ARTICULATED LOCOMOTIVES.

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Had the capital values created since the beginning of civilisation to bear interest, the burden by now would have been insupportable, but capital wastes and the world is not called upon to carry this load. It is otherwise with information.

Since the blessed art of printing has become a bad habit, and the beauty of illustration a temptation, we are in danger of multiplying our sources of information beyond the purposes of investigation—we cannot see the trees for the wood. When the Athenians spent their time in nothing else but either to tell or to hear some new thing, it was not considered a sign of merit. To-day we do worse, we not only talk and listen, but see and publish.

The Author does not propose, therefore, to attempt any addition to our recorded knowledge, but rather to render the bulk somewhat more accessible by presenting a modest catalogue of one class of machine:—

THE ARTICULATED LOCOMOTIVE.

(1) In 1804* it was discovered that a wheel revolving on a rail was sufficiently adhesive to its successive points of contact therewith to impart a tractive force to the bearings of its axle in proportion to the weight which presses the wheel rim down on the rail.

(2) In 1815† it was found that if a succession of wheels were linked together and made to revolve the tractive effort of the machine in which they were combined was in exact proportion to the total weight on all the wheels so coupled; “exact” as long as they revolved in the same plane.

(3) When it was necessary for the locomotive to work

* Trevithick, Merthyr Tydvil Railway.

† George Stephenson, Killingworth.

round curves, this plane of revolution of coupled wheels had to be continuously deflected from its successive directions.

To facilitate this action, it was found desirable to place in front of these coupled wheels a mechanism which would act as deflector of the engine and relieve the tractive agents (namely the coupled wheels) of side friction as far as possible.*

The developed form of this mechanism was a four-wheeled bogie to which successive lateral impulses were given by the continuous slips of its tyre flanges on the constraining rail. This bogie communicated the turning movement to the complete structure through the medium of delaying devices such as springs, inclined planes or swing links.

(4) The straight line element of the machine (that is the coupled wheel unit) could not exceed a certain length according to the radius of the curve, lest it bind across the track.

These are the simple premises invested with an air of false originality by pompous phraseology, which have called forth the device of the articulated engine for special service on curving lines; and the problems arising from these premises form the basis of the consideration of the different systems.

The first requirement is that an engine should pull as heavy a train as the largest power unit (boiler, etc.) that can be accommodated in it can operate.

The adhesive weight of the coupled wheels has to be increased in proportion. The permissible axle load determines the number of such wheels required; the curve limits the coupled wheel base. And the articulated system provides a means by which two separate coupled wheel units, each short enough to pass the curves, can be associated under one boiler complete with fuel and water supply, and managed by one crew of men.

In the subsequent descriptions the abbreviations used are as follows:—

Co.—Locomotive Engineering, 2 vols., by Zerah Colburn, Collins, London.

Er.—Engineer.

Eg.—Engineering.

P.I.C.E.—Proceedings Inst. Civil Engineers.

* Where the speed is sufficient to render centrifugal force formidable, it causes friction on bogie and coupled wheels alike.

Rd.G.—Railroad Gazette, New York.

Ry.G.—Railway Gazette, London.

G.E.R.—General Electric Review, Schenectady, N.Y.

In the "Railroad Gazette" of 1891 (vol. 23, p. 674) there is a catalogue of the different types of articulated engines, beginning in 1832. The list shows that at fairly regular intervals the requirements of railroads have pointed to the need of such engines, and the Author wishes to acknowledge the value of the list, as a parallel reference in this research.

Another source of information is to be found in the diagrams produced by Mr. Theodore West, of Darlington, and published by Mr. Harrison Penny, of the same place, in June, 1885.

FIG. 1. STEPHENSON'S ENGINE. 1815.

Ref.: Co., v. 1, p. 19.

Date: 1815.

Designer:

R. Stephenson. **Maker:** Stephenson. **Rly.:** Not known.

The first appearance of the articulated system was connected with Stephenson's earliest designs. In 1815 he coupled together the engine wheels by rods working upon crank axles, and the tender wheels by means of an endless chain, Fig. 1. The use of a chain for transmitting power in a locomotive is not dead. The modern exquisitely accurate developments of chains may cause them to reappear, but during the century under review they have not been used.

In 1831 an engine was designed by Mr. Horatio Allen for the South Carolina Railroad which actually saw service, but does not appear to have been repeated. At the time there were two main objections to placing the engine on

six or eight wheels. One arose from the vertical and the other from the horizontal inequalities of the lines of support. In the description of the engine it was stated that the difficulties arising from vertical irregularities were overshadowed by others. But the fact that they were noted is

FIG. 2. DOUBLE BOGIE LOCOMOTIVE. SOUTH CAROLINA R. RD. 1831. *From the designs of Mr. Horatio Allen.*

Ref.: Eg. 11, 254. **Date:** 1831. **Designer:** H. Allen.
Maker: West Point Foundry, N.Y. **Rly.:** South Carolina.

most interesting, for it reminds one that in the actual life-time of some we know, the rail path metals, which now weigh 100 lbs. per yard, consisted of plates which were no more than ribbons of iron nailed on to longitudinal baulks of timber.

The illustration, Fig. 2, attracts our attention to the adventurous position of the driver, and the curious arrange-

ment of double boilers. By this means Mr. Allen probably intended to keep the centre of gravity low, while he centred his wheel-carrying points under the barrels; at any rate, by this system he obtained the adhesion of two pairs of wheels without coupling them. Each pair was in a bogie* carriage, as far as can be conjectured, connected to the boiler by a centre pin, each barrel being supported on rollers resting upon the sides of the carriage frames.

Ref.: Co. 1, 84. **Date:** 1842. **Designer:** Baldwin.
Maker: Baldwins. **Rly.:** Not known.

In 1840 it had become necessary to adopt some special device to meet the difficulties met with on the curves of mountain roads, and Mr. Baldwin made several patents, in one of which he placed the first and second pair of leading coupled wheels in a flexible beam truck. The journals were arranged with spherical boxes, and appear to have provision for the lengthening and shortening of the rods by clearance in the bearings. This design cannot be passed over without mention, but as the axles of the truck were kept parallel to those of the driving axle, it is not to be reckoned as of the type of an articulated engine.

Ref.: Co. 1, 85. **Date:** 1852. **Designer:** Maffei, Munich.
Maker: Maffei, Munich. **Rly.:** Semmering Incline, Vienna and Trieste.

In 1852 the experience of the locomotive world was drawn upon by the Austrian Government for the Semmering Climb. The curves had a minimum radius of $9\frac{1}{2}$ chains.

In a general competition, the prize was won by Maffei. In this locomotive the wheels of the tender were coupled with the others by means of an endless chain, thus repeating the Stephenson of 1815. The engine was conspicuously defective, and rapidly superseded.

Ref.: Co. 1, 85. **Date:** 1852. **Designer:** Engerth.
Maker: Maffei. **Rly.:** Semmering Incline.

Maffei's articulation, however, did not succeed, and the tender was altered by Engerth, who carried the frames far enough forward to take a portion of the weight of the fire-

* The term bogie appears to be a dialect word, N. English and Scotch, meaning a low, strongly built truck. Derivation unknown. It did not originate in America, but arrived with the early English locomotive descriptions.

box. He then brought the leading tender axle near enough to the driving axles to be coupled with them.

Nor did this design give much satisfaction, although the engine continued to work.

Ref.: Eg. 1, 84. **Date:** 1854. **Designer:** Cockerill, Seraing, Belgium. **Maker:** Cockerill, Seraing, Belgium. **Rly.:** Semmering Incline.

In 1852 Cockerill & Co. distinctly anticipated the jointed type of the future. A double boiler was carried on two steam-driven bogies by means of pivots on the barrels. The steam reached the cylinders through bent copper pipes whose flexibility was sufficient to provide for the motion of the bogies. The exhaust was conducted by a swinging pipe to a ball and socket joint fixed in the blast pipe.

Ref.: Eg. 2, 331 and 334. **Date:** 1863. **Designer:** Petiet. **Maker:** Gouin & Co., Paris. **Rly.:** Nord, France.

Two engines, designed by Mons. Petiet and made by Messieurs Gouin et Cie. in 1860, have the appearance of being of the Articulated type, but whatever the relative movement of the different wheels, they are confined to parallelism as far as the axles are concerned, and the engines are only mentioned for a negative purpose.

Ref.: Eg. 1, 180. **Date:** 1866. **Designer:** R. Fairlie. **Maker:** J. Cross & Co., St. Helens. **Rly.:** Anglesea.

Mr. Robert Fairlie (Eg. 40, 133) was an ardent advocate of reducing the cost of railways by increasing the capacity of lines with light rails, sharp curves and narrow gauges. To meet this problem, he designed the type of engine known by his name.

The contrivance which he originated (with a good deal of force of character in support) proved the real beginning of the practical work of Articulated Engines.

The general arrangement requires no special description in 1920, but a perusal of the design will perhaps reawaken interest in this symmetrical, ingenious and successful device. In the earliest engines, as far as can be judged from the small scale drawing of Fig. 3, the swinging and plunging movement of the cylinders relative to the main structure was not more than could be taken up by a steam pipe coiled round in the interior of the smokebox. The orifice of the blast, being in the essence of things lineable

with the chimney centre, was coupled to the exhaust by sliding and ball socket joints.

The motion gear for both steam-driven bogies was worked with one reversing lever, the relative movement of

FIG. 3. FAIRLIE. ANGLESEA RLY. JAMES CROSS & CO. 1865.

the two systems being provided for by knuckle joints at the ends of the connecting rod.

An interesting list of these engines appears in Eg. 18, 142, date 1874. This shows that at least 18 different designs had been produced, the gauges varying from 1ft. 11 $\frac{3}{4}$ in. to 5ft. 0in., the localities from South America

in the West to Russia in the East. A modern example is shown by Fig. 4.

FIG. 4. FAIRLIE. MEXICAN RLY. NEILSON & CO.

Ref.: Er. 93, 491. **Date:** 1902. **Designer:** General, Messrs. R. P. & T., and Vulcan Fdy. Co., Ltd.; *Details,* Vulcan Fdy. Co., Ltd. **Maker:** Vulcan Fdy. Co., Ltd. **Rly:** Burmah.

A class of engine has been made by Messrs. the Vulcan Fdy. Co., Ltd., in which the boilers were separate, but similar in other characteristics of the Fairlie type as noted in the above reference.

Mr. A. Sturrock, in 1863, designed a locomotive which embodied a novel practice, and ran on the G.N. Rly. of England. The engine proper and the tender were each steam-driven and each six-wheel coupled, the engine with 16in. cylinders and 5ft. wheels, the tender with 11½in. diameter cylinders and wheels 4ft. 6in. diameter, Fig. 5.*

The steam pipe for the latter appears to have been fastened at the front of the tender and to be free from that point up to its connection with the dome; the joints necessary for the concertina action between the engine and tender are not recorded. The regulators for the engine and tender systems were separate. The reversing gear was worked from two handles; the brake gear was on the tender alone. Though the number put into service reached 50, they were objected to because the trains they hauled were too long and unwieldy, and because the increased work in handling was unpopular with the drivers.

* Through the courtesy of the Editor of "The Engineer," we are enabled to publish a sectional drawing.

Légende.

- A. Tuyau pour conduire la vapeur de régulateur aux cylindres du Tender.
- B. Régulateur pour alimenter les cylindres du Tender.
- C. Le cylindre du Tender.
- D. Tuyau d'échappement qui conduit la vapeur aux tuyaux à condenser.
- E. Les tuyaux à condenser, qui peuvent être construits selon le dessin, ou autrement à volonté. La vapeur d'échappement passe dans la chambre ou boîte (f) et se trouve condensée en parcourant le long des tuyaux.
- F. Tuyau qui conduit la vapeur qui n'est pas condensée, à l'atmosphère.
- G. Essieu moteur du Tender.
- H. Les manivelles extérieures, les roues étant accouplées à l'ordinaire.

AUXILIARY STEAM TENDER.

Scale of Feet

Echelle Métrique

Arch. d'Invent.

	When empty	When full.
Weight of Tender	6 ton. 4 cwt.	9 1/4
Loading	6 " 18 "	10 5
Driving	5 " 1 "	9 8
Trailing	18 " 3 "	29 7
Total weight of D.	18 " 5 "	

	When empty	When full.
Weight of Engine	10 2	11 ton. 8 cwt.
Loading	10 " 1 "	11 " 5 "
Driving	10 " 1 "	11 " 2 "
Trailing	30 " 7 "	33 " 15 "
Total weight of D.		

The weight Full, has sufficient coal and water to take 45 waggons 25 miles

THIS LITHOGRAPH SHOWS ALTERED ENGINE TO TAKE 45 WAGGONS, THE WEIGHT OF THE ENGINE IS NOT INCREASED MORE THAN 10 CWT.
THE DOTTED LINES SHOW ORIGINAL 0° 30° 0°

Description.

- A. Pipe for conveying steam from the regulator to Tender cylinders.
- B. Regulator for supplying steam to the Tender cylinders.
- C. Tender Cylinders.
- D. Exhaust pipe for conveying the steam to the Condenser.
- E. Condensing apparatus, which may either be made according to the design, or to any other plan if preferable.
- The exhaust steam enters the chamber or box (f) and condenses whilst passing along the tubes.
- F. Pipe for conveying the uncondensed portion of the steam into the atmosphere.
- G. Tender crank axle.
- H. Outside Cranks, the wheels being coupled in the ordinary manner.

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A feed water heater was fitted in the tender tank, through which exhaust steam from the tender cylinders passed, but no record is given as to whether the blast from one pair of cylinders was sufficient to raise steam to feed two pairs, and the story of the short lives of these engines has passed into an oblivion which is perhaps hardly deserved.

FIG. 5. STURROCK. GREAT NORTHERN RLY. KITSON & CO.
Ref.: K. & Co. **Date:** 1865. **Designer:** A. Sturrock.
Maker: Kitson & Co. **Rly.:** Great Northern, England.

FIG. 6. MEYER'S DESIGN. LONDON EXHIBITION. 1862.
Ref.: Eg. 4, 75-76. **Date:** 1862 Exhibition, London.
Designer: Meyer. **Maker:** Not made. **Rly.:** —.

The design by Meyer was well thought out. It was the first scheme of a type of engine from which various designs have been evolved, but the engine shown by Fig. 6 was never made.

Ref.: Eg. 7, 191. **Date:** 1869. **Designer:** Meyer.
Maker: Cie Fives, Lille. **Rly.:** Nord, France.

A locomotive of this type was put on the lines of the Chemin de Fer du Nord of France in 1869. It was named "L'Avenir." In this case the water tanks and coal bunker were carried on the bogies (as of the Garratt engine later on); but the engine was not found as satisfactory as those built on the Fairlie system.

Ref.: Eg. 16, 35-36. **Date:** 1873. **Designer:** Meyer.
Maker: Compagnie Belge, Brussels. **Rly.:** Grand Central, Belgium.

A more advanced example was shown at the Vienna Exhibition in 1873. The principle was a superstructure, consisting of boiler, coal bunker and water tank. The positions for the driver and fireman were like those of the ordinary tank engine. The upper portion was carried by two steam-driven bogies, and the driver operated the motion for each of these bogies by reversing gears that could be worked separately or together. The smokebox end bogie supported the front end of the boiler together with the tank, by means of a pivot working in a socket fixed to the barrel of the former. The firebox end bogie carried its part of the superstructure by brackets on the frames supporting spherical bearings on sliding plates, at either side of the back end of the firebox. The steam was taken to either bogie through long copper pipes, the curves of which when supplemented with sliding joints appear to have given sufficient flexibility for the movement.

The exhaust steam from the leading cylinders passed through the hollow centre of the forward pivot casting, and so to the blast pipe. From the trailing cylinder the exhaust was carried to the same receptacle through a junction pipe that was connected at its two ends with ball and socket joints. The smokebox end bogie supplemented the pull of the firebox bogie by means of a long rod that clasped the pivot casting. The adjustment required by the changing relative positions is made by a crosshead and link motion, called the Stradal Draw Apparatus. The draw gears on the outer ends of the bogies were also of the Stradal type.

FIG. 7. TWIN TANK ENGINES. CAPE GOVT. RLYS.
KITSON & CO. 1875.

Ref.: K. & Co. **Date:** 1875. **Designer:** K. & Co.
Maker: K. & Co. **Rly.:** Cape Government.

In 1875 Twin Engines were made by Kitson & Co. for the Cape Government Railways. These were practically two similar engines coupled back to back, the regulator, reversing and brake gears being separate, so that each engine could be used independently (see Fig. 7).

FIG. 8. STEPHENSON'S PATENT LOCOMOTIVE. 1914.

Ref.: R. S. & Co. **Date:** 1914. **Designer:** R. S. & Co.
Maker: Not made. **Rly.:** —.

In 1914 the method of using Twin Engines which were capable of acting as separate entities, was worked out in an interesting patent by Messrs. Stephenson (see Fig. 8). Here the driver's platform is separate from each engine, and connected to the wheel structure at pivot points, through which the draw from engine to engine is transmitted. The weight of the intermediate frame is not carried at the pivots, but on side brackets, fixed on the frames of each unit; provision

is also made for carrying part of the weight, at the back of each unit, to ensure its accurate distribution.

FIG. 9. JOHNSTONE. MEXICAN CENTRAL RLY.

Ref.: Eg 43, 81. **Date:** Before 1887. **Designer:** F. W. Johnstone. **Maker:** Not known. **Rly.:** Mexican Central.

In this design a bold departure is made from the simple rule of straight line engine movement, the superstructure is carried by two bogies, separated so far as to allow any size of firebox to come in between them (Fig. 9). The two pairs of cylinders were on the main frames; in each case the force of the piston was transmitted to a point on a lever, the fulcrum of which was shifted as the bogie swung to and fro by a tie rod attached to the bogie frame. From a lower point on this lever, the crank pin connecting rod received its motion.

The horizontal angularity of the eccentric rods appears to be rendered possible by the provision of swivel joints. The performance of the constructed engine is not recorded.

Ref.: Eg. 80, 440. **Date:** 1905. **Designer:** M. du Bosquet. **Maker:** Rly. Co., Nord, France. **Rly.:** Nord, France.

A most interesting example in the evolution of the "Meyer" type for the Nord, of France, is recorded in the above reference. It well deserves attentive study, as the details are very explicitly set forth. The design calls for no further comment, except to note that a large engine built on this principle has been found to give excellent service. Its total loaded weight is 102 tons and adhesive weight 86 tons (English).

FIG. 10. MALLET. DECAUVILLE RLY. PARIS EXHIBITION. 1889.

Ref.: Eg. 47, 482. **Date:** 1889. **Designer:** A. Mallet.
Maker: Decauville Co. **Rly.:** Decauville, Paris Exhibition.

Mons. Mallet suggested a special type of engine which is perhaps the most important example of the class which we are considering. The smokebox end bogie was used for tractive adhesion, and was articulated at a position in its rear, being coupled to a pin just forward of the firebox.

The weight of the smokebox end was carried on a curved slide across the bogie frames. When therefore the engine was deflected round a curve by its bogie, the centre of gravity of the superstructure was transferred outside the arc, and its forward support towards the outside of the bogie. As to the gears, the knuckle joint necessitated in the brake

gear was at the pivot; that in the reversing gear was carried on the main frame forward of the pivot.

The design admitted an admirable arrangement of steam distribution; the hind or firebox cylinders, having no motion relative to the boiler, took steam at high pressure. The exhaust steam passed through the necessary flexible joints to the low-pressure cylinders in the bogie, and thence continued its course to the smokebox blast pipe.

FIG. 11. MALLET. ATCHISON TOPEKA & ST. FÉ R. RD.
BALDWIN LOCO. CO.

Ref.: Er. 111, 495. **Date:** 1911. **Designer:** Mallet.
Maker: Baldwin. **Rly.:** A. T. & St. Fé.

One of the largest Mallet engines was made by the Baldwin Co. in 1911 for the Atchison Topeka & St. Fé (Fig. 11), and was at that time the heaviest locomotive in the world.

Ref.: Ry. G. 20, 638. **Date:** 1914. **Designer:** N.B. Loco. Co. **Maker:** N.B. Loco. Co. **Railway:** South African.

A very well-designed English example of the Mallet type was provided in 1914 for the South African railways by the North British Locomotive Co., and is admirably described in the above reference.

The developments of this class of engine have been remarkable. Their gauges vary from 1ft. 11 $\frac{3}{8}$ in. to 4ft. 8 $\frac{1}{2}$ in., the diameter of their adhesive wheels from 1ft. 11 $\frac{3}{8}$ in. to 4ft. 3in., and their weight from 11.3 tons to 380 tons fully loaded, as in the Atchison Topeka engine.

An extension of the Mallet principle was employed in a patent by Mr. Henderson, of the Baldwin Loco. Works, when he patented a main frame engine with a steam-driven bogie

FIG. 12. HENDERSON TRIPLEX. ERIE RAILROAD.
BALDWIN LOCO. WORKS.

Ref.: Ry. G. 20, 763. **Date:** 1914. **Designer:** Henderson.
Maker: Baldwin. **Rly.:** Erie.

both fore and aft (Fig. 12). The title given to the locomotive is "triple articulated compound"; the two H.P. and four L.P. cylinders are all of the same size, the H.P. being the main frame engine. The blast is obtained from the smokebox end bogie cylinders alone, the exhaust from the tender bogie cylinders being used for feed water heating.* At full power more coal is used than can be fired by hand, and a Street mechanical stoker is applied. The starting drawbar pull is 160,000lbs., and has not been equalled in any other design.

FIG. 13. HAGAN. PRUSSIAN STATES RLY.
HAGAN LOCO. WORKS.

Ref.: Eg. 58, 831. **Date:** Before 1894. **Designer:** Herr Hagan.
Maker: Hagan, Erfurt, Prussia. **Rly.:** Prussian States.

* It is interesting to note that the disposal of the exhaust steam is similar to that of Sturrock's Locomotive (Fig. 5).

In the Hagan design there is a trailing bogie, the wheels of which are driven and add to the traction, while the power is derived from the main engine cylinders (Fig. 13). In order to transfer the power, the reciprocating motion of the crosshead is reproduced by a copying device on the bogie. As the distance between the engine and bogie wheels on the two sides opens out and closes in respectively when the bogie is inclined to the engine axis on passing a curve, the bogie copying lever is moved bodily by a linked motion in such a degree as to make the necessary correction.

The engines are complementary to the Mallet in that whereas in the latter the smokebox end is carried by a power-driven bogie and the firebox end is fixed, the Hagan smokebox end is the fixed portion and the firebox end is carried by the bogie unit.

There have not been many repetitions of the Hagan design. Perhaps this fact admits of easier explanation than the principle of the mechanism.

FIG. 14. KITSON-MEYER. COLOMBIAN NATIONAL RLY.
KITSON & CO., LTD.

Ref. : K. & Co. **Date :** 1894. **Designer :** K. & Co.
Maker : K. & Co. **Rlys. :** Various.

In 1894 Mr. Robert Stirling, of the Anglo-Chilian Nitrate and Railway Co., having to deal with a line 17 miles long of 1 in 25 gradient, 75 per cent. of which was combined with curves 181ft. radius, suggested to Messrs. Kitson a design on the lines of that made by Meyer. The principals of the firm had already noted the type on the

Continental railways, and it has since been developed in many various designs.*

Two engines of the design shown by Fig. 14 for the Colombian National Rly. Co. were exhibited by Messrs. Kitson & Co., Ltd., to the members prior to the meeting, one of which was tried in steam, and another recorded on the weighing table the evenness of the distributed weights on the rails.

FIG. 15. TYPES OF BALL AND SOCKET JOINTS.

The general design of the ball and socket joints as used for the steam and exhaust pipes is illustrated by Fig. 15, and details of the articulations of the reversing and brake gears do not differ fundamentally from those of other types. The pivots on this and other engines are shown in Fig. 16. The Author has no records by which one is proved to be better than another. It would seem, then, that provided the surfaces are sufficient to bear the pressure, that there is access for lubricant and provision for its retention, the situa-

* It was subsequently found that an engine of this type had been made two years before by the Baldwin Co. It was compounded on the Vauclain system, but beyond general dimensions, no particulars were available.

Ref.: Rd. G. 24, 344. Date: 1892. Designer: Baldwin. Maker: Baldwin. Rly.: Sinnemahoming.

tion is met equally well by a ball in a bowl, a bulb in a basin, or a cup on a cone.

In the Kitson-Meyer superstructure the fuel and water supplies for the boiler are carried on a pair of girders, and this superstructure is supported on two steam-driven bogies. The firebox and ashpan may be of any size required. The

FIG. 16. TYPES OF BOGIE PIVOTS.

boiler is easily washed and examined and the ashes are easily cleared. While the weight of this portion is transmitted through a pivot to each bogie, it is checked from rolling by plates concentric with each centre, and from pitching by slides at the end of each bogie.

FIG. 17. KITSON-MEYER. ANTOFAGASTA RLY., CHILI.
KITSON & CO., LTD.

Ref.: Kitson & Co., Ltd. **Date:** 1908. **Designer:** General, Messrs. Livesey, Son & Henderson; *Details*, Kitson & Co., Ltd. **Makers:** Kitson & Co., Ltd. **Rly.:** Antofagasta, Chili.

A development of the above principle is to be found in the Antofagasta Engine illustrated above.

The smokebox end of the locomotive is carried on a steam-driven bogie, and the firebox end of the superstructure is pivoted and supported by the front end of the tender, which is itself steam-driven.

The engines are duplicate, that at the firebox end being assisted by a four-wheel bogie in carrying the tender.

Ref.: Eg. 71, 469. **Date:** 1901. **Designer:** Krauss, Munich. **Maker:** Krauss, Munich. **Rly.:** Bavarian.

The Krauss system is referred to because at first sight the appearance of a driving wheel in the middle of the bogie truck would seem to indicate the articulation quality. But these central wheels are quite independent of the truck. They are normally held clear of the track by spiral springs and are depressed on to the rails by steam cylinders when required as auxiliaries. Adequate safeguard being made (it is expressly stated) to prevent the auxiliary engine working while the wheels are suspended.

Ref.: Eg. 71, 605. **Date:** 1901. **Designer:** Krauss, Munich. **Maker:** Krauss, Munich. **Rly.:** Bavarian.

In the Krauss bogie the trailing wheels thereof were the first pair of the coupled wheels and were allowed a lateral play which was controlled by the movement of the first pair of bogie wheels. At the same time the bogie axles remained parallel to the other driving axles, and the device,

though of considerable general interest, does not bring the type into the class of articulated engines.

Ref.: Et. 97, 106. **Date:** Before 1897. **Designer:** Klien-Lindner. **Maker:** Klien-Lindner. **Rly.:** Saxony State.

In the Klien-Lindner designs also the end coupled axles maintain parallelism with the other coupled axles, but the end pairs of wheels adjust themselves on curves by a quill driven from the centre of the axle. (It would appear that a paper on the subject of relief on curves for parallel axles would be of great interest.)*

FIG. 18. SHAY. ST. LOUIS EXHIBITION. 1904.
LIMA LOCO. CO., U.S.A.

Ref.: Eg. 77, 876. **Date:** 1904. **Designer:** Shay. **Maker:** Lima Loco. Co., U.S. **Rly.:** St. Louis Exhibition.

The "Shay" locomotive is carried on three four-wheeled trucks, each right-hand wheel of which carries a toothed rim that engages with a pinion on a horizontal flexible shaft (Fig. 18). Power is given to this shaft by a system of vertical cylinders.

The shaft is in sections, each being connected by a universal joint and expansion coupling, so that while rigid in revolution, it is flexible in all other directions and able to adjust itself when the locomotive is passing round curves. The tractive power of each truck is clearly communicated to the superstructure through the weight-bearing pivots, and thence to the train. Such an engine is suitable for slow work with big loads on heavy grades and sharp curves in very special circumstances.

* The quill arrangement of axle was used by Mr. A. P. Heywood in locomotives constructed for the 15in. gauge railway at Duffield Bank, near Derby, as described by him in "Engineering," v. 32, p. 66, 15/7/1881.

FIG. 19. GARRATT. TASMANIAN GOVT. RLY.
MESSRS BEYER, PEACOCK & CO., LTD.

Ref.: Eg. 94, 355. **Date:** 1912. **Designers:** Beyer, Peacock & Co., Ltd. **Makers:** Beyer, Peacock & Co., Ltd. **Rly.:** Tasmanian Govt.

The Garratt engine is well-known and has been thoroughly described in an excellent brochure issued by Messrs. Beyer, Peacock & Co., Ltd., and in an admirable paper read by Mr. H. W. Dearberg before the Institution in London on 29th April, 1916. The boiler is carried by girders, the ends of which are supported on pivots in the two steam-driven bogies. The points of support at first sight appear to be remarkably near the end of these bogies, but the balance is corrected by the cylinders, fuel bunker and water tank. The boiler can be of any size required and yet its centre of gravity kept low. Owing to the absence of wheels and axles from the vicinity of the firebox, the boiler and firebox can be made as wide and deep as desired and unusual facilities for washouts provided. The whole engine is symmetrical and is worked equally well with smokebox or firebox to lead. When on a sharp curve the superstructure forms a chord of the arc and its centre of gravity will tend to keep the engine on the line. There are no overhanging ends while it passes over sharp curves, because the bogies form the extremities. The ashpans are large and can easily be cleared of ashes and admit the fullest supply of air required; the boiler and firebox are unobstructed by tanks. A recent example is shown by Fig. 19.

Ref.: P.I.C.E. CXCV., 157. **Date:** 1912. **Designer:** General, Messrs. Livesey, Son & Henderson; *Details*, Esslingen Co. **Maker:** Esslingen. **Rly.:** Transandine.

This reference is to the description of an articulated engine that combines the functions of an adhesion and of a rack engine by respective steam-driven bogies.

Here the smokebox end bogie carries the front end of the boiler by its central pivot. The back end of the firebox foundation ring slides and turns on a die and pin in the other bogie. The latter bogie is hinged to the back of the first-described bogie truck. The tank and bunker are attached to the firebox end. The traction is direct from bogie to bogie, and the relative movement of the component parts is reduced by the compactness of the locomotive. On the other hand, the heat of the firebox would seem too close to the valve gear of one bogie, and the boiler and ashpan are rendered comparatively inaccessible.

Ref.: K. & Co. **Date:** 1907. **Designer:** *General*, Messrs. Livesey, Son & Henderson; *Details*, Kitson & Co., Ltd.
Makers: Kitson & Co., Ltd. **Rly.:** Transandine.

The same traffic is handled by a Kitson-Meyer engine and the whole subject is ably discussed and explained in Papers by Mr. Henderson on the "Transandine Railway" and Mr. Lucy's "Notes on the Working of a Rack Railway"—both in the Proceedings of the Inst. of Civil Engineers, the former in Vol. CXCIV., p. 151, and the latter in Vol. CCII., p. 2.

FIG. 20. C. M. & ST. P. R. RD. GEN. ELEC. CO., SCHENECTADY, N.Y. 3,000 V.D.C. PASSENGER LOCO.

Ref.: G.E.R. 22, 1004. **Date:** 1919. **Designer:** Gen. Elec. Co., Schenectady, N.Y. **Maker:** Gen. Elec. Co., Schenectady, N.Y. **Rly.:** Chicago, Milwaukee and St. Paul.

A catalogue of articulated engines would not be complete without some record of the electric giant lately placed on the Chicago, Milwaukee and St. Paul Railway for passenger work (Fig. 20). The driving wheels are 3ft. 8in. diameter, guiding wheels 3ft., rigid wheel base 13ft. 11in.; total wheel base, 67ft. Length inside knuckles, 76ft.; weight on drivers, 204½ tons (English); total weight, 236½ tons. Its normal service is to haul 856 tons (English) trailing against a grade of 2 per cent. at 25 m.p.h., increasing in an emergency to 1,000 tons. Of the fourteen axles, twelve are driving. They are distributed between two eight-wheeled trucks flanked by two six-wheeled trucks, the extreme wheels being guiders. Its starting tractive effort is stated as 115,000lbs., and it is interesting to note this, as against the 160,000lbs. starting traction of the Erie triplex steam locomotive of Fig. 12.

The various dispositions of the

A —Axis of articulation of unit

a —Axis of articulation of truck or bogie

S —Primary support of superstructure

S₁—Secondary support of superstructure for rolling

S₂—Secondary support of superstructure for pitching

T —Internal point of traction

———— Coupled Wheels

require juxtaposition in order that they may present the interesting questions which arise in the study of these engines. The diagrams (Fig. 21) show the attitude of each engine better than letterpress description. There is a fundamental difference in one function, the transmission of tractive force. In the Hagan, Mallet and Esslingen the lines of pull are tangential to the curve and connect outside it. In the Seraing, Fairlie, Johnstone, Garratt and Kitson-Meyer the pull is direct from pivot to pivot of the bogies and lies as a chord within the curve.

An attempt to estimate the difference of the loss in passing round curves is beyond the scope of this Paper, but generally speaking it may be said that the line of force as delivered from the cylinders is deflected in its course. The greater the angle through which the displacement occurs the greater the loss of power, and the nearer the bogies lie together the less the angle. This is a notable merit in the Mallet and the Esslingen. A merit, however, that carries

its own disabilities, for instance, the firebox is difficult of access and near to the motion. In the Garratt a greater angularity of the mutual directions of the bogies is accepted in order to give a clear boiler in between. In the

FIG. 21. DIAGRAMS SHOWING:—

— SEMMERING INCLINE LOCOMOTIVE "SERRAING". 1854.—

— G.N.R. STEAM TENDER. 1863.—

FIG. 5.

— A.R. FAIRLIE'S LOCOMOTIVE. 1869.—

FIGS. 3 & 4.

— MEYER'S LOCOMOTIVE. 1862.—

FIG. 6.

— D.R. MALLET'S COMPOUND LOCOMOTIVE 1887.—

FIG. 10.

— ERIE RLY. HENDERSON'S COMPOUND TRIPLE LOCOMOTIVE. 1914. —

FIG. 12.

— A.C.N. & R. CO. KITSON-MEYER LOCOMOTIVE 1894. —

FIG. 14.

— SHAY'S LOCOMOTIVE PATENT 1903. —

FIG. 18.

— T.G.R. GARRATT LOCOMOTIVE. 1912. —

FIG. 19.

— C.T.R. ESSLINGEN LOCOMOTIVE. 1912. —

— STEPHENSON'S LOCOMOTIVE PATENT 1914. —

FIG. 8.

FIG. 21.

Kitson-Meyer a compromise is established, the firebox alone is the distance piece between the moving structures.

The matter does not end with the curve coefficient; there is the internal friction of the machine; there is also the effect upon the rails. With regard to the latter it will be found that in passing a curve the Mallet smokebox end moves outwards, takes up a greater lateral space, brings more weight on the outside wheels and rails and accentuates the effect of centrifugal force.

In quick-running down a sinuous grade, this action tends to drive the curve in front of it, and so to be deleterious to the track and subsequent service by sharpening the curves or spreading the gauge.

To sum up the systems, I am going, in all becoming modesty, to say that the mean is provided by the Kitson-Meyer; it gives a clear firebox, its centre of gravity on a sharp curve is within the arc resisting the tilt of centrifugal force, and its bogies twist easily round their centres in the generally accepted fashion. The quality of easy movement can be definitely modified by springs to counteract, where required, the lateral oscillation of the engines. The relationship of the bogies is a compromise between the extreme positions. The mean is a golden one for the purchaser, if not always for the producer.

Mr. Hartley Wicksteed of Leeds, famous as a machine designer, President of the Mechanical Engineers in 1903, once said to the Author that when you bring a mechanical contrivance to perfection, you will find that it is superseded. In incorporating every possible improvement you have rendered it so expensive that men set about finding other processes.

The engines that have been shown are expensive enough in all conscience, but they are not the last word in expansion—or expense. They are powerful and complicated it is true, but there is a margin for growth. Therefore do not fear that the class of work on outpost lines in difficult country will be taken up at once by the very convenient electrical locomotive until the steam type has developed yet further and until capital becomes cheaper. A locomotive driven by internal combustion engines which can disregard the quantity and quality of water is still far from realisation. There is ample field in steam locomotives for the most enterprising of inventors. Where coal is excessive in price or firing too onerous oil or powdered fuel will certainly be used, and the mechanical possibilities of the articulated steam engine are by no means exhausted.

The Author hopes, therefore, that a mere recital of dimensions and details has proved interesting, and if worthy of attention, would ask the audience to go a little further, to touch the subject with imagination, to make a picture for themselves of the terrain in which these engines have done and are doing service. They appear as super-machines on the prosaic slopes leading upward from Liege; they are there 10,500ft. up on the Andes, between Chili and Argentina; they are serving in the arid deserts which rise to the Nitrate grounds above Iquique, in the luxurious valleys that run up to little known Bogota, on the slopes of Snowdon, in Burmah, in Mexico, and on many great banks in Northern America. If we were with them looking up at the mountains or down into the valleys, passing over bridges high in the air, or burrowing into the earth, there, where articulated locomotives have been to-day, 12th October, 1920, we should feel that articulated engines were ministers of romance.

DISCUSSION.

Mr. H. N. Gresley: Mr. Chairman, Gentlemen,—Of course the Chairman cannot call upon anybody to propose a vote of thanks to himself, but I can at any rate be permitted, I think, to reply to the vote of thanks which he proposed should be accorded to me. I appreciate it very much, and during the two years I was Chairman of the Leeds Centre I derived great benefit from the discussions which took place here. I am confident that still greater results will accrue to the Institution under the able leadership of the new Chairman. I think the Leeds Centre of the Institution of Locomotive Engineers is to be congratulated upon its Chairman, and I should like to take this opportunity of congratulating him and thanking him for the most interesting, excellent and instructive address to which we have just listened.

The question of articulated locomotives for English engineers employed on railways is of great interest but not of much practical value so far as England is concerned because, except for Snowdon and one or two small railways, they do not exist and there is no necessity for them. The English railways are so straight, and having the broad gauge, engines can be built with sufficient tractive power to accommodate the trains for which the sidings are long enough, and until the sidings in England are lengthened considerably, the ordinary simple type of engine will be sufficient.

I think, however, it is very interesting to railway engineers to see the enormous difficulties which have confronted the designers of these articulated engines and the successful way in which they have been overcome.

Many of us this afternoon had the opportunity of inspecting one of these engines, and speaking for myself, I was extremely interested. I have never had the opportunity of examining one before, and congratulate Messrs. Kitson upon the fine workmanship which we saw upon that engine.

The Chairman said that it is not usual to criticise, but gave us permission to do so on this occasion. I do not propose to criticise, but he raised the question relating to steam tenders, and he wished to know if there was any record at Doncaster to explain the running of the steam pipe from the dome to the tender engine. I have looked up several drawings that we have, but I have not seen that there was any special device, but it apparently depended upon the flexibility of the long copper pipe.

I think it was said that the engines were taken off because the men objected to the long trains. That may have had something to do with it. I came across some very interesting records made by Mr. Stirling over a number of years showing the coal consumption of these engines for six months, some of the ordinary engines and some of the engines with steam tenders, and in those days they did work out the coal consumption and the train loads of each train in ton miles, and the consumption of coal per ton mile was very much higher in the steam tender type. That is the reason why they were dropped.

Might I point out one omission in your most comprehensive Paper which I happened to notice, and which I think constitutes an articulated engine. That is the American Booster. They have on a Mikado engine a little engine on the trailing truck, the centre line of the axle of which certainly does not remain parallel with the other axles on going round curves.

There is only one point upon which I want to speak further, and that is with regard to the transmission of tractive force. Your Chairman has very rightly drawn attention to the question as to where the force should be transmitted, and rather, I thought, indicated that the Garratt engine, where the centres are so far apart, would not be quite so satisfactory as an engine where the centres were comparatively close together. I do not quite follow his argument about that, because it seems to me very like a question of having two locomotives. I am not aware that

when going round curves the fact of these two locomotives being a certain distance apart in any way reduces the tractive power or increases the friction. You might take an extreme case; I say that two locomotives in front of the train have no more friction than if you had one locomotive in front of the train and one at the rear pushing it. What I do think would be a very bad practice would be, instead of the power being transmitted through the centre, if it were transmitted through a coupling on what I would call the buffer beam on the end plate of the bogie. It is obvious that then in going round curves the front engine would be pulling the other one, and therefore would be tending to straighten the bogies and therefore cause a great deal of extra flange friction. So long as the pull is through the centre I would submit that it does not cause extreme friction whether the centres are close together or wide apart.

I would take this opportunity of proposing a vote of thanks to our Chairman for the most interesting and instructive Paper he has given us.

Mr. C. N. Goodall (Darlington): Mr. Chairman and Gentlemen,—I have been asked to perform a very pleasant duty, and that is to second the vote of thanks to our Chairman. I feel sure that everybody here will agree with me when I say that it has been one of the most interesting Papers we have had, and I venture to predict that it will remain one of the most successful among an interesting series still to come.

There is so much to be said on articulated locomotives that I rather hesitate to start on the subject.

Generally speaking, in this country we have comparatively little practical experience of the working of articulated locomotives. The makers of them can be counted on the fingers of one hand, and even with them the examples turned out are few and far between compared with what is done in the United States. The number of articulated engines actually working in this country is practically negligible. We have little information at first hand as to the troubles from which they are usually said to suffer when in service, and are somewhat at a disadvantage in consequence. I should like therefore to suggest to the Secretary that members abroad—who have this kind of engine under their charge—should be asked to contribute by correspondence to this discussion; I feel sure the result would be very helpful. From published accounts and reports that come to hand from time to time, we do hear something as to the difficulties

which arise in working these engines, but always, or nearly always, at second hand. With this qualification, then, we can enumerate generally the difficulties the designer is likely to meet when he sets out to plan an articulated locomotive.

Firstly, they are said to be uncertain with regard to the steam tightness of their articulated joints, and secondly, to cost a great deal in upkeep and repairs, but as they are seldom called upon to run at high speeds, both these ought to be curable.

In certain cases, as in the Mallet design, which commonly has a tender, special turntables are required and special accommodation in the running shed. Further than this, it goes without saying that their details will seldom interchange with those of ordinary engines. These seem to be some of the difficulties which have to be met.

Practically there are only two competitors at present in the field—the internal combustion engine and the electric locomotive, but as the Author has hinted, it is doubtful whether either of these has any advantages over the articulated steam engine when all the circumstances are taken into consideration.

I am entirely in agreement with him when he suggests that the steam engine has yet a considerable future before it. All modern locomotives are extremely complicated and expensive compared with those commonly in use 30 or 40 years ago, but the same can be said of machine tools and almost any class of modern machinery. Yet nobody can doubt that, complicated as they are, they are immensely more efficient when judged from the cold commercial standpoint of earning capacity. If you can double the carrying capacity of any given section of a railway, the amount spent on a certain number of locomotives for this purpose is not much compared with the alternative of duplicating the permanent way, and even if you only increase the capacity by a smaller amount, the expense may well be worth while. The first aim then seems to be to diminish as far as possible the troubles which are commonly attributed to articulated engines; after that there remain superheated steam, feed-water heating, and liquid or pulverised fuel all clearly in sight as possible efficiency factors.

It seems to me that with these points in view, if the designer and builder collaborate with the user, the articulated steam locomotive will give both the internal combustion and electric engine a very interesting time in the future. But one must remember that one of these is a very efficient heat engine and that both are in many respects well adapted to

the conditions which brought the articulated engine into being.

The Author has mentioned one interesting point which I should like to see further elaborated. That is the resistance due to a long chord between the power units of an articulated engine on a sharp curve. On easy curves this is a matter perhaps which has little significance, but there are cases when it might well be a serious factor. Two cases have come within the recent experience of my own firm. The first was a request for an engine of about 31,000lbs. tractive force, and a maximum axle load of $12\frac{1}{2}$ tons; this implied an adhesive weight of something like 62 tons, and consequently the equivalent of five coupled axles. Yet this engine was required to pass round a 150ft. curve on the 4ft. 8 $\frac{1}{2}$ in. gauge. Another case was one for a 2ft. gauge, tractive power required being 13,700lbs., and an axle load limit of 8 tons. Allowing 30 tons for adhesion, at least four coupled axles or their equivalent would be necessary. In this case the minimum curvature was 60ft. Of course, with curves like this it is obvious that the further you put the power units apart, the more you are losing in draw-bar pull, owing to transmission of power from one unit to the other through a long chord. It was this that led us to look into the question of concentrating the power by shortening the total wheel base and using in the adhesive group single flexible axles on the Klien-Lindner principle, which the Author has illustrated. This, as you know, is a German device, but it is interesting to note that, like a good many such, it had its origin in England. In Mallet's Paper "Locomotives a Adherence Totale" he makes the following statement:—

"This ingenious arrangement appears to have been first adopted about 1880 by a Mr. Percival Heywood for a small locomotive with six coupled wheels weighing $2\frac{1}{2}$ tons in working order and running on an experimental railway of 15in. gauge at Duffield Park."

Since then it seems to have been neglected by us—like superheat, pulverised fuel, and a great many other devices originally started in this country—and to have been taken up and developed by foreigners. Recently in Germany and Austria this axle has been used in quite large units for heavy main line work. I believe the Germans used a large number of narrow gauge engines on this principle on the Western front during the war. Some of these, I believe, were captured by the British and used in our lines. It is said that they were particularly successful, and it would be most interesting if any member could give us further information on

this point. At the same time I should like to know if any information can be given as to the loss of power on sharp curves due to the motor units being placed some distance apart in articulated engines.

With regard to the "Duplex" engine designed by myself and shown by the Chairman in one of his slides, I only have to say this. Expensive engines of a special kind are sometimes built for purposes more or less experimental. The conditions may be of a temporary nature lasting only a few years, as a test for final electrification, for example. It is always possible, too, that the special engine may fail to fulfil the requirements, in which case it cannot be used in normal traffic and generally goes to the scrap heap. In such cases the use of two engines of existing normal types seems to offer advantage if brought under proper control as one machine. That is briefly what this "Duplex" engine is. There are no articulated steam pipes; the parts, and sometimes practically the whole of one unit, will interchange with the owning company's standards. No turntables are required, and no special running shed accommodation. If the services of such an engine are required only for a few years, at the end of that time the greater part of two useful units are still available for ordinary traffic.

The design has been worked out in a great deal of detail to ensure absolute control from one set of handles to make the units easily detachable and to facilitate repairs, so that the engine may be kept regularly in service with the facilities usually available in dealing with the ordinary types of locomotive. These are the chief points aimed at in the design—the way they have been met constitutes the difference between this and other "double" engine designs which have appeared previously, nearly all of which appear to have been sufficiently incomplete to prejudice their chances of success.

And now, Mr. Chairman and gentlemen, it only remains for me to second the vote of thanks proposed by Mr. Gresley, which I do with the greatest pleasure; at the same time I should like to add my congratulations to the Leeds Centre on the prospects before them in the coming Session.

The Chairman: I thank you very much for the vote of thanks. I consider it a great honour that gentlemen like those whom I see before me in the company have been present on the occasion of the reading of this Paper. I humbly think that as it is really a catalogue it will prove of more interest when you come to see it actually in print, because it was necessary to close the statements about the different

kinds of engines into so compact a form as to make them sometimes intelligible.

I wish to conclude the subject by a reference to the admirable paper by Mr. Anatole Mallet which was presented at the Annual Meeting of the American Society of Mechanical Engineers in December, 1915, which appears in the "Railway Engineer," Vol. 37, April, 1916, pages 90/93. This scholarly piece of work came into my hands after the above researches and analysis had been made.

Mr. Alex. Campbell (the Hunslet Engine Co.) and **Mr. A. C. Stamer** (N.E. Rly.) expressed their interest in the paper in a few words.

COMMUNICATION.

Mr. S. J. Lucas : References have been made to the loss of traction, between straight and curved lines, due to the articulations of the locomotives described.

No tests or experiments appear to record this, nor does it appear possible to obtain an exact comparison from Mathematics, in consequence of the number and complexity of the factors involved in producing it.

The following considerations and approximate calculations are therefore submitted for a few of the principal types.

Loss of traction on curves beyond that on straight lines, is caused by friction created from side pressures between the tyres and rails; for this friction the tractive force transmitted from unit to unit is mainly responsible, because it produces the lateral forces met by the rails, whose reaction prevents the units from being pulled into or pushed out of alignment.

Relative movement at the articulations, due to angular displacement of the units, and oscillations arising from the unbalanced reciprocating parts of the engines, also produce lateral forces. But in consequence of their variability and small extent, one due to the change of curvature on transition curves, and the other to inertia and change of speed, they are omitted from further consideration.

The reactions, *i.e.*, the lateral pressures develop wear of flanges and rails, at a rate depending on their intensity, on the hardness of their material and the speed of movement; and a tendency to derailment, proportionate to the maximum flange pressure in relation to the weight carried by its wheel, on the rail.

The sum of the lateral pressures between the tyres and

rails and their coefficient of friction, measures the loss of traction.

In the inception of the Fairlie, Kitson-Meyer and Mallet types, it was considered desirable in each case, to produce a total adhesion locomotive; and the first locomotives of these types had coupled wheels only in each unit.

To simplify analysis, it is assumed that each unit has coupled wheels only, that the end pairs resist the lateral forces, and that two flanges only are simultaneously in contact with one or both rails. That the tractive force, length of wheel base and position of the pivot in relation to the wheel base are the same in both units of each type. Also, that the friction between the wheel bosses and axleboxes, due to the side pressures, may be neglected.

With these premises and the following symbols, approximate values may be deduced for the relative wear of flanges, tendency to derailment, and loss of traction for some of the types illustrated.

T = the total tractive force of the locomotive on a straight line.

t = the tractive force of one unit = $\frac{1}{2}T$, since both are of equal power.

C = the distance from centre to centre of the pivots.

r = the distance from centre of pivot to centre of coupled wheel base.

w = the length of the coupled wheel base of each unit.

W = the distance between the centres of the wheel bases when on a straight line.

μ = the coefficient of friction between the tyres and rails.

R = the radius of the curve.

2α = the central angle formed by the chord W , and radius R .

The factors to be in corresponding units, for each denomination.

The geometry involved by the above is illustrated in the following diagram, from which it will be seen, that on straight lines, $C + 2r = W$; and that $r = 0$ when $W = C$; and when $C = 0$ then $W = 2r$; also, that r and C may have any value between these limits.

Further, that on curved lines the following equality occurs:—

$$C + 2r \cos \alpha = 2R \sin \alpha \quad (1)$$

This may be written as $\sin \alpha = \frac{C + 2r \cos \alpha}{2R}$ and

within the limits of general practice, *i.e.*, when the central

angle 2α does not exceed 6° , the sine and tangent of α may be approximately taken as equal to each other, and the cosine as equal to unity. The angle may therefore be approximately obtained from

$$\tan \alpha = \frac{C + 2r}{2R} = \frac{W}{2R} \quad (2)$$

The tractive force t , produces at the centre of the pivot a lateral force f , acting in a direction at right angles to the longitudinal centre of the coupled wheel base, inwardly when pulling and outwardly when pushing. For these conditions f equals $t \tan \alpha$, and from (2) its value is approximately expressed by

$$f = \frac{tW}{2R} \quad (3)$$

This normal force f , is resisted in each unit by the lateral pressures P and p it produces between the tyres and

FIG 22.

rails, and these are indicated in the diagram. When the pivot is placed out of the centre of the coupled wheel base, P represents the pressure on the flanges nearest the pivots, and p that on the flanges furthest from the pivots.

The pressure P acts in the same direction as the force f , and both are considered to be positive, whether acting in an inward or outward direction. Since P is nearest to the pivot, its amount is greater than that of p and it is therefore a max. pressure.

As previously stated, the amount of P determines the max. relative wear of the flanges, and in relation to the weight carried on the rail by its corresponding wheel, is proportionate to the tendency to derailment. Its value, given by (3) and the leverages of r and w , is represented by

$$P = f \left(\frac{1}{2} + \frac{r}{w} \right) . \quad . \quad . \quad (4)$$

The pressure p acting on the flanges furthest from the pivots, is the min. one on the rails, and is positive or negative according to the value of the proportion r/w . Its amount, also obtained from (3) and the distances r and w , is given by

$$p = f \left(\frac{1}{2} - \frac{r}{w} \right) . \quad . \quad . \quad (5)$$

The arithmetic sum of P and p , determines the total pressures producing friction, and for the complete locomotive equals

$$S = 2 (P + p) \quad . \quad . \quad . \quad (6)$$

Therefore the force to overcome the friction of the complete locomotive is measured by

$$F = 2 (P + p) \mu \quad . \quad . \quad . \quad (7)$$

and this also determines the loss of traction.

The algebraic sum of (4) and (5) expressed by $\{ P + (\pm p) \}$ is equal to the normal force f , and this is a necessary condition for the equilibrium of these forces.

From (4) and (5) it is evident, that when the pivot is placed at the centre of the unit wheel base, *i.e.*, when $r = 0$, the pressures P and p are equal and both are positive.

When the pivot is placed out of the centre and within the wheel base, *i.e.*, when $r/w < \frac{1}{2}$, the pressures P and p are unequal but positive.

Again, when the pivot is placed outside the wheel base, so that $r/w > \frac{1}{2}$, the pressures are unequal and p becomes negative, *i.e.*, it acts in a direction opposite to that of the pressure P , and an effort is then produced to twist the wheel base across and spread the track.

These general results may be applied to special cases as follows:—

The Fairlie and Kitson-Meyer types are articulated by a pivot placed approximately at the centre of the wheel base in each unit, i.e., $r = 0$; and for this condition $r/w = 0$, and $W = C + 2r = C$.

These values inserted in the general equations, (4), (5) and (7), give

$$P = p = \frac{1}{2}f, \text{ and } F = 2f\mu = \frac{TW}{2R}\mu$$

The forces P and p are therefore equal and act in the same direction as f .

The traction of one unit is transmitted directly to the other, from centre to centre of the wheel bases, by a force acting through the superstructure from pivot to pivot, because the pivots are placed at these centres.

Further, nearly all the weight of the superstructure is carried through the pivots; so that the bolster slides, which are placed as near as possible to the pivots, carry only a small amount of weight, and thereby minimise friction on transition curves. The articulation is consequently similar to that of double bogie carriages which run at the highest speeds of express services with safety.

As a result of this method of articulation, the bogies adjust their positions normally to the curves, with little or no tendency to twist across the track or spread the gauge.

Locomotives of the Kitson-Meyer type have run satisfactorily and safely at speeds up to 50 m.p.h. Further, numbers have been in service many years, working on curves of very small radius, and are constantly repeated. From the conditions of their service, the friction they produce on curves of constant radius, given above by F (where $R = 10W$ and $\mu = 1/5$), is approximately represented by $T \ 1/100$. Consequently their loss of traction for these curves and conditions, i.e., due to articulation alone, is only about 1 per cent. of their total traction on straight lines. With this percentage the absolute loss of traction is a very small amount, even when T has its max. value.

The remaining part of the friction on curves, which arises from the slipping of the wheel treads on the rails in consequence of the outer wheels travelling a greater distance than the inner ones, is common to all locomotives.

The Garratt type is articulated by a pivot placed some distance r from the centre of the wheel base, in each unit; but it is not essential that it should be the same in each bogie.

In some cases, this distance has been of the approximate value, $r = \frac{1}{2}w$, so that $r/w = \frac{1}{2}$, and $W = C + 2r = C + w$.

These values give from the general equations (4), (5) and (7)

$$P = f, \quad p = 0, \quad \text{and} \quad F = 2f\mu.$$

With this proportion of r/w , the flanges of the wheels at the pivot centres resist all the normal force f , and the other flanges none.

The max. flange pressure P is twice as great as in the preceding types, with a corresponding increase in the relative flange wear; and for the same weight on the rail, with a proportionate increase in the tendency to derailment.

The friction F has the same value as the previous types.

The traction of one unit is transmitted indirectly to the other, in consequence of the pivots being placed out of the centres of their wheel bases, therefore the pressures P and p are unequal, and with the proportions taken the min. pressure $p = 0$, as shown above.

This type may be compared with the cases of twin engines or two normal tank engines coupled together; the distance C between the pivots being represented by the length of the links coupling the draw hooks, when these have no lateral movement.

The Mallet type has the two units directly articulated together, one of which retains the alignment of the superstructure; consequently, the angular displacement of its bogie from the superstructure is twice as great as in the previous types.

In some examples of this type, the distance between the centres of the pivot and wheel base is approximately the same as the length of the wheel base; so that $r = w$ and $r/w = 1$, $C = 0$, and $W = C + 2r = 2w$.

The general equations (4), (5) and (7) give with these proportions

$$P = f\left(\frac{1}{2} + 1\right) = 1\frac{1}{2}f, \quad p = f\left(\frac{1}{2} - 1\right) = -\frac{1}{2}f, \quad \text{and} \quad F = 4f\mu.$$

Other things being equal, the max. flange pressure is three times as great as in the Fairlie and Kitson-Meyer types, and one and a half times as great as in the Garratt; with a relative flange wear and tendency to derailment increased in the same proportion. The min. flange pressure p is negative, so that the direction of the force producing it is in the opposite direction to that of the max force P .

The value of F is twice as great as in the previous types, with a corresponding increase in the loss of traction.

It might be repeated that in this case, as in others, where the articulation is outside the wheel base, the lateral

pressures act on opposite rails and a positive effort is created to spread the track, which increases with the traction and the central angle.

The position of the axis of articulation is an important one, because if it be incorrectly placed, there arises a further increase in the effort, referred to in the preceding paragraph, to spread the track and to the tendency of derailment on sharp curves.

It is possible then for the max. pressures P to become so great (by large tractive forces transmitted through an articulation placed at a long and possibly incorrect distance out of the wheel base) that derailment might more readily occur at the wheels nearest the pivots than at the leading or guiding wheels. Further, the articulation pin carries none of the weight of the superstructure, and the bogie unit carries its part of the weight on supporting slides placed at some distance from the joint pin, which thereby further increases P in this unit when traversing transition curves.

In the determination of the axis of articulation it is usual to allow for both directions of running, by arranging the centres of the end coupled axles in both units to be coincident with the centre of the track when on a curve. The longitudinal centre lines of the wheel bases must then pass simultaneously through these points and the point of articulation.

Assuming that the wheel bases are unequal and that N represents the length of the short wheel base, M that of the long one and S the distance between them; it follows from the above that the correct articulation point for all curves, is found in S by the proportion n/m , which is given by the following graphic solution:—

FIG. 23.

The axis of articulation is represented by xx , and $S = n + m$, also n and m are adjacent to N and M respectively, as shown.

The vertical distances $N + S$ and $M + S$ are drawn on the centre lines of the axles joined by S ; they may be drawn to any scale, but both must be to the same scale.

From this it will be seen that when $N = M$, then $n = m$, i.e., the axis is central between the wheel bases; also, when they are unequal in length, that its position moves towards the longer wheel base.

The preceding construction for placing the axis of articulation refers to non-reverse curves only.

The faults arising from an incorrect position of the articulation, may be alleviated by an increase in the normal freedom of movement between the following parts:—Tyre flanges and rails, axleboxes, journals and hornblocks, the articulated joint itself, or in a combination of these. But they can only be considered as palliatives, and not as the true remedy, which is to be found in its correct position.

If at any time reverse curves should meet one another, as may occur in crossovers, then it might be necessary to increase the freedom of movement mentioned in the preceding paragraph, so that the wheel bases may not bind or spread the gauge in passing over.

This perhaps may be realised by the following figure which indicates in a somewhat exaggerated scale for clearness of definition, that if the articulation pin be omitted the joint holes would slide relatively to each other in traversing reverse curves, and that their maximum separation, denoted

xx = REVERSE CURVE.

yy = STRAIGHT LINE

xz = NON-REVERSE CURVE.

FIG. 24.

by A, would occur at the point of contra-curvature. Further, that over straight lines or non-reverse curves with the axes of articulation correctly placed, they would not separate.

When the pin is in position the joints are unable to separate, therefore on reverse curves of small radii the wheel bases would bind or spread the gauge, unless special and possibly undesirable clearances were introduced.

The *Hagan* and *Esslingen* designs come in the category of the Mallet type, as regards the articulated control of their wheel bases, the former being designed to eliminate articulations in the steam pipes of the articulated unit; and the latter to reduce the angular displacement of the articulated pipes which occurs in the normal Mallet engines. The remarks regarding the position of the axis of articulation apply to these types.

The *Johnstone* design may be regarded as of the Kitson-Meyer type with reference to the articulated control of its unit wheel bases; and the *Henderson* of the Mallet type for the same functions.

As far as articulation is concerned, the greatest friction occurs on transition curves; because to the friction F , (7), of the curves of constant radius, must be added that arising from the relative movement at all the articulations and bolster slides, which is produced by the varying curvature.

On straight lines and curves of constant radius, there is no relative movement at the articulations, and consequently no friction at these joints due to angular displacement of the units.

It appears then, that as regards traction on curves, an articulated locomotive requires greater tractive force for traversing a transition curve than it does for a curve of constant radius, to which it is continuous.

These considerations indicate the difficulty of obtaining absolute results from all the varying causes of loss of traction on curves.

The general equations, however, give for the cause considered (para. 4) approximately correct values regarding relative flange wear, tendency to derailment and loss of traction, for the types considered.

The conclusions deduced from these investigations show that :—

1. The loss of traction on curves, due to the articulations alone, is comparatively small; smallest in the Fairlie and Kitson-Meyer types, greatest in the Mallet, and of an intermediate value for the Garratt.

2. In all types, the internal points of traction should be as near as possible to the centres of the coupled wheel bases.

3. Movement at the articulations is minimised when W , the distance between the centres of the wheel bases, is as small as possible, and when both units are flexibly connected to the superstructure.

4. The bolster slides for the superstructure should, when possible, carry only a small part of its weight, and that in proximity to the axis of articulation.

5. When W or the proportion r/w is reduced, the loss of traction is reduced. To obtain a small value for r/w , it may be essential to increase the length of the unit wheel bases by the addition of running wheels, with side play laterally controlled, and this notwithstanding they are only weight-carrying wheels.

6. Twin engines or two normal tank engines coupled together, are in a position between the Garratt and Mallet types, as regards tractive efficiency on curves. Their loss of traction would therefore be greater than that of a Garratt doing the same work; and greater financially because of their higher first cost, and that two crews would be needed in place of one. Further, the irregularities of traction produced by dual control, are automatically eliminated in articulated locomotives.

7. The Mallet produces the greatest relative flange wear for equal traction, the greatest tendency to derailment for equal weights on the rails, and the greatest effort to spread the track. These deductions regarding comparative flange wear and derailment, appear to be confirmed by reports of their services. Many locomotives of this type have been made of enormous dimensions in the United States of America, as illustrated in the Paper.

8. The articulations of the Fairlie and Kitson-Meyer types produce no effort to spread the track, give great ease and flexibility for traversing curves at the highest speeds, with a minimum value for wear of flanges, tendency to derailment and loss of traction.

The Author of the Paper writes: I wish to thank Mr. Gresley for mention of the Booster. This mechanism—described in Bulletin, International Railway Association, September, 1920, Vol. II., No. 9, p. 600—converts, as he says, the engine into an articulated locomotive, and therefore differs from the Krauss bogie referred to in the Paper. It would be appreciated if a further description of the device could be pointed out, as the above article practically confines itself to the method of admitting steam to the cylinder and does not deal with the motion arrangement.

With regard to the horizontal inclination of one bogie to another, Mr. Gresley makes a shrewd comparison by

reference to two engines on one train, but as Mr. Goodall touches on the principle, I will not venture further comment, except to say that the communication by Mr. Lucas introduces the mathematical consideration of this difficult subject.

Mr. Goodall, in explaining the idea underlying his patent engine, introduces a new point in general policy that is far-sighted and most valuable, and I must not leave the subject of articulated engines without referring to a letter—"Engineer," 27th June, 1902, page 634—by Mr. Robert Stirling, who did some very good work in the design of articulated engines.

In concluding the expression of my gratitude to all the gentlemen who have been good enough to consider the Paper, I would refer with special pleasure to the calculations and thoughts that Mr. Lucas has embodied in his exhaustive and thoughtful communication. It will be felt by students of the whole subject that he has introduced a true scientific spirit of the most important character.

Mr. F. Burtt: In 1905 the Northern Railway of France introduced a very powerful 0-6-2-2-6-0 type of tank engine to replace the 4-6-0 type of goods engine for working in the colliery districts of Northern France (Fig. 25). 48 of these engines were built between 1905 and 1911, and numbered 6,121 to 6,168.

They are probably the only examples in regular work in France, and have come quite up to expectations.

The section of line between Valenciennes and Hirson, and also between Busigny and Hirson, having opposing gradients as severe as 12 m/m. per metre, it was necessary for coal trains of 950 tonnes working on the Nord railway on to the Chemin de Fer du l'Est to be cut in two at Valenciennes or Busigny to continue their journey towards Hirson. To avoid this breaking up of trains, the Nord built an articulated double bogie compound tank engine, No. 6121 (Fig. 25), capable of hauling on the 12 m/m. grades (1 in 83.33) the same load hauled by the six-coupled engines on the 6 m/m. grades (1 in 166.6).

On the easier parts of the run from Lens to Valenciennes or Busigny on grades of 3 m/m., the new power of the engines was utilised to increase the train speed, the runs being made at from 50 to 60 km. per hour (31.06 to 37.28 m.p.h.), while on the Valenciennes or Busigny to Hirson runs, the speed on the 12 m/m. (1 in 83.33) grades was reduced to 18 or 20 km. per hour (11.18 or 12.42 m.p.h.).

As an example of the results obtained from two different trains, the following particulars will demonstrate their capabilities :—

1. VALENCIENNES TO HIRSON, 75km. (46.60m.).

Time required for run, 3hrs. 48mins. = including 45 minutes in intermediate stops.

Load hauled	969.5 tonnes (953.98 tons).
Speed on 12 m/m. grade (1 in 83.33)	18 to 20km. per hour (11.18 to 12.42 m.p.h.).
Speed on 10 m/m. grade (1 in 100)	20 to 25 km. per hour (12.42 to 15.53 m.p.h.).
Speed maximum	50km. per hr. (31.06 m.p.h.).
Maximum drawbar horse-power	943 chevaux (929.79 h.p.).
Fuel consumed per km. ...	34.66kg. = 76.45lbs.
Water consumed per km. ...	294.5 litres = 64.5 gals.

2. LENS TO LA PLAINE ST. DENIS, 228km. (141.67m.).

Time required for run, 9hrs. 13mins., including 1hr. 38mins. of stops.

Load hauled	1,450 tonnes (1426.8 tons).
Speed up 5 m/m. grades ...	28km. per hr. (17.39 m.p.h.).
Speed on level	40 to 50 km. per hour (24.85 to 31.06 m.p.h.).
Drawbar horse-power ...	About 1,000 h.p. (maximum 1,090).
Fuel consumed per km. ...	27.9kg. = 61.4lbs.
Water consumed per km. ...	227 litres = 49.8 gals.

Mr. P. C. Dewhurst (Jamaica): If it is permissible to make any comment on a Presidential Address, the writer, as one having locomotives operating over rather severe curves on main lines, would like to offer the following remarks on Col. Kitson Clark's most interesting address.

Clearly the fundamental point is that owing to the inherent higher first cost and higher cost of upkeep of all types of articulated locomotives compared with normal types, they should only be used where it is unavoidable.

The writer in his own practice has specially developed a normal type of locomotive of 33,000lbs. rated tractive force with a maximum axle load of $13\frac{1}{2}$ tons necessitating four axles coupled, capable of successfully negotiating $3\frac{1}{2}$ chain curves at 18 miles per hour, and it can be definitely said that large eight-coupled engines can be designed to satisfactorily negotiate main line curves as severe as 240ft. radius, and large six-coupled engines to suit curves of 210ft. radius. Such results, together with reasonable wear and maintenance expenses, are obtainable by incorporating special designs of bogie control, arrangement of wheel-base, absence of flanges on certain wheels, special allowance of lateral play

FIG. 25.

on other wheels, and provision for lateral movement on coupling rods, etc.

It is true that such engines have not the advantage of the centre of gravity coming within the arc of the curve as is the case with the Kitson-Meyer and Garratt types, nor can the boiler be kept very low (the writer's experience is that with properly elevated outer rails on curves, locomotives with a high centre of gravity suffer less flange wear than those with a low centre of gravity), but against this must be set the considerably less total wheel-base of a special design of normal locomotive. In fact, an articulated locomotive might be of such a length of wheel-base as actually to suffer greater loss of power due to the considerable angularity of its bogies than the other from its bogies and closely following semi-rigid wheel-base.

Further, the articulated locomotive as usually built does its curving work with driving or coupled wheels over a wheel-base of three axles or more, whilst the advantage of doing all curving by means of two unencumbered axles in a bogie, which may very easily be removed for flange turning and replaced without dismantling rods and other driving gear, is very evident—the normal locomotive can be so designed that the flanges of the leading or even second wheels of their rigid wheel-base do not normally come into action on curves whilst running forward.

It is premised, of course, that most of the work of the engine is done running forwards; in the case of a service requiring an equal amount of forward and backward running the articulated locomotive is undoubtedly necessary as the placing of a bogie at each end of a normal type engine would leave insufficient adhesion weight for the driving and coupled wheels of a locomotive of reasonable tractive power. In the special design of normal type locomotive previously mentioned, provision for negotiating the same severe curves referred to when running backwards is made by a modification to the rear axle of the rigid wheel-base, which allows the curves to be traversed satisfactorily at 14 miles per hour.

Regarding a point of detail concerning the Kitson-Meyer type, the writer would mention that it is unnecessary to run the exhaust pipes from the cylinders to the blast pipe via the neighbourhood of the bogie centre; it is preferable to run as direct as possible. It is also unnecessary to have packed "expansion" or "sliding" joints on the exhaust piping, a sufficient length of piping in the form of a sleeve and fitted with three rings (of the ordinary piston ring type), a few inches apart being preferable, and giving excellent results in conjunction with the direct run piping.