lbs. to the locomotive's tractive power, bringing it up from 54,500 to 69,500 lbs.

The tender has a water capacity of 9,500 U.S. gallons, and a fuel capacity of 3,000 U.S. gallons. It weighs, in working order, 88 tons. The locomotive weighs 103 tons 1 cwt.

The tender bogie frames are made in one solid cast-steel piece, the auxiliary engine being supported by a cross-transom at the rear end. The diameter of the wheels is 3 ft. 3 ins. The exhaust can be discharged either direct into the atmosphere or through a feed-water heater in the tank. The total heating surface of the boiler is 2,515 sq. ft. exclusive of the superheater surface, 574 sq. ft., so an ample supply of steam is available.*

* These locomotives handle loads on either bank of the Mississippi at New Orleans, where they deal with 800 ton trains on the 4 per cent. grades that lead to the train ferries.

2-8 + 8-2 Norfolk and Western Mallet, with 0-4 + 4-0 Tender Equipped with Two Auxiliary Engines.—Standard gauge.

In 1927, for comparative purposes, this Company equipped the tenders of two *Mallet* locomotives, the one with two Bethlehem auxiliary engines, the other with two Franklin reversible boosters. In both cases the tender trucks have two coupled axles each, which have been substituted for the original three-axle trucks.

These locomotives are used for switching and hump yard service* at Portsmouth terminal, where 2-8 + 8-2 *Mallets* bring in from Williamson, Va., 113 miles away, 95-car trains, weighing 9,500 short tons.

The grades on the hump vary from level to 3·1 per cent. for a distance of 520 ft. It requires 128,900 lbs. tractive force to start a train on this line, of which 74,600 lbs. are necessary to start the portion situated on the hump and 54,100 lbs. for the portion on the level.

Previously to the introduction of the booster, the trains had to be limited to seventy-five cars, making 7,500 short tons. They were classified over the humps by a *Mallet* locomotive similar to the road engine, with a Consolidation to assist it.†

* This tender weighed 128,000 lbs. light, and 264,000 lbs. with 18 short tons of coal and 12,000 U.S. gallons of water.

Locomotive 2006 exerts a tractive force of 141,870 lbs., of which 34,500 are contributed by the two auxiliary engines.

Principal dimensions as under (Table 110) :—

Cylinders	25 and 39 ins. × 32
Boiler pressure	240 lbs.
Total heating surface	7,640 sq. ft.
Grate area	96 ,,
Weight, adhesive	478,000 lbs.
,, total, locomotive	531,000 ,,
,, tender, loaded	264,000 ,,
Factor of adhesion, locomotive engine	4·45
,, ,, auxiliary engines	3·72

† Here are a few comparative dimensions of the locomotives :—

	Without Booster.	With Booster.
Drivers, diameter	4 ft. 9 ins.	4 ft. 8 ins.
Tractive power	107,313 lbs.	109,272 lbs.
Cylinders	25 and 30 ins. by 32 ins.	
Boiler pressure	240 lbs. per sq. in.	

This was wasteful and inconvenient, owing to the number of cars to be classified in the twenty-four hours.

With two tender truck boosters which were fitted in March, 1928, the yard *Mallets* (of which there are three) have been working sixteen hours a day, and the rating of the road locomotive has been increased from 7,500 to the 9,500 tons quoted above.*

Missouri Pacific Ry. Locomotives and 0-4-2 + 0-4-2 Tenders Equipped with Auxiliary Engines.—Standard gauge.

In recent types of the Missouri Pacific Ry. (a 2-8 + 8-2 *Mallet* and a 2-10-2 rigid locomotive), two axles of each of the tender's six-wheeled bogies are driven. This gives a most powerful machine, whose total available tractive effort is increased by 30,000 lbs. in one case, and by 28,000 lbs. in the other.

These locomotives are used as switchers in the Dupo, Illinois, hump-yard, where heavy coal traffic has to be dealt with. The south-bound traffic consists of empty cars and general merchandise loads, the gradients ranging from 0 to 2·3 per cent. The north-bound traffic consists mostly of coal trains and the gradients range from 0·17 to 2·2 per cent.

Type 2.—The Franklin Reversible Locomotive Booster

The main principles which governed the provision of an auxiliary engine for using the weight of trailers for propulsion when the boiler produces more steam than the adhesion of the driving wheels enables them to use (that is to say at low speeds) applies with equal force to the weight borne by the tender's trucks.

One of the most pressing needs was to so equip them that a locomotive of given type should be able to switch a main-line train which it brought in or which had been brought in by a locomotive of the same class, over hump yards. This meant, of course, that extra power should be available, and that when

* Tests showed that the locomotive could deal with 127-car trains (10,336 short tons) without taking slack, and could weigh and classify it in thirty-five minutes.

The average maintenance cost of the boosters on the three locomotives equipped with them is, oil included, about one-third of a cent per mile.

working in either direction. Hence the "Franklin reversible booster," introduced at the end of 1927.

This was done by modifying the gear, clutch and control system of an ordinary locomotive booster. With this end in view, a new valve has been substituted to the reverse lever pilot valve. The clutch cylinder operates both ways.

The booster engine always revolves in the same direction, gearing being used for reversing.

In the forward motion, air is admitted to the under-side of the piston in the clutch cylinder, and in the reverse to the upper side. In the first case, the idler gear ratchet moves in the same direction as the clutch cylinder, which meshes the top idler gear with the axle gear, and the axle itself moves forwards.

In the reverse, the cylinder piston moves the lower idler gear into mesh with the axle gear, which transmits the drive from the crankshaft to the top idler gear, thence to the lower and to the axle gear.

The lower idler gear is smaller than the upper one. It has seventeen teeth instead of twenty-five.

When the booster is thrown out of action, the idlers are no longer in mesh. Suitable arrangements prevent interference between the forward and backward gears.

A single control mechanism is used when two boosters are employed; either booster may be thrown out of action separately.

Two axles of two or three axle tender bogies are coupled by ordinary coupling bars.

High-pressure steam is taken from the main chests of the engine through suitable piping with flexible connections. This piping runs back along the locomotive's main frame and then down beneath the footplate, from which a regulator controls it. The cylinder cocks are manipulated by air pressure.

The tender's drivers are coupled up to the cylinders of the bogies through mechanically operated mainshafts and gearing.

The driving shaft and driving pinion are forged in one piece. An idler gear transmits the engine's power to a large gear situated on the bogie's leading axle. It is always in mesh with the driving pinion, but can at will be thrown in or out of mesh with the large gear of the bogie's axle.

One or two auxiliary locomotives may be employed as the case may be. Thus the tender of the 2-8-2 locomotives of the

Missouri, Kansas and Texas has two four-wheel bogies, the latter of which only has an auxiliary engine, whereas both the six-wheel tender bogies of the 2-10-2 locomotives of the Missouri Pacific R R. have auxiliary engines with two axles out of each three coupled. These locomotives are used for switching over hump marshalling yards.

2-8 + 8-2 Locomotive with Two Tender Reversible Boosters

In 1927 the Norfolk and Western equipped the tenders of two locomotives of this class with motor equipments, and, for comparative purposes, ordered Bethlehem auxiliary engines for the tender of locomotive 2006, and Franklin boosters to the tender of locomotive 1702.

This latter weighs 262,030 lbs. in service, and 131,500 lbs. light. It carries 16 short tons of fuel and 12,000 U.S. gallons of water.

The two reversible boosters have a tractive force of 33,900 lbs. which, added to the locomotive's 109,286 lbs., bring the total up to 143,186 lbs.* These locomotives classify cars at the East Portsmouth, Ohio, yards, where the hump has gradients of 2·773 per cent. one way, and from 0·3 to 1·55 per cent. in the opposite direction.

With the reversible tender booster, we reach the end of our study of articulated locomotives of all classes, which have been used under a variety of conditions and on all kinds of railways.

To conclude, and to show how great is the diversity of types that have been evolved, and many of which survive, we append a list of those we have examined, with the dates of their first appearances.

* Principal dimensions of these locomotives (Table 111) :—

Cylinders . .	25 and 39 ins. × 32 ins.	Drivers, diameter .	56 ins.
Weight, total . .	526,000 lbs.	Boiler, pressure .	240 lbs.
Weight, adhesive .	472,000 ,,	Heating surface .	7,850 sq. ft.
Weight, tender .	262,000 lbs. in service.	Grate area . .	96 ,,

The factor of adhesion is 4·30 for the engine and 3·88 for the tender (light).

APPENDICES

I. CHRONOLOGICAL SEQUENCE OF THE INVENTION AND PROGRESS OF ARTICULATED LOCOMOTIVES

THOUGH in describing the various types of articulated and of semi-articulated locomotives we have followed quite a different order, it is useful to append a list of the various types in the order of their appearance. It shows, incidentally, that not only have certain of them subsisted down to the present day, but that others have appeared quite recently.

We have also listed a few instances when important alterations of principle have taken place, even when they do not concern the articulated system itself.

1832—**Horatio Allen** invented the first articulated locomotive. Built by the West Point Foundry for the South Carolina R.R.

1834—**Miller** patented a system for transferring part of the weight of the tender to the locomotive.

Applied by Baldwin to locomotives for the Philadelphia and Trenton R.R.

1841—First **Baldwin** geared locomotive.

1841—**Baldwin** built a locomotive with front bogie coupled by chains to a countershaft.

1842—**Thouvenot's** patent for transferring part of the tender's weight to the locomotive. Never applied.

1842—**Tourasse and Hardery** patented a semi-articulated locomotive with rear motor truck and drivers of two different diameters.

1842—**Verpilleux** patented first steam tender, built in 1843, for the Saint-Etienne and Lyons Ry.

1843—**Norris's** patent for jointed coupling rods. Never applied.

1851—The Semmering Contest on the Sudbahn Ry. The following took part in it :—

The "**Bavaria,**" articulated locomotive and tender, the three groups of coupled wheels being coupled by chains. Builder, Maffei, of Munich. Never duplicated.

The "**Seraing,**" a double-boiler articulated locomotive designed by Lausmann and built by Cockerill, Seraing, Belgium. Not reproduced in this form.

The "**Wiener-Neustadt,**" articulated locomotive built by Wilhelm Gunther (now the Wiener-Neustadt Locomotive Works). Not reproduced.

1852—**Engerth** patented a geared locomotive wherein the tender's wheels were also driven and part of the tender's weight was transferred to the locomotive.

First used on the Sudbahn.

1852—First **twin** or **duplex locomotives** patented by Sommeiller, Grandis and Ruva.

First built for the Giovi line by Stephenson, Darlington, and by Cockerill, Seraing, in 1853.

1854—First **modified Engerths** produced on the Ch. de fer du Nord-Belge by suppression of gearing and coupling of tender's wheels.

1855—The **Engerth-Creusot** modified locomotive, first introduced by the P.L.M. Ry.

1855 (about)—**Rarchaert's** original design for transmission of the cylinder's action by means of oscillating levers. This was several times improved upon, notably in 1859, but was never executed.

1857 (November 30th)—**Verpilleux and Baldeyrou's** patent for a compound steam tender locomotive.

1858—**André Kœchlin's** patent semi-articulated locomotive with front truck and double, inner and outer coupling rods.

1860 (about)—**Gouin and Larpent's** patent with the same object.

1860—**Behne's** design for a two-boiler locomotive, with one engine and two vertical central cylinders. Never built.

1861 (March 15th)—**Jean-Jacques Meyer**, of Mulhausen, patented his articulated locomotive, all four cylinders being located in the centre. Plans exhibited in London in 1862. (See 1868.)

1862—Project by **Boutmy** of semi-articulated locomotive with rear truck. Exhibited in Paris in 1867.

1862—The **Fink** system of semi-articulated locomotive with transmission by countershaft.

First employed on the "Steierdorf" of the Austrian State Rys.

1863—**Behne-Kohl** locomotive with part of the tender's weight transferred to the locomotive.

First built by the Hanover Locomotive Works in 1863 for the Brunswick Local Rys.

1863—**Archibald Sturrock's** steam tender first applied to the Great Northern Ry.

1863—**Charles Thouvenot**, of Bex, proposed an articulated double-boiler locomotive for crossing the Alps. (See also 1867.)

1863 (May 12th)—**Robert Fairlie** patented his articulated locomotive with either a simple or a double boiler.

Utilised many years. (See 1865, 1869.)

1865—First **Fairlie** locomotive, "Progress," built by Cross and Co. for the Neath and Brecon Ry.

1866—**Urban's** steam tender locomotive built at Louvain for the Belgian Grand Central Ry.

1867—**George Thomas Lommel**, of St. Gall, designed a locomotive on the Thouvenot system for use with Fell central rail for the projected transalpine Lukmanier Ry.

1868—**de Bergue's** design for transmission by coupling rods.

1868—First **Meyer** locomotive, "l'Avenir," built by Parent, Schacken and Co., Fives-Lille, tried on the Nord and other railways and finally purchased by the Ch. de fer de l'Herault.

1869 (about)—The first **single Fairlie** locomotive built for the Great Southern and Western Ry., Ireland.

1870—**Adolph Brunner** single-boiler articulated locomotive, by Cockerill, Seraing.

1871—**Mason-Fairlie** built the "Janus" in America. It differed from the Fairlie type design in details only.

1873 (about)—Third **Rarchaert** semi-articulated locomotive with converging rear axles supplied to the Ch. de fer de Vitré.

1873—Improved **Meyer** locomotive, built by Charles Evrard, of Brussels, for the Ch. de fer du Grand-Central Belge, and exhibited in Vienna. It served as basis for the future development of the type.

1875—The **Aliger** design.

1876—**Adolph Brunner** designed his " Omnibus locomotive " with two motor trucks. Built the same year for the Ch. de fer de Lausanne Echallens Bercher, Switzerland.

1878—**Weidknecht's** patent for semi-articulated locomotive with connecting rods on the axis of the locomotive.

1878—First **Mason-Fairlie** single locomotive. Supplied to a railway in Colorado.

1878—First **Felix Rimrott** locomotive with swivelling rear truck derived from the Engerth system.

1880—**Heywood** was the first to use hollow sleeve-axles.
A semi-articulated locomotive making use of it was supplied in this year to the Duffield Bank Ry.

1880—First **Shay** geared locomotive built for a logging railway.

1883—The **Krauss-Helmholz** bogie designed and finally patented in 1887. (See 1888.)

1884 (June 13th)—**Anatole Mallet** patented his system of semi-articulated compound locomotive with swivelling front truck carrying the L.P. cylinders.

1885—**Winterthur** geared articulated locomotive constructed for an industrial line in the South of France.

1885—First **Klose** semi-articulated locomotive built for the Swiss Union Ry. A certain number of others followed for this and other lines.

1885—**Johnstone** compound double-boiler locomotive designed.
A powerful locomotive was built by the Rhode Island Locomotive Works (Providence) for the Mexican Central Ry.

1886—**Johnstone** single-boiler locomotive designed.

1886—A chain-transmission locomotive built by the **Winterthur** Works.

1887 (June 3rd)—**Péchot-Bourdon** patent double-boiler articulated locomotive, established after the Fairlie lines.

Adopted for the French military railways (0·60 m. gauge) and tried on the Paris Exhibition Ry. in 1889.

1887—First **Mallet** locomotive (0·60 m. gauge), "l'Avenir," built in Belgium by the Société Métallurgique, of Tubize. Tried on the military railways of Toûl, then at Laon in 1888, and put into regular service on the Paris Exhibition Ry. in 1889. Thousands have been built since.

1888—First locomotive with **Krauss-Helmholz** bogie supplied by the Krauss Locomotive Works to the Bavarian State Rys. (See 1883.)

1888—**Klien-Lindner** patent for coupling hollow-axle locomotives first applied.

1889—**Krauss,** of Munich, built an articulated locomotive, with suspended boiler and tanks on the end bogies. Cylinders fixed to main frame and motion transmitted by countershafts. Supplied to the military.

1889—**Lange and Livesey** patent for twin locomotives.

First applied to locomotives built by Beyer, Peacock and Co. for the Interoceanic Ry. of Mexico.

1889—**Weidknecht** patent for twin locomotives.

1889—**Mallet** patented a combined rack and adhesion semi-articulated locomotive, the rack engine having L.P. cylinders.

1889—**Fritz Rimrott**, of Halberstadt patented his semi-articulated compound locomotives, with rear swivel-truck. We do not believe any were ever built.

1890—First standard gauge **Mallet** locomotive. Built by Maffei, of Munich, for the St. Gothard Ry. It was, at the time, the most powerful locomotive in Europe.

1890—First **Fairlie compound** locomotives. Built by the Chemnitz Works for the Saxon State Rys.

1890—**Adolph Brunner** patented a modification of the Mallet locomotive, so as to be able to use it, if desired, as a H.P. locomotive, the rear truck only being operated.

1891—**Hagans** patent for semi-articulated locomotives.

1892—**Baldwin** built a compound articulated locomotive for the Sinnemahoning Valley Ry.

1892—**Cowles** applied Heywood's hollow axles to articulated locomotives with a single pair of cylinders situated between the trucks.

Built for a Kentucky railway.

1893—**Krauss's** patent for an auxiliary engine for working, on occasion, carrying axles of the locomotives.

1893—**Hagans's** device for semi-articulated locomotives first applied to locomotives delivered to German railways.

1893—**Köchy's** transmission by countershafts to two sets of driving wheels patented, but never used.

1893—Three-cylinder **Klose** locomotive, built for the Wurtemberg locomotives. It could work either simple or compound.

1894—First **Heisler** geared locomotive built by the Stearn Manufacturing Co. for a Mexican firm.

1894—First **Meyer-Kitson** locomotive with cylinders at the rear of each bogie.

Built by the Kitson Works, of Leeds, for the Anglo-Chilian Nitrate and Ry. Co.

1894—The **Vogel** design. Never used.

1901—**Baldwin** system of twin locomotives.

Compound locomotives of this type supplied to the McCloud River R.R.

1902—**Orenstein and Koppel** locomotives with end axles coupled by gearing.

1902—First **Mallet** four H.P. cylinders built, in spite of the inventor's protests, for the Trans-Siberian Ry. by the Briansk Works.

1902—**Modified Fairlie** locomotive with two separate boilers designed by the Vulcan Foundry, Newton-le-Willows, and built the same year for the Burma Rys.

1904—First **Mallet** locomotives built in the U.S.A. by the American Locomotive Co. for the Baltimore and Ohio R.R. The most powerful built to date.

1905—Modified **Mallet** with cylinders at the outer ends, built in New Zealand for the Government Rys. Never duplicated.

1905—The **du Bousquet** articulated locomotive with all cylinders grouped at the centre.

First built by the Ch. du fer du Nord at its own shops, and repeated by several other railways.

1907—**Meyer-Kitson combined** rack and adhesion articulated locomotive, with auxiliary engine, supplied to the Chilian Transandine Ry.

1908—Improved **Meyer-Kitson** locomotives with cylinders at the outer ends of the bogies.

First built for the Antofagasta (Chile) and Bolivia Ry.

1909—**Canadian Pacific** derived Mallet locomotive, with compound cylinders located at the centre and altered frame connections.

1909—First **Garratt** articulated locomotives. These were compound locomotives for the 2 ft. gauge lines of the Tasmanian Government Rys.

1910—**Mallet** locomotive with articulated boiler built by the Baldwin Locomotive Works for the Atchison, Topeka and Santa Fé Ry.

1911 (about)—**Mallet** locomotive with driving wheels of two diameters supplied by the North British Works to the South African Rys.

1911 (about)—**George Henderson's** patents for combined rack and adhesion locomotives.

1911—**Canadian Pacific** four H.P. cylinder modified Mallet tried and not adopted.

1911—**Meyer-Kitson** rack and adhesion articulated locomotive without auxiliary engine supplied to the Argentine Transandine Ry.

1911—**Esslingen** combined rack and adhesion semi-articulated locomotive, with swivelling rear truck, supplied to the Chilian Transandine Ry.

1911—First **Garratt** simple locomotives.

Built by Beyer, Peacock & Co., for the Darjeeling-Himalayan Ry. (2 ft. gauge).

1911—First **Garratts** built on the Continent, by the Ateliers de Saint-Léonard, Liége, for the Mayumbé Ry. (Belgian Congo).

1912—Eight-cylinder **Garratt** built for the Tasmanian Government Rys.

1912—Henderson's patent for **Triplex** locomotive. (See 1914.)

1913—**Esslingen** rack and adhesion locomotive introduced on the Arica-La Paz Ry.

1913—**Garratt** experimental locomotive with return-flame boiler, built by the Ateliers de St. Léonard, Liége, for the Congo Ry. Not successful.

1914—First **Triplex** locomotive supplied to the Erie R.R., on George Henderson's patents. Both the first and third swivelling trucks are hinged to the central rigid truck.

Others followed for the Erie and for the Virginian Ry.

1914—**Robert Stephenson's** patent for twin locomotives. Not applied so far.

1919—**Ingersoll** first applied a **booster** to a locomotive of the New York Central. (See 1925.)

1922—Patents granted for the **tender auxiliary engine**. First applied to a Delaware and Hudson locomotive. (See 1925.)

1923—First **Garratt** locomotive used in England (by the V. and S. Works).

1924—The **Hanomag** (Hanover Locomotive Co.) took out a patent for rear swivelling truck semi-articulated locomotive. Not applied so far.

1924—Patents of **Golwé** articulated locomotive taken by Messrs. Goldschmidt and Weber. (See 1928.)

1924 (about).—Patents for **Mallet-Garratt** and **Turbine Garratts** taken by Beyer, Peacock & Co.

1925—First **booster** used in England, by the L. & N.E. Ry.

1925—**Bethlehem auxiliary engine,** a modification of the 1922 type.

1925—First six-cylinder **Garratt**, for the L. & N.E. Ry.

1925—**Modified single-boiler Fairlie** locomotives with bogies further apart.

First built by the North British Locomotive Co. for the South African Rys.

1926 (about)—First **Schwartzkopff** chain locomotive supplied to Peru.

1927—The **Poultney** system of steam tender. Patents acquired by the Yorkshire Engine Co. (See 1928.)

1927—First **Union-Garratt** locomotives built by Messrs. Maffei, of Munich, for the South African Rys.

1928 (January)—First locomotive **booster** used for locomotive trailing four-wheeled truck on the Texas and Pacific R.R.

1928—**Reversible booster.**

1928—First **Bethlehem auxiliary engine** applied to six-wheeled tender bogie.

1928—First **Poultney** locomotives supplied by the Yorkshire Engine Co. to the Ravenglass and Eskdale Ry. (15 ins. gauge).

1928—First **Golwé** locomotives supplied to the Ivory Coast Ry. (metre gauge).

II. ALPHABETICAL LIST OF SYSTEMS OF ARTICULATED LOCOMOTIVES

III. ALPHABETICAL LIST OF RAILWAYS QUOTED IN THIS WORK AND WHICH HAVE USED OR USE ARTICULATED LOCOMOTIVES

So as to facilitate references, we have designated the more usual types of articulated locomotives by a letter which we have placed before the page where the locomotive is dealt with. We have given full names for the more unusual systems of locomotives.

The abbreviations we have made use of are the following :

boos . booster.
Clim . Climax type of locomotive.
du B du Bousquet locomotive.
Eng . Engerth locomotive.
FF . Fairlie two-boiler locomotive.
f . Fairlie single-boiler locomotive.
F . Fairlie double-boiler locomotive.
G . Garratt locomotive.
Gear Geared locomotive.
Heis . Heisler locomotive.
Klien Klien Lindner system.
Lutter Luttermöller system.
M . Mallet tender locomotive.
m . Mallet tank-engine.
MS . Mallet simple admission locomotive.
Meyer Meyer locomotive.
mod . Modified.
Rar . Rarchaert.
Shay. Shay locomotive.
Tend. Steam tender locomotive.
T, boos Tender Booster or Bethlehem auxiliary engine.
Twin. Twin or Duplex locomotive.

IV. ALPHABETICAL LIST OF BUILDERS OF ARTICULATED LOCOMOTIVES QUOTED IN THIS BOOK

AUSTRIA

Lokomotivfabrik Krauss & Co., Linz and Munich.
Wiener-Neustädter Lokomotivfabrik (formerly *G. Sig*), W. Neustadt.

BELGIUM

Soc. Anglo-Franco-Belge de Matériel de Chemin de fer, La Croyère.
Les Ateliers Métallurgiques (Nivelles, Tubize and la Sambre).
Soc. John Cockerill, Seraing.
Evrard, Brussels.
Usines métallurgiques du Hainaut, Couillet.
Soc. an des Forges, Usines et Fonderies de et à Haine-Saint-Pierre.
Soc. de Marcinelle et Couillet.
Soc. des Ateliers de construction de la Meuse, Ougrée.
Soc. an. de Saint-Léonard, Liége.

CANADA

The Montreal Locomotive Works.

FRANCE

Soc. Alsacienne de Constructions Mécaniques, Belfort and Grafenstaden.
Soc. de Construction des Batignolles, Paris.
Soc. Decauville, Petitbourg.
Soc. Française de Constructions Méchaniques (*Anciens Etablissements Cail*), Denain.
Cie. de Fives-Lille, Paris and Lille.
Gouin et Cie, Paris.
Works of the Ch. de fer du Nord.
Schneider et Cie, le Creusot.
Weidknecht & Cie, Paris.

GERMANY

Berliner Maschinenbau, A.G., formerly *L. Schwartzkopff*, Berlin.
A. Borsig, Tegel-Berlin.
Maschienenfabrik Esslingen ; in Esslingen, Wurtemberg.
Hannoversche Maschienenfabrik (Hanomag), Hanover.
Richard Hartmann, Chemnitz, Saxony.
Henschel und Sohn, Cassel.
Hohenzollern A.G. für Lokomotivbau, Dusseldorf (Grafenberg).
Arnold Jung, Jungenthal bei Kirchen a. d. Sieg.

GERMANY—*continued*

Maschienenbau ges., Karlsruhe.
Krauss & Co., Linz and Munich.
Krupp A.G., Essen.
Linke-Hoffmann Werke.
J. A. Maffei, Munich.
Orenstein & Koppel (former Orenstein and Koppe and Arthur Koppel Works, amalgamated), Berlin.
Sächsische Maschienenfabrik vorm. *R. Hartmann*, Chemnitz.
F. Schichau, Elbing.
Stettiner Maschienenfabrik, Vulcan, Stettin (Bredow).

GREAT BRITAIN

Sir W. G. Armstrong, Whitworth & Co., Scotswood Works, Newcastle-on-Tyne.
The Avonside Engine Co., Ltd., Bristol.
Andrew Barclay, Sons & Co., Ltd., Kilmarnock, Scotland.
W. Beardmore & Co., Ltd., London.
Beyer, Peacock & Co., Gorton Foundry, Manchester.
Cross & Co., St. Helens.
R. and W. Hawthorn, Leslie & Co., Forth Bank Works, Newcastle-on-Tyne.
The Hunslet Engine Co., Leeds.
Kerr, Stuart & Co., Ltd., Stoke-on-Trent.
Kitson & Co., Leeds.
Nasmyth, Wilson & Co., Patricroft, Manchester.
Neath Abbey Works.
The North British Locomotive Co., Ltd., Glasgow, Scotland.
Robert Stephenson & Co., Ltd., Darlington.
Vulcan Foundry, Ltd., Newton-le-Willows.
The Yorkshire Engine Co., Ltd.

HOLLAND

Werkspoor, Amsterdam.

HUNGARY

Works of the Hungarian State Rys., Budapest.

ITALY

The Breda Works, Milan.

NEW ZEALAND

New Zealand Government Rys. Shops.

RUSSIA

The Briansk Locomotive Works, Leningrad.

SWITZERLAND

Soc. Suisse pour la construction de locomotives et de machines Winterthur.

UNITED STATES OF AMERICA

The American Locomotive Co., New York works.
The Baldwin Locomotive Works, Philadelphia.
The Bethlehem Steel Co., Bethlehem, Pa.
Climax Manufacturing Co., Corry, Pa.
Heisler Locomotive Works, Erie, Pa.
Lima Locomotive Works, Lima (Ohio).
Pennsylvania Ry.'s Shops.
Rhode Island Locomotive Works, Providence.
Southern Ry.'s Shops.
West Point Foundry.

VICTORIA

Victoria Government Ry.'s Shops.

V. LIST OF TABLES OF PRINCIPAL DIMENSIONS OF LOCOMOTIVES

BOOK I.—ARTICULATED LOCOMOTIVES, PROPERLY SO CALLED

Part I.—Locomotives with One Engine and but One Driven Axle

Part II.—Articulated Locomotives with One Engine and Two or Several Driven Bogies

Part III.—Articulated Locomotives with Two Engines and Two Steam Driven Bogies

The Meyer Group

The Fairlie Group

The Garratt Group*

The du Bousquet Group

BOOK II. SEMI-ARTICULATED LOCOMOTIVES

PART I.—A SINGLE ENGINE WITH TWO SETS OF DRIVEN WHEELS

The Klien-Lindner Group (Quill Transmission)

* See also Tables 111 and 112 in the Addenda.

PART II.—TWO SETS OF DRIVEN WHEELS AND TWO ENGINES WITH TWO SETS OF CYLINDERS

The Mallet Group of Tank Engines

The Group of Mallet Locomotives with Separate Tenders

The Group of Modified Mallet Locomotives

The Twin or Duplex Locomotives

BOOK III. TEMPORARILY ARTICULATED LOCOMOTIVES

BOOK IV. STEAM TENDERS

ADDENDA—GARRATT LOCOMOTIVES

VI. LIST OF ILLUSTRATIONS

BOOK I. ARTICULATED LOCOMOTIVES, PROPERLY SO CALLED

PART I.—ONE ENGINE, ONE DRIVEN AND ONE UNDRIVEN BOGIE

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The Shay Group of Geared Locomotives

The Climax Group of Geared Locomotives

The Baldwin Group of Geared Locomotives

The Heisler Group of Geared Locomotives

Locomotives with Rod Transmission

PART III.—TWO ENGINES AND TWO STEAM DRIVEN BOGIES

Gear Transmission

Chain Transmission

The Meyer Group of Locomotives

SUB-GROUP I. A.—THE MEYER LOCOMOTIVES

SUB-GROUP I. B.—THE MEYER-KITSON LOCOMOTIVES

The Fairlie Group of Locomotives (with two pairs of cylinders)

SUB-GROUP II. A.—THE PRE-FAIRLIE TYPES

SUB-GROUP II. B.—THE FAIRLIE DOUBLE-BOILER LOCOMOTIVES

SUB-GROUP II. C.—TWO-BOILER FAIRLIE LOCOMOTIVES

SUB-GROUP II. D.—SINGLE-BOILER FAIRLIES AND DERIVED TYPES

The Garratt Group of Locomotives*

SUB-GROUP III. A.—THE GARRATT LOCOMOTIVES

* See also Fig. 212 hereafter.

SUB-GROUP III. B.—LOCOMOTIVES DERIVED FROM THE GARRATT NORMAL TYPE

The Du Bousquet Group of Locomotives

BOOK II. SEMI-ARTICULATED LOCOMOTIVES

PART I.—ONE ENGINE AND TWO DRIVEN SETS OF WHEELS

The Klien-Lindner Group

Part II.—Two Engines and Two Driven Sets of Wheels

The Mallet Group of Locomotives

Mallet Tank Engines

Mallet Tender Locomotives

Modified Mallet Locomotives

Twin or Duplex Locomotives

BOOK III. TEMPORARILY ARTICULATED LOCOMOTIVES

BOOK IV. STEAM TENDERS

ADDENDA—GARRATT LOCOMOTIVES

ADDENDA

GARRATT LOCOMOTIVES

WHILST this book has been in the press, a few noteworthy developments have occurred in connection with Garratt locomotives.

They concern broad, standard and meter gauge locomotives, and more especially 3 ft. 6 in. gauge **Garratts**, which are particularly noteworthy.

NOTE 1.*—**4-6-2 + 2-6-4 (Double-Pacific) and 2-8-2 + 2-8-2 (Double-Mikado) Garratt Locomotives of the Central Aragon Ry. (Spain)**.—1m.67 (5 ft. 6 ins.) gauge.

We have had occasion to quote this railway previously in connection with early *Mallet* tank and tender locomotives. Owing to increase of traffic and to competitive operation over long stretches of heavy banks, the Company has placed orders for six passenger and six goods train *Garratts*, according to the following requirements :—

The passenger *Garratts* must haul 300 metrical ton trains on gradients 18 km. (11 miles) long, of 2·5 per cent. with non-compensated curves of 300 m. radius (985 ft.), at a speed of 40 km. an hour (25 miles) and at a speed of 100 km. an hour (62 miles) on the level.

The goods locomotives must haul 500 metrical tons over the same gradients at a speed of 18 km. an hour (11 miles).

Such conditions call for more powerful *Garratt* locomotives than have appeared so far on broad gauge lines. The track is relatively light and the maximum axle load is 15·5 metrical tons only.

NOTE 2.†—**4-8-2 + 2-8-4 (Double-Mountain) Garratts, South African Rys.**—3 ft. 6 ins. gauge (Figs. 212 and 213).

We have previously drawn attention to the difficult section of

* Concerns p. 214.   † Concerns p. 219.

Tables 111 and 111a.—Principal Dimensions of the Latest Garratt Locomotives

Gauge Railway		1m.67 Central Aragon.		5 ft. 6 in. Central Aragon.		3 ft. 6 ins. South African.	3 ft. 6 in. Rhodesia.
Builder		Euskalduna.	Babcock & Wilcox.	Euskalduna.	Babcock & Wilcox.	Beyer, Peacock.	Beyer, Peacock.
Date Type		1929. **4-6-2 + 2-6-4**	1929. **2-8-2 + 2-8-2**	1929. **4-6-2 + 2-6-4**	1929. **2-8-2 + 2-8-2**	1929. **4-8-2 + 2-8-4**	1929. **2-8-2 + 2-8-2**
Cylinders, diameter	mm.	482	440	19″	17¾″	22″	18½″
,, stroke	mm.	660	610	26″	24″	26″	24″
Boiler, centre line	m.	2·90	2·60	9′ 6¼″	8′ 4$\frac{7}{16}$″	8′ 6″	—
,, diameter	m.	2·06	1·93	6′ 9½″	6′ 4$\frac{1}{16}$″	7′ 3⅜″	6′ 6″
,, length	m.	8·96	8·14	29′ 5″	26′ 8⅝″	14′	13′
,, pressure	kg./sq. cm.	14·0	15·0	lb./sq. in. 199	213	200	180
Tubes, number		44–266	43–195	44–266	43–195	50–263	38–214
,, diameter	mm.	133–48	130–50	—	—	5½″–2″	5¼–2″
,, ,, superheater	mm.	35·0	35·0	⅜″	⅜″	1½″	1⅜
Firebox, width	m.	1·99	2·00	6′ 6⅝″	6′ 6¾″	—	—
,, length	m.	2·48	2·10	8′ 1¾″	6′ 10¾″	10′ 9″	—
Heating surface, firebox	sq. m.	20·0	15·9	215 sq. ft.	171 sq. ft.	340 sq. ft.	212 sq. ft.
,, ,, tubes	,,	297·3	181·0	2,985 ,,	1,948 ,,	3,036 ,,	2126 ,,
,, ,, total	,,	297·3	196·9	3,200 ,,	2,012 ,,	3,376 ,,	2338 ,,
,, ,, superheater	,,	60·7	68·5	653 ,,	737 ,,	809 ,,	480 ,,
Grate area	,,	4·9	4·2	53 ,,	45 ,,	74·5 ,,	49·5 ,,
Wheels, diameter	m.	0·91	0·85	2′ 11⅝″	2′ 9½″	2′ 4½″	2′ 9″
,, ,,	m.	1·75	1·20	5′ 9″	3′ 11¼″	4′	4′
,, ,,	m.	1·07	0·85	3′ 6$\frac{3}{16}$″	2′ 9½″	2′ 9″	2′ 9″
Wheelbase, driving 1 group	m.	3·81	4·20	12′ 6¼″	13′ 9½″	13′ 3″	—
,, driving 2 groups	m.	18·36	18·00	60′ 3¾″	59′ 1$\frac{3}{16}$″	63′ 3″	—
,, total, 1 group	m.	8·99	7·65	29′ 6$\frac{3}{16}$″	25′ 1⅜″	27′ 8″	—
,, total, both groups	m.	25·53	22·50	83′ 9¼″	73′ 10$\frac{13}{16}$″	83′ 7″	24′ 9″
Pivot centres	m.	13·34	11·00	43′ 10″	36′ 11″	41′ 6″	73′ 7½″
Overall dimensions, height	m.	4·34	4·25	14′ 3″	14′	13′	—
,, ,, width	m.	3·05	3·20	10′	10′ 6″	10′	—
,, ,, length	m.	28·00	25·30	91′	83′	91′	—
Tractive force (at 75 per cent.)	kg.	13,540	22,220	40,900 lbs.	49,000 lbs.	78,650 lbs.	46,200 lbs.
Water tanks	cub. m.	23	22	5,060 galls	4,840 galls.	7,000 galls.	4,500 gals.
Fuel bunkers	t.	9	9	19 t. 16 cwt.	19 t. 16 cwt.	12 t.	6 t.
Weight, maximum 1 axle	t.	15·5	13·5	15 t. 6 cwt.	13 t. 5 cwt.	18 t. 10 cwt.	13 t. 7 cwt.
,, adhesive	t.	93·0	108·0	106 t. 6 cwt.	91 t. 10 cwt.	147 t. 9 cwt.	—
,, empty	t.	138·0	118·0	135 t. 16 cwt.	116 t. 3 cwt.	—	—
,, in service	t.	181·0	157·0	178 t. 3 cwt.	154 t. 10 cwt.	214 t. 2 cwt.	150 t. 13 cwt.
Other locomotives same wheel formation, see Table		39	41	39	41	42	42

line which leads from the Natal coast to the uplands, and to the ever larger articulated locomotives which the South African Rys. have ordered to work there.

The old Natal line has uncompensated 1 in 30 gradients with 300 ft. (and even one 275 ft.) radius curves, having 80 lbs. rails with $4\frac{1}{2}$ ins. cant. As reverse curves occur without intermediate tangents, the rigid wheel base of the powerful locomotives under notice has been reduced to 9 ft. only, the end coupled wheels being flangeless.

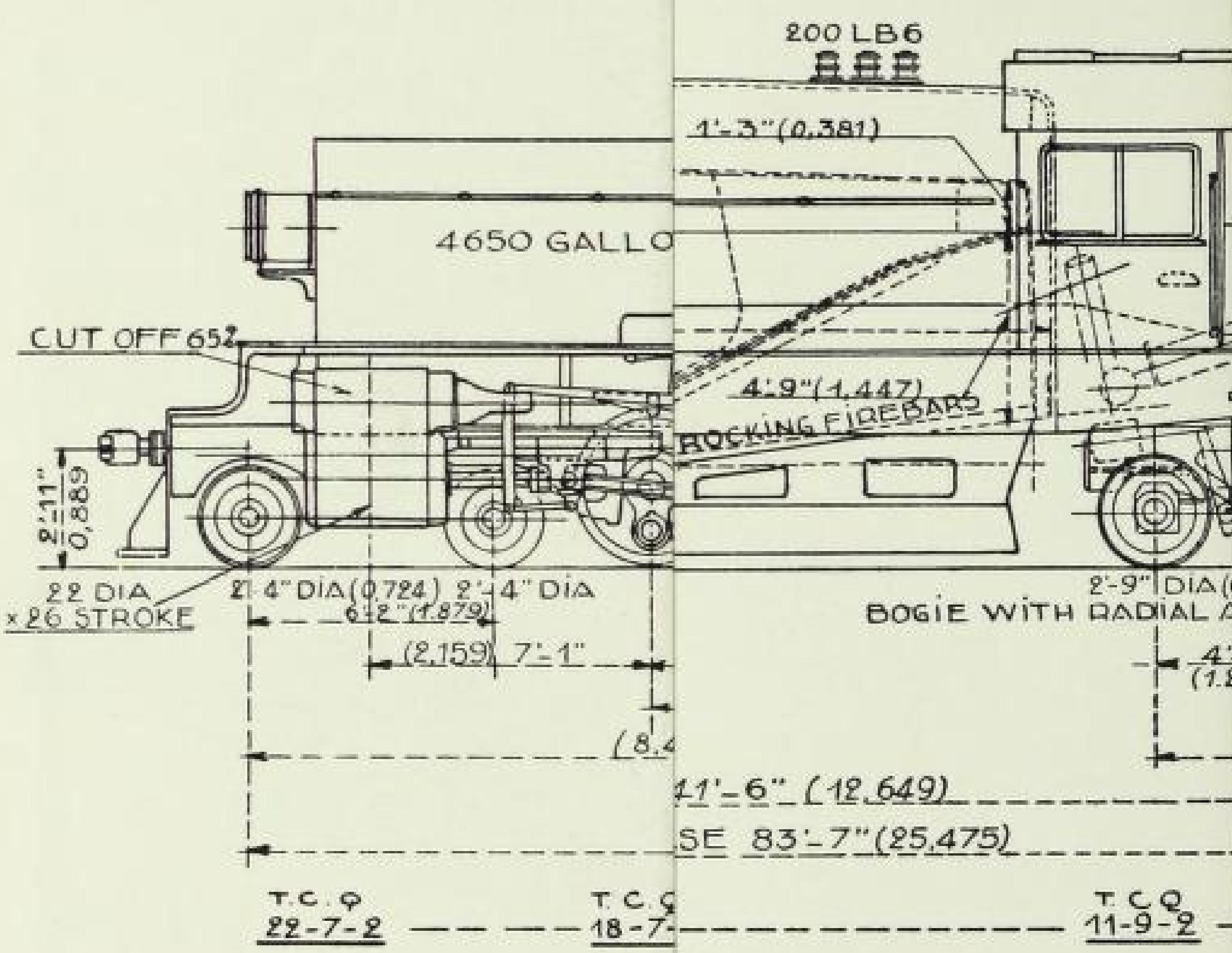
The new 40-mile line's conditions are far better: gradients of 1 in 65 and curves of 700 ft. radius being compensated. It should be noted, however, that there are ten tunnels aggregating over 2 miles in length. So that the crew should not suffer, a turbine-driven air compressor supplies fresh air to the cab, and any surplus steam from the safety valve release cock is carried to the rear tank.

These *Garratts* are the latest that have been supplied to the railway. Ordered in 1928, they were delivered in August, 1929, and call for special comment, not only because they develop 48 per cent. more tractive power than any other locomotives of the South African Rys., but also as being far and away the most powerful locomotives ever built for the 3 ft. 6 ins. gauge and the heaviest locomotives built outside the U.S.A. for any gauge.

They embody no novel features, but every element has been studied so that the whole should have maximum efficiency. Under present conditions, it would seem that these locomotives are the most powerful that can be devised for this gauge and the maximum 18·5 ton axle load to which they are restricted. The track is laid with 80 lbs. rails and the maximum total weight allowed was 215 tons. The locomotives under notice weigh 214 tons 2 cwt. This approaches so closely to limitations and shows such mastery in general and detail design that we have pleasure in congratulating Messrs. Beyer, Peacock and Co. on this achievement. These locomotives develop 524 lbs. per pounds M.E.P., at 75 per cent. boiler pressure and 367 lbs. tractive force per ton in working order.

The front pivot is spherical with spring controlled side rollers: the back pivot is flat and is adjustable.

We have previously stated the advantages of the *Garratt's* boilers, and these are noticeable in the instance under con-



South African Railways (3 ft. 6 in

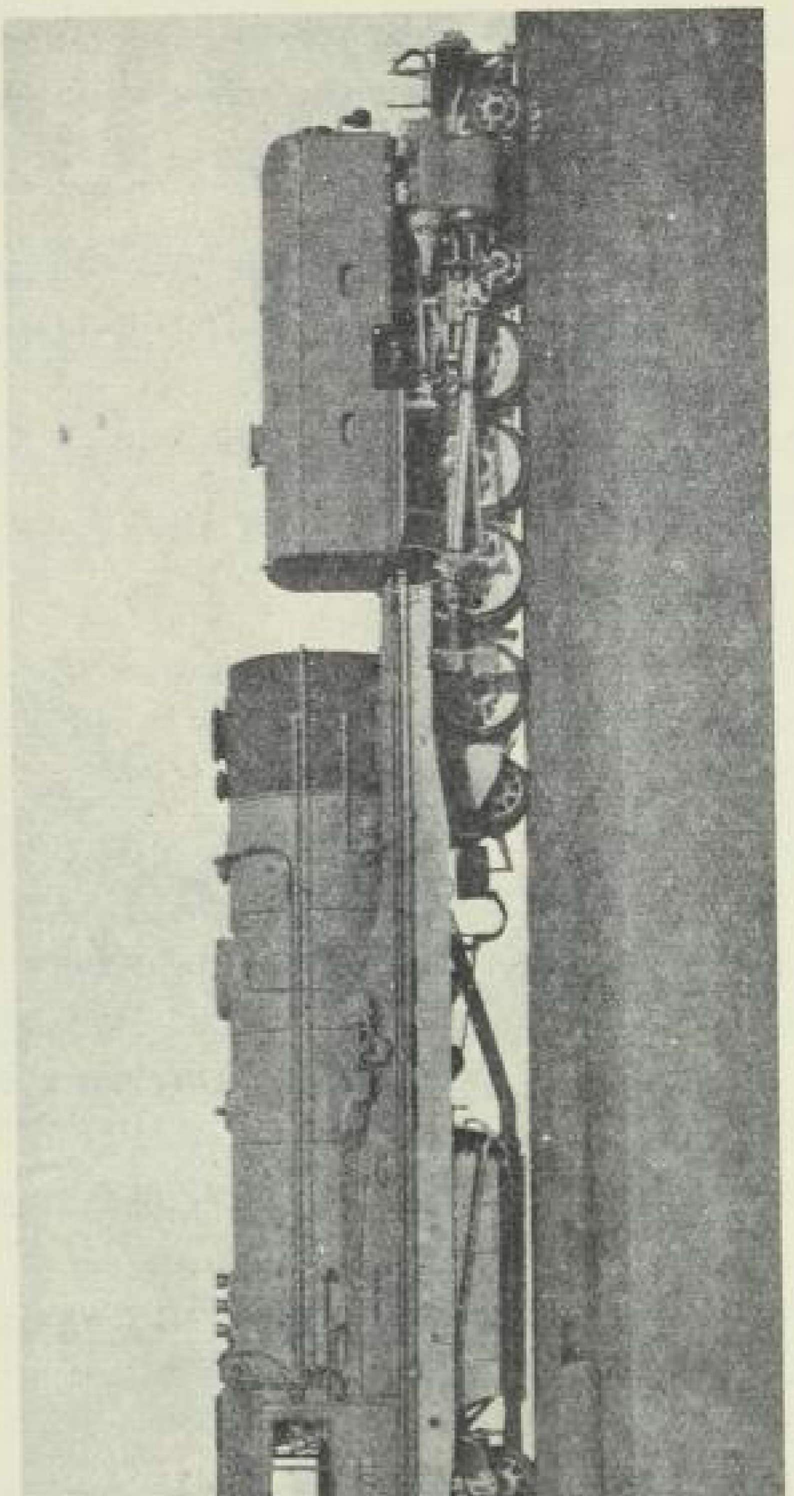


FIG. 213.—Latest 4-8-2 + 2-8-4 Garratt Locomotive South African Rys. (3 ft. 6 in. gauge). Built by Beyer, Peacock & Co.

sideration. For a centre line which is relatively low owing to restrictions imposed by the loading gauge, the boiler's diameter is no less than 7 ft. $3\frac{3}{8}$ ins. maximum outside diameter.

The firebox has two arch tubes and two Nicholson thermal syphons.

The wheels are compensated in two groups. The frames are of the cut-bar type which was introduced on the Brazil Rio Grande do Sul railways in 1907.

Coal is fed into the firebox by a Duplex mechanical stoker.

NOTE 3*.—**0-6 + 6-0 Locomotives of the Belgian National Light Rys. Co.**—Meter gauge.

This company's system is a rather curious one, consisting, as it does, of a number of separate lines, many of which are laid along the high roads and which aggregate as large a mileage as that of the principal Belgian railways. Traffic on some of the lines is exceptionally heavy, and as they often have very sharp curves, two total adhesion *Garratt* locomotives have been ordered at the end of 1929. They must haul twenty-five 15-ton gross wagons, at a speed of $12\frac{1}{2}$ miles an hour up a 1 in 50 bank $1\frac{1}{4}$ miles in length. The radius of the curves is 98 ft. only (30 metres) in the horizontal, and 3,280 ft. (1,000 metres) in the vertical plane.

One of these experimental locomotives will be put to work at Eysden ; the other will probably be exhibited at the Liége (1930) Exhibition.

So far the total adhesion *Garratts* have been confined to narrower gauges, and indeed they seemed to have been given up. The special conditions which arise in Belgium seem to have given them a new lease of life, though we rather fancy that with slippery rails and short curves, it may be found advisable to add guiding trucks to them.

We quote their leading dimensions on p. 627.

Other Recent Garratt Locomotives.—We quote the leading dimensions of the latest Rhodesian *Garratts* which we mentioned on p. 217. Like their predecessors, they have bar frames.

Finally, the London, Midland and Scottish Ry. has passed an order for thirty further *Garratts*.† They seem, therefore, to have passed the experimental stage and to have been

* Concerns p. 192.

† Refers to p. 200.

TABLES 112 AND 112A.—GARRATT LOCOMOTIVES SUPPLIED TO THE BELGIAN NATIONAL LIGHT RYS. CO.

Builder gauge of the lines.		Saint-Léonard.	
		1 meter.	3′ 3⅜″
Cylinders, diameter	m.	360	14⅜″
,, stroke	m.	350	13⅞″
Boiler pressure	kil.	13	185 lbs.
Tubes, number		24–154	24–154
,, diameter	m.	110–41	4⅜″–1⅝″
Heating surface:			
Firebox	sq. m.	8,0	85,4 sq. ft.
Tubes	,,	78,5	844,5 ,,
Total	,,	86,5	1,130,0 ,,
Superheater	,,	18,6	200,0 ,,
Grate area	,,	2,1	22,3 ,,
Wheels, diameter	m.	0,85	2′ 9⅜″
Wheelbase, one group	m.	6,50	21′ 4″
,, total	m.	13,90	45′ 7″
Water	cub. m.	4,5	990 gals.
Fuel	t.	2,5	2t., 10 cwt.
Tractive force	t.	9	9 tons
Weight, maximum 1 axle	t.	10	10 ,,
,, total in service	t.	58	57 t., 1 cwt.

adopted by a leading British railway, in much the same way as they have found a home on many a foreign line.

It is pleasant to finish our book with a description of these locomotives, as they show in a striking fashion what remarkable results can be achieved by articulated locomotives on all gauges and even on such a seemingly unlikely gauge as the 3 ft. 6 ins.

Errata

P. 106. Type of locomotive in fifth column, read **2**-8 + 6-0 instead of **1**-8 + 6-0.

P. 369.—Sub-title Class H., read 2-6 + 6-**0** instead of 2-6 + 6-**8**.

THE ARTICULATED IN NORTH AMERICA

THE DEVELOPMENT of the articulated locomotive in the United States is without parallel elsewhere in the world. The long era of articulated-steam construction began in 1832 with Horatio Allen's double-boiler two-cylinder 2-2-0+0-2-2 Fairlies for the South Carolina Railroad and ended in 1952 with the erection at Roanoke of a Norfolk & Western 2-8-8-2 compound Mallet. During this 120-year period some 50 variants of the articulated theme had been produced, about as many as the permutations in rigid versions. All but two were of local manufacture. The foreign ones were an English double-Fairlie 0-4+4-0T built for the 3-foot Denver & Rio Grande in 1873, and a German 0-4-4-0 2-foot-gauge Mallet which came secondhand from Mexico to the Cripple Creek & Victor (Colorado) tourist operation 90 years later.

Following Allen's spasm of thermodynamic aberration, Matthias Baldwin produced a few locomotives embodying a front truck driven by combinations of chains, gears, and rods; one design had a flexible truck frame which allowed the axles to skew around curves. This initial burst of invention was succeeded by three decades of inactivity, broken finally in 1871 by William Mason who constructed a solitary 0-6+6-0T double-Fairlie operated on the Lehigh Valley. Thereafter (beginning in 1878), Mason confined his articulated activities to more successful single-boiler machines of Fairlie construction. Meanwhile, the Europeans had been busy with all sorts of jointed contrivances; but further U. S. activity proceeded in a different direction.

The first of the new breeds was the Shay (1880), which was followed by the less unconventional Climax in 1888, and a Dunkirk Engineering Climax copy in 1890. Two years later Baldwin turned out its two (and only) 0-6-6-0T Vauclain-compound monstrosities for the Sinnamahoning Valley, and in 1894 the first Heisler engine chugged out of the shops. Another decade was to pass before the first articulated Mallet (0-6-6-0) went into service on the Baltimore & Ohio. The logging and mining businesses looked so good to Baldwin and Davenport that both began to produce geared articulateds in 1912. Baldwin's logger was actually a Climax with altered gearing, while Davenport's entry was an 0-4+4-0T with independently powered geared trucks. Two years later the first triplex Mallet was constructed by Baldwin for the Erie Railroad. By 1922 the trailing-truck booster was at work, and three years later tender trucks were provided with power to utilize idle weight and unused steam capacity. The last new concept came in 1932 — a Vulcan locomotive much like the Davenport arrangement but without gearing. The whole process of development had taken just a century; subsequent years would see only refinement of the basic principles.

The range in size and weight of U. S. articulateds was enormous. At one extreme was a tiny 2-foot-gauge two-cylinder 6-ton Shay; at the other were monsters in the million-pound category — Great Northern 2-8-8-2's, Northern Pacific 2-8-8-4's, Union Pacific 4-8-8-4's, Virginian and Santa Fe 2-10-10-2's, and Virginian and Erie Triplexes. The amplitude of power was equally wide: less than 100 h.p. for the smallest engines to 7000 h.p. for modern high-pressure single-expansion examples. In countless instances, great size alone appeared to have been a mania among mechanical departments which designed engines capable of consuming steam faster than their boilers could generate it. The reasoning seemed to be that the splicing of a low-pressure unit to an existing locomotive somehow would deliver increased power, a fundamental error which was committed numerous times. Yet this did not deter Baldwin from dreaming of quadruplexes and quintuplexes which could make the pressure gauge read "0" within one revolution of their manifold drivers. A modern high-powered locomotive required 20 to 30 square feet of grate area per driving axle (Santa Fe 4-6-4's had 33), but main-line Mallets were constructed with as little as 7½ square feet (Erie Triplex). No wonder such ill-proportioned power plants became exhausted at only 10 mph.

Just what motivated Horatio Allen to design his South Carolina jointed contraptions is not known, although we are aware that Matthias Baldwin's abhorrence of idle axles accounted for his early efforts. Mason's only double-Fairlie was an unsuccessful attempt to place two engines under the control of one crew, a concept which was born prematurely. The originators of Shay, Climax, Dunkirk, Heisler, Baldwin, Davenport, and Vulcan engines, which spread their slight weights over two, three, or four (the Shay only) trucks, possessed the more practical idea. The offspring of these inventors were supposed to operate anywhere, even on wooden poles (the Climax, with spool wheels), up 10 per cent grades (Western Maryland), around 82-degree curvature (Uintah), and through any obstacle of forest or mountain.

But mainline Mallets were a different creature entirely. At first they were used as helpers, replacing two or more smaller ones. A few years were to pass, though, before they were accepted at the head of a train. Somewhat later their low-speed capabilities were utilized in heavy transfer (on the Pennsylvania) and hump-yard (on New York Central) duties. Some railroads indulged in Mallets only to a limited extent (New York Central and Pennsylvania); others relied on them extensively for passenger (Southern Pacific) and freight (Northern Pacific) operations. Huge articulateds roamed everywhere on the principal lines of Union Pacific, Rio Grande, and Norfolk & Western; they were confined to specific areas on other railroads (Santa Fe, Chesapeake & Ohio, and Great Northern). Within the short span of 25 years the mainline articulated had grown from a 167-ton helper into a powerful 386-ton road hauler which scarcely needed assistance from anything else.

Why, then, one might ask, if the articulated was so successful in the U. S., did it vanish in the space of a mere decade? The answer to this perceptive inquiry is neither obvious nor simple; it involves a host of considerations, many of which have nothing to do with economics or operations. Moreover, railroad managements did not exhibit unanimity in the particular reasons for abandoning steam articulated locomotives; and even today some of the conversions to other power appear to lack rational conviction. The subject is far too deep for this brief commentary.

All in all, close to 4 per cent of U. S. steam-locomotive production (about 180,000 engines) was represented by articulated machinery, almost evenly divided between Mallet variety and the powered-truck (geared) types. Of these 7000-odd engines, some 1 per cent still exist, principally as muted memorials of more boisterous and grimier times. A handful are still working toward the day when some irreparable catastrophe makes final disposition an inevitable decision. Like the bison of the Great Plains, the articulated steam locomotive in the U. S. is close to extinction; but unlike the shaggy buffalo, the articulated is unlikely to be rescued from this fate.

Alaska — Canada — Mexico

North of the border, the mighty Mallet was a *rara avis*. Only the Canadian Pacific possessed any — six Angus-built 0-6-6-0's with all four cylinders grouped amidships. Despite the English influence in Canadian railroading, Garratts and Fairlies failed to be represented by even a single example. On the other hand, U. S. exports of Shays, Climaxes, and Heislers in all customary configurations found immediate acceptance in the forest lands of British Columbia. In the far Northwest, only the 3-foot-gauge Climax was to be found: four of Class A and three of Class B in Alaska; and a single Class C (secondhand from Colorado) which may have been the only steam-driven articulated to cross the international boundary on a regular basis.

Mexican railroads presented a contrasting picture. The geared engines were rare, but Mallet, Fairlie, and Johnstone locomotives formed a noticeable proportion of the national iron-horse population. The biggest Mallets were 2-6-6-2's — the most recent examples having been single-expansion models for both 4′-8½″ and 3-foot gauges. The smallest ones were tiny German 0-4+4-0's built for a mining operation. Mexico's early railroads, like Canada's, were financed with English capital, a circumstance which yielded a fascinating collection of unusual motive power, much of which could be cataloged as freaks. Among the more interesting exhibits were English 0-6+6-0T double-Fairlies, Rhode Island 2-6+6-2T Johnstones, and Lange & Livesey Patent twin 2-6-0+0-6-2's of English origin. Less unconventional designs included 2-6-6T Mason-Fairlies and some "left-handed" Shays. Unlike U. S. railroads, which barely tolerated mechanical unconventionality, the Mexican companies employed their curious beasts for a great many years, perhaps because the difficulty of obtaining replacements from a distant and obdurate management was the greater of two evils.

Robert A. Le Massena

LIONEL WIENER

ANATOLE MALLET, George Henderson, and others to whom the steam locomotive owes its development were his contemporaries and correspondents. Railroad construction occupied a portion of his broad career. An enthusiasm for railroads led him to write and publish several works which soon became classics of documentation. Lionel Wiener, a Belgian, came from a technical and military background. Before World War I he had participated in the building of railroads in India, Brazil, and the Balkan states. He achieved high rank in Belgian railroad circles after the war, and was until his death in 1940 a member of the board of directors and the committee of direction of the Compagnie Belge de Chemins de Fer et d'Entreprises. He taught railroading at the University of Brussels. Yet he was far broader and even more prolific than this. He composed operettas. He documented in two massive volumes the history of the Brussels theater. His interests ranged from railroads and music to stamp collecting and printing. Wherever he went, and whatever he did, Lionel Wiener was acknowledged as an authority.

THE connoisseur will recognize the workings of a Norfolk & Western Y6 in the dust-jacket photo, by Bruce R. Meyer. Wiener notes N&W's massive and successful 2-8-8-2's. But he implies that a 2-8-0+0-8-2 Garratt just might have had even more to offer!

REMEMBER FRISCO'S 4400'S WITH SCULLIN DISCS? PENNSY'S J1'S FROM C&O PLANS? THIS BOOK DOES!

THERE was no catalog of steam locomotive models. Too many ideas, too much individualism existed for that. What Santa Fe required, Delaware & Hudson could not have embraced. N&W saw articulation differently than did NP. So in the days when the erecting floors and machine shops were finally quiet, it remained for David P. Morgan to compile the biography of steam's finest examples. One hundred and one of North America's notable steam locomotives return in this book. Some are deservedly famous for what they were or what they did. Some, less well-known, are selected because they represent the majority. All have much to say about the variety and versatility that characterized American steam. The book is built to accommodate them: large in format, horizontal because locomotives are long. For each of the chosen engines there is an action photo, a builder's side view, a commentary, the vital statistics. Morganesque text introduces the subject, reviews steam in geographical context, wraps up an unforgettable era. Not recommended as a cure for nostalgia: **Steam's Finest Hour, edited by David P. Morgan, 128 large pages, $15.**

KALMBACH BOOKS