

RECENT LOCOMOTIVE PRACTICE IN FRANCE.

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(Translated from the French.)

Recent locomotives on the French railways are chiefly remarkable for their high power, rapid increase in the power of locomotives being not, however, peculiar to France.

Four-cylinder compound locomotives are frequently used: there are to-day in France more than 800 locomotives of this kind in service or under construction. The four cylinders drive either two, three, or four axles. With two driving axles the machines have large wheels, and are intended specially for working express trains, but they may also be employed advantageously for the heaviest passenger trains and even in certain cases for goods trains. The locomotives with three axles have also large wheels. They draw easily long goods trains or heavy passenger trains; they have been employed to work express trains, but exceptionally rather than regularly. This type of engine renders very great service, since it is suitable for almost all trains; it allows considerable increase in speed for goods trains, which becomes more and more necessary on the network of the principal French lines.

For heavy and slow trains, principally on steep inclines, four driving axles are used; but this type of machine is generally less in favour than the preceding: almost all engines with four driving axles have already become a little antiquated.

It is important to observe that much importance is attached to the preservation of the coupling of these axles together, instead of

driving separately one axle or a group of axles by each pair of cylinders.*

The advance in the power of engines has brought about an increased weight upon each pair of wheels. A load of about 17 tons per axle is generally allowed to-day in France, although a few years since 15 tons were seldom exceeded.

Amongst the details of construction one should notice first of all the dimensions of the fire-grates and of boilers. To obtain a sufficiently large diameter, especially with large wheels, the axis of the boiler has been raised much more than was done formerly; generally a height of 2.50 metres (8 feet $2\frac{7}{16}$ inches) above the rail-level is to-day the normal height, although formerly this dimension was nearer 2.15 metres (7 feet $0\frac{1}{8}$ inch). This necessitates the short chimneys characteristic of modern locomotives. It is scarcely necessary to add that engineers have never regretted this increased elevation of boilers; if there still exists a divergence of opinion in this matter, it is between those who think that there is no disturbance in the stability and those who think that there is a distinct advantage in this respect.

The effective pressure of steam in boilers has been carried to 14, 15, and even 16 kilogrammes per square centimetre (199, 213, and even 228 lbs. per square inch), the compound system making good use of these high pressures.

Referring to the frames of locomotives, the leading bogie has come into general use in France. All compound locomotives with four cylinders and two or three driving axles are thus furnished, with the exception of four constructed before 1889; many of the simple locomotives have also a bogie. Another instance of the favour with which bogies are regarded in France is seen in the addition of the bogie to old machines. It is also worthy of remark that elegance in the design of locomotives now receives more attention than formerly.

* This remark does not apply to M. Mallet's articulated locomotives employed in France on the light railways of one-metre gauge, with which the present Paper does not deal.

The following information concerning the seven great railway lines of France, Nord, Ouest, État, Paris-Orléans, Midi, Paris-Lyon - Méditerranée, Est,* has been gathered with the kind co-operation of the chief mechanical engineers of these administrations, MM. du Bousquet, Clérault, Desdoutis, Solacroup, Moffre, Baudry, and Salomon.

The present Paper does not deal with light railways of one metre, which would merit special consideration; it does not treat either of electric locomotives on trial or on order for the working of special lines. The author prefers to abstain from all comparison with English locomotives or those of other countries. Compound locomotives with four cylinders, other locomotives, and various details of construction will be examined successively.

I.—COMPOUND LOCOMOTIVES WITH FOUR CYLINDERS.

Table 1 (pages 398-399) gives a list of the compound locomotives with four cylinders in service or on order on 1st January 1900† for French railways (not including the Mallet locomotives for light railways of one metre as stated before). Amongst these locomotives of normal gauge, four (Nos. 2801-2804 État), constructed in America, are of the Vaclain system with superposed cylinders; twenty others (Nos. 4101 to 4120 Nord, constructed in 1889) have tandem cylinders with three piston-rods in each group and one valve for a group of two cylinders; these locomotives do not belong to the category of ordinary compound machines with intermediate receiver, but to that of the Woolf type with steam traversing direct from one cylinder to the other.

Putting on one side these two categories of locomotives, all others have four separate cylinders, each with its own valve and valve gear. The oldest of these locomotives is No. 701, Nord, Fig. 1,

* These seven lines work the greater part of the network of French railways; there remains a system composed of light railways, generally with one-metre gauge.

† Since that date new orders have been given for locomotives of this kind. The Western Railway has decided on the construction of 40.

Plate 43, designed, like several of the following, by M. de Glehn, director of the Société alsacienne de constructions mécaniques. The two driving axles of this locomotive, No. 701, are not coupled. The high-pressure cylinders are inside and the low-pressure outside the frames.

In the following locomotives the positions of the cylinders have been changed, which gives the double advantage of placing the exhaust passage from the low-pressure cylinders beneath the smoke-box and fixing the smaller cylinders outside.

Locomotives with two driving axles developed from the first type have been constructed of larger and larger power; then followed the type with three driving axles, often with wheels large enough to permit their taking all except the most rapid trains. In order to still further increase the dimensions of the boilers of high-speed engines with two driving axles, the type called "Atlantic," with one carrying axle placed behind the two driving axles, Fig. 11, Plate 46, has been introduced. Two locomotives of this type are being constructed for the Northern Railway. One may consider the "Atlantic" type as derived from the three-axles-coupled machine, where the trailing axle ceases to be a driver.

There is considerable uniformity among the two- and three-driving-axles locomotives employed on the different French railways; however the Paris-Lyon-Méditerranée has designed types of two, three, and also four-coupled axles which are peculiar to this line.

As already said, the coupling-rod has been preserved for two driving axles, to omit which would appear possible without inconvenience. It has been found in France that the disturbing forces due to the reciprocating movement of the pistons and the obliquity of the connecting-rods can be diminished by thus coupling the wheels; the machine runs more smoothly and wears the permanent way less. In addition to this, the coupled wheels are less prone to slip; in fact, with two independent axles, if one slips, the steam immediately acts with greater effort upon the other, making it slip in its turn.

Table 2 (pages 400–407) gives various dimensions of four-cylinder locomotives. In the most recent locomotives it will be seen that the grate area is about 2·5 square metres (27 square feet); for certain among them the heating surface approaches 200 square metres (2153 square feet). These heating surfaces are reckoned on the side of the plates and tubes in contact with the flame and hot gases. The surfaces indicated are not always comparable, for they are not always calculated in exactly the same manner; with the *Serve-ribbed* tubes very frequently used, the depth allowed in the calculations for the ribs is not always the same; besides, more or less is allowed for the omission of the ribs for expanding purposes at the two extremities of each tube.

The greater number of locomotives have a brick arch in the fire-box. On certain engines of the Paris-Orléans and Midi railways the Tenbrinck heater exists.

The weights have been given, in Table 2, as they appear on the reports furnished to the author; but it is clear that these weights cannot be exact within 50 kilogrammes (1 cwt.); they must vary with the condition of the engine. The weights cannot be given for certain very recent and not yet completed locomotives.

Figs. 2 to 20, Plates 43 to 48, represent the particular types of four-cylinder locomotives. Those of the Paris-Orléans and State railways not given resemble the later types of the Southern line, with the exception of the American locomotives of the State railway.

The Walschaert valve-gear is employed generally in locomotives with four cylinders. This mechanism, having only one eccentric, is suitable for outside cylinders. It is also applied for inside cylinders; nevertheless the Gooch link has been employed for inside cylinders on the latest compound engines on the Paris-Lyon-Méditerranée. The Walschaert system gives good distribution of steam at the various points of cut-off.

The two lifting-shafts, one for the two high-pressure cylinders, the other for the low-pressure cylinders, are actuated by two reversing screws placed opposite each other, Fig. 21, Plate 49, or one a prolongation of the other, Fig. 22; the two can be reversed at will, either together or separately. The drivers are thus able to adjust

suitably the distribution for all requirements, and have found from practice in a very short time the best working positions. Admission of steam to the large cylinders should always be at least from 40 to 50 per cent. of the stroke, and later for higher speeds.

On the Paris-Lyon-Méditerranée the reversing-shafts are, on the contrary, actuated at the same time, so that they always take the same fixed relative position.

In order to give the engines a sufficient starting effort, a special valve permits the direct admission of steam from the boiler into the receiver, where a safety valve limits the pressure. When the two connecting-rods situated on the same side of the engine are opposite one another, at 180° (the outside for the high-pressure cylinder, the inside for the low-pressure cylinder), the starting effort is not sufficient in certain positions of the engine, on account of the counter pressure upon the small piston of the steam admitted to the receiver; it has been found necessary to place between the two groups of cylinders special starting apparatus, Fig. 23, Plate 50. It consists of a large cock which can interrupt the passage from the small to the large cylinder, and which opens at the same time a direct escape for the small cylinders. A similar cock exists on each side of the engine. The opening of this cock transforms the locomotive to a simple 4-cylinder engine; in case of injury to one group of cylinders, it renders possible working with the other group only.

The system of the Est, Fig. 24, consists of a special box furnished with a flap-valve, which serves to separate the high-pressure and low-pressure cylinders, and a valve which opens a direct escape for the former. This apparatus receives the exhaust pipes from both high-pressure cylinders.

If the two cranks for the high and low pressure, instead of being opposite each other, are constructed with a suitable angle, a sufficient starting effort in all positions of the engine may be obtained without special apparatus other than the admission valve direct to the receiver. This was done on the first locomotives of the Paris-Lyon-Méditerranée; but this arrangement, which does not balance the weights of the parts so well, has been abandoned in recent designs.

For lubricating pistons and valves, the best apparatus consists of a kind of oil-pump, set in motion by the locomotive gear. This pump distributes oil to the four cylinders in precisely regulated quantities.

The preference given in France to four-cylinder compound locomotives appears justified. In the first place, when a very great power of the locomotive is required, the compound system permits the use of steam at a high pressure, 14 to 16 kilogrammes per square centimetre (199 to 228 lbs. per square inch), whilst preserving simple distribution and ordinary valves. The system gives economy of steam, or a larger power for the same expenditure, and when the engine has to be driven hard, this economy increases because the boiler is less forced.

In addition to this, compound locomotives with four cylinders have certain advantages over those which have only two or three; each cylinder producing only a smaller fraction of the total work, the engines are less strained, and remain in good order a longer time. It is well known to what rapid wear very powerful locomotives with two cylinders are exposed, because it is scarcely possible to give to the wearing parts sufficient bearing surface. In practice the cost of maintenance does not appear greater with four than with two cylinders from this reason.

The arrangement of four cylinders, whilst preserving the coupling of driving axles, leads to a balancing of the moving parts. The oscillations of the locomotives and the variation of the weights upon the rail are reduced. In one example, given by M. Baudry, Chief Engineer of the Paris-Lyon-Méditerranée, the additional weight upon each wheel due to speed was only from 1,100 to 1,200 kilogrammes ($1\frac{1}{16}$ to $1\frac{3}{16}$ ton) instead of 3,600 ($3\frac{1}{2}$ tons) for locomotives with two driving axles, and from 1,400 to 2,500 kilogrammes ($1\frac{3}{8}$ to $2\frac{1}{2}$ tons) in place of 6,600 kilogrammes ($6\frac{1}{2}$ tons) for locomotives with three driving axles, the wheels being 1 metre 50 ($4\text{ feet } 11\frac{1}{16}\text{ inches}$) diameter.

If compound locomotives with four cylinders cost a little more than ordinary two-cylinder locomotives, this excess is largely compensated for by economy in fuel, because the cost of up-keep

and repair does not appear to increase. The observations made upon locomotives 501 and 502 of the Ouest, which have been in service for some years, confirm these favourable opinions. These two machines have been compared with eight equivalent two-cylinder locomotives of the series 900. Care has been taken to put them to various duties, to employ exactly the same kind of fuel for all the engines, and to change the men often. The two compounds compared with the other engines have shown an economy in coal of 12 per cent. This economy would have been greater if the total amount used by engine 502 had not been always greater than that of engine 501, due no doubt to some small hidden defect. The cost of oil has not been greater for these compounds than for other locomotives.

With regard to wear, the tyres of locomotives 501 and 502 have run about 58,000 kilometres (or 36,000 miles), between each returning, whilst the other locomotives have run about 52,000 kilometres (32,000 miles): the removal of the wheels is the occasion of a slight general repair to the mechanism. The wear of the valves is considerably less with the compound locomotives, in spite of the high pressure in the boiler (14 kilogrammes per square centimetre in place of 12, 199 lbs. per square inch in place of 171 lbs.): the valves of the eight ordinary locomotives have been withdrawn after running about 69,000 kilometres (about 43,000 miles). The valves of the compounds have given the following services:—

Locomotive 501	. H.P. valves, 215,000 and 332,000 kilometres (134,000 and 206,000 miles).
	. L.P. valves, 311,000 kilometres (193,000 miles) for both.
Locomotive 502	. H.P. valves, 206,000 and 265,000 kilometres (128,000 and 165,000 miles).
	. L.P. valves, 362,000 kilometres for both (225,000 miles).

II.—OTHER LOCOMOTIVES.

It may be interesting to mention in this section of the Paper the more important series of locomotives which have been in use for some time, but which are still doing good service, and the more recent non-compound types, as well as some special types.

1. *Simple Locomotives for High Speed.*—With the exception of very old locomotives, principally of the Crampton type, which only do secondary work, there are no longer in France any locomotives with independent axles. All express engines have two axles coupled; and, as stated above, locomotives with three-coupled axles and wheels of 1 metre 750 (5 feet 8 $\frac{3}{4}$ inches) are now being employed in certain cases for express trains.*

The Nord employs bogie locomotives with inside cylinders and outside frames, Fig. 25, Plate 51, a type that has been in use for twenty years. The Ouest possesses sixty bogie locomotives, Fig. 26, of the type which was shown at the International Exhibition of 1889, the bogie having lateral play. Some État locomotives have two driving axles between two carrying axles, Nos. 2,602 to 2,620, Fig. 27, with the Bonnefond valve-gear. Each cylinder carries four valves, two for exhaust and two for admission. The latter are disposed for rapid closing by the action of a click.

It is interesting to note this application of the Corliss system to locomotives; the results appear satisfactory in practice, but up to the present it does not seem likely that the system will receive any considerable extension.

The État possesses also some two-axles-coupled locomotives, with the bogie having lateral displacement, and outside cylinders, constructed in 1896; these engines are furnished with cylindrical valves.

The Paris-Orléans has for a long time remained faithful to its old type with two coupled axles between two carrying axles, Fig. 28. Although in theory this type of locomotive presents certain inconveniences, it must be recognised that it has done long service with speeds often very high upon the Paris-Orléans system. These locomotives have outside cylinders, except three constructed in 1888, Nos. 101 to 103. The eight locomotives, Nos. 576 to 583,

* Fifteen years ago the Nord employed, for express trains between Calais and Boulogne, locomotives with three-coupled axles and wheels, 1·650 metre (5 ft. 4 $\frac{1}{2}$ ins.) diameter. The inclines are 8 per 1000, or 1 in 125. On down grade the speed often reached 96 kilometres (59 $\frac{1}{2}$ miles) per hour.

constructed in 1898, have the Durant and Lencauchez valve-gear with four independent valves for the cylinders. These valves oscillate round axes perpendicular to the cylinder axis, like those in Corliss engines, but there is no rapid closing of the admission valves. The distribution of the exhaust is regulated, in forward gear, by a point in the link more distant from the centre than the point which controls the admission distributors, in such a manner that the steam admission may be considerably reduced without unduly increasing the compression.

The principal dimensions of these locomotives, Nos. 576 to 583, are as follows:—

Grate area	2.11 sq. metres (22 $\frac{3}{4}$ sq. ft.)
Heating surface	173.68 „ (1869 sq. ft.).
Boiler pressure	15 kg. (213 lbs. per sq. in.)
Diameter of cylinders	420 mm. (16 $\frac{1}{2}$ inches).
Stroke of pistons	650 mm. (25 $\frac{9}{16}$ inches).
Diameter of driving wheels	1,800 mm. (5 ft. 10 $\frac{3}{8}$ ins.).
Weight in working order	47,900 kg. (47.14 tons).
Adhesive weight	32,000 kg. (31.49 tons).

The high steam-pressure, which is rarely used for simple expansion locomotives, is here noticeable. Similar locomotives in other groups have larger driving wheels.

The Est has applied the Durant and Lencauchez valve-gear upon two experimental locomotives. This mechanism appears suitable, but its use is, as yet, very limited. The old express locomotives of the Midi have two coupled axles, and a leading carrying axle. The cylinders are outside, and the driving crank pins are upon the hind axle.

The Paris-Lyon-Méditerranée has a large number of locomotives with two driving axles between two carrying axles, Fig. 29, Plate 52, similar to the Paris-Orléans arrangement. Formerly these engines hauled all the express trains. Today bogie engines are preferred for very high speeds. A certain number of these old engines have however been transformed to bogie engines, Fig. 30, and the employment of the Serve ribbed tubes has permitted a considerable shortening of the boiler barrel.

The old express locomotives of the Est have two coupled axles with one leading carrying axle. The driving crank-pins are upon the hind axle. To this type has succeeded a type, remarkable for its high power, constructed in 1890, Fig. 31; the arrangement of driving directly upon the trailing axle has been kept, but a leading bogie has been added. The boiler is of the double-bodied type by M. Flaman. The Est possesses forty locomotives of this kind (constructed between 1890 and 1895) of which the following are the principal dimensions:—

Grate area	2·418 sq. metres ($23\frac{1}{2}$ sq. feet).
Heating surface	168·29 „ ($1811\frac{1}{2}$ sq. feet).
Boiler pressure. . . .	12 kg. (171 lbs. per sq. inch).
Diameter of cylinders	470 millimetres ($18\frac{1}{2}$ inches). (500 ($19\frac{1}{4}$ ins.) on the first engines).
Stroke of pistons	660 mm. ($26\frac{1}{8}$ inches).
Diameter of driving wheels	2·090 metres (6 ft. $10\frac{5}{8}$ ins.).
Weight in running order	56,766 kg. (55·87 tons).
Adhesive weight	33,396 kg. (32·87 tons).

The construction of these engines marks a step in advance in the power of locomotives.

2. *Simple Locomotives with Three- and Four-coupled Axles.*—All French railways possess locomotives with three-coupled axles without a carrying axle, employed for ordinary passenger trains and goods trains. The cylinders are sometimes inside and sometimes outside. Several of these locomotives have a leading or a trailing carrying axle or a leading bogie. The Ouest constructed in 1896 four powerful locomotives of this description, with three-coupled axles and a bogie, Fig. 32, the cylinders and valve-gear being outside. These engines do good service, but the corresponding four-cylinder compounds are preferred.

Amongst the four-axles-coupled locomotives may be named those, Fig. 33, Plate 53, of which the Nord possesses a large number. The Woolf locomotive described above differs from these engines only in the arrangement of its cylinders.

3. *Tank Locomotives.*—Almost all tank locomotives of recent construction have three-coupled axles, but the Nord ordered, in

1891, 1893, and 1894, sixty two-axles-coupled bogie locomotives with outside cylinders, Fig. 34. These engines, of moderate power, are intended to draw light trains.

The État has also very small locomotives with two-coupled axles, and one carrying axle, Fig. 35, for secondary trains. In order to distribute suitably the weight upon the axles, a van (*fourgon*) has been added on the same frame.

The Ouest possesses a large number of tank engines with three axles, Fig. 36, very compact and convenient for local service. This type was built in 1883. Others were ordered in 1898; the modifications added to the engines during this period are of little importance. Similar engines are being built for the Ceinture (Girdle) Railway of Paris.

Recently the Ouest has ordered twenty-five more powerful tank locomotives with three-coupled axles and a bogie, Fig. 37, Plate 54, having outside cylinders and valve-gear. These locomotives are remarkable for their large capacity in storing water and fuel, often too limited in tank engines. This enables them to run considerable distances, and makes them suitable for a large number of passenger and goods trains. During some trials, one of these locomotives has attained a speed of 118 kilometres ($73\frac{1}{3}$ miles) per hour, although the diameter of the wheels is only 1.510 metre (4 feet $11\frac{7}{16}$ inches).

The principal dimensions are as follows:—

Grate area	. . . . .	1.80 sq. metre ($19\frac{3}{8}$ sq. ft.).
Heating surface	. . . . .	131.60 „ ($1416\frac{9}{16}$ sq. ft.).
Boiler pressure	. . . . .	12 kg. per sq. cm. (171 lbs. per sq. in.)
Diameter of cylinders	. . . . .	460 mm. ($18\frac{1}{8}$ inches).
Stroke of pistons	. . . . .	600 „ ($23\frac{9}{16}$ inches).
Diameter of driving wheels	. . . . .	1.510 metre (4 ft. $11\frac{7}{16}$ in.).
Capacity of water-tanks	. . . . .	7 cub. metres (1540 gals.).
Capacity of coal-bunkers	. . . . .	2.500 kg. (2.46 tons of coal).
Weight in running order	. . . . .	58,900 kg. (57.97 tons).
Adhesive weight	. . . . .	43,900 kg. (43.21 tons).

The outside position of the mechanism is very handy; when it is inside, the side tanks render access difficult.

The Est has employed for some time powerful tank locomotives with three-coupled axles, having a trailing carrying axle, Fig. 38;

the cylinders are inside with outside frames, an arrangement seldom used. The principal dimensions are as follows :—

Grate surface	2·26 sq. metres (24 $\frac{5}{8}$ sq. feet).
Heating surface	129·32 sq. metres (1392 sq. feet).
Boiler pressure	12 kg. per sq. cm. (171 lbs. per sq. inch).
Diameter of cylinders . .	460 mm. (18 $\frac{1}{8}$ inches).
Stroke of piston	600 „ (23 $\frac{9}{16}$ inches).
Diameter of driving wheels .	1·560 metre (5 ft. 1 $\frac{7}{16}$ in.).
Capacity of water-tanks . .	5·220 cub. metres (1149 gals.).
Capacity of coal-bunkers . .	3,000 kg. (2·95 tons of coal).
Total weight in working order .	60,027 kg. (59·08 tons).
Adhesive weight	45,236 kg. (44·52 tons).

It has been recently found advantageous to transform these locomotives by the addition of a leading bogie, Fig. 39, in order to permit high speeds without inconvenience. It has been decided to transform 50 machines out of 130.

The Paris-Orléans constructed some years ago powerful tank locomotives with three-coupled axles without a carrying axle, with exhaust condensing apparatus in the tanks, in order to work underground lines in Paris.

III.—DETAILS OF CONSTRUCTION.

New boilers are most often of the Belpaire type, the crown plates of the inside and outside shells being horizontal and stayed together. The smoke-box is long, in order to contain a large quantity of cinders. For some years ribbed tubes have been in general use. The tubes are generally 70 millimetres (2 $\frac{3}{4}$ inches) external diameter; but the Paris-Lyon-Méditerranée use those of 65 millimetres (2 $\frac{9}{16}$ inches) diameter. The trials made in the workshops of the Paris-Lyon-Méditerranée and of the Nord have shown that these tubes were just as suitable as ordinary tubes having the same internal surface in contact with the hot gases; the results obtained in service confirm these trials. The tube plates appear to last longer with these large tubes, because the distance between the holes is generally larger than with the ordinary tubes. On the

other hand, one might have anticipated that the ribbed tubes would have an injurious action upon the plates, because they expand more than ordinary tubes, the ribs being more highly heated; but no inconvenience due to this cause appears to have been proved. For cleaning these tubes, a jet of steam is generally employed; but this jet does not always suffice, and it is necessary from time to time to clear out the deposits of coke from between the ribs.

Boilers are frequently constructed of mild steel plates; the fire-boxes are of copper; the trials of steel fire-boxes do not appear to have given any economy. For high pressures the plates are butt-jointed with covering strips (*couvre-joints*). The width of the two covering strips for longitudinal seams is not always the same, Fig. 41, Plate 55.

Direct-acting safety-valves (Adams, Lethuillier-Pinel, etc.) are more and more re-placing the old arrangement with a lever; these valves should be always kept in good order, as they are liable to give excessive escapes of steam.

In former French construction the barrel of the boiler rested on an intermediate support, which is now frequently omitted, the boiler being carried only by the smoke-box and the fire-box.

The injectors are often of the Sellers or Friedmann lifting type. They are not unfrequently mounted upon the fire-box back-plate with an internal delivery pipe.

For constructing parts such as cross ties and slide-bar brackets, cast steel is frequently employed. Cast steel is rarely used in France for wheels, which are usually made of stamped wrought iron after the Arbel type.

As has already been remarked, bogies are frequent. Whilst at the International Exhibition of 1889, only locomotives of the Nord and Ouest in the French section were furnished with bogies, engines are now no longer constructed in France without one, unless they are for suburban or shunting service.

The former bogie of the Nord had a fixed pivot, whilst that of the Ouest had a lateral movement; the latter arrangement is now always adopted, the lateral play being controlled by springs. The bogie of the Ouest with internal frames is still one of the simplest on French railways.

In order to facilitate the setting of the valves, and also for instruction of the men, an arrangement, already applied in Belgium by M. Guinotte on stationary engines, has been adopted upon some locomotives of the Ouest system; the piece which drives the valve spindle carries a templet of the longitudinal section of the valve, which moves over a fixed piece representing in section the cylinder ports, Fig. 42.

The tyres are often fixed simply by means of screws; frequently however they are fixed by the aid of a lip (*talon*) upon the tyre, and a steel ring locked in a groove in the tyre and riveted over the rim, Fig. 43.

Compound locomotives with two cylinders are little employed in France. In 1893 the Est constructed two engines of this kind with three coupled axles, Fig. 40, Plate 54. By mounting the cylinders between the outside frames a large space is afforded for fixing them; thus it has been possible to adopt diameters of 530 and 850 millimetres ($20\frac{7}{8}$ and $33\frac{7}{8}$ inches). Similar locomotives, but with two simple cylinders, have been constructed at the same time, and have been more successful in service.

The Midi is now rebuilding old locomotives as compounds with two cylinders.

The Nord has experimented with a three-cylinder compound engine, the middle cylinder being high pressure and the outside cylinders low pressure, all driving upon the same axle. This engine had three coupled axles, and a leading radial axle. Although this has not given bad results, it remains a unique example.

Cylindrical valves have been applied for a considerable time to a great number of locomotives on the État system, but up till now this mode of construction has spread but little in France. The Adams balanced valve has been used on a considerable number of locomotives on the Nord. The Est for some years past has made trials of this valve, and of the Richardson American valve. The latter railway is preparing an experiment on cylindrical valves. The general adoption of the compound system, which reduces the pressure on ordinary valves, explains the reason why these arrangements are somewhat neglected in France.

References.

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The Paper is illustrated by 13 Plates, Nos. 43–55.

APPENDIX.

ABBREVIATIONS FOR THE METRIC UNITS.

The utility of abbreviations for the names of the different metric units is obvious; too frequently such abbreviations are made at random and without any sensible rule, as for instance *kil*, which means kilomètres as well as kilogrammes. The International Committee of Weights and Measures,* at a meeting held on 2nd October 1879, arranged a list of such abbreviations in a simple and symmetrical manner, which are extensively used in the official publications of several countries, in a large number of periodicals and books, and in the proceedings of many societies; in fact, they are supposed to be everywhere understood without explanation, and none other should ever be used. These abbreviations are given on page 394.

As will be seen in this Table, for the names of the simple units, such as mètre, gramme, the initial letters *m*, *g*, are used; for the multiples, déca (10), hecto (100), kilo (1000), the initials *da*, *h*, *k* and for the fractions déci (0.1), centi (0.01), milli (0.001), the letters *d*, *c*, *m*. In addition, to the micron (one-thousandth of a millimètre) corresponds the Greek letter μ ; λ and γ express the microlitre (0.001 *ml* or one *mm*³) and the microgramme (0.001 *mg*). Of course, these symbols must always be written without the addition of an *s*.

Some remarks may be made on the different parts of the Table. As regards Length, no abbreviations are provided for the *décamètre* (10 m.) and the *hectomètre* (100 m.), which, although convenient, are seldom used (according to the rules, these would be *dam* and *hm*). The *myriamètre* (10 *km*) is left out, for the same reason. The tenth and the hundredth of a millimètre have no symbols and even

* This Committee was instituted in the year 1879, and included at the beginning sixteen countries: the United Kingdom joined it in 1884.

ABBREVIATIONS OF METRIC UNITS.

(As adopted by the *International Committee of Weights and Measures.*)

Length.	Surface.	Volume.	Capacity.	Weight.
Kilomètre . . km.	Square kilomètre km ² .	Cubic mètre . m ³ .	Hectolitre . hl.	Tonne . . t.
Mètre . . . m.	Hectare . . ha.	Stère . . . s.	Décalitre . . dal.	Quintal métrique q.
Décimètre . . dm.	Are . . . a.	Cubic décimètre dm ³ .	Litre . . . l.	Kilogramme . kg.
Centimètre . . cm.	Square mètre . m ² .	Cubic centimètre cm ³ .	Déclitre . . dl.	Gramme . . g.
Millimètre . . mm.	Square décimètre dm ² .	Cubic millimètre mm ³ .	Centilitre . . cl.	Décigramme . dg.
Micron . . . μ.	Square centimètre cm ² .		Millilitre . . ml.	Centigramme . cg.
	Square millimètre mm ² .		Microlitre . λ.	Milligramme . mg.
				Microgramme . γ.

no special names. This is to be regretted, as the tenth of millimètre is frequently mentioned in mechanical construction, and even the hundredth for very precise work, such as in the manufacture of guns. This deficiency might usefully be made up by the International Committee.

On the other hand, for greater units than the myriamètre, which would be useful in physics, geodesy, and astronomy, names are altogether missing. According to a well-known rule, the *mégamètre* might be adopted and would mean 1,000,000 *m* or 1,000 *km*; but this would not be sufficient in all cases. With too small or too large units, the numbers have too many figures, which convey no clear idea to our minds, and are not easily remembered.

In regard to Surface, the *are* is a square *décamètre*, or 100 *m*², and the *hectare* a square *hectomètre*, or 1000 *m*²; to these is sometimes added the *centiare*, which is but a useless synonym of a square metre.

In respect to Volume, a *stère* is a cubic mètre of wood cut for fuel: it has only a limited use, and might be dropped out without serious inconvenience, at least in Great Britain.

In the measures for Capacity, a very bad feature indeed of the metric system is seen, as they have been established in defiance of the very principle of the system, no doubt with regard to old measures and customs. They are used for liquids and for solids, such as corn, peas, even potatoes, which easily fill a receptacle. The fundamental unit is the *litre*, or a cubic *decimètre*; there is no objection to the use of this short and useful name. But, multiplied by 10 and by 100, it gives the *décalitre* and *hectolitre*, which are false units, as the true measures of solidity, being the cubes of the measures of length, are each one thousand greater than the preceding; more specially from a didactic point of view, for children in the schools, for poorly educated people these units of capacity, which progress by ten, are destructive of any clear conception of the geometrical notions of length, square, and cube.

For teaching purposes, in the United Kingdom, it would be quite sufficient to say that the litre is a cubic decimètre, leaving aside these multiples and fractions of a litre.

The same criticism applies in some respect to the measures of weight, as the weights are derived from the volumes, one cubic decimètre of water being approximately a kilogramme. The only real units of weight are then the milligramme, the gramme, the kilogramme and the *tonne*; a *quintal* is only a certain number of kilogrammes (100 kg.) and not a real unit.

A more general remark applies to the name "units of weight": weight being a variable and not well defined property of matter, no unit of weight exists: these units are really units of mass, and should always be denominated as such.

TABLES 1 and 2.

TABLE 1 (continued on opposite page).

*Four-cylinder Compound Locomotives,
in use or on order on 1st January 1900.*

(Ordinary French gauge.)

LOCOMOTIVES WITH TWO DRIVING AXLES.

Fig.	Railway.	Nos. of the Series.	No.	Total.	Year ordered.	Remarks.
1	Nord (Northern)	701	1		1885	{ Driving axles not coupled; radial axle in front.
5		2121-2123, 2137	17		1890 and 1892	
2		2138-2157	20		1894	
11		2158-2160, 2161-2180	23		1895 and 1897	
3	Ouest (Western)	501-502	2		1893	Type "Atlantic."
and 6		503-542	40	42	1897 and 1899	
	Etat (State)	2701-2706	6		1895	{ American locomotives, Vaucelain system.
		2801-2804	4	10	1899	
	Paris-Orléans	1-20	20	20	1898	
7	Midi (Southern)	1701-1714	14		1893	Two driving axles between two carrying axles.
8		1751-1774	24		1895 and 1896	
		1775-1784	10	48	1897	
	P. L. M. (Paris, Lyons, and Mediterranean)	C 1-2	2		1887	
		C 3	1		1892	
		C 11-12	2		1891	
		C 21-60	40		1893	
9		C 61-150	90	135	1898	
10	Est (Eastern)	2401-2432	32	32	1898	
Total No. of Locomotives with 2 driving axles }				350		

(concluded from opposite page) TABLE 1.
Four-cylinder Compound Locomotives,
in use or on order on 1st January 1900.
 (Ordinary French gauge.)

LOCOMOTIVES WITH THREE DRIVING AXLES.

Fig.	Railway.	Nos. of the Series.	No.	Total.	Year ordered.	Remarks.
13	Nord (Northern) }	3121-3170	50	50	1897	{ Locomotives with four driving- axles converted.
14) 15)	Ouest (Western) }	2501-2525	25	25	1898	
	Paris-Orléans	1701-1725	25	25	1899	
17 15	Midi (Southern) }	1301-1302	2		1895	
		1303-1312	10		1897 and 1898	
		1401	1		1895	
16		1402-1415	14	27	1898	
	P. L. M. (Paris, Lyons, and	3261-3300	40		1897	
18	Mediterranean) }	3401-3550	50	90	1898	
12	Est (Eastern) }	3401-3460	60	60	1898	
Total No. of Locomotives) with 3 driving axles }				277		
LOCOMOTIVES WITH FOUR DRIVING AXLES.						
20	Nord (Northern) }	4101-4120	20		1889	{ Woolf's system of tandem cylinders.
	P. L. M. (Paris, Lyons, and Mediterranean) }	3201-3202	2		1887	Converted engines.
		4301-4302	2		1887	
		3211-3260, 3301-3362	112		1892 and 1893	
		4501-4540	40	176	1891 to 1895	
Total No. of Four-cylinder Locomotives .				803		
(This does not include Mallet double locomotives for the mètre-gauge light railways.)						

TABLE 2 (continued to page 407).

Principal dimensions of the Four-cylinder Compound Locomotives.

Fig.	Railway.	Nos. of the series.	Boilers.			Tubes.			Grate area.						
			Internal diameter.	Height of axis above rail.	Pressure.	Length between plates.	External diameter.	No.	Square Metres.						
										Mètres.	Mètres.	Kg. per Sq. Cm.	Mètres.	Milli-mètres.	Sq. Feet.
LOCOMOTIVES WITH TWO DRIVING AXLES.															
1	Nord (Northern)	701	1·236 4 0 $\frac{5}{8}$	2·150 7 0 $\frac{1}{8}$	11 156	3·560 11 8 $\frac{1}{8}$	45 1 $\frac{3}{4}$	204	2·27 24 $\frac{7}{16}$						
		2121-2122	1·260 4 1 $\frac{5}{8}$	2·250 7 4 $\frac{9}{16}$	14 199	3·900 12 9 $\frac{1}{2}$	70 2 $\frac{3}{4}$	94	1·99 21 $\frac{7}{16}$						
		2123-2137	1·260 4 1 $\frac{5}{8}$	2·250 7 4 $\frac{9}{16}$	14 199	3·900 12 9 $\frac{1}{2}$	70 2 $\frac{3}{4}$	94	1·95 21						
5		2138-2167	1·256 4 1 $\frac{7}{16}$	2·250 7 4 $\frac{9}{16}$	15 213	3·900 12 9 $\frac{1}{2}$	70 2 $\frac{3}{4}$	94	1·99 21 $\frac{7}{16}$						
		2158-2160	1·350 4 5 $\frac{3}{16}$	2·450 8 0 $\frac{7}{16}$	15 213	3·900 12 9 $\frac{1}{2}$	70 2 $\frac{3}{4}$	107	2·30 28						
		2161-2180	1·350 4 5 $\frac{3}{16}$	2·450 8 0 $\frac{7}{16}$	15 213	3·900 12 9 $\frac{1}{2}$	70 2 $\frac{3}{4}$	105	2·30 28						
2		2641-2642	1·456 4 9 $\frac{5}{16}$	2·520 8 3 $\frac{1}{4}$	16 228	4·200 13 9 $\frac{3}{8}$	70 2 $\frac{3}{4}$	126	2·74 29 $\frac{1}{2}$						
		3 4 6	Ouest (Western)	501-502	1·296 4 3 $\frac{1}{16}$	2·235 7 4	14 199	3·800 12 5 $\frac{9}{16}$	70 2 $\frac{3}{4}$	88	2·00 21 $\frac{9}{16}$				
				503-542	1·380 4 6 $\frac{3}{8}$	2·485 8 1 $\frac{1}{8}$	14 199	3·800 12 5 $\frac{9}{16}$	70 2 $\frac{3}{4}$	96	2·40 25 $\frac{1}{8}$				
État (State)	2701-2706			1·256 4 1 $\frac{7}{16}$	2·250 7 4 $\frac{9}{16}$	15 213	3·900 12 9 $\frac{1}{2}$	70 2 $\frac{3}{4}$	94	2·05 22 $\frac{7}{16}$					
	2801-2804	1·588 5 2 $\frac{1}{2}$	2·745 9 0 $\frac{7}{16}$	15 213	3·670 12 0 $\frac{7}{16}$	50 2	282	2·38 25 $\frac{3}{8}$							
	Paris—Orléans	1-20	1·378 4 6 $\frac{1}{4}$	2·450 8 0 $\frac{7}{16}$	15 213	3·900 12 9 $\frac{1}{2}$	70 2 $\frac{3}{4}$	111	2·46 26 $\frac{1}{2}$						

(continued on next page) TABLE 2

Principal dimensions of the Four-cylinder Compound Locomotives.

Heating Surface.	Cylinders.				Driving Wheels.	Weight in working order.		Remarks.
Square Metres.	High-Pressure.		Low-Pressure.		Diameter.	Total.	Adhesive.	
	Diam.	Stroke.	Diam.	Stroke.	Mètres.			
	Milli-mètres.	Milli-mètres.	Milli-mètres.	Milli-mètres.		Kg.	Kg.	
Sq. Feet.	Inches.	Inches.	Inches.	Inches.	Ft. Ins.	Tons.	Tons.	
LOCOMOTIVES WITH TWO DRIVING AXLES.								
103·03 1109	330 13	610 24	460 18½	610 24	2·100 6 10½ ¹ / ₈	37,800 37·20	27,600 27·16	Low-pressure side cylind
155·27 1671 ⁷ / ₈	340 13½	640 25½	530 20½	640 25½	2·130 6 11½	47,800 47·04	30,500 30·02	
155·24 1671	340 13½	640 25½	530 20½	640 25½	2·130 6 11½	48,620 47·85	30,520 30·04	
155·10 1669½	340 13½	640 25½	530 20½	640 25½	2·130 6 11½	48,930 48·16	30,770 30·29	
175·75 1891½	340 13½	640 25½	530 20½	640 25½	2·130 6 11½	50,460 49·66	31,010 30·52	Atlantic type
173·00 1862½	340 13½	640 25½	530 20½	640 25½	2·130 6 11½	52,400 51·57	32,400 31·89	
211·30 2274½	340 13½	640 25½	560 22	640 25½	2·040 6 8½ ⁵ / ₈	64,000 62·99	33,000 32·48	
123·20 1326 ³ / ₈	320 12 ⁹ / ₈	640 25½	500 19½ ¹ / ₈	640 25½	2·010 6 7½	46,050 45·32	28,650 28·20	
133·70 1439 ³ / ₈	340 13½	640 25½	530 20½	640 25½	2·010 6 7½	49,500 48·72	31,000 30·51	Vauclain syst
157·66 1697½	340 13½	640 25½	530 20½	640 25½	2·130 6 11½	50,000 49·21	32,135 31·63	
176·87 1903½	330 13	660 26 ¹ / ₈	560 22	660 26 ¹ / ₈	2·140 7 0½	54,880 54·02	32,060 31·56	
175·61 1890 ⁵ / ₈	350 13½	640 25½	550 21½	640 25½	2·090 6 10½ ⁵ / ₈	— —	— —	
Tenbrinck] he in the fire-b								

TABLE 2 (continued on next page).

Principal dimensions of the Four-cylinder Compound Locomotives.

Fig.	Railway.	Nos. of the series.	Boilers.			Tubes.			Grate area.	
			Internal diameter.	Height of axis above rail.	Pressure.	Length between plates.	External diameter.	No.	Square Metres. Sq. Feet.	
			Mètres.	Mètres.	Kg. per Sq. Cm.	Mètres.	Milli-mètres.			
			<i>Ft. Ins.</i>	<i>Ft. Ins.</i>	<i>Lbs. per Sq. In.</i>	<i>Ft. Ins.</i>	<i>Inches.</i>			
LOCOMOTIVES WITH THREE DRIVING AXLES.										
13	Nord (Northern)	3121-3170	1·380 4 6 $\frac{3}{8}$	2·420 7 11 $\frac{1}{2}$	15 213	4·100 13 5 $\frac{7}{16}$	70 2 $\frac{3}{4}$	107	2·34 25 $\frac{3}{16}$	
14 15	Ouest (Western)	2501-2525	1·446 4 8 $\frac{1}{16}$	2·410 7 10 $\frac{7}{8}$	14 199	4·300 14 1 $\frac{5}{16}$	70 & 45 2 $\frac{3}{4}$ & 1 $\frac{3}{4}$	117	2·45 26 $\frac{3}{8}$	
	Paris—Orléans	1701-1725	1·380 4 6 $\frac{3}{8}$	2·420 7 11 $\frac{1}{2}$	15 213	4·100 13 5 $\frac{7}{16}$	70 2 $\frac{3}{4}$	107	2·38 25 $\frac{3}{8}$	
	Midi (Southern)	1301-1302	1·380 4 6 $\frac{3}{8}$	2·420 7 11 $\frac{1}{2}$	14 199	4·100 13 5 $\frac{7}{16}$	70 2 $\frac{3}{4}$	111	2·46 26 $\frac{1}{2}$	
17		1303-1312	1·376 4 6 $\frac{3}{16}$	2·420 7 11 $\frac{1}{2}$	15 213	4·100 13 5 $\frac{7}{16}$	70 2 $\frac{3}{4}$	111	2·49 26 $\frac{1}{16}$	
		1401	1·380 4 6 $\frac{3}{8}$	2·345 7 8 $\frac{3}{8}$	14 199	4·100 13 5 $\frac{7}{16}$	70 2 $\frac{3}{4}$	111	2·46 26 $\frac{1}{2}$	
16		1402-1415	1·376 4 6 $\frac{3}{16}$	2·345 7 8 $\frac{3}{8}$	15 213	4·100 13 5 $\frac{7}{16}$	70 2 $\frac{3}{4}$	111	2·49 26 $\frac{1}{16}$	
	P. L. M. (Paris, Lyons, and Mediterranean)	3261-3300	1·400 4 7 $\frac{1}{16}$	2·260 7 4 $\frac{1}{8}$	15 213	3·000 9 10 $\frac{1}{8}$	65 2 $\frac{9}{16}$	139	2·45 26 $\frac{3}{8}$	
18		3401-3550	1·440 4 8 $\frac{1}{16}$	2·435 7 11 $\frac{1}{8}$	15 213	3·400 11 1 $\frac{3}{16}$	65 2 $\frac{9}{16}$	150	2·48 26 $\frac{1}{16}$	
12	Est (Eastern)	3425-3450	1·466 4 9 $\frac{3}{4}$	2·450 8 0 $\frac{7}{16}$	16 228	4·100 13 5 $\frac{7}{16}$	70 2 $\frac{3}{4}$	130	2·51 27	

(continued on next page) TABLE 2.

Principal dimensions of the Four-cylinder Compound Locomotives.

Heating Surface.	Cylinders.				Driving Wheels.	Weight in working order.		Remarks.	
Square Metres.	High-Pressure.		Low-Pressure.		Diameter.	Total.	Adhesive.		
	Diam.	Stroke.	Diam.	Stroke.	Mètres.				
	Milli-mètres.	Milli-mètres.	Milli-mètres.	Milli-mètres.		Kg.	Kg.		
Sq. Feet.	Inches.	Inches.	Inches.	Inches.	Ft. Ins.	Tons.	Tons.		
LOCOMOTIVES WITH THREE DRIVING AXLES.									
180·70 1945 $\frac{5}{8}$	350 13 $\frac{3}{4}$	640 25 $\frac{1}{8}$	550 21 $\frac{5}{8}$	640 25 $\frac{1}{8}$	1·750 5 8 $\frac{1}{8}$	58,570 57·65	42,470 41·80	113 ribbed tubes of 70 mm., or 2 $\frac{3}{4}$ inches, and 4 smooth tubes of 45 mm., or 1 $\frac{1}{4}$ inch diam.	
194·00 2088 $\frac{1}{4}$	350 13 $\frac{3}{4}$	640 25 $\frac{1}{8}$	550 21 $\frac{5}{8}$	640 25 $\frac{1}{8}$	1·720 5 7 $\frac{1}{8}$	58,400 57·48	41,500 40·84		
187·97 2023 $\frac{3}{8}$	350 13 $\frac{3}{4}$	640 25 $\frac{1}{8}$	550 21 $\frac{5}{8}$	640 25 $\frac{1}{8}$	1·750 5 8 $\frac{1}{8}$	—	—		
181·51 1953 $\frac{1}{8}$	350 13 $\frac{3}{4}$	640 25 $\frac{1}{8}$	550 21 $\frac{5}{8}$	640 25 $\frac{1}{8}$	1·750 5 8 $\frac{1}{8}$	57,500 56·59	41,700 41·04		
181·74 1956 $\frac{5}{16}$	350 13 $\frac{3}{4}$	640 25 $\frac{1}{8}$	550 21 $\frac{5}{8}$	640 25 $\frac{1}{8}$	1·750 5 8 $\frac{1}{8}$	60,100 59·15	44,300 43·60		
181·51 1953 $\frac{1}{8}$	350 13 $\frac{3}{4}$	640 25 $\frac{1}{8}$	550 21 $\frac{5}{8}$	640 25 $\frac{1}{8}$	1·600 5 2 $\frac{1}{8}$	56,500 55·61	40,700 40·06		
181·74 1956 $\frac{5}{16}$	350 13 $\frac{3}{4}$	640 25 $\frac{1}{8}$	550 21 $\frac{5}{8}$	640 25 $\frac{1}{8}$	1·600 5 2 $\frac{1}{8}$	59,900 58·96	44,100 43·41		
154·74 1665 $\frac{3}{8}$	360 14 $\frac{3}{16}$	650 25 $\frac{9}{16}$	590 23 $\frac{1}{4}$	650 25 $\frac{9}{16}$	1·500 4 11 $\frac{1}{16}$	58,110 57·19	44,010 43·32		Converted engines.
189·51 2039 $\frac{1}{8}$	340 13 $\frac{3}{8}$	650 25 $\frac{9}{16}$	540 21 $\frac{1}{4}$	650 25 $\frac{9}{16}$	1·650 5 4 $\frac{1}{8}$	—	—		
205·31 2210	350 13 $\frac{3}{4}$	640 25 $\frac{1}{8}$	550 21 $\frac{5}{8}$	640 25 $\frac{1}{8}$	1·750 5 8 $\frac{1}{8}$	65,368 64·34	47,096 46·35		Pressurere reduced to 15 kg. per sq. c.metre, or 213 lbs. per sq. inch.

TABLE 2 (concluded from page 400).

Principal dimensions of the Four-cylinder Compound Locomotives.

Fig.	Railway.	Nos. of the series.	Boilers.			Tubes.			Grate area.
			Internal diameter.	Height of axis above rail.	Pressure.	Length between plates.	External diameter.	No.	Square Mètres.
Mètres.	Mètres.	Kg. per Sq. Cm.	Mètres.	Milli-mètres.	Sq. Feet.				
<i>Ft. Ins.</i>	<i>Ft. Ins.</i>	<i>Lbs. per Sq. In.</i>	<i>Ft. Ins.</i>	<i>Inches.</i>					
LOCOMOTIVES WITH FOUR DRIVING AXLES.									
20	Nord (Northern)	4101-4120	1·478	2·050	10	4·099	50	199	2·08
			4 10 $\frac{3}{16}$	6 8 $\frac{1}{16}$	142	13 5 $\frac{3}{8}$	1 $\frac{5}{16}$		22 $\frac{3}{8}$
	P. L. M. (Paris, Lyons, and Mediterranean)	3201-3202	1·400	2·260	15	4·350	40 & 45	307 & 247	2·45
			4 7 $\frac{1}{16}$	7 4 $\frac{1}{16}$	213	14 3 $\frac{1}{4}$	1 $\frac{9}{16}$ & 1 $\frac{3}{4}$		26 $\frac{3}{8}$
		4301-4302	1·500	2·260	15	4·150	50 & 55	247 & 210	2·21
			4 11 $\frac{1}{16}$	7 4 $\frac{1}{16}$	213	13 7 $\frac{7}{16}$	1 $\frac{5}{16}$ & 2 $\frac{3}{16}$		23 $\frac{3}{4}$
		3211, 3260 and 3301-3362	1·400	2·260	15	3·000	65	139	2·45
			4 7 $\frac{1}{16}$	7 4 $\frac{1}{16}$	213	9 10 $\frac{1}{8}$	2 $\frac{1}{16}$		26 $\frac{3}{8}$
		4501-4510	1·500	2·260	15	2·995	65	184	2·10
			4 11 $\frac{1}{16}$	7 4 $\frac{1}{16}$	213	9 9 $\frac{7}{8}$	2 $\frac{1}{16}$		22 $\frac{5}{8}$
		4511-4520	1·500	2·260	15	3·007	65	184	2 14
			4 11 $\frac{1}{16}$	7 4 $\frac{1}{16}$	213	9 10 $\frac{3}{8}$	2 $\frac{1}{16}$		23
	19	4521-4530	1·500	2·260	15	3·007	65	184	2·10
			4 11 $\frac{1}{16}$	7 4 $\frac{1}{16}$	213	9 10 $\frac{3}{8}$	2 $\frac{1}{16}$		22 $\frac{5}{8}$

(concluded from page 401) TABLE 2.

Principal dimensions of the Four-cylinder Compound Locomotives.

Heating Surface.	Cylinders.				Driving Wheels.	Weight in working order.		Remarks.
Square Metres.	High-Pressure.		Low-Pressure.		Diameter.	Total.	Adhesive.	
	Diam.	Stroke.	Diam.	Stroke.	Metres.			
	Milli-mètres.	Milli-mètres.	Milli-mètres.	Milli-mètres.		Kg.	Kg.	
Sq. Feet.	Inches.	Inches.	Inches.	Inches.	Ft. Ins.	Tons.	Tons.	
LOCOMOTIVES WITH FOUR DRIVING AXLES.								
124.30 1338	380 15	650 25 ⁹ / ₁₆	660 26 ¹ / ₁₆	650 25 ⁹ / ₁₆	1.300 4 3 ³ / ₈	52,800 51.97	52,800 51.97	Tandem cylinders.
164.74 & 154.89 1773 ⁵ / ₁₆ & 1667 ¹ / ₂	340 13 ³ / ₈	650 25 ⁹ / ₁₆	540 21 ¹ / ₄	650 25 ⁹ / ₁₆	1.500 4 11 ¹ / ₈	56,900 56.00	56,900 56.00	307 tubes of 40 mm., or 1 ⁹ / ₁₆ ins., on one engine, and 247 of 45 mm., or 1 ³ / ₄ ins., on the other.
159.55 & 151.12 1777 ⁷ / ₁₆ & 1626 ¹ / ₈	360 14 ³ / ₁₆	650 25 ⁹ / ₁₆	540 21 ¹ / ₄	650 25 ⁹ / ₁₆	1.260 4 1 ⁵ / ₈	57,100 56.20	57,100 56.20	
154.74 1665 ⁵ / ₈	360 14 ³ / ₁₆	650 25 ⁹ / ₁₆	590 23 ¹ / ₄	650 25 ⁹ / ₁₆	1.500 4 11 ¹ / ₈	53,700 52.86	53,700 52.86	247 tubes of 50 mm., or 1 ¹ / ₂ ins., on one engine, and 210 of 55 mm., or 2 ¹ / ₈ ins., on the other.
202.06 2175	340 13 ³ / ₈	650 25 ⁹ / ₁₆	520 20 ⁷ / ₁₆	650 25 ⁹ / ₁₆	1.300 4 3 ³ / ₈	51,500 50.69	51,500 50.69	
202.10 2175 ⁷ / ₁₆	340 13 ³ / ₈	650 25 ⁹ / ₁₆	520 20 ⁷ / ₁₆	650 25 ⁹ / ₁₆	1.300 4 3 ³ / ₈	50,900 50.10	50,900 50.10	
202.88 2183 ⁷ / ₈	340 13 ³ / ₈	650 25 ⁹ / ₁₆	520 20 ⁷ / ₁₆	650 25 ⁹ / ₁₆	1.300 4 3 ³ / ₈	51,660 50.85	51,660 50.85	
Converted locomotives.								

Discussion.

Mr. JOHN A. F. ASPINALL, Vice-President, considered that locomotive engineers in this country were again indebted to his friend M. Sauvage for giving them the benefit of his experience on the Continent. It was not the first time that M. Sauvage had given, in the most lucid way, his figures and his facts. With regard to the use of compound locomotives on the French railways, there was one thing which he would like to elicit from the author, and that was, whether they were using those engines continuously for stopping trains as well as for through trains, and if so what had been the result in fuel consumption. Hitherto in this country there had been an idea that the compound locomotive was much more suited for fast traffic, where heavy trains were pulled over long distances without stopping, than it was for stopping trains, and that, where a compound locomotive was used for stopping trains, much of the economy that might be obtained by compounding was run away with by having to admit high-pressure steam to the low-pressure cylinders for starting purposes. If M. Sauvage could say definitely what had been done on the French railways in the way of saving fuel, he thought it would be a most interesting fact. It was the old question of economy in the coal, and after all that was a most important thing. It was a question of what could be saved by compounding. The question was becoming a very serious one, particularly in the North of England. There had recently been an increase in the price of coal of about 60 per cent., and that made it necessary to look round and see if anything could be done by compounding. But taking what might be considered a high price for coal, and leaving out the question of the 60 per cent. increase which had now come, speaking about coal at a fairly high price for the North of England, about 10s. a ton, and assuming that a locomotive burnt 1,000 tons of coal in the year, and without taking the rosy figure of 12 per cent. which M. Sauvage talked about as a saving, calling it 10 per cent., it was a very easy calculation to see that if 10 per cent. were saved on 1,000 tons of coal costing 10s.

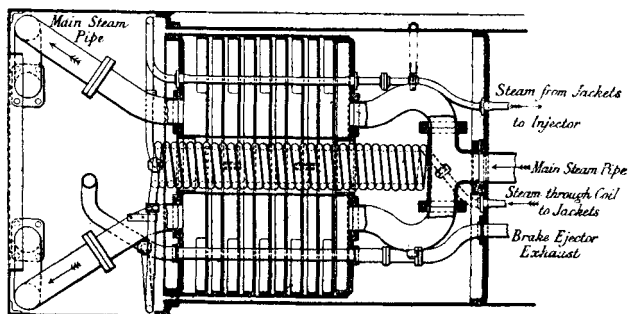
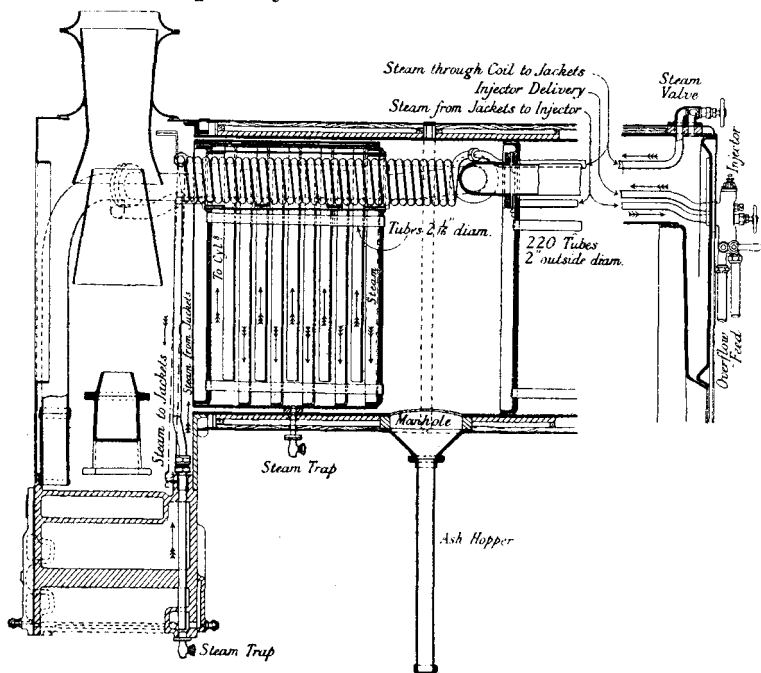
per ton, £50 a year would be got out of it. But £50 a year would very soon be run away with in the maintenance of the extra parts used for the compounding engines, and therefore he pressed the question of economy in fuel.

Turning to another matter which M. Sauvage had mentioned—engines of the Atlantic type, Plate 46—there had been built on the Lancashire and Yorkshire Railway recently twenty large engines of that type, and with a view to reducing the coal bill without adding to the number of working parts, all those engines had had steam-jacketed cylinders, 19 inches by 26 inches, Fig. 45, page 411; and in order to ensure that the driver should continuously make use of the arrangement, the steam which worked the injector was made to sweep through the jacket on its way to the injector so that the cylinder took up a certain amount of heat, the cylinders were kept hot, and the condensed steam was not lost. The officials of the railway thought they were getting some advantage from that. Special arrangements were of course made for taking away any water of condensation, such as accumulated when the engine was standing at the station, but otherwise during the whole journey the injector was kept going, and any little water that was made in the cylinder jacket was swept into the injector and back into the boiler. That was one thing. Another thing was that of that lot of engines nineteen were built all alike, while the twentieth had its boiler barrel shortened internally. Externally the appearance was exactly the same as the others, but internally the boiler barrel was considerably shortened, and that gave, as it were, a kind of extended smoke-box inwards, and the space in that smoke-box was made use of to insert a large superheater, Fig. 44, page 410, which was cylindrical in shape, with two tube-plates at either end. Through those tube-plates were a number of tubes equal in number to those going through the boiler barrel, slightly larger in diameter, to enable the boiler tubes proper to be withdrawn for repairs, and a space was left between the superheater and the tube-plate of the boiler proper, with suitable arrangements for getting in between, so that the boiler tubes proper could be thoroughly cleaned out, as well as the tubes that went through the superheater. The superheater had, in addition to the tubes running horizontally through it, about four or five diaphragms,

(Mr. John A. F. Aspinall).

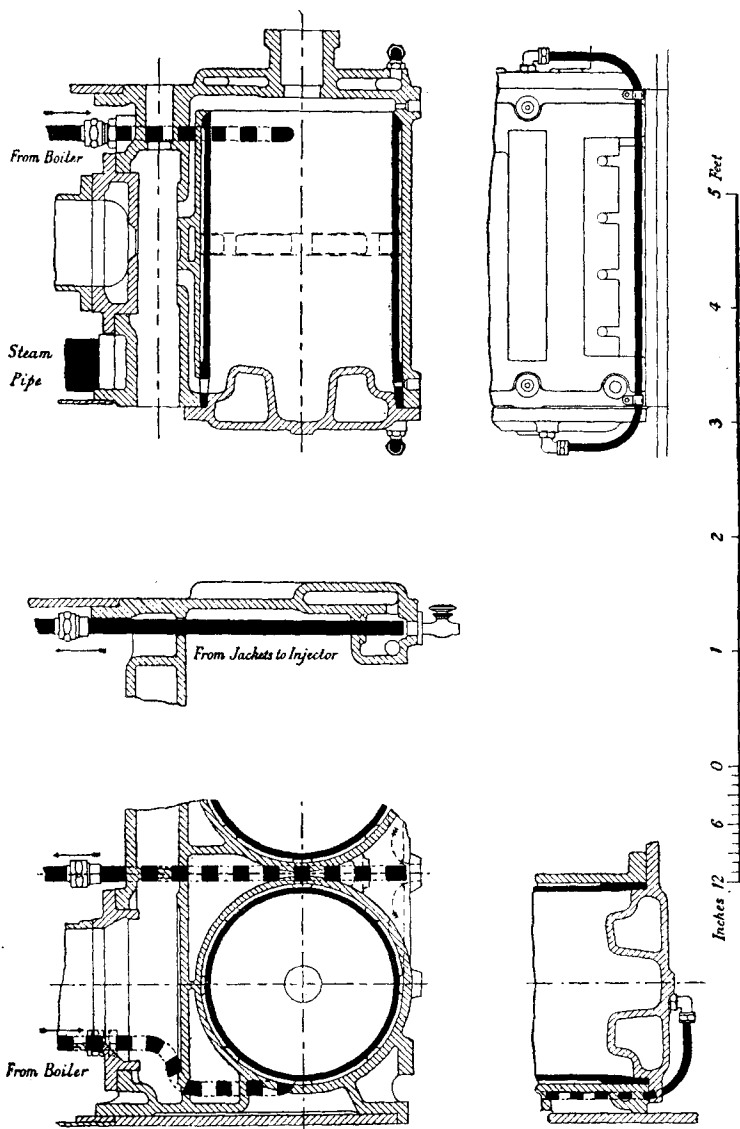
FIG. 44.—Arrangement of Steam Superheaters
for Main Steam and Jackets.

10-Wheeled Bogie Passenger Engine, L. and Y. Ry.
4 wheels coupled, Cylinders 19 inches diam. 26 inches stroke.



Scale $\frac{1}{32}$

FIG. 45.—*Arrangement of Steam-Jacketed Cylinders.*
L. and Y. Ry.



(Mr. John A. F. Aspinall).

running vertically, through which the tubes passed, so that the steam which came from the regulator was made to pass through the superheater down to the bottom of the superheater, come up again past the diaphragm, and so on, picking up the heat from the exterior surface of the tubes on its way to the cylinders. It certainly had resulted in enabling very dry steam to be got to the cylinders, but the experiment had not been conducted sufficiently long to enable anything to be said as to whether it was really a great commercial success. After all, what was desired to know was what influence that was going to have upon the coal heap, and that was why he asked his friend, M. Sauvage, to say what influence his compounding had had upon his coal consumption.

Mr. HENRY A. IVATT, Member of Council, was sure the Members were all very much indebted to M. Sauvage for bringing his very interesting Paper before them, and adding such valuable information to the Proceedings of the Institution, and he thought they were further indebted to him for reading the Paper in English. Speaking for himself he should be very sorry to stand up before a French audience and try to say anything about locomotives in broken French. The thing that struck him about the Paper was the great increase in the power of locomotives which had taken place in France during the last ten years. The measure of the power of a locomotive was the boiler. Mr. Sturrock, who left the position, which he himself now occupied on the Great Northern Railway, over thirty years ago (and who he was glad to say came to see him at Doncaster and talk locomotives now and then), said that the measure of the power of a locomotive was "its capacity to boil water." It would be seen from the Paper that a great many of the boilers of the French locomotives were quite up to 2,000 feet of heating surface, and a great many of the fire-boxes had over 20 feet of grate area, and in many cases the pressure was over 200 lbs. It was no use having large cylinders, and figuring the power of the engine from the cylinders, unless one had a boiler that would keep the cylinders properly supplied. A large purse was not of much advantage unless the bank account was capable of keeping it well filled. One of the

difficulties which locomotive engineers had to deal with was trying to pull very big trains at very high speeds. When a locomotive engineer made an engine that was capable of pulling a church, he was at once asked to hitch on the schools as well! What was required for running heavy fast expresses was to start with an engine of the dray-horse type, capable of exerting great tractive force, and quickly getting up the speed to about 50 miles an hour; then to take that engine off, and put on another of the quick trotter or high-flyer type. Of course that was impossible in practice, but it seemed to him that the four-cylinder compound, with plenty of adhesive weight, was likely to be a solution of the difficulty. A four-cylinder compound, with a boiler big enough to allow all four cylinders to work by high pressure, not for a short distance only, but for many miles when necessary, fitted with a simple arrangement which would allow the engine to be worked compound at will, might perhaps assist in the direction he had tried to indicate. The author was quite right when he said that there were two sets of opinions on locomotive matters; sometimes the drawing-office size of a blast-pipe was not *the same as the steam-shed size*. In 1895 he compounded one of the express engines on the Great Southern and Western Railway of Ireland, and that engine had been running ever since. The experience obtained with that engine went to show that the cost of repairs and renewals was not greater than with other non-compound engines. That bore out what the author said with reference to the cost of upkeep of compound engines, and with regard to fuel consumption he was informed by Mr. Coey, present locomotive engineer of the Great Southern and Western Railway, that the engine was no better and no worse than other simple engines doing the same work. In conclusion he congratulated M. Sauvage on his interesting Paper.

Professor L. P. BRECKENRIDGE said he was certainly very glad to step on the platform of the Institution of Mechanical Engineers. Within the last two or three years he had been interested in perfecting certain devices at the University of Illinois which, co-operating with certain of the trunk lines running through the

(Professor L. P. Breckenridge).

town, had been used to make some experiments with locomotives. The University engineers had been able to construct a test-car on what was called the "Big Four" railroad, and this had been in operation for two years, during which numerous experiments had been made with it. Before he left America, the Illinois Central Railway had completed a second railway test-car for the University of Illinois, in order that the University might co-operate with the railway in making certain tests. He had attended at a great many Railway Clubs in America, and was glad of the opportunity of seeing M. Sauvage and other gentlemen who knew about those things. He found in the Proceedings of the Institution, which were in his library from the initial volume of 1847, a great many things interesting to Americans about the construction and operation of locomotives. He had stepped off the steamer about twenty-four hours previously, and had gone directly to the locomotive. It looked really peculiar to him. It did not seem at first sight as if the engineers in this country knew how to build locomotives, although he expected they did. He found, as he grew older, he appeared to know less, and was inclined to think that by the time he had lived to be thirty or forty years older he might be able to see some things which he did not understand now as to the reason of the peculiar construction of locomotives which were seen in Great Britain and on the Continent. The question of the "Serve" tube had interested him a great deal. He had tested them in his laboratory, to determine their transmission of heat, as compared with that of plain tubes of different thicknesses and compositions. He was trying to carry out a series of experiments to determine the fall of heat through tubes of different sizes when coated with different thicknesses of scale. The question of feed-water for locomotives was a very serious one in America, and after six months' service, or sometimes after two months' service, scale on the tubes appeared to him to be occasionally one-eighth of an inch thick. Compared with compounding, this question of making steam, even with a large boiler, was of greater importance to them. He thoroughly agreed with the remarks that had been made as to there being two sides to the locomotive question. He had found that what one official in the

executive department thought right was not always in accord with the experience of the operator. The question of the best size of the exhaust, which was mentioned by Mr. Ivatt, had opened a question which had for some time been under investigation in the laboratory at the University of Illinois, and the members might be interested to know that recently one of his students had invented an exhaust-tip, which appeared new to him, but might be old with people in this country. Instead of the usual circular tip, it consisted of eight radial trapezoidal ports, aggregating 20 per cent. greater area than the usual circular area. Indicator diagrams and observations on the smoke-box vacuum had been made with those engines, and the eight blades of steam had been arranged with the idea of entraining between the blades the gases in the smoke-box. He thought that the action of the blast was largely due to two things—the jet action and the entraining action. In the new tip the entraining action was the most important part. It had been found to reduce the back-pressure against the piston at least 50 per cent. in a large number of the engines to which it had been applied, and at the same time the vacuum in the smoke-box had been actually increased. That had reduced the coal consumption in twenty-five locomotives over 7 per cent. It was now in use on over fifty engines on the Illinois Central. It had been put in within the last year, and he spoke of it more because it originated from the experimental work of one of the graduates in the department of Mechanical Engineering. The serious back-pressure of 12 lbs. to 18 lbs. per square inch had thus been considerably reduced. They had been thus far applied to simple engines, about 18 inches to 26 inches, and in all of these the fire seemed to burn much better. In America the cheapest coal that could be bought was frequently used on the locomotive. He thought that with the device described very little trouble had been experienced. There seemed to be a more uniform continuous draught through the fire than there was with the other intermittent and jumpy sort of draught.

Mr. BRYAN DONKIN, Member of Council, said there was only one question he wished to ask on the interesting Paper of M. Sauvage---

(Mr. Bryan Donkin).

for which the Institution ought to be very grateful—and that was with reference to the general economy of the compound over the ordinary locomotive engine. If he had understood it rightly, it was about 12 per cent. He did not understand whether in each case the cylinders were jacketed or otherwise, and also whether the pressure of the steam was about the same in the two sets of trials. To make a fair comparison, the pressures of steam in the boilers should be similar.

Mr. BOWMAN MALCOLM did not know that he could add very much to what had been said before, beyond stating that he was a "compound man." For the past ten years he had worked compound engines on the two-cylinder principle, and the economy found had been something over 12 per cent., but it was right to mention that the pressure was 15 lbs. greater in the compound than in the simple engines. As Mr. Ivatt had said (page 413) with regard to the engine he compounded on the Great Southern and Western Railway, there was no additional cost in maintenance, there were no additional working parts, and in every way the engines had proved most satisfactory. He had no experience of four-cylinder compounds, but he was inclined to agree with the statements made in the excellent Paper which had just been read, as he thought in future it was necessary to have larger engines. The weight of trains was continually increasing, and the accommodation given to travellers was very much in excess of what it was in former years, and he fancied the limit had been reached of the biggest engine it was possible to make with two cylinders. His own compound engines were all two-cylinder engines, and each was fitted with an apparatus by which it always started as a simple engine, high-pressure steam passing to both cylinders at starting, and in cases of emergency the driver had power to let the steam out of the reservoir on the high-pressure side of the intercepting valve, so that high-pressure steam continued to go to the low-pressure cylinder, and the full boiler-pressure was effective on the high-pressure cylinder—an arrangement which gave the engine a tremendously high starting power. It was only valuable however at very slow speeds, and was simply an

emergency valve, but it was found of very great advantage, especially in the case of goods engines.

He had used the Walschaert valve-gear for all his compound engines (both inside and outside cylinder), and found it in every way satisfactory; not only did this valve motion give a good distribution of steam at the various points of cut-off, but it was very easily and economically maintained; and in the case of inside cylinder engines, as only one eccentric is required for each cylinder, it gave ample room for long journals—the journals of the coupled axles of his engine being 11 inches long. With regard to the working of the engines, he wished to state that they were used for all kinds of traffic, express passenger, ordinary passenger, suburban, and goods, and owing to the peculiar circumstances of the line all classes of engines had a considerable amount of shunting to do—both passenger and goods—and in his experience they performed all classes of work, even the shunting, as smartly as simple engines, but many traffic officials were of a different opinion. This he attributed to the fact that the engines were less “fussy,” only beating twice per revolution instead of four times; in fact he had satisfied himself by repeated experiments that compound engines started as quickly, either light, lightly loaded, or heavily loaded, as simple engines of the same type and power. He also found that the emission of sparks—doubtless owing to the softness of the blast—was much less than in the case of simple engines, and doubtless from the same cause compound engines ran a much longer distance than simple engines without the fire being cleaned; and the accumulation of ashes in the smoke-box was much less. He wished to add his word of thanks to M. Sauvage for the very interesting Paper, which he thought would be a great addition to the information on locomotives already contained in the Proceedings of the Institution.

Mr. JOHN RIEKIE said it gave him great pleasure to be allowed to say a few words about the question of increase in cylinder capacity in locomotives, which he believed was the main cause of increase in the power. Taking, for instance, the largest of the four cylinders of the French engines that were now running, the increase in

(Mr. John Riekie.)

cylinder capacity was about 60 per cent. larger than could be had with a two-cylinder simple engine having 20-inch cylinders. That increase in power was no doubt looked upon as a substantial gain, especially when it was considered that it was effected without any increase in steam consumption, the same weight of steam being used over larger piston surface. If it was acknowledged that greater power could be obtained by an increase in cylinder capacity, then he failed to understand why locomotive engineers were adopting the very type of engine that prohibited them from increasing the cylinder capacity to its maximum limit. It was well known that the greater the area of the low-pressure cylinder the greater would be the power when a given volume of steam was used to a very low pressure. It was also known that the more work got out of the steam, the greater would be the economy, and to get that it was necessary to use as large a low-pressure cylinder as practicable, with as low a pressure of steam as possible. The adoption of the four-crank locomotives limited the diameter of the low-pressure cylinder to 24 inches, owing to the restrictions in gauge and leading dimensions. He thought the members would agree with him when he said that they could not expect very great power from such a low-pressure cylinder as one 24 inches in diameter, especially if steam of 15 to 20 lbs. was to be used in the cylinder. If on the other hand steam of a very high pressure was used, then the engine might be a very powerful one, but in his opinion would not be an economical one. He would try and show how it was practicable to get not only a greater cylinder power but at the same time economy in steam consumption. When designing an engine he adopted a three-crank one, but a very important feature was that the three cranks had to be placed at angles of 120° apart, for by so doing he could make use of very large high-pressure cylinders. Again he had had to adopt a new ratio of cylinder area to suit his system. In that way he was able to use up a given weight of steam for a larger piston surface than any system hitherto used. For instance, when applying the system to a locomotive he could use two high-pressure cylinders outside the frames having a diameter of 24 inches, and one inside the frames with a diameter of 38 inches. Those cylinders gave a piston surface

of 1,931 square inches, or 90 per cent. more than could be had with the four-cylinder engine under discussion. It had been said that the English locomotive had reached its limits of power, but he thought that such was not the case, and that there were means at hand by which it could be almost doubled. For the present light loads now hauled by engines, and often two engines, he would recommend an engine having two 20-inch high-pressure cylinders, and one 31½-inch low-pressure one, or 40 per cent. more than the four-cylinder engine which had been mentioned, leaving a fair margin for a future day to haul the heavy palatial Pullman cars that were being sent over from America. Two engines on that system were at work on the Indian State Railways, and were giving very satisfactory results.* He would be pleased to show any member a model of the pistons and cranks, which would show very clearly how he was able to get more work with a given weight of steam than could be obtained by any other system, which was applicable to all and every type of engine from a motor car to the largest and most powerful engine.

Professor WILLIAM H. WARREN, of Sydney University, said he was very sorry he had been asked to speak, as he had not been interested in such matters for years. He might just describe an experiment that was made some years ago in New South Wales. About five years ago he was made a member of the Royal Commission to enquire into the merits of certain engines from America which were made by the Baldwin Locomotive Co., of Philadelphia. Trials of those engines were made on the grades of one in forty and one in thirty, and indicator diagrams were taken. The water, coal, speed, and all the necessary data were measured as far as possible to get at the actual performances of the engine. About the same time a number of engines were made by Messrs. Beyer Peacock and Co., of Manchester, of exactly the same power—they were of the same size and about the same weight, the Beyer Peacock engine weighing 87½ tons, and the Baldwin engine 93 tons. They each had three

* "The Engineer," 20 July 1900, page 55.

(Professor William H. Warren.)

axles coupled, and a double bogie in front. They were designed for the same traffic, and were as nearly as possible the same. The performances were, however, somewhat different. The Beyer Peacock engine was capable of drawing a heavier load at a higher speed on the inclines. Both engines were carefully tested, and the curious thing was that the Beyer Peacock engine burnt very much less coal. He mentioned this matter because the Paper under discussion dealt with compound engines, and Messrs. Beyer Peacock also designed an engine exactly the same as the before-mentioned 10-wheel engine, and made it a compound engine. There was not space to put on a larger low-pressure cylinder, and consequently they had two low-pressure cylinders and one high-pressure. The boiler pressure was the same, and the engines were the same in every particular, and were tested under the same conditions. The result was that the compound engine indicated about 150 horse-power less than the simple engine. It certainly did not burn quite so much coal, but it would not give out the power, and so they had been converted back to the original type of engine. With the conditions under which the engines were used, the compound did not appear to have any very great advantages. Probably if instead of the two cylinders which were necessary on account of the space, one low-pressure cylinder had been used, there would have been better results, but it was not possible to do it under the circumstances, nor could it be done in this country on account of the existing station-platforms and other restrictions. Those were the facts, and he would not express an opinion upon them, because there were so many members present more competent to do so than he was.

Mr. WILLIAM SCHÖNHEYDER said Mr. Riekie (page 419) had mentioned that he had been able to obtain certain results, better than anybody else could, by having two high-pressure cylinders and one low-pressure cylinder. He did not remember quite the sizes which were mentioned, but it appeared to him that he added together the capacity of the three cylinders, and then because that capacity was large, thought he was therefore able to get very high

results. The capacity of a compound engine was practically measured by the capacity of the low-pressure cylinder, and if that cylinder was small it was impossible to get any high advantage from compounding.

Professor WILFRID J. LINEHAM said there was only one point to which he wished to call attention, and as the real question under discussion was economy, he did not think he was departing from the subject of the Paper. The members all knew that the most wonderful economy in land engines had been obtained when drop valves had been used. The slide-valve was known to lose a quantity of the engine's energy by steam leakage, but drop valves could always be kept tight. The old objection to drop valves was that they were not fit for rapid vibration, on account of their weight and the consequent hammering action. This had been proved no objection at all in the recent motor car experience. Such valves vibrated at an enormous rate, about 1,000 times per minute, and why therefore were drop valves not permissible on locomotives? He did not believe that he should at present have locomotive engineers with him; he believed they had an objection to drop valves, but he seriously thought such valves should be tried, and he expected to find the before-mentioned economy by their use. He should further like to draw the attention of the members to the intimate connection that appeared to exist, according to Professor Breckenridge (page 413), between the engineering schools and the railway lines in America.

Mr. JAMES E. DARBISHIRE said there was a little information he might be able to add to what had been said about compound engines. Professor Warren (page 419) had mentioned an experiment made on the New South Wales Railways with an engine that was hardly a fair example, because it was built under restricted conditions as regards space, and therefore the builders, Messrs. Beyer Peacock and Co., with whom he was connected, had to put two low-pressure cylinders instead of one, and as Professor Warren said, it handicapped the engines to some extent. Another reason was that the pressure in the compound engine was the same as it was in the simple, and therefore

(Mr. James E. Darbishire.)

the engines were not quite under equal conditions. A compound engine was naturally a means of using a higher pressure than could be used in a simple engine. He might mention that some other engines were built by the same firm for a railway abroad; the first was simple, but as the superintendent, who was not in favour of compounding at all, was desired by his directors to try compound engines, a second was built at the same time, exactly the same as the simple, excepting that it had a higher pressure, and was compounded on the Worsdell and von Borries' system. The compound engine gave very considerably better results in economy of fuel than the simple engine. Therefore the superintendent, who was an Englishman, began to think about it, and concluded that it was only on account of the higher pressure; he then ordered a simple engine of the same type with the higher pressure—the same pressure as the compound. That engine gave very much better results than its sisters with the lower pressure, as was to be expected, but it was not quite equal to the compound engine. The superintendent at last came to adopt the compound entirely, and all his engines on that line had been since compounded. The case there was one to which Mr. Aspinall had alluded—of pulling a big train without stopping. It was only a metre-gauge line, but the trains were made up to as much as the engines would take; the inclines were heavy, and the curves sharp, and it was hard collar work for perhaps 15 or 20 miles at a time, then a short run down, and then more collar work. It was all hill climbing with a big train. There it seemed that the compound engine obtained an advantage. The same thing had been found in the Argentine Republic on the broad gauge, where they had enormous trains with very level lines; the engines were steadily "pegging away" for miles without stopping. But when the compound engine had been introduced, as it had been frequently, for what might be called local service, it did not seem to answer. It might work perfectly well, but the economy was not there. He was speaking entirely of the two-cylinder system of compounding, because he had never had any experience of the four cylinders. The latter system might, and very likely would, answer quite as well as the

two-cylinder system, and it seemed to him to have advantages on 4 feet 8½ inch railways such as had to be dealt with in this country and in France, because it was not possible with comfort to get two large cylinders in between the frames. His friend Mr. Malcolm had gained very satisfactory results with inside cylinder compound engines, but he had a 5 feet 3 inch gauge, which was much larger than the gauge in this country. It made a great difference if it was possible to get plenty of bearing surface for the axles by having a broad gauge. That could not be had in this country, and therefore it seemed to him it was necessary to use three or four cylinders if compounding was to be done. He desired to ask M. Sauvage whether on any of the French railways a type of tank engine had been adopted, which was common in this country. He had never seen one in France, but then he had not travelled much there. He referred to the type of suburban engine with four wheels in front coupled, and a four-wheel hind bogie. It was very common in this country, and, so far as he had been informed, a very successful type.

Mr. J. D. TWINBERROW wished to say a few words upon one point in M. Sauvage's excellent Paper which he considered constituted the chief merit of the four-cylinder compounds as developed with such success in France, namely, the self-balancing of the reciprocating parts. He did not think there could be two opinions amongst railway engineers as to the desirability of completely balancing the reciprocating parts for high-speed work. He believed that the designs originated by M. de Glehn provided for the balance of the primary forces only, leaving the couples unbalanced. At the time when Mr. Yarrow was achieving a notable success by balancing high-speed marine engines by applying reciprocating bob-weights, he, the speaker, ventured to throw out the suggestion that the same end might more readily be attained by adjusting the masses of the reciprocating parts, and by selecting suitable angles between the cranks, in order that there should be self-balancing of multi-cylinder engines. He noticed M. Sauvage referred to the fact that these engines would start better without an intercepting valve, if the

(Mr. J. D. Twinberrow.)

angle between the adjacent high and low pressure cranks diverged somewhat from 180° , but when that divergence had been tried the balance had been interfered with. In view of the conspicuous success which Messrs. Yarrow and Co. had obtained in working out the self-balancing of engines, and because a compound four-cylinder locomotive would start better, and have a more even torque with that arrangement of angles between the cranks, he should like to ask M. Sauvage whether it had ever been considered advisable in France to apply that method of balancing (now known as the Yarrow, Schlick, and Tweedie system) to the locomotive, in order that not only the primary forces but also the couples and secondary forces due to angularity might be completely balanced. He also wished to point out that it was very undesirable to couple, as had sometimes been done, four cylinders on to one driving axle. That increased the stresses on the crank axle, and also those on the coupling rods, and it did not in any way improve the balance. The correct principle was undoubtedly that which had been adopted throughout the four-cylinder engines built in France, of coupling the high-pressure cylinders to one axle, and the low-pressure to another. It was interesting to observe that the consumption of lubricating oil for the four-cylinder engines had not gone up as compared with the simple engines. He did not think the same could be said for any other class of compound engine. If he could venture to prophesy he would be inclined to think that the next development would be the enclosing of the working parts, and the supply of oil under pressure to every joint. The system which had been so successful in stationary work, if applied to the locomotive, would lead to an increase in mechanical efficiency, dispensing largely with wear and tear, and, more important than all, would enable a better daily mileage to be obtained from engines, because it would eliminate a very considerable portion of the time occupied by the engine men in attending to trimmings, oiling up, and wiping up the four or five drops of oil that were wasted for every one that did useful work. With respect to coal consumption, he did not think any compound engine had surpassed the relative results that had been achieved by the compound goods engine of Mr. T. W. Worsdell. Compared with modern standards

they were only a low powered class, but they could be relied upon, when not hampered by frequent stoppages or much shunting, to show a saving of about 16 per cent. as compared with a similar class of engine with simple cylinders. They had special starting valves, which enabled them to make one stroke as ordinary engines. They were not handy in shunting, and were slow in starting, but if they were fitted with a simple form of intercepting valve between the cylinders, of the type used on the Northern of France Railway, as illustrated in the Paper, it would enable them to get away and to shunt as ordinary simple engines, and in all probability the type would then be much more widely adopted. He thought M. Sauvage would agree that in connection with nearly all classes of traffic it should be said that "*Le démarrage doit être rapide !*" and unless it was so, it was impossible to get economy with a compound engine where the stops were at all frequent and where shunting had to be done.

Mr. ALFRED SAXON said the one point that had struck him most about the discussion was that while locomotive engineers were looking about them for larger cylinders and larger boilers, they seemed to be overlooking one fact entirely, namely, that this was an electrical age. Although an electric locomotive had proved more or less of a failure, still he thought locomotive engineers ought to be considering the application of electricity to train traction in this country, especially as it was such a small country. America was so large a country that it could hardly tackle such a question as the electric traction of trains, but it was possible to do so in this country, and he was rather surprised that locomotive engineers were looking to every other source but the source which they would have to deal with before long.

M. SAUVAGE, in reply, said, although many interesting remarks had been made on the Paper, he would confine himself to the more direct questions, as time was much limited. With regard to the chief point, coal consumption, he had been asked whether it must be expected to find in practice the 10 to 15 per cent. economy, which had been proved in nearly all experiments. That was a difficult

(M. Sauvage.)

question to answer with precision, because the working conditions differed so much from the experimental conditions. Every time a compound locomotive had been compared with a simple one under similar conditions, economy of steam had been found to be 10 to 15 per cent. ; nearly every published experiment agreed in that respect. In actual practice was it possible to guarantee that, by using a compound engine, 10 or 12 per cent. of coal would be saved ? This had been found in actual practice,* but of course it depended on the working conditions. As a rule the compound engines replaced ordinary locomotives which were less powerful. With heavy trains, some economy might result merely from the use of a more powerful locomotive with a larger boiler, an economy which was quite independent of the system used—simple or compound. On the other hand, if large compound engines were used to take light trains, the consumption might be unduly increased. In fact, the coal consumption depended in some respects upon the use which was made of the locomotive ; it was naturally expected that the locomotive would be used as intelligently as possible. Still, in some cases the working conditions would not always allow the best utilisation of locomotives. For these reasons it might be sometimes difficult to prove that in practice an economy of 10 to 12 per cent. resulted from the use of compound locomotives, but everything tended to show that it existed. Taking for instance the Western Railway of France, the engineers of that line thought that, when it was suggested to build the four-cylinder compound engines, they could guarantee that the cost, taking everything into account, would not be greater than with less powerful simple engines ; they even believed the cost would be a little less. With these four-cylinder compounds the initial cost was a little higher ; the cost for repairs was the same, and the cost for fuel less, thus compensating largely for the higher initial expenditure.

Another question was, were the compound locomotives fit for trains which frequently stopped ? Compound locomotives had not yet been used in France for suburban trains (Mallet engines

* See page 431.

excepted), but in some cases they took ordinary trains, which made frequent stoppages, and in those cases they were found to work well. As the number of these locomotives did not at present amount to 10 per cent. of the whole stock in France, and as they were the best and most powerful, they were generally used for the more important passenger and goods trains; but there was no objection in principle to making use of them for ordinary trains. The starting mechanism, which transformed the compound into a locomotive with four single cylinders, was in fact not much used. In many cases the locomotive could start without working that device at all. When the special starting apparatus was worked, it was in most cases only for one or two revolutions, so that the extra steam consumption could not be very large on that account, and nevertheless a good speed might be attained in a short time, which was of capital importance, as remarked by Mr. Twinberrow. Of course there was always the loss of heat while the locomotive was standing, or running down a grade without steam on, and that slightly lowered the percentage of economy due to compounding. Mr. Donkin (page 416) asked if the steam pressure in the boiler was the same in compound and ordinary locomotives. The steam pressure has been generally a little less in the ordinary locomotive, namely, 12 kilogrammes per square centimetre for ordinary locomotives of the latest construction, instead of 14 or 15 with the compound. Although from this higher pressure may result a saving not due to compounding proper, in the ordinary locomotive with single cylinders it was rather difficult to make use of such a high pressure, at least with the ordinary mechanism for distributing steam. It must be regarded as an advantage of the compound system that it permitted the use of a very high pressure, which could not be used in the old engine with the ordinary valve motion. The cylinders were not jacketed; and it was a great pleasure to have heard that such an able engineer as Mr. Aspinall had succeeded in applying jackets, which certainly were very good additions. It was only from difficulties in construction that as yet they had not been more used.

(M. Sauvage.)

With regard to the best size of cylinders, certain average dimensions were generally adopted for a given class of locomotives, according to the size of the boiler; but these dimensions could not be calculated to an extreme nicety, and the cylinders might be a little smaller or a little wider than the average. From his own practice, it seemed advisable to have cylinders a little too small rather than too large; pressure was more easily maintained in the boiler, and, under ordinary circumstances, the engine worked better. No definite rules could be laid down in that respect.

A question had been put as to the balancing of the engine, which was a most important question. The balancing of the four-cylinder compound was not complete. Only the reciprocating parts were balanced, and not completely, as the parts moving in opposite directions were in different planes; but with the four-cylinder compound system the balancing was better than on the ordinary locomotive.

With regard to the use of tank engines with coupled wheels in front and a bogie (page 423), that type was not employed in France. The nearest approach to this type was seen in some locomotives, used on the Northern Railway with three-coupled axles under the boiler and a bogie in the rear. The last question was with regard to setting the two cranks for the high pressure and for the low pressure. Engines had been made by one railway company to dispense with a starting apparatus, by setting the corresponding high and low pressure cranks at a different angle than 180 degrees; but now every one agreed that the balancing was of greater importance than the saving of a small starting apparatus. This special setting of the cranks had been abandoned in the latest designs. In conclusion, the author thanked the members for their kind appreciation of his Paper.

The CHAIRMAN, in moving a hearty vote of thanks, which was accorded to M. Sauvage for his interesting Paper, hoped that he would reply in writing to any other point which had been raised in the discussion.

Communications.

Mr. DUGALD DRUMMOND wrote that he had read M. Sauvage's Paper with some interest, but regretted to find no information to enable an opinion to be formed in comparing the two systems of locomotives dealt with in his Paper. It would therefore be interesting if the author would kindly give full particulars as in Tables 1 and 2 (pages 398-407) of the two-cylinder engines of modern type which were being replaced by four-cylinder engines, supplementing it with the train load, speed, and a complete set of indicator diagrams of both classes of engines working express trains, the coal consumption per horse-power per hour and the coal consumption per ton of train per mile.

He noticed that the economy in coal consumption of 12 per cent. of the Ouest 501 series over the 900 might be almost entirely due to the difference in boiler pressure, which was 28 lbs. per square inch higher in the four-cylinder than in the other. In order to make comparisons, and to form a correct judgment as to the system now adopted in France being comparable with the practice adopted in this country, with a view to economy, it was absolutely necessary that the engines should be working under similar conditions.*

Mr. DAVID JOY wrote that, when he excused himself at the Meeting from entering into the discussion on M. Sauvage's Paper, he was so deeply interested in listening to the information being given on the question by the many able and practical men who spoke on the subject, that he quite forgot his own obligations to his fellow-members, and that he had something to say on the compounding of locomotives, a subject in which he had been practically interested from the first, as well as in the allied and earlier question of compounding at sea. He regretted to note the confirmed report of a saving of only 12 per cent., which admittedly only covered extra expenses, while in marine practice the application of compounding and triple compounding had proved to be the life of the steam-engine at sea.

* See also pages 416, 420, and 422.

(Mr. David Joy.)

He had had the good fortune, after a lengthened and practical connection with railway working, to be placed in a somewhat similar connection with marine work, and thus to have been in touch with some of the early applications of the compound system at sea. From the first these gave much more satisfactory results than 12 per cent. saving in fuel, as well as more promising prospects, which had been in every way realized. Referring to the early applications and the subsequent treatment of compounding at sea, and on the rails, it would have to be admitted that the system had had a far better chance on the former than on the latter. To quote one of the earliest cases at sea, namely the application of this system to the steamers of the Pacific Steam Ship Co., by Messrs. Elders:—the engines were entirely renewed on designs to meet the new requirements for steam; the pressure and the piston area were doubled, thus affording a large margin for the employment of a degree of expansion. The result was an increased speed on half the consumption of fuel, which had been followed up, and greatly advanced upon; while in the earlier locomotives, in which the ordinary boilers, or those slightly strengthened, were used, the pressures were but little raised above that usually employed, the piston-area being increased only about 50 per cent., and having but a slight margin for increased expansion and little room for saving fuel. The practice had not been enlarged upon to any considerable extent since, and nothing to allow of the high degree of expansion that might be advantageously employed at the high speeds run, and the consequent high piston-speed attained.

The writer thought that the solid advances made at sea in every direction gave certain promise of at least a large advance in the same direction on the rails, but it would be by the employment of much higher degrees of expansion, which meant a higher pressure and a larger piston-area. He had held for a long time that there was a far better result to be obtained on the rails than the standard 12 per cent., by following more nearly in the course adopted at sea.

M. SAUVAGE wrote that on the Western Railways, as was customary in France, a certain allowance of coal was made,

calculated after the average work of each engine, and premiums were paid to the crews for economy on these allowances. These consisted of two parts, a fixed weight of 4·5 to 5 kilogrammes (9·92 to 11 lbs.)* for each kilomètre of train, and a certain weight for each ton carried at a distance of 1 kilomètre. This second part varied from 38 to 50 grammes (1·25 to 1·60 ounces) for each ton-kilomètre. The figures differed for express, ordinary, and goods trains, and were the same for all engines from one running shed, according to the local conditions of service; but for the two-coupled compounds a reduction of 5 per cent. on these last figures had been made, and of 10 per cent. for the three-coupled compounds. Notwithstanding the coal premiums paid, economy of fuel with these compounds was rather high, and a further reduction might take place.

The actual consumption in 1899 was, for the ordinary express locomotives (series 900) and for the two-coupled compounds (Nos. 503-522), as follows:—

	Compound Locomotives.	Ordinary Locomotives.
Total No. of kilomètres run	533,452	978,599
Average weight of trains, in tons (1,000 kg.) .	185	127
Kilogrammes of coal per kilomètre	9·25	9·23
„ „ per 100 tons × 1 kilomètre†	5	7·22

M. Baudry, Engineer-in-chief (locomotive superintendent) of the Paris-Lyon-Méditerranée Railway, had kindly furnished the author with the following information, which was of special importance, as this railway had been using a large number of four-cylinder

* These figures were calculated for a standard quality of coal; they varied after a fixed proportion when other qualities were burned.

† That is—per one hundred metric tons carried a distance of one kilomètre.

(M. Sauvage.)

compounds for several years. He said that, "although the comparison between compound and ordinary locomotives was influenced in practice by the numerous differences of the old and new types of engines, the same advantages were found in actual service and in trials, namely 7 to 16 per cent. economy of fuel, according to the type of engine."

A satisfactory reply to Mr. Dugald Drummond's question (page 429) would involve a complete study of the compound locomotive as compared with the simple one. The author felt flattered by such a question, which however went beyond the scope of his present Paper, which merely intended to give a short account of locomotive design in France. He hoped to be able at some future time to publish such a comparison as that desired by Mr. Drummond. Such a publication would require the careful perusal of a large number of documents and some new experiments. Although very desirous of responding to the great attention paid to his Paper, he felt, after a careful consideration of the question, that at the present time he could give only an insufficient answer to the question.

Mr. Drummond was quite correct in saying that for a fair comparison it was absolutely necessary that the engines should work under similar conditions. But it was very difficult to realise these conditions. There were, in nearly all cases, differences between the locomotives compared, other than the use of simple or double expansion, and in regular service the weights, speeds, and atmospheric conditions frequently varied. It seemed that a really precise study would require special tests in a laboratory, where all conditions might remain unaltered for any length of time, and might be modified one by one. The expense of such experiments would certainly be great, but that difficulty could be easily surmounted if the leading railway companies of one country would agree to contribute for this object of common utility.

Mr. Joy (page 429) had remarked that the saving of 12 per cent., which resulted from the use of four-cylinder compound locomotives, was low when compared with the economy that attended the introduction of the compound system in marine engineering, which

no doubt was due to the very variable conditions of locomotive service. The power and speed of locomotive engines seldom remained constant for any length of time. Frequently they worked with a degree of expansion, which was far from being the most economical. A certain waste, which of course was the same with ordinary and with compound locomotives, resulted from periods, sometimes prolonged, when the locomotive fire was standing idle. Greatly enlarging the cylinders of the locomotive, with a view to expanding the steam more completely, seemed hardly practicable in a non-condensing engine, where the pressure at the end of the expansion must in no case fall below that of the atmosphere.

Fig. 1. No. 701, Nord.

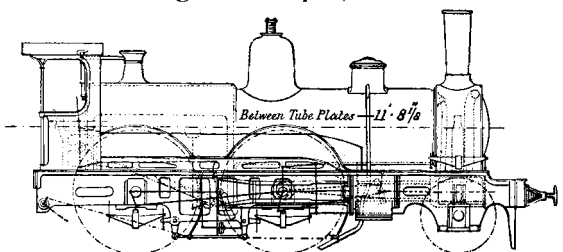


Fig. 2. Nos. 2161—2180, Nord.

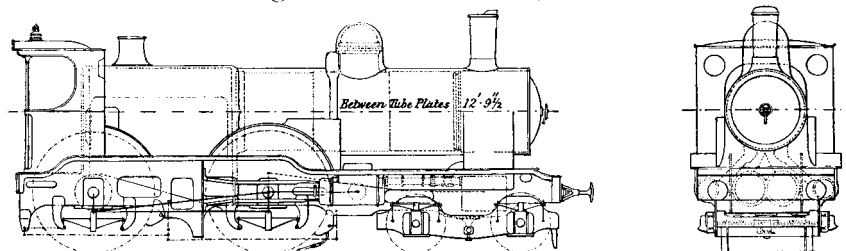


Fig. 3. Nos. 501 and 502, Ouest.

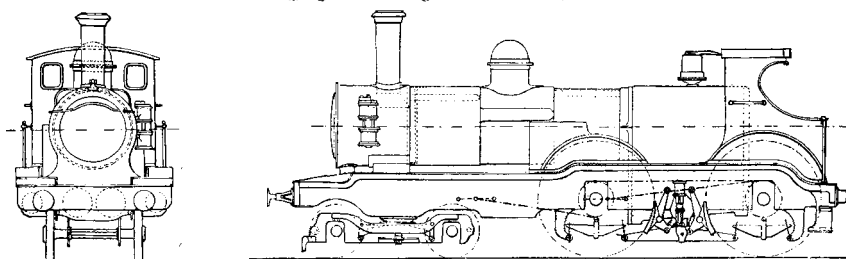
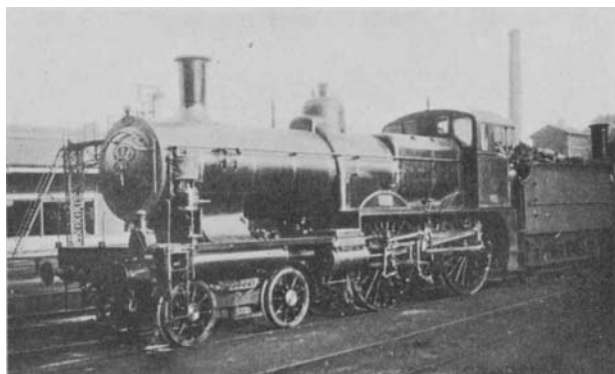


Fig. 4. No. 508, Ouest.



Mechanical Engineers 1900.

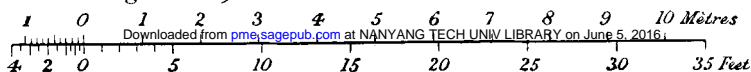


Fig. 5. Nos. 2138—2157, Nord.

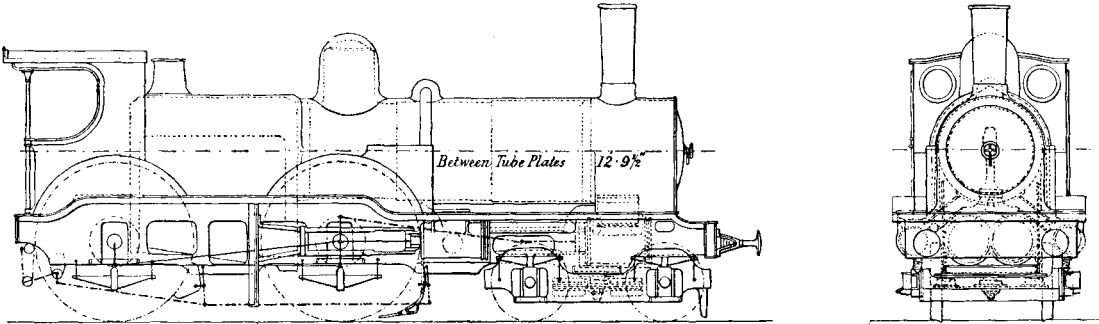


Fig. 6. Nos. 503—542, Ouest.

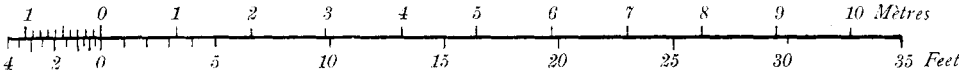
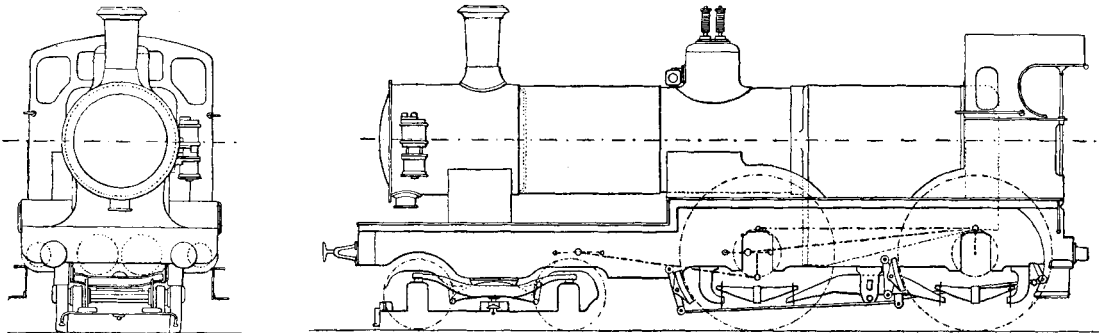


Fig. 7. Nos. 1701—1714, *Midi.*

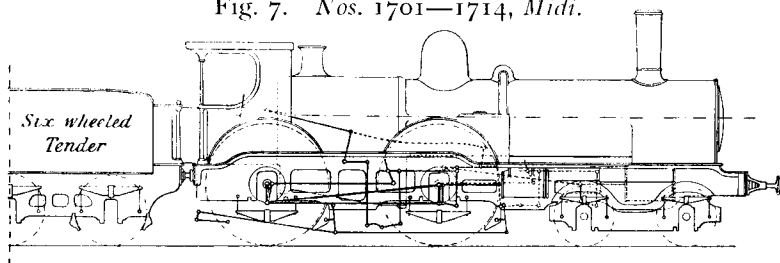


Fig. 8. Nos. 1751—1774, *Midi.*

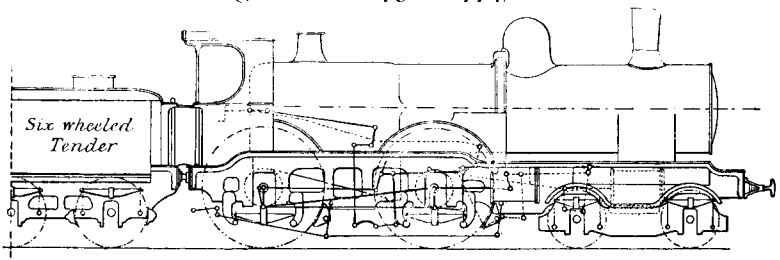


Fig. 9. Nos. C 61—150, *Paris-Lyons-Méditerranée.*

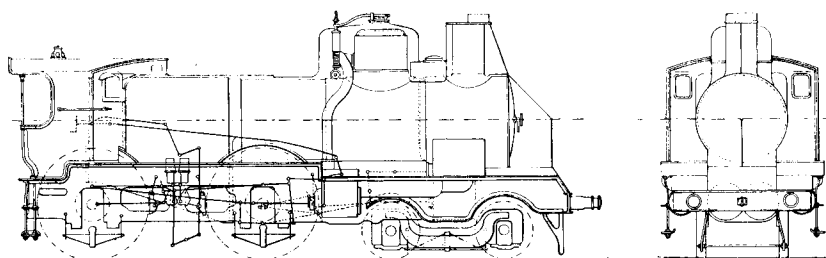
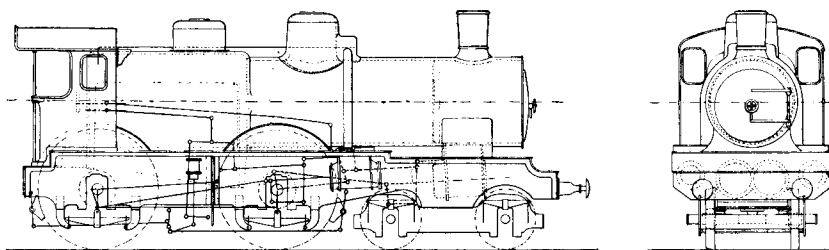


Fig. 10. Nos. 2401—2432, *Est.*



Mechanical Engineers 1900.

FRENCH LOCOMOTIVE PRACTICE.

Plate 46.

Fig. 11. Nos. 2641 and 2642, Nord. "Atlantic" type.

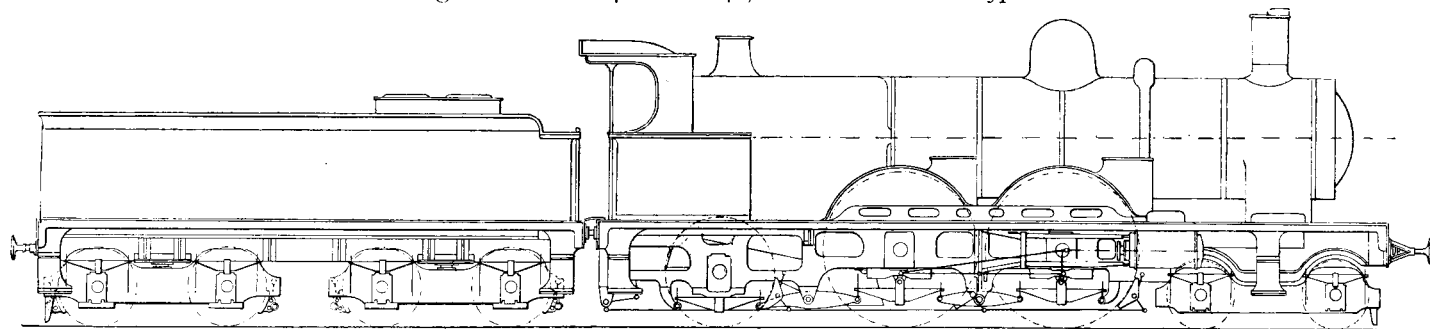
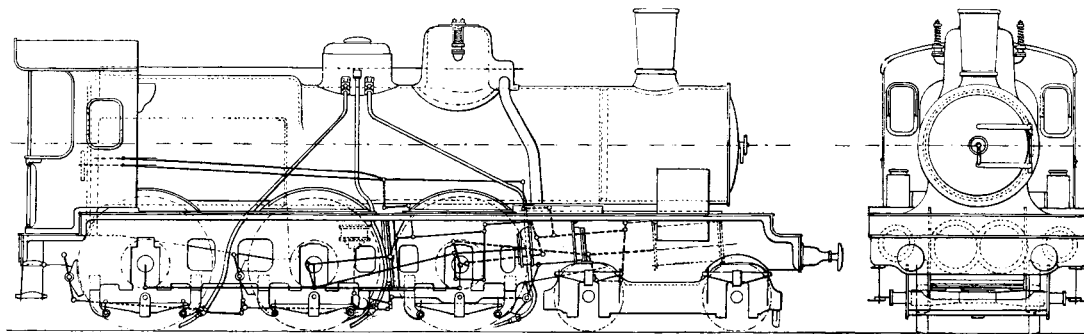


Fig. 12. Nos. 3401—3450, Est.



(Scale see
Plate 44.)

Fig. 13. Nos. 3121—3170, Nord.

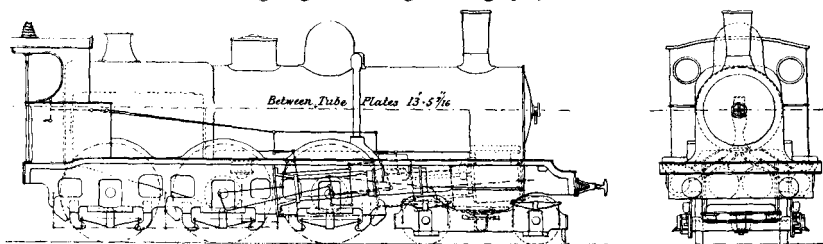


Fig. 14. Nos. 2501—2525, Ouest.

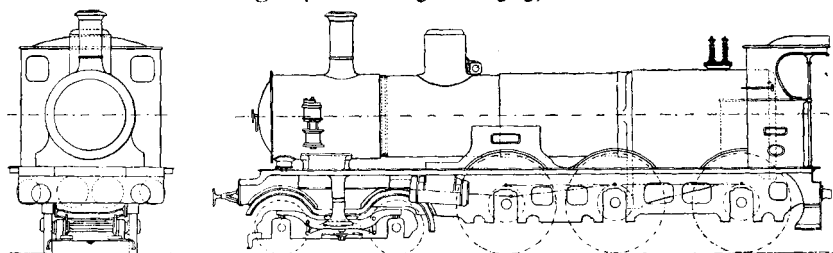


Fig. 15. No. 2504, Ouest.

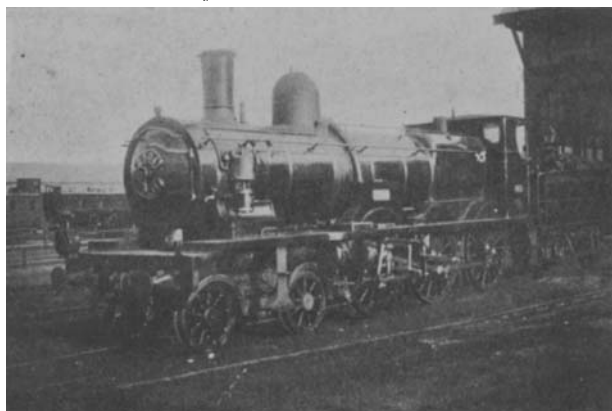
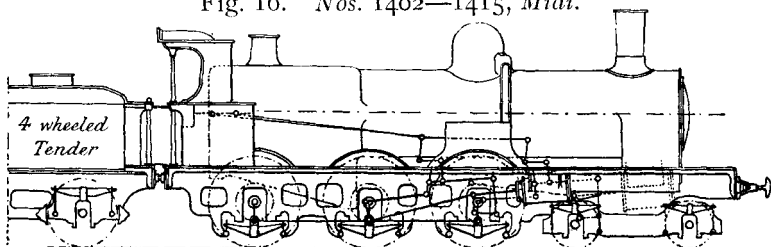


Fig. 16. Nos. 1402—1415, Midi.



Mechanical Engineers 1900.

Fig. 17. Nos. 1303—1312, *Midi.*

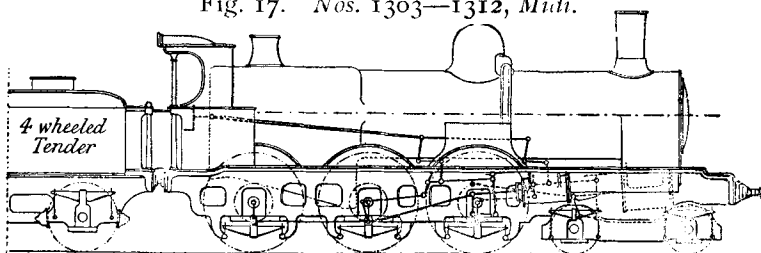


Fig. 18. Nos. 3401—3550, *Paris-Lyons-Méditerranée.*

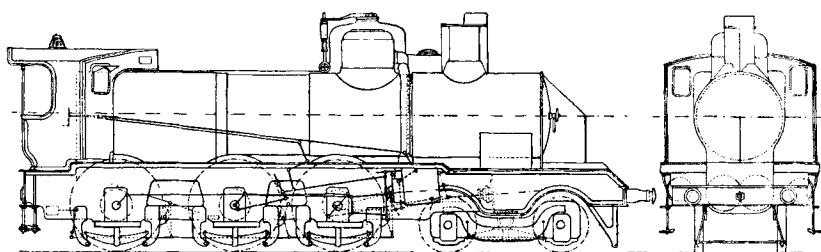


Fig. 19. Nos. 4521—4530, *Paris-Lyons-Méditerranée.*

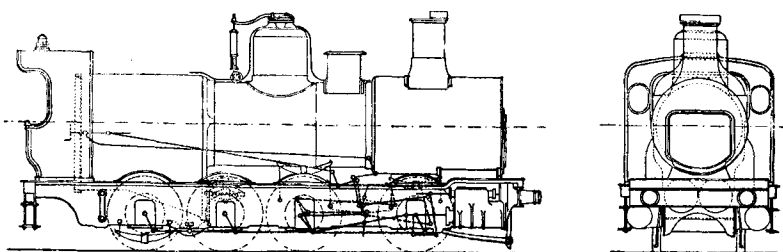
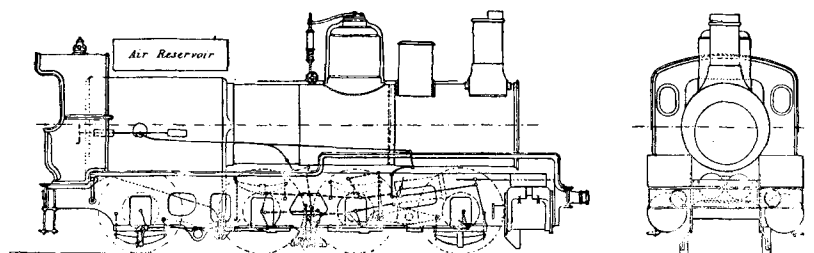


Fig. 20. Nos. 3211—3260, 3301—3362, *Paris-Lyons-Méditerranée.*



Mechanical Engineers 1900.

FRENCH LOCOMOTIVE PRACTICE. *Plate 49.*
Reversing Gears for 4-Cyl. Compound Locomotive.

Fig. 21. *With parallel screws.*
Scale 1/8th.

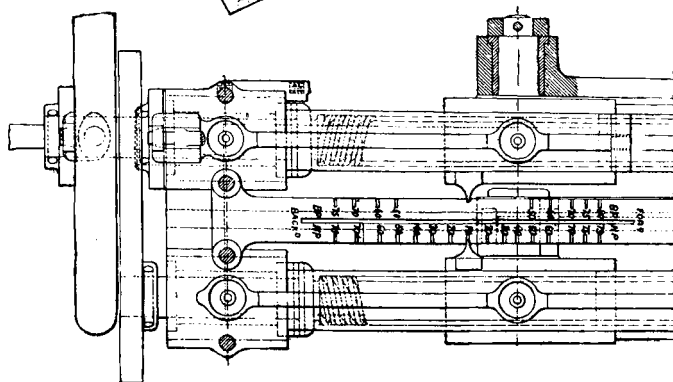
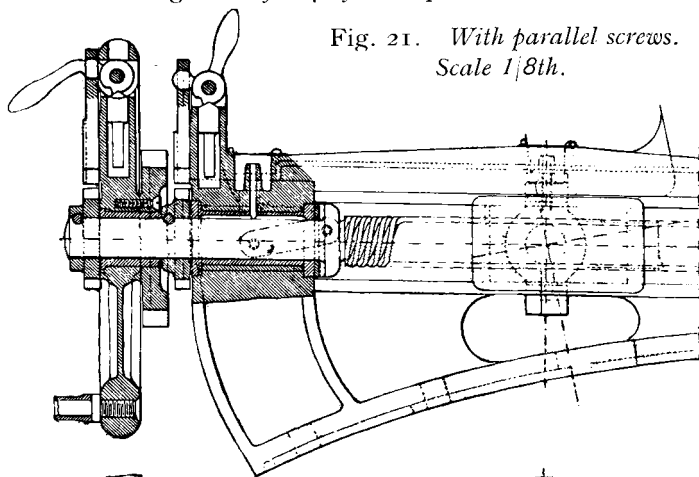


Fig. 22. *With Fine-Screw Adjustment.*

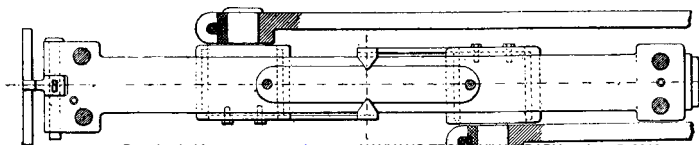
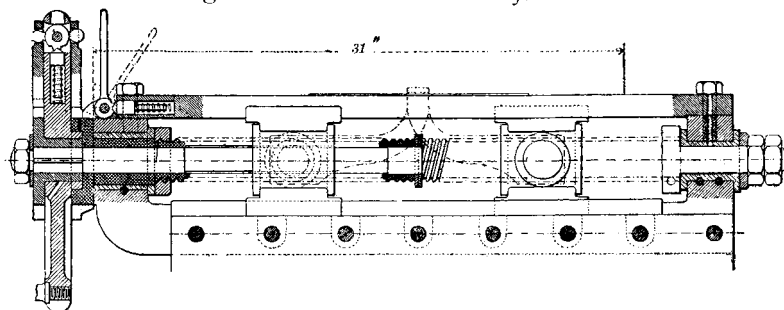


Fig. 23. *Starting Gear of the Société Alsacienne
with Mechanical Cut-off Gear
for 4-Cylinder Compound Locomotives.*

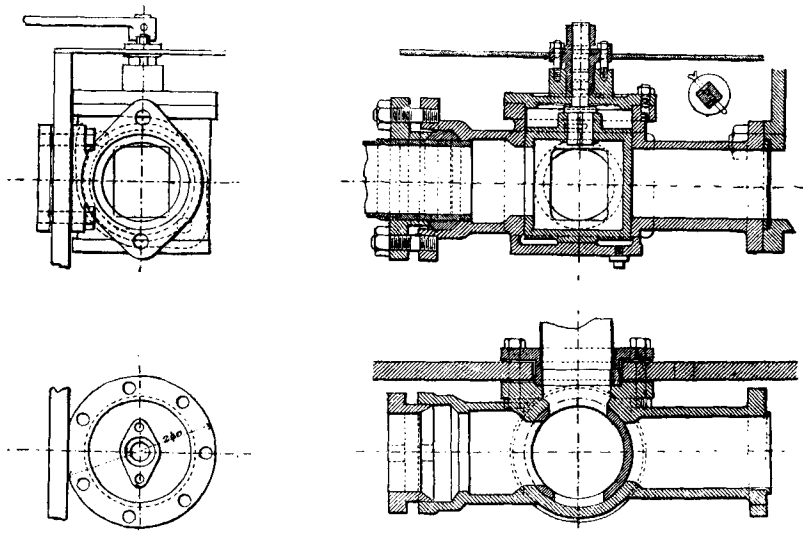
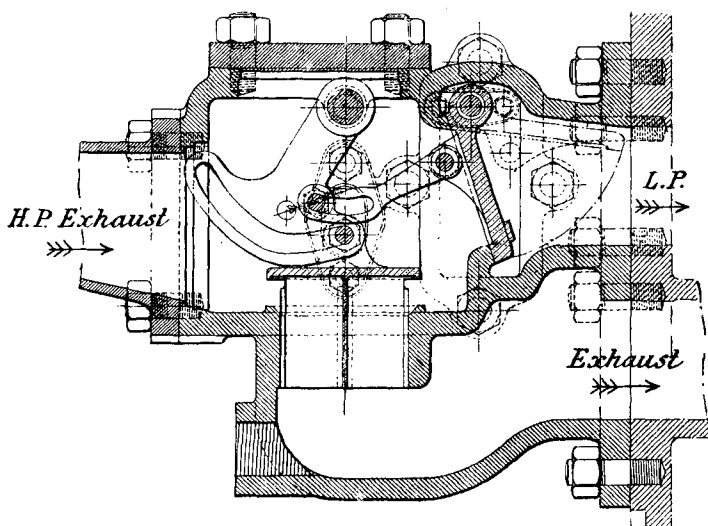


Fig. 24. *Starting Gear of the Est
for Compound Locomotives.*



FRENCH LOCOMOTIVE PRACTICE. *Plate 51.*

Fig. 25. Nos. 2861—2911, Nord. 1877 Type.

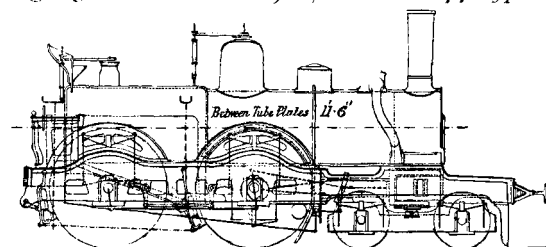


Fig. 26. Nos. 939—998, Ouest. 1889 Type.

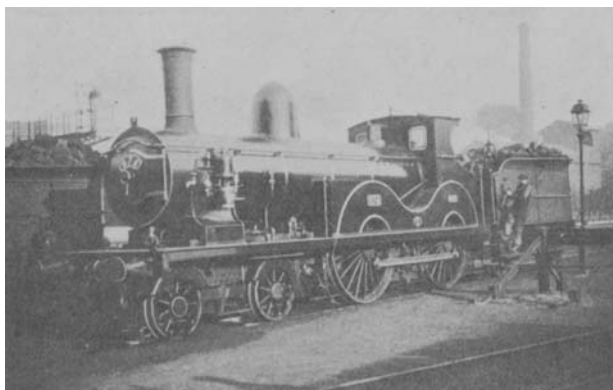


Fig. 27. Nos. 2602—2620, Etal. Bonnefond's Valve-gear.

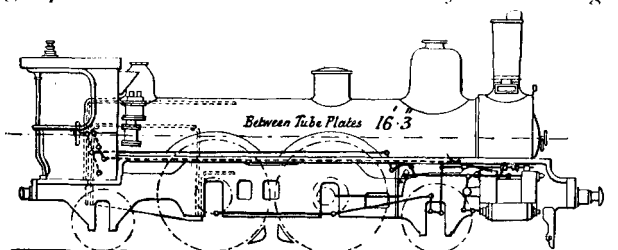
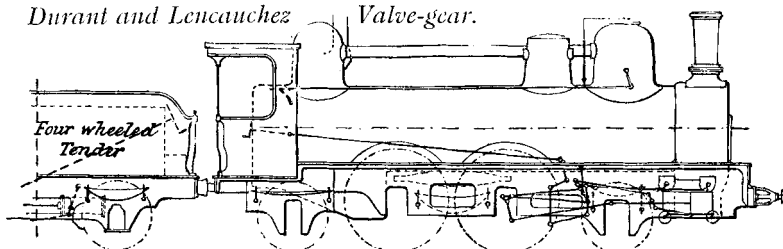


Fig. 28. Nos. 576—583, Paris-Orléans.
Durant and Lencauchez Valve-gear.



Mechanical Engineers 1900.

Fig. 29. Nos. 112—400, *Paris-Lyons-Méditerranée*.

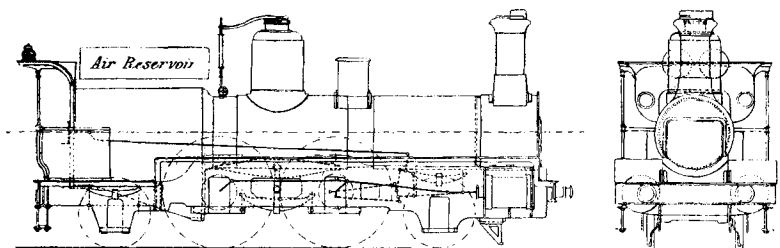


Fig. 30. *Paris-Lyons-Méditerranée*. Rebuilt with bogie.

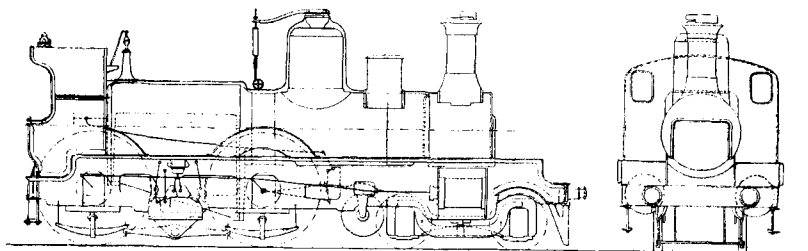


Fig. 31. Nos. 801—840, *Est*. Bogie with *Flaman* Boiler.

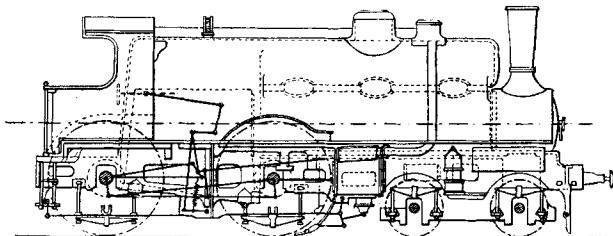
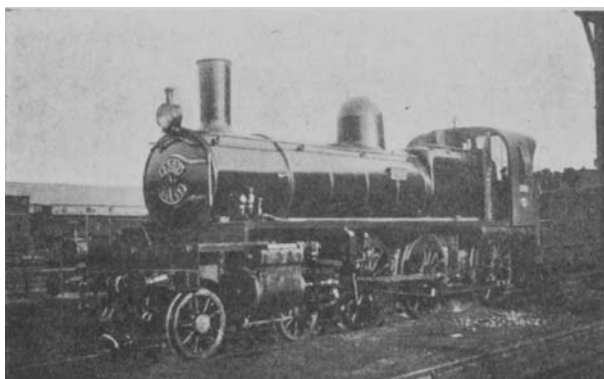


Fig. 32. Nos. 2301—2304, *Ouest*.



Mechanical Engineers 1900.

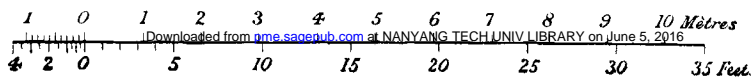


Fig. 33. Nos. 4046—4075, 4001—4005, 4636—4990, *Nord*.

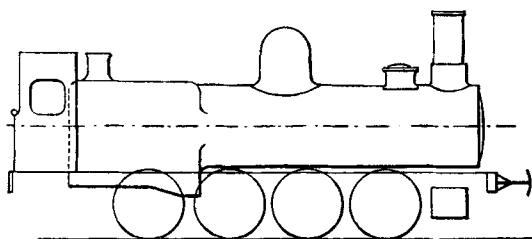


Fig. 34. *Nord*. 2-axles-coupled. *Bogge*. Tank.

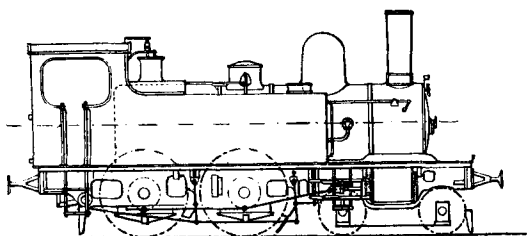


Fig. 35. Nos. 221—230, *Étal*. Van.

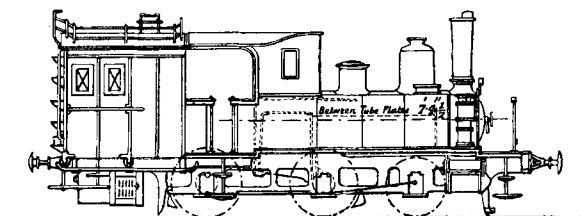
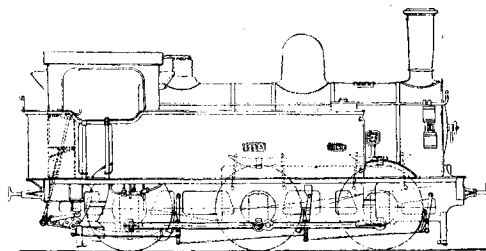


Fig. 36. Nos. 3001—3031, 3501—3602, *Ouest*. Tank.



Mechanical Engineers 1900.

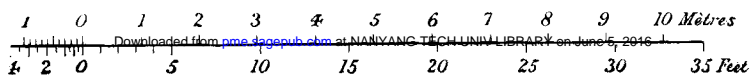


Fig. 37. Nos. 3701—3725, Ouest. Bogie. Tank.

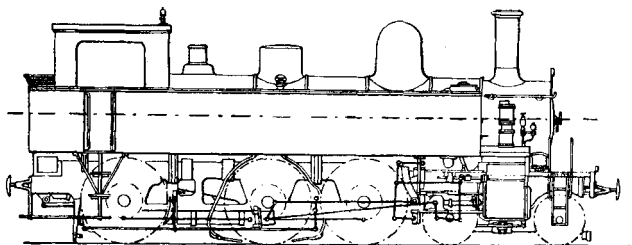


Fig. 38. Nos. 684—742, Est. Tank with a carrying axle.

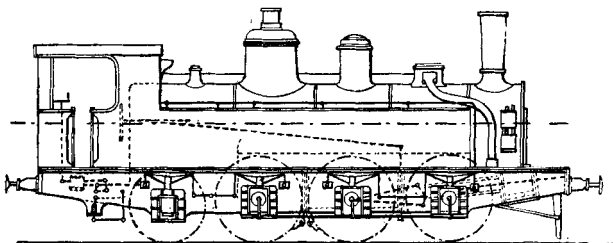


Fig. 39. Est. Rebuilt with leading-bogie.

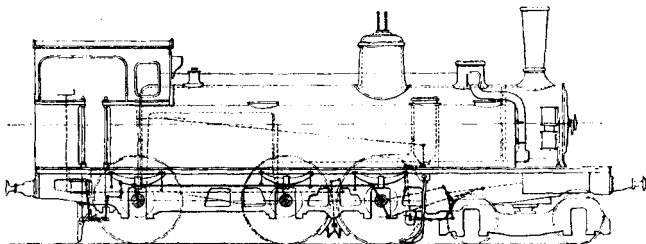
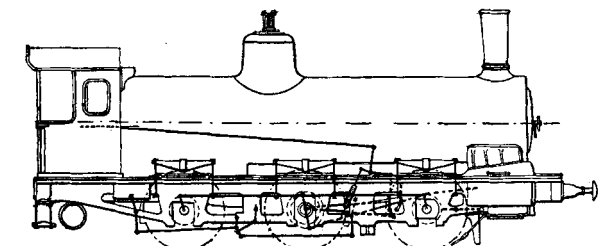


Fig. 40. Nos. 1002 and 1003, Est.



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Fig. 41. Longitudinal Boiler Joint for Unequal Lap.

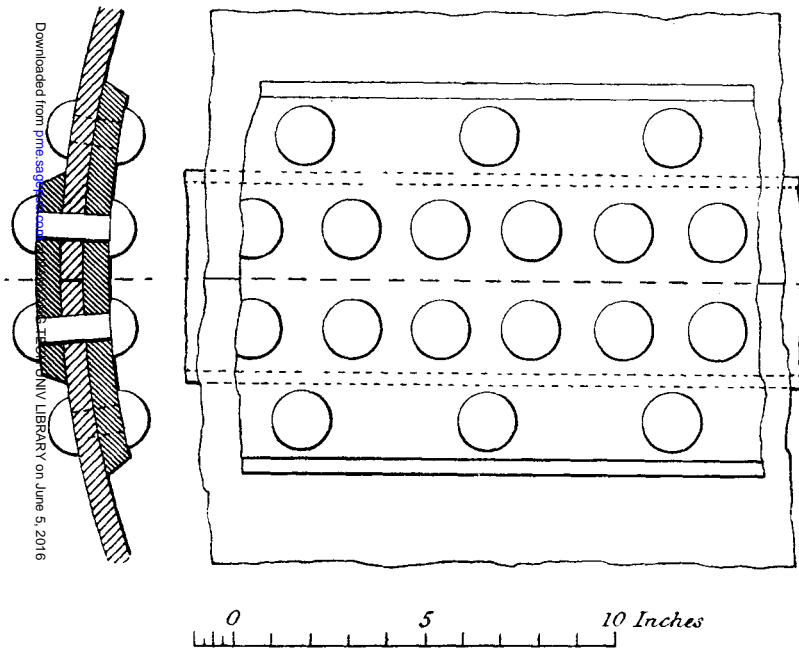


Fig. 42. Ouest. Valve-Gear showing Valve.

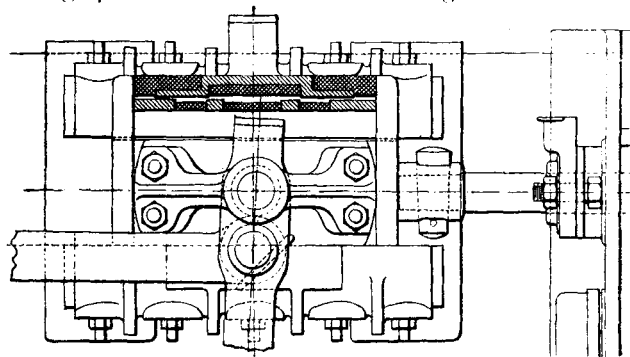


Fig. 43. Tyre Fastening.

