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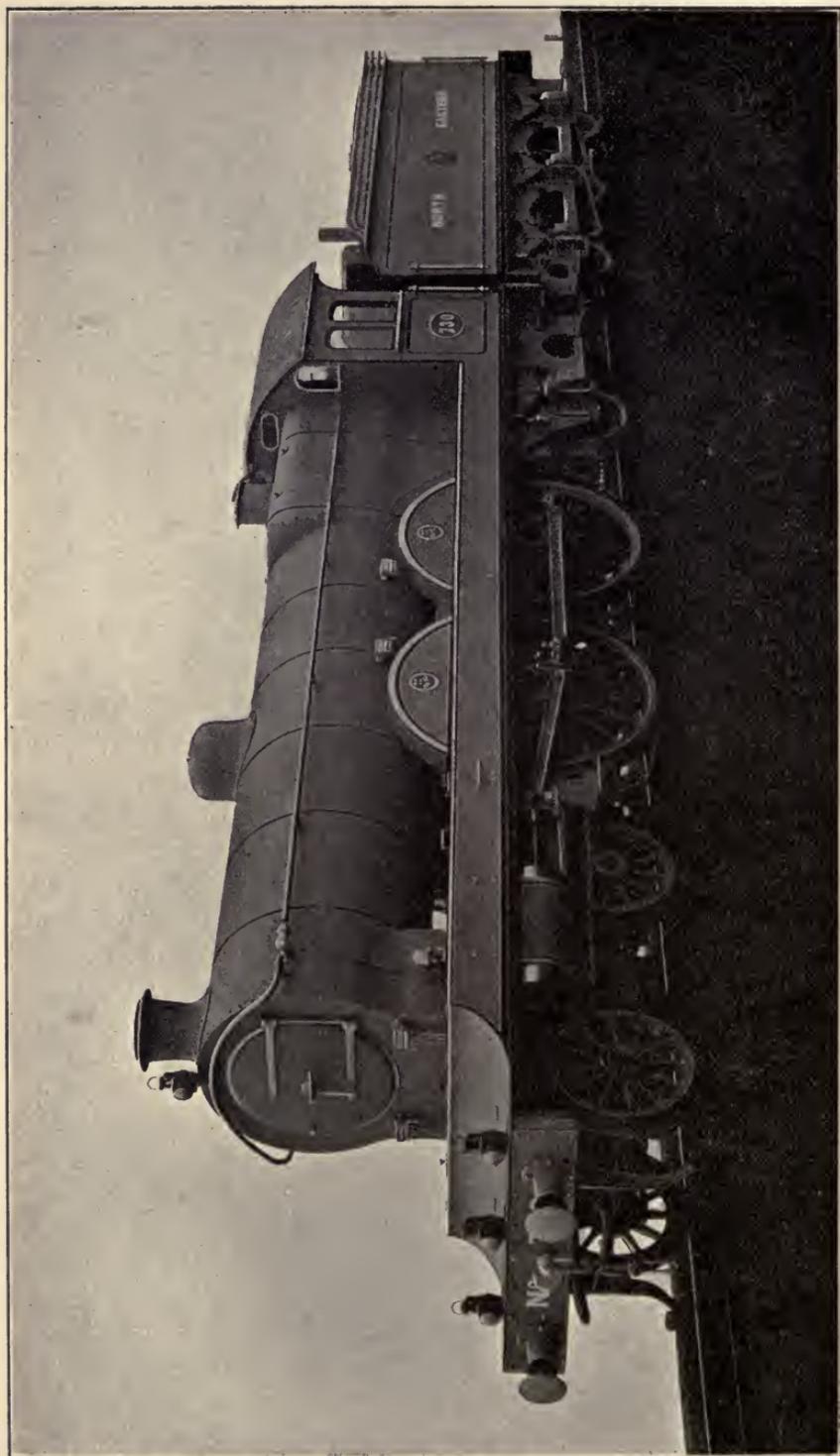
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GENERAL

P R E F A C E.

It is now just upon thirty years since the first practical compound locomotives were built, but even yet the compound locomotive does not occupy the universally accepted position which theory would suggest that it should do. But whereas in the early years of its existence as a definite feature of locomotive engineering practice it was looked upon in most quarters with disfavour and distrust, and the engineers first concerned with the design of such engines had to contend against prejudice and opposition, and had no easy task to obtain even a trial of their systems, now the position is far more favourable, and compound locomotives according to many different systems are to-day in use to the number of many thousands in various parts of the world. In fact, it is not claiming too much to say that the compound locomotive occupies to-day an assured position, and it is probable that before many years have passed it will become a standard feature of locomotive engineering in all countries.

As regards compounding for locomotives, Great Britain has maintained its reputation for conservatism, for its record in this respect is not a very satisfactory one as compared with the experimental and original work to be attributed to foreign locomotive engineers; but this is largely the result of different circumstances and policy.

In this country the Locomotive Superintendent or Chief Mechanical Engineer of a railway is responsible for the design and efficiency of large numbers of locomotives doing very hard and greatly varied work; but he is not encouraged to experiment or to depart radically from standard methods: and in most cases he has to design engines which are developments of previously existing designs, each class being somewhat more powerful, more reliable, and yet more simply and cheaply constructed proportionately than its predecessors. The engines are also generally required to be capable of doing much work for which they are not specially designed. Consequently, actual novelties are few in British locomotive history, and notable experiments and changes in methods of design occur only once or twice during, it may be, a long term of service of a particular engineer as locomotive chief. Individual originality of persons not occupying principal positions has very little opportunity in this country, rightly

so in view of the important interests at stake when a change of engineering policy may entail the expenditure of many thousands of pounds, probably with no satisfactory benefit, but unfortunately also with the loss of much valuable experimental work, which, even if a failure, may add greatly to engineering knowledge.

In the case of British locomotive building firms little scope is provided for original work on their part, though, as they deal with many railways both at home and abroad, their experience and opportunities are, in some ways, more extensive than in the case of the railway officials; but as a rule they are employed to build engines to designs provided by the railway officials, and such an occurrence as the building of an engine by the Vulcan Foundry Co., Ltd., to their own designs, for the Great Northern Railway, in 1905, is very rare indeed.

Abroad, however, the Chief Mechanical Engineers or Motive Power Superintendents are in many cases responsible principally for the maintenance and repair of locomotives, and the design of new engines is largely the duty of superior engineers retained by the railway, or of consulting engineers whose position is more independent than our own Locomotive Superintendents, while the various locomotive building firms are encouraged to introduce novelties and to experiment in new directions, sometimes in competition with one another; their orders being, in many instances, to provide engines which are capable of doing certain work with the greatest efficiency, the builders having, in a large measure, a free hand. As an example of this may be mentioned the official competition instituted in Germany at the beginning of 1905, when a number of locomotives designed wholly by individual firms, and in several cases embodying radical departures from ordinary methods, were officially tested, a number of similar engines being afterwards ordered for regular service in two or three instances, though not all the competing engines were successful.

On the other hand it must be remembered that Great Britain is only a small country, without an extensive assortment of varying circumstances and conditions of work, while Europe comprises many countries of large area which provide almost every conceivable set of conditions to be provided for by locomotive engineers. There is therefore much greater justification for special and unusual locomotive design abroad than in Great Britain, where, generally speaking, all requirements can be met by locomotives of selected standard classes.

The foregoing remarks will, it is thought, go far to explain the fact that, as regards the compound use of steam for locomotives, three or four names only can be mentioned as of special note among British engineers in this respect, whereas thirty or forty engineers and firms require corresponding mention in connection with Continental and American practice, while, as regards the use of superheated steam, the credit must almost entirely be divided between German, Canadian, American, and Belgian engineers.

Having thus provided some explanation of the fact that in this work about 80 per cent. of the matter included relates to the work of foreign engineers, a few notes regarding the scheme followed by the writer in its preparation will be in place.

The subject of compounding for locomotives has received frequent attention in the technical press of this and other countries, articles in some cases being fairly comprehensive within their scope, and containing much valuable information as regards technical and theoretical matters; but, so far as the present writer is aware, only three really technical publications may be considered as being properly indicative of the world's practice. These are:—

(1) The late Professor Wood's book on *Compound Locomotives*, published in the United States in 1892-3.

(2) Mons. Edouard Sauvage's articles, which appeared in 1897 in *La Revue des Mécaniques*.

(3) Herr E. Brückmann's paper, which appeared in 1896 in *Der Zeitschrift des Vereines deutscher Ingenieure*.

As will be seen, none of these are sufficiently up to date to cover recent practice, and although Mons. Sauvage has to some extent noted later development by many contributions to the French Engineering Press, and by papers presented to our own Institution of Mechanical Engineers, it is correct to state that no approximately thorough review of locomotive compounding has ever been published in this country, nor has any work of this kind been published for many years in any country.

To provide a substantially complete and systematic work on this subject has been the object of the writer, who, in addition to his own very considerable knowledge of the world's locomotive practice, has been favoured with private information from locomotive engineers and locomotive building firms. Articles which have appeared in technical magazines and journals, as well as papers read before engineering societies, have also been carefully considered, and general acknowledgment is hereby made of such assistance. Specific reference is gratefully made to the following gentlemen, firms, and journals in particular:—

(a) Messrs A. Mallet, A. G. de Glehn, C. Baudry, G. du Bousquet, Walter M. Smith, S. M. Vauclain, F. J. Cole, the late A. von Borries, K. von Gölsdorf, A. Lindner, A. Brunner, etc.

(b) The firms of Alsatian Works, Hanover Engine Works, Saxon Engine Works, Baldwin Locomotive Works, American Locomotive Co., Rogers Locomotive Works, A. Borsig, J. A. Maffei, C. Breda, etc.

(c) The chief engineers of the French State, Eastern and Southern Railways, and of the Hungarian and Swedish State Railways, etc.

(d) The Proceedings of the Institutions of Mechanical and Civil Engineers, the American Master Mechanics' Association, the French Institution of Civil Engineers, *The Engineer*, *Engineering*, *La Revue Générale des Chemins de Fer*, *Railroad Gazette*, *Locomotive Magazine*,

and *Cassier's Magazine*. In the latter case, some extracts are included from the writer's own articles in that magazine.

In a few instances where the illustrations are reproduced directly from the publications named, acknowledgment is specially made. As a rule, however, the illustrations are merely adapted where private drawings were not available. The photographs reproduced are all from official sources.

Acknowledgment must also be made of the loan of several blocks by the Baldwin Works and the American Locomotive Company.

The author has not devoted much space to the theoretical and highly technical aspects of locomotive compounding and superheating, partly because the late Professor Wood has provided a work of this character which can never be quite out of date in this respect, but principally because it seemed preferable to present a review of practice and methods of applying compounding and superheating to locomotives, together with a general consideration of the peculiar problems which complicate these subjects as applied to locomotive engineering as compared with compounding and superheating for other steam engines. Consequently the early portion of this book contains only a glossary of terms, an introductory chapter, a chapter dealing with the special conditions governing the application of compounding and superheating to locomotives, a chapter on the classification of compounding systems, and a brief historical chapter, the remaining chapters being devoted to special divisions of our subjects and dealing with past and present practice, though some argumentative and technical matter is included.

As regards the use of superheated steam for locomotives, the subject is of such recent importance that a collection of matter relating to the various apparatus in use has not hitherto been presented in any technical book on the locomotive engine, and this work provides a convenient and suitable opportunity for presenting a general review of this branch of locomotive engineering.

J. F. GAIRNS.

LONDON, *Jan.* 1907.



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GLOSSARY OF TERMS.

Most of the technical terms which will be used in this book are common to all branches of steam engineering, and are fully explained in any text-book dealing with steam and the steam engine; but for the benefit of general readers and for completeness, this glossary of terms is presented in introduction, the explanations being couched in some cases in language particularly appropriate to the subjects under consideration. As a rule, the glossary is based upon that provided in Professor Wood's book referred to in the Preface, though amplified. Only the most important terms are, however, included, terms which explain themselves being generally omitted.

Back Pressure.—In a compound engine, as the steam from the exhaust side of the high-pressure piston passes to the steam side of the low-pressure piston it exerts pressure for a time in two directions, for while it tends to force the low-pressure piston forwards, it also tends to force the high-pressure piston backwards against the pressure of steam on the steam side. This backward pressure is generally referred to as "back pressure"; and while the two cylinders are in communication, the actual work being done in the high-pressure cylinder is only the difference between that done on one side of the piston by the boiler steam and that on the other side by the low-pressure steam.

The term is also used generally to indicate any pressure which acts oppositely to the steam pressure, due to the "choking" of the exhaust steam in consequence of the ports or passages through which it escapes being restricted, or from other causes.

By-Pass Valve.—A valve which, when opened, allows communication through a pipe or passage between the two ends of a cylinder.

Compound Engine.—An engine wherein the steam is used in one cylinder for one stage of expansion, and is then passed to a second cylinder for a second stage of expansion. Strictly, there are only two stages of expansion in a compound engine, though the term is sometimes used loosely to describe any engine wherein expansion is carried out in stages. Properly speaking, however, three-stage expansion engines should be described as "triple-expansion engines," four-stage engines as "quadruple-expansion engines," and so on.

Compounding.—This term is employed to describe the general principle of expansion by stages, whether in two, three, four, or more stages.

Continuous Expansion.—In many cases steam cannot be passed directly from one cylinder to the other in a compound engine, owing to the fact that the pistons of the respective cylinders do not reach the ends of their strokes at the same time; but in other cases they do so, and the steam can therefore pass from one cylinder to the other unchecked. The term "continuous expansion" is sometimes used to describe the latter method of working, but it is not very generally employed. An example of its use in another connection is given in Chapter IV.

Cut-off.—The point where the admission of steam to a cylinder is cut off. It is

generally expressed at so much per cent., or as a fraction of the stroke, though occasionally, where the length of stroke is known, it is stated as so many inches. For example, if the stroke is 24 inches and steam is admitted for a quarter of the stroke, the ratio of cut-off may be expressed as "25 per cent.," or "at quarter-stroke ($\frac{1}{4}$)," or "at 6 inches,"—the first of these is, however, most general, unless the cut-off can be expressed by a simple fraction, as "quarter-stroke," "one-third stroke," etc.

Cylinder Condensation.—The condensation or deposition of moisture that is suspended in the steam owing to the fall in pressure and temperature of the steam, or in consequence of contact of the steam with the cylinder walls when they are colder than the steam.

Cylinder Re-evaporation.—The re-evaporation of condensed water resulting from cylinder condensation in a cylinder on the entrance of a fresh steam supply from which the necessary heat is extracted for the purpose.

Exhaust Pressure.—The pressure at which the steam, after use, leaves a cylinder, either to pass away to the atmosphere or a condenser, or to another cylinder for compound working.

Expansion.—The increase in volume of steam enclosed in a cylinder after cut-off. As the steam expands, it forces the piston along, increasing in volume and losing pressure as it does so.

Final Pressure.—The pressure of the steam when exhausted from the low-pressure or last cylinder in compound working.

High-Pressure Cylinder.—The cylinder in which the first stage of expansion is carried out in compounding. In this work the abbreviation "H.P. cylinder" will often be employed.

Initial Pressure.—The pressure of steam at the beginning of a stroke. In connection with compounding, the term is often used to indicate the pressure at which steam is admitted to the high-pressure cylinder, in contrast to "terminal" or final pressure, which indicates the pressure at which steam is finally exhausted from the last or low-pressure cylinder of a series of cylinders.

Indicator Diagram.—The diagram obtained by means of an instrument known as an "indicator," whereby the variation of steam pressure in the cylinder throughout a stroke is indicated in the form of a curve, from which the amount of work being done can be computed.

Intercepting Valve.—A valve whereby communication may be closed between the respective cylinders of a compound or multiple-expansion engine when required, so that the cylinders can be operated independently with boiler steam, as at starting in the case of a compound locomotive engine, or for the temporary exertion of very great power. In many cases the intercepting valve also governs a passage whereby the exhaust steam from the high-pressure cylinder or cylinders of a compound locomotive can pass to the chimney when boiler steam is being used in the low-pressure cylinder or cylinders.

Intercepting valves are constructed in many different forms, but they can all be classed as "automatic" or "non-automatic." In the former case they are operated or moved from one position to the other according to which side the steam exerts the greatest pressure; in the latter case they require to be mechanically operated.

Intermediate Cylinder.—In triple-, quadruple-, or other multiple-expansion engines, the first and last cylinders are referred to as high- and low-pressure cylinders, the cylinder or cylinders between being known as the intermediate cylinder or cylinders, or as the first, second, etc. intermediate cylinders when there are two or more of them.

Low-Pressure Cylinder.—The cylinder in which the last stage of expansion is carried out in compounding. In this work the abbreviation "L.P. cylinder" will often be employed.

Multiple Expansion.—Expansion in more than two stages, as in a triple- or quadruple-expansion engine.

Mean Pressure.—The average pressure of steam which is exerted in an engine cylinder during a stroke.

Non-compound Engines.—Engines wherein steam is expanded in one stage only, compounding not being employed.

Non-Receiver Engines.—Engines for which no receiver or steam-storage chamber is employed between high- and low-pressure cylinders, the steam passing directly from one cylinder to the other. The term is to some extent synonymous with “continuous expansion.”

Ratio of Cylinders.—The relative proportions of the volumes of the respective cylinders of a compound or multiple-expansion engine.

Ratio of Expansion.—The ratio which the admission pressure of steam bears to the exhaust pressure in one cylinder, or which initial pressure bears to final pressure in a compound or multiple-expansion engine.

Receiver.—The chamber or space wherein steam is contained before passing from one cylinder to the next in a compound or multiple-expansion engine. The term is generally used to describe a chamber or length of piping specially provided in order to receive steam from one cylinder when it is not able to pass at once to the next cylinder.

Receiver Engine.—A compound or multiple-expansion engine having one (or more) receivers.

Re-evaporation.—See “Cylinder Re-evaporation.”

Saturated Steam.—Steam as generated in contact with water, as in a boiler, so that it holds water in suspension,—wet steam. Under ordinary conditions all steam is saturated steam.

Sequence of Cranks.—The order in which the cranks of the respective cylinders of an engine follow one another in rotation.

Simple Expansion.—The same as non-compound.

Single Expansion.—The same as non-compound.

Superheating.—The heating of steam after generation for the purpose of evaporating moisture contained there and for increasing its temperature and volume.

Tandem Compound Engine.—An engine wherein cylinders are placed one behind the other, the respective pistons being mounted on the same piston rod, or in an equivalent manner.

Terminal Pressure.—The same as “final pressure.”

Total Expansion.—The ratio between initial steam pressure and the terminal or final pressure in a compound or multiple-expansion engine.

Wet Steam.—See “Saturated Steam.”

Wiredrawing.—The throttling of steam through a small aperture; a reduction of pressure by restricting the flow of steam.



LOCOMOTIVE COMPOUNDING AND SUPERHEATING.

CHAPTER I.

INTRODUCTORY.

CONTENTS :—The Compound Use of Steam—The Objects of Compounding—Two-stage Expansion *versus* One-stage Expansion—Division of Work between two Cylinders—Cylinder Condensation and Re-evaporation—Cylinder Heating and Cooling—Uniformity of Thrust and Pull transmitted through Piston Rod—The Use of Superheated Steam in Engines—The Objects of Superheating.

The Compound Use of Steam.—The compound use of steam in steam engines has been known for more than a hundred years, and it has been a standard feature of steam engineering, except for locomotive engines, for at least forty or fifty years, while it is now almost universal for large marine and stationary engines.

The Objects of Compounding.—The objects of compounding are (1) To enable the power represented by the steam generated under pressure to be applied in such a manner that full advantage can be obtained from expansion without incurring the disadvantages which become serious if too great an expansion is attempted in one cylinder.

(2) To allow of a greater range of expansion being utilised than is practically possible by non-compound methods, and so to more efficiently and economically use the steam before it is discharged.

(3) To maintain a more uniform pull or thrust upon the piston rod throughout the stroke than is possible when steam is cut off early in the stroke in a non-compound engine.

(4) To obtain mechanical advantages by the use of a multiplicity of cylinders without imposing additional strain upon the boiler.

(5) To allow of high-pressure steam being used with full advantage. Unless extended expansion can be carried out, the higher the initial pressure, the higher will be the exhaust pressure, so that part of the gain due to the use of high-pressure steam cannot be fully realised unless compounding is resorted to.

Two-stage Expansion *versus* One-stage Expansion. Division of Work between two Cylinders.—These objects are attained by using

the steam in stages, first in one cylinder, where it does a certain amount of work, and then in another cylinder, or two or more cylinders successively, where it does further work before it is finally passed away to the atmosphere through the chimney, or to a condenser.

In a steam engine cylinder the steam is admitted for part of the stroke only, and the steam supply is then cut off, the steam working during the remainder of the stroke by expansion, though as it expands it loses pressure, owing to the fact that it occupies a gradually increasing space. Thus, for example, steam at 180 pounds per square inch may be admitted for one-third of the stroke, after which it is allowed to expand, doing further work, but of gradually lessening amount, until it is permitted to "exhaust" at a pressure of, say, 80 pounds per square inch.

It is bad practice to allow steam to pass away at a pressure which indicates that there is still much working power remaining, and to exhaust at 80 pounds per square inch is clearly wasteful; it is therefore desirable that as much of the expansive power of the steam shall be utilised as possible.

Theoretically, this can be done in one stage by cutting off very early in the stroke, say at 5 per cent., so that the steam pressure may fall from admission at 180 pounds per square inch to exhaust at 10 pounds or less; but in practice this becomes well-nigh impossible because of other considerations, and for that reason the work is best divided over two (or more) cylinders, thus constituting a compound engine.

Cylinder Condensation and Re-evaporation. Cylinder Heating and Cooling.—Of these considerations, the principal is "cylinder condensation." This occurs owing to the fact that as the pressure falls the temperature falls also; and as boiler steam always contains a considerable amount of suspended moisture, while its capacity for holding such moisture decreases with the temperature, it follows that not only do the cylinder walls become cooler to a greater or less extent by the time a stroke has been completed, but some of the suspended moisture becomes deposited as water. When a second supply of steam is admitted to the cylinder for the next working stroke, it meets the cylinder walls, whose temperature is less than that of the entering steam, and an interchange of heat units takes place to equalise matters. This causes the steam to lose some of its heat, and therefore to lose some of its pressure, before it can do any useful work, and a certain amount of its moisture is deposited. But this moisture, together with that remaining from the previous stroke, requires to be evaporated before work can be commenced, and there is a further loss of heat and pressure, so that some of the gain due to expansive working is negatived, owing to the cylinder walls being alternately heated and comparatively cooled, and the condensation and re-evaporation of the deposited moisture.

The cooling and reheating of cylinder walls, and cylinder condensation and re-evaporation, must always occur, though, by using superheated steam, or by providing the cylinder with a jacket in

which steam or furnace gases circulate, these results are lessened; if, however, an extensive range of expansion is attempted, these effects become serious, and there is therefore a practical limit to the cut-off ratio that can be satisfactorily employed. It will be seen, then, that by ordinary methods it is not possible to utilise all the work contained in the steam.

Another result attending early cut-off is a want of uniformity in the thrust or pull transmitted through the piston rod owing to the fact that there is great difference between the steam pressure at the commencement of the stroke and that at the end of the stroke. There are also other difficulties, such as the necessity for a special valve gear, whereby satisfactory steam distribution can be obtained at all times whether the cut-off is late or early.

Uniformity of Thrust and Pull.—By compounding, however, the work is distributed, the steam being used first in one cylinder with a late or reasonable cut-off, where it works under satisfactory conditions with limited cylinder condensation, and giving a fairly uniform thrust or pull upon the piston rod; it is then passed to another cylinder, or to two or more cylinders in series, where further work is done under satisfactory conditions.

As a result, steam can be expanded to a degree that is impossible when all the work has to be done in one cylinder, and this is effected without the incidental disadvantages of one-stage expansion with an early cut-off.

Another possibility which is sometimes very valuable is due to the fact that as more than one cylinder is necessarily employed, more driving impulses per revolution can often be obtained, although, were this attempted by merely multiplying cylinders, it would be difficult to maintain sufficient steam supply therefor without introducing extravagant methods of working.

It will therefore be seen that compounding is desirable for all steam engines, and is practically a necessity when high steam pressures are employed if economy is to be obtained; and this fact is appreciated in marine and stationary steam engineering, in connection with which it is well-nigh universal; but when its employment for locomotive engines is in question, although there is no doubt whatever as to its desirability, other considerations complicate matters to a great extent, as will be set forth in the next chapter.

The Use of Superheated Steam in Engines constitutes a means for obtaining nearly the same objects as those achieved by compounding, but it differs therefrom principally in that by this method of working extended expansion can be carried out in one cylinder, though in some cases superheating is used in connection with compounding.

Objects of Superheating.—In superheating, the steam is heated in a chamber or in passing through tubes exposed to the effect of

furnace gases (usually the waste gases from the boiler furnace, so that heat is utilised that would otherwise be wasted), whereby its temperature is raised above that proportionate to the pressure at which it is generated (its volume also becomes increased to some extent); and the moisture suspended in the boiler steam (generally referred to as "saturated" steam) becomes evaporated, so that the effects of cylinder condensation are minimised, and there is a reserve of heat available for reheating the cooled cylinder walls as steam is admitted to the cylinder, and for re-evaporating water of condensation if any is present in the cylinder. By its use, therefore, steam can be very efficiently utilised either for single-stage expansion or in compound working, though, rather curiously, in locomotive engineering, the trials which have been conducted in various parts of the world, notably Germany and Canada, have shown that there is comparatively little advantage by combining compounding and superheating, thus indicating that in large measure they constitute equivalent methods of using the steam.

The fact that the volume of the steam is also increased is also the cause of economy, as a greater quantity of steam at the required pressure is therefore available at the cylinders than is actually generated by the boiler, the necessary additional work units represented thereby being obtained by the utilisation of heat from the furnace gases before they finally pass away, and after they have passed through the boiler fire tubes.

CHAPTER II.

THE COMPOUND USE OF STEAM FOR LOCOMOTIVE ENGINES.

CONTENTS :—General Remarks—Comparison of Locomotive and other Steam Engines as regards Compounding—Reasons for and against Compounding for Locomotives—Adaptation of Locomotive Engines for greatly varying Conditions of Work—Direct and Indirect Economy due to Compounding—Mechanical Advantages obtained by Compounding—Additional First Cost and Complication—The Influence of Compounding on the Fireman's Work.

General Remarks.—The question of the advantages, or otherwise, of compounding for locomotives has provided subject-matter in past years for some of the most heated controversies ever conducted in the technical press, and even to-day, after nearly thirty years of practical use of compound locomotives, the engineering world is not yet altogether decided as to whether compounding for locomotives is really satisfactory for all-round miscellaneous work. Compound locomotives are to-day in use to the number of many thousands, and about thirty systems of compounding have been introduced, on a more or less large scale ; but for one locomotive engineer who favours compounding, at least two can be cited who do not consider compounding really satisfactory, or who, in their practice, continue to design non-compound engines. Moreover, if one deletes from a list of engineers in favour of compounding the names of those who are actually connected with a particular system, the balance of opinion, as evidenced by practice, becomes still more pronounced against compounding.

As an example showing the great diversity of opinion which exists among responsible locomotive engineers, it may be mentioned that the writer recently received letters from, among others, the Chief Locomotive Engineers of three important American railways, wherein statements were made which substantially amounted to—(1) "I have no compound locomotives, and do not desire any"; (2) "I have a large number of compound locomotives, but found them unsatisfactory until important alterations and modifications had been made"; and (3) "I have a large number of compound locomotives, and as I find them eminently satisfactory, I do not intend to revert to the employment of non-compound engines."

In Great Britain the compound locomotive appears to be in

particular disfavour, for, except for a few desultory experiments, only two railways, the London and North-Western and the North-Eastern, have ever introduced compound locomotives in large numbers; and on both of these lines many such engines have been scrapped or converted to non-compound, and superseded by simple engines, while on other lines, until the past two or three years, the few compound engines have all been converted to non-compound, with the exception of the Belfast and Northern Counties and the Belfast and County Down Railways in Ireland. Recently, however, engines have been built which indicate a revival of interest in locomotive compounding, and a number of modern compound engines are to-day in use on the North-Eastern (one three-cylinder engine and two new four-cylinder engines), Midland (about forty three-cylinder engines), Great Western (three four-cylinder de Glehn compound engines, purchased in France), Great Central (two three-cylinder engines, just introduced), Lancashire and Yorkshire (two experimental four-cylinder engines), and Great Northern (two engines of different four-cylinder systems) Railways. On the Belfast and Northern Counties Railway (now amalgamated with the English Midland Railway) a few two-cylinder engines have been built since the commencement of the twentieth century, and these are the only recently built two-cylinder compound engines in Great Britain.

Some of the Webb compounds on the London and North-Western Railway are of recent date, but otherwise the above list of new engines represents the total number of modern compound locomotives used in Great Britain at the time of writing (October 1906).

This can hardly be considered as a strong argument in favour of compounding for locomotives, though recent work provides, to some extent, an indication that British engineers are more dissatisfied with compound systems than with compound locomotives. On the other hand, it must be remembered that many British engineers prefer to work on non-compound lines, and to design engines which can do all and any work required of them, than to introduce new features or special classes of engines merely because of economy, coupled, perhaps, with a want of elasticity for varied service.

Abroad, however, the compound locomotive is in many cases regarded with great favour, though in numerous instances the situation is very similar to that existing in this country. In France and Austria all the important railways now employ compound locomotives almost exclusively, while in Germany, Italy, Hungary, Russia, Norway, Sweden, Switzerland, and America (North and South) there are large numbers of compound locomotives in use; but in Belgium (the year 1905 has witnessed the introduction of a number of compound trial engines), Holland, Denmark, Spain and Portugal, Canada, Australia, India and New Zealand, compound engines are used in small numbers, or they exist only according to old designs, being superseded by modern non-compound engines, or all engines are non-compound.

It will thus be seen that, to account for this diversity of opinion

and practice among locomotive engineers, it must be allowed that compounding for locomotives is not nearly so advantageous as compounding for other steam engines, or else there must be special reasons why compound locomotives should be so largely regarded with disfavour, though where they are used extensively one hears nothing but praises of their performances and economy; and, as a first step towards the elucidation of the complicated problem thus presented, it will be most satisfactory if the main conditions of marine and stationary steam engineering, and of locomotive engineering, as regards compounding, are stated side by side, for purposes of comparison.

Comparison of Locomotive and other Steam Engines as regards Compounding :—

For Marine and Stationary Steam Engines :

(1) The range of pressure rendered available for useful work by compounding extends from boiler pressure down to atmospheric pressure, or to about 10 or 12 lbs. per square inch below when a condenser is employed. Thus, if the initial pressure is 180 lbs. per square inch, and by ordinary one-stage expansion this can be reduced to 60 lbs. per square inch, the final pressure may (by compounding) be as low as 5 lbs. per square inch, or as low as - 10 lbs. per square inch, a gain of 55 or 70 lbs. of steam pressure.

For Locomotive Steam Engines :

(1) The range of pressure rendered available for useful work by compounding extends from boiler pressure down to (at least) 20 lbs. per square inch, if not a higher pressure, as no condenser can be employed, and a sufficient final pressure must be maintained for blast purposes. Thus, if the initial pressure is 180 lbs. per square inch, and by ordinary one-stage expansion this can be reduced to 60 lbs. per square inch, the final pressure may (by compounding) be about 20 or 25 lbs. per square inch, so that the possible gain is an additional 40 or 35 lbs. of steam pressure.

It will therefore be seen that the possible advantages due to compounding may not be much more than half that possible with other types of engines, particularly those working with a condenser. When high initial pressures are used, however, unless very early cut-off is used, which may be unsatisfactory, it is only compounding that will enable sufficiently extended expansion to be carried out, to avoid the exhaust steam being discharged at a wastefully high pressure.

(2) The speed of running is almost invariable.

(3) The amount of work being done is nearly constant.

(4) The engine is designed and specially adapted for given conditions.

(5) The engine runs for long periods under specified and almost invariable conditions.

(6) The engine is usually controlled by a governor, or is controlled in such a way that the individual methods of the engineer in charge are not matters of great importance.

(7) The engine works under favourable circumstances, and it can be designed, as regards dimensions, without very severe restrictions.

(8) Valve gear is adjusted for the best and most satisfactory steam distribution, and when adjusted, is rarely varied. If desirable, complicated and special

(2) The speed of running is continually varying.

(3) The amount of work being done is continually varying, within wide extremes.

(4) The engine is designed so as to be suitable and satisfactory for extreme variations of working conditions.

(5) The engine rarely runs for many minutes without the conditions and requirements varying, owing to change of grade, increase or decrease of speed, curves, weather conditions, etc. Moreover, a particular engine has to meet requirements which vary with every train it works, and from day to day, even when the same train is worked over the same road.

(6) The engine is controlled and adjusted, as conditions and requirements vary, by a driver who cannot be expected to work the engine in the best and most economical way at all times. Moreover, the methods of a particular driver are important matters, one driver working an engine so as to give very good results, while another driver will work the same or a similar engine with only average or with unsatisfactory results.

(7) The engine often works under unfavourable circumstances, and its design is usually controlled by dimensional limitations and other considerations. The engine is, moreover, subjected to severe strains, owing to the fact that it forms part of a travelling power station.

(8) A simple form of valve gear must be employed, and it must be capable of an extensive range of adjustment, in all cases giving a fairly good steam distri-

valve gears can be conveniently employed.

(9) Various refinements of design can be employed, such as expansion gear, governors, etc.

(10) The boiler has to provide a regular supply of steam with little variation; and once the rate of steam generation required to supply the engine is settled, it works with regular strain and under favourable conditions.

tribution, while the engine rarely works for long under conditions for which the valve gear will give a really economical steam distribution.

(9) Simplicity and general reliability are far more important features than refinements of design, and special devices can rarely be employed.

(10) The boiler has to be a rapid steam generator, and able to supply sufficient steam to meet greatly varying requirements, and sometimes to meet special strain. It therefore follows that it cannot always be operated in an economical manner.

When the above comparisons are carefully considered, it will be seen that the operation of steam in the locomotive engine is necessarily controlled in so variable a manner, and the conditions of work vary so greatly, that it is not surprising that in many cases the greater proportion of any gain which should result from compounding is neutralised by other considerations, and that at times the non-compound engine may be more suitable for the required conditions than the compound engine.

It must, however, be understood that in thus presenting the case for the compound locomotive, the writer does not wish to infer that compounding is not satisfactory for locomotives, for experience has shown that compounding can be and is satisfactory and advantageous, but rather to explain why it is that the gain is not so great as it should theoretically be, and why the compound locomotive in many instances has shown little apparent advantage for very varied duty.

So far, compounding for locomotives has been considered merely as a principle, but it is applied in many different ways, and it is sometimes employed in such a way that mechanical and other advantages are incidentally obtained; and as a second step in argument, the principal reasons for and against compounding for locomotives will now be considered.

Reasons for and against Compounding for Locomotives.—When two cylinders only are employed, one high-pressure and the other low-pressure, the engine depends for its efficiency as a compound principally on its economy, though there are also advantages due to the uniformity of pull and thrust transmitted through the piston-rods, and in many systems provision is made for working non-compound to provide additional power on occasions. The latter

considerations are not, however, of very great importance in the case of two-cylinder engines, apart from economy.

Adaptation of Locomotive Engines for varying Conditions of Work.—For starting, a two-cylinder engine must have means for working the low-pressure cylinder with boiler steam, for otherwise, should it stop when the high-pressure crank is on a dead centre, or the slide valve be closing both steam ports, the engine would be unable to start if such means were not provided; and in many cases this provision is utilised to enable the engine to work non-compound for some time after starting, or, on other occasions, to overcome temporary difficulties. The presence of devices for this purpose—starting and intercepting valves constitute the usual arrangements, either automatic or under the driver's control—introduces complication and adds to the number of fittings which can get out of order, while, if not intelligently controlled by the driver (if under his control), the engine may operate unsatisfactorily, and when not under his control, the driver may be more or less seriously handicapped in operating the engine to suit all sorts of work. In fact, what is termed a want of “elasticity” is one of the principal reasons which have caused the rejection of two-cylinder compound locomotives in many cases.

A compound engine with two cylinders only generally requires to be kept fairly closely to the work for which it is designed. It may be able to exert very great power at times, and in many instances, when a long steady pull with a heavy train over several miles of rising gradient is necessary, a compound engine can keep a train moving, owing to the uniformity of its effort, when a non-compound engine would be “stalled”; but against this must be set the fact that if non-compound working is maintained for long, the steam may become choked or be used in a very extravagant manner, so that the advantage of compounding at other times is more than counter-balanced.

Furthermore, if a late cut-off is employed for the high-pressure cylinder, it is generally necessary to cut off fairly late in the low-pressure cylinder also; and when the engine works for a considerable time the division of work between the two cylinders may be very unequal, so that the engine works not only uneconomically but unsatisfactorily, whereas a non-compound engine may work at its best under these conditions as regards power, although it is, of course, temporarily extravagant.

Therefore, if a two-cylinder compound engine for express passenger service can be always employed on fast work, or a goods engine be always used with heavy trains for long distances, both working over fairly level lines with long hauls, it may be taken as a foregone conclusion that it will prove satisfactory and economical as compared with a non-compound engine; but when the duty is varied, one trip express, the next with frequent stops; one day with heavy long-distance trains, the next with a light short-distance train; one turn requiring the engine to work over severe gradients, another

entailing a long easy journey; then it is hardly to be wondered at that the advantage obtained in some cases is neutralised by weakness or extravagance in other cases. For tank engines with frequent stops and short runs, and with very miscellaneous duties, two-cylinder compound engines are rarely quite satisfactory, though many of them are in existence and do good work.

In countries where fuel is very expensive, it may be that two-cylinder compound engines provide sufficient economy to justify their extensive use, but where the advantage in this direction is less, as it is in this country, the comparative disadvantages due to causes above specified may justify a preference for non-compound engines.

Moreover, British non-compound locomotives are well known to be economical in coal consumption, so that the compound locomotive has less opportunity to show its superiority than in some other countries.

It must also be remembered that where work is greatly varied, the personal equation of the driver is a most important factor; and one British locomotive superintendent once stated that he could obtain greater economies by selecting his drivers than were claimed for compounding, while another engineer, himself the introducer of one of the most widely-used systems of two-cylinder compounding, stated that a principal reason for his adoption of compounding was the endeavour to force the drivers to work their engines economically, whereas they often worked somewhat extravagantly when they possessed the free hand given by simple working.

Mechanical Advantages obtained by Compounding.—When more than two cylinders are employed, compounding introduces other possibilities besides that of direct economy, and there is little question that it is because of these that compounding is now regarded with greater general favour than formerly, though many three- and four-cylinder compound locomotives have been in use for a number of years.

In all multi-cylinder compound engines there is a balance of parts, the cylinders being similarly arranged on either side of the longitudinal centre-line, and therefore, no matter how the work is divided between high- and low-pressure cylinders, it is distributed nearly equally for the longitudinal halves of the engine, whereas a two-cylinder engine has two cylinders of different sizes, and the steam distribution cannot always be arranged so that the forces upon the two cranks are equal, or nearly so.

It therefore follows that in a three- or four-cylinder engine it is not absolutely necessary that the work of the respective cylinders be equally divided, though it is advisable that this be so, and under average working conditions it is necessary for efficiency.

With tandem and other two-crank systems the chief advantages are the same as those obtained by two-cylinder compounding, together with a few other advantages due to the multiplicity of cylinders; but with three- and four-crank systems various mechanical and other advantages may also be obtained, which advantages are in some cases

of greater importance than direct economy of fuel and steam consumption.

One of these advantages is that the cranks can be so arranged that they follow one another with a more frequent crank sequence than is the case with two cranks at right angles, as in two-cylinder or two-crank engines, thus dividing the work up more equally, and giving a more regular turning-moment, while balancing is assisted. These matters are dealt with more fully in the next chapter.

Another advantage is that the work can be distributed over separate axles when three or four cylinders are employed, and parts can be made lighter and the strains due to the momentum of moving bodies reduced, while the division of work sometimes enables wheel arrangements to be used which are not possible satisfactorily when all the work is transmitted through one axle which is coupled with all other driving wheels.

Direct and Indirect Economy due to Compounding.—But a principal advantage attending the use of three or four cylinders consists in the fact that while direct economy may be obtained by the compound use of steam under favourable circumstances, indirect economy may be obtained at other times, owing to the fact that it is possible to arrange for greatly augmented power by working non-compound temporarily, whereby the engine is enabled to deal with trains which would otherwise require an assisting engine, possibly only necessary for a small section of a total journey, though such assisting engine may, for traffic reasons, have to go the whole or a large portion of a trip; or to do work for which another engine would be severely handicapped. The provision of such facilities may also render very fast bookings with heavy trains practicable, owing to the fact that the engine is able to exert abnormal power at times, as for obtaining rapid acceleration, so that temporary extravagant working is really synonymous with valuable indirect economy.

It will be gathered from the foregoing that the writer is more in favour of compounding with three or four cylinders operating three or four cranks than with two-cylinder or two-crank systems, and this seems to be borne out by recent practice and the performances of recent locomotives in all parts of the world; but it has to be acknowledged that, when conditions are favourable, two-cylinder compound engines can and do work very satisfactorily, and four-cylinder two-crank engines must be ranked between the two-cylinder and the four-cylinder four-crank engines for efficiency.

The advantages thus briefly reviewed are not in all cases obtained with every system of the class, as some systems possess features which either render them specially satisfactory or militate against their success in work; but, as general statements, the above may be said to be fairly accurately descriptive of the main divisions of practice.

The principal advantages which can or should be obtained by compounding may be briefly stated as follows:—

(1) **Two-Cylinder Systems.**

(a) Economy of fuel and steam consumption.



- (b) Uniformity of pull and thrust.
- (c) Temporary augmentation of power by using boiler steam (generally proportionately reduced in pressure for use) after starting, according to many systems.
- (2) **Three- or Four-Cylinder, Three- or Four-Crank Systems.**
 - (a), (b), and (c) as above.
 - (d) Regular turning-moment due to use of three or four cranks.
 - (e) Partial balancing.
 - (f) Large reserve of power by non-compound working, which may be continued for comparatively long periods.
 - (g) Division of work over two driving axles (some systems only).
- (3) **Four-cylinder Two-crank Systems.**
 - (a), (b), and (c) as above.
 - (d) Incidental advantages due to multiplicity of cylinders.

Before concluding this chapter, reference must be made to first cost and complication, and to the matter of compounding in reference to the work of the fireman.

Additional First Cost and Complication.—At one time very great objection was raised to compound locomotives, especially those having three or four cylinders, on the score of increased first cost and constructional complication; but it has been shown by practice that these matters are by no means so serious as they might appear to be.

With two cylinders these items are comparatively small, the only features whereby such engines are differentiated from non-compound engines being (1) the use of a small and a large cylinder, and (2) the provision of starting and intercepting valves or equivalent devices, and mechanism for controlling them (if not automatic), complication relating only to such valves and mechanism.

With four-cylinder two-crank systems there are necessarily additional cylinders, pistons, valves, etc., but additional valve gears and motion are not required, and the starting arrangements may be of a simple character.

With four-cylinder four-crank engines and with three cylinders, each cylinder requires a complete set of motion, though two valve gears can be made to control the steam distribution of four cylinders, and the additional first cost may be considerable, though starting arrangements are usually simple; but experience has shown that this is more than repaid by increased efficiency, and the fact that there are additional parts liable to failure and increased complication is not so serious as it might appear to be. Indeed, some engineers argue that to attempt to economise by using two valve gears only or by arranging all cranks on one axle is not the best policy, and that the increased complication, if it tends to efficiency, is most advantageous in the long-run.

The Influence of Compounding on the Fireman's Work.—In the case of a simple engine the blast is usually somewhat violent, and waste of fuel sometimes results because incompletely consumed coal

is drawn through the boiler tubes and ejected before it has been properly burnt. This occurs particularly when the engine is working hard, and just at the time when the strain upon the boiler is most severe, owing to the necessity for a large supply of rapidly generated steam; and at other times the intense blast may tend to "drag the fire to pieces," as it is termed.

With a compound engine, however, the blast is usually a soft one, owing to the large volume and low pressure of the escaping steam, and in some engines there are only two exhausts per revolution instead of four as usual. Consequently the fuel is not so often, if at all, ejected from the chimney or drawn through the tubes half consumed, although no difficulty should be experienced in maintaining steam when the fireman has learnt how to fire under these circumstances, and thus economy results quite apart from the compound use of steam.

CHAPTER III.

A CLASSIFICATION OF COMPOUND SYSTEMS.

CONTENTS:—Principal Features of Classification—Cylinder Arrangements for (1) Two-cylinder Systems; (2) Three-cylinder Systems; (3) Four-cylinder Four-crank Systems; (4) Four-cylinder Two-crank Systems; (5) Tandem Systems; (6) Articulated Engines—Cylinder Ratios—Receivers and Receiver Capacities—Arrangement of Cranks, Division of Power, Balancing—Valves, Valve Gears, Independent Adjustability of Valve Gears for High- and Low-Pressure Cylinders, Character of Steam Distribution—Starting and Intercepting Valves.

Principal Features of Classification.—The various systems which have been, or are now, employed for compound locomotives may be classified in several ways, and the following sets forth the principal features upon which any classification must be based:—

- (1) The number of cylinders employed.
- (2) The location and character of the cylinders.
- (3) The ratio between high- and low-pressure cylinder volumes.
- (4) The number of axles directly driven from these cylinders.
- (5) The arrangement, or not, of the cylinders, motion, and cranks to facilitate balancing.
- (6) The provision, or not, of a receiver, and the ratio of receiver to cylinder volume.
- (7) The relative angles at which the cranks are placed (for three- or four-cylinder systems only).
- (8) The employment of one slide or equivalent valve to control the steam distribution of each cylinder, or of each pair of cylinders, one high- and one low-pressure.
- (9) The employment of two, three, or four sets of valve gear for two or four, three or four cylinders respectively, and the provision, or not, of means whereby the high- and low-pressure valve gears can be independently adjusted, or whereby the high-pressure valve gear can be adjusted while the low-pressure valve gear maintains a constant cut-off ratio.
- (10) The nature and design of starting and intercepting valves.

(a) Automatic, the engine starting with boiler steam (generally at a reduced pressure) in the low-pressure cylinder or cylinders, and the valve or valves closing automatically as soon as the high-pressure exhaust attains sufficient pressure for working in the low-pressure

cylinder or cylinders. The change from non-compound to compound working usually takes place after three or four strokes only, so that engines having valves of this class cannot be worked non-compound even temporarily. In fact, the principal reason for fitting starting and intercepting valves is to enable the engine to start with the low-pressure cylinder (in the case of a two-cylinder engine) when the high-pressure crank is on a dead centre.

(b) Under driver's control, so that the engine can be worked with boiler steam in the low-pressure cylinder or cylinders for as long as required at starting, or temporarily at other times.

(c) Combined automatic and under driver's control, automatic working resulting immediately after starting, unless the driver has manipulated a device whereby he can continue non-compound working.

(d) In several systems no starting valve, and sometimes no intercepting valve, is fitted, starting being provided for otherwise, or the engine being confined to compound working.

Starting valves and intercepting valves can also be classified, as will be seen in subsequent chapters, according to their types—flap, piston, double piston, slide or lift valve—and according to whether they are separate valves, or whether one valve serves both purposes. They can also be classified according to whether the intercepting valve is automatic in operation, the starting valve being non-automatic, or whether both are automatic or both non-automatic.

Strictly speaking, the construction, arrangement, and operation of the starting and intercepting valves, or other starting devices or means for working non-compound, constitute the principal features whereby the various systems are differentiated, for other features are more or less dependent thereupon.

In practice, however, it is not convenient to classify the systems so elaborately as in the foregoing list of divisions, and therefore a simpler classification will be followed in this chapter, as under:—

- (A) The number, location, character, and relative proportions of cylinders.
- (B) The use or non-use of a receiver, and the ratio of receiver to cylinder capacity.
- (C) Crank angles, number of cranks, division of power over two axles, balancing, etc.
- (D) Slide valves, number of sets of valve gear, relative adjustability of high- and low-pressure valve gears, character of steam distribution, etc.
- (E) Starting and intercepting valves or equivalent devices.

A. — I. *Two-cylinder Systems.*—Most of the earlier compound locomotives had two cylinders only, a primary object of their designers being to adapt engines of existing types and designs for compounding with as little alteration and as much simplicity as possible, while in many instances old engines were adapted as compounds for experimental purposes. Provision had also to be made in some cases for the easy conversion of compound engines to non-

compound engines in the event of their proving unsatisfactory. During succeeding years two-cylinder compound locomotives were introduced in all parts of the world; and although three- and four-cylinder engines have been built in large numbers for many years, it is probable that the two-cylinder engines still outnumber all other compound locomotives.

In all two-cylinder compound locomotives the high-pressure cylinder has a diameter about equal to that of a corresponding non-compound engine, and the low-pressure cylinder has a considerably larger diameter, the proportions being such that the work done in each cylinder shall be about equal under average conditions.

In consequence of their similarity to ordinary engines, two-cylinder compound locomotives rarely differ to any appreciable extent, except in respect of the starting arrangements and the fact that one cylinder is larger than the other; and therefore, for present purposes, no more need be said than to refer to figs. 1 and 2, which represent diagrammatically the cylinder arrangement for an inside-cylinder and an outside-cylinder engine respectively.

FIG. 1.—Arrangement of Inside Cylinders—Two-cylinder Systems.

FIG. 2.—Arrangement of Outside Cylinders—Two-cylinder Systems.

II. *Three-cylinder Systems—One High-pressure and Two Low-pressure Cylinders.*—Two systems are, or have been, in use, having the three cylinders thus distributed, though similar systems have been proposed, some of them in the very early days of compounding for locomotives. Both of these systems are, or have been, applied according to two methods—(1) the three cylinders all actuating the same axle (fig. 3), or (2) the high-pressure cylinder driving one axle and the two low-pressure cylinders driving another axle (fig. 4).

The system identified with the Swiss Locomotive Works of Winterthur has been applied somewhat extensively in past years, almost exclusively, however, for engines for Swiss railways, but is now largely superseded by four-cylinder systems.

The Smith system, of British origin and use, is, on the other hand, essentially a recent one, and it appears probable that its use will be

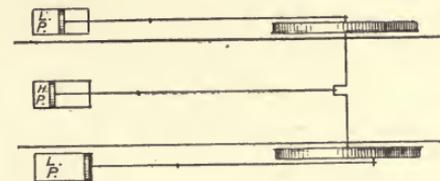


FIG. 3.—Arrangement of Cylinders—Three-cylinder Systems (one H.P. and two L.P.).

largely extended in the near future. At present, all of these engines (with the exception of two) have the three cylinders driving the same axle, but the system can be equally well applied so that the work is distributed over two axles. The system appears to indicate that the compound locomotive may have an important future quite irrespective of direct economy, for in actual use its chief advantage seems to lie in the fact that it provides for a great and yet variable

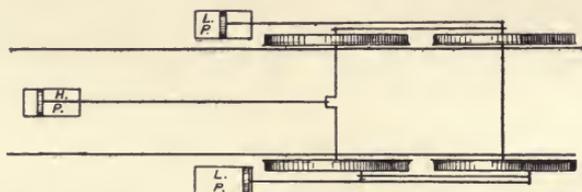


FIG. 4.—Arrangement of Cylinders—Three-cylinder Systems (one H.P. and two L.P.).

reserve of power, which can be drawn upon to surmount gradients or to deal with very heavy loads.

III. *Three-cylinder Systems—Two High-pressure and One Low-pressure Cylinders.*—These systems, two in number, are both of British origin, and each of them admits of the driving of one axle only, or of two, by the cylinders.

The Webb system, used so largely on the London and North-Western Railway at one time, is now superseded, and the seventeen similar engines supplied to France, South America, India, and the United States many years ago, were never multiplied; but this somewhat paradoxical system constitutes one of the most important links in the development of the compound locomotive.

In the case of the passenger and tank engines (fig. 5), the system

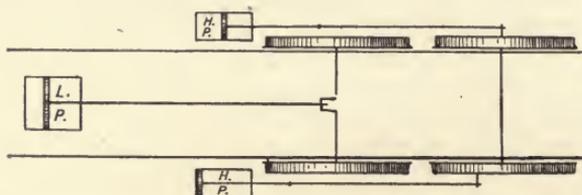


FIG. 5.—Arrangement of Cylinders—Webb Three-cylinder System.

was applied so that coupling rods could be dispensed with, the two H.P. cylinders driving one pair of wheels and the single L.P. cylinder driving another axle; but in the case of a numerous series of eight-coupled mineral engines the three cylinders actuated one axle (fig. 6), and the wheels were necessarily coupled.

The Riekie system, also indicated by fig. 6, has been experimentally fitted to converted engines in India, but has not been applied otherwise. It is, however, possible that it will be applied in British

practice at an early date. Its principal characteristics are—(1) the arrangement of the cranks at angles of 120° apart; (2) the non-provision of any special starting means; and (3) the fact that the high-pressure cylinders are designed to operate in exactly the same way as the two cylinders of a non-compound engine, cutting off early in the stroke, the function of the low-pressure cylinder being to enable further work to be extracted from the steam before it is exhausted up the chimney. This system has been applied with the cylinders all driving one axle, but it can be applied with the H.P. cylinders driving one pair of coupled wheels, and the L.P. cylinder driving another pair of wheels.

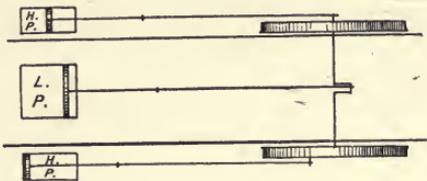


FIG. 6.—Arrangement of Cylinders—Three-cylinder Systems (two H.P. and one L.P.).

IV. *Four-cylinder Balanced Systems.*—Engines having four cylinders actuating separate cranks on one axle are generally termed “balanced” compound engines, as there is always one piston working in exactly opposite phase to another, so that balancing by counterweights on the driving wheels is largely reduced. Several systems of this class are in extensive use. As a rule, the high-pressure cylinders are placed outside the frames (fig. 7), but in some cases the low-pressure cylinders

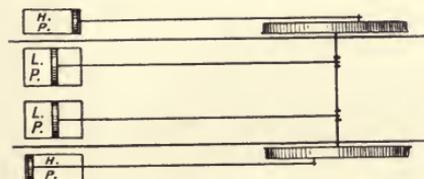


FIG. 7.—Arrangement of Cylinders—Four-cylinder Balanced Systems.

occupy that position (fig. 8). According to most systems, the pistons of adjacent high- and low-pressure cylinders always move oppositely, so that steam can pass directly from one to the other, the cranks of the two cylinders on one side of the centre line being arranged 180° apart, while the cranks of the other two cylinders are at right angles to the first-mentioned cranks, but at angles of 180° to each other. In fig. 7 the cranks at each side are at angles of 90° , and in fig. 8 they are arranged as mentioned.

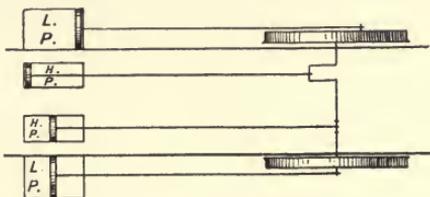


FIG. 8.—Arrangement of Cylinders—Four-cylinder Balanced Systems.

V. *Four-cylinder Divided and Balanced Systems.*—Systems of this class provide for two pairs of coupled driving wheels, one pair being operated by the high-pressure cylinders and the other pair by the low-pressure cylinders. As the wheels are coupled, these systems provide for balancing, but the work is divided over two axles; hence the usual descriptive term “divided and balanced.”

In fig. 9 the outside high-pressure cylinders are set back on the frames and drive the rear pair of wheels. Occasionally the positions of the respective cylinders are reversed. In fig. 10 the four cylinders are placed in line, the outside cylinders having long connecting rods.

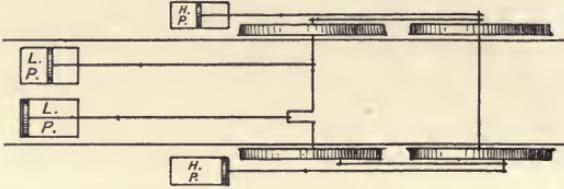


FIG. 9.—Arrangement of Cylinders—Four-cylinder Divided and Balanced Systems.

Fig. 11 corresponds to fig. 10, but low-pressure cylinders are placed outside the frame. The arrangement shown by fig. 12 has only been used for a few engines, but it is worthy of note. In this case the high-pressure cylinders are set back between the frames, and are

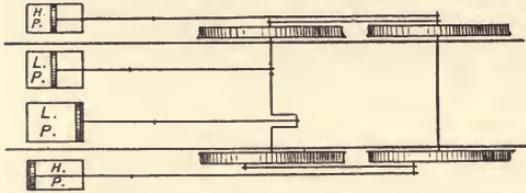


FIG. 10.—Arrangement of Cylinders—Four-cylinder Divided and Balanced Systems.

placed at an angle so that their rods can pass over the front coupled axle to drive cranks on the second coupled axle.

Most of the compound systems which are being applied for recent engines on a large scale, such as the de Glehn, von Borries, Gölsdorf, and Vaucrain, together with other recent systems, such as the Webb,

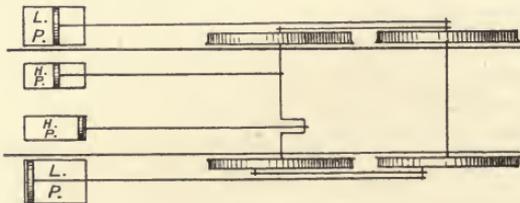


FIG. 11.—Arrangement of Cylinders—Four-cylinder Divided and Balanced Systems.

Cole, Ivatt, etc. systems, belong to one or other of these two four-cylinder classes, as will be seen hereafter.

VI. *Four-cylinder Two-crank Tandem Systems.*—Experimentally, the use of four cylinders arranged tandem fashion dates back right to the early days of compounding for locomotives, for it has the

advantage that only two sets of motion are employed, and ordinary locomotives can be fairly easily adapted by using the original cylinders for low-pressure, and fitting smaller high-pressure cylinders in front, the pistons of each pair being upon the same rod. About 1886 and 1887 there were several experiments carried out in Great Britain with such engines, and for some dozen years or so they have been built occasionally in the United States, a few of the engines being recent and notable machines. Their principal employment

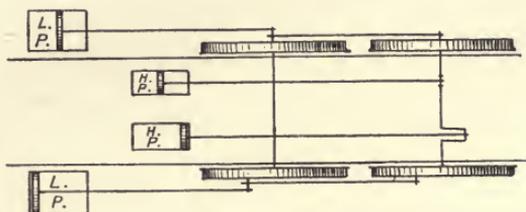


FIG. 12.—Arrangement of Cylinders—Four-cylinder Divided and Balanced Systems.

has been, however, in Hungary and Russia, and in the history of French locomotive development they are to be found as far back as 1882 and as recently as 1905, all of the engines being still in service.

Tandem compound locomotives can be divided into two main divisions: (1) where each pair of cylinders (one H.P. and one L.P.) are closely connected, one slide valve controlling the steam distribution; and (2) where the cylinders are separated, each having its own

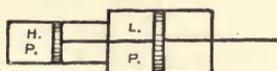


FIG. 13.—Arrangement of Tandem Cylinders.

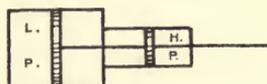


FIG. 14.—Arrangement of Tandem Cylinders.

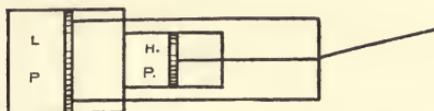


FIG. 15.—Arrangement of Tandem Cylinders with three Piston Rods.

slide valve, though necessarily the two slide valves of each side of the engine are fitted on the same valve rod. These features are dealt with specifically in Chapter IX.

In fig. 13 the high-pressure cylinder is placed in front of the low-pressure cylinder; in fig. 14 the arrangement is reversed. The arrangement shown in fig. 15 has been employed in a few cases, the low-pressure piston having two piston rods, which pass one on either side of the high-pressure cylinder, so that there are three piston rods connected to each crosshead.

VII. *Four-cylinder Two-crank Systems (other than Tandem).*—In this division two systems are included, so far as actual practice is concerned.

According to the Vaucain system (used very largely in America), there is a high- and a low-pressure cylinder superposed at each side, the piston rods of each pair being connected to the same crosshead,

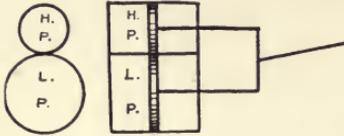


FIG. 16.—Arrangement of Superposed Cylinders—Vaucain System.

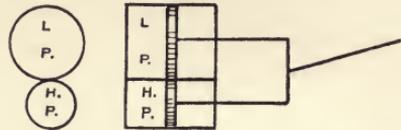


FIG. 17.—Arrangement of Superposed Cylinders—Vaucain System.

so that the engine corresponds in other respects to an ordinary two-cylinder non-compound engine. The steam distribution of each pair of cylinders is controlled by one special piston valve. In fig. 16 the high-pressure cylinder is uppermost, and in fig. 17 the low-pressure cylinder occupies that position. The former arrangement is generally employed for passenger engines and the latter for goods engines.

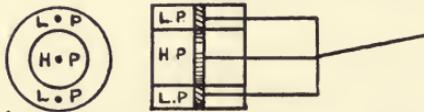


FIG. 18.—Arrangement of Cylinders—Johnstone Annular System.

two piston rods, the three piston rods being connected to one crosshead (fig. 18).

VIII. *Four-cylinder Articulated Systems.*—Locomotives compounded in this fashion have the coupled wheels arranged in two distinct sets, two cylinders driving one set of coupled wheels and two cylinders driving the other set of coupled wheels. In most cases the Mallet



FIG. 19.—Arrangement of Wheels and Cylinders—Articulated Compound System.

system is employed, according to which the rear coupled wheels are operated by the high-pressure cylinders and the front coupled wheels are mounted in a pivoted frame and operated by the low-pressure cylinders (fig. 19). The Meyer-Lindner system sometimes includes this cylinder arrangement, but, as a rule, the cylinders are located between the two sets of coupled wheels, one pair driving towards the front of the engine and the other pair towards the rear. In some

instances both sets of coupled wheels and cylinders are mounted on pivoted bogie trucks.

It is believed that compounding has also been applied for double bogie Fairlie engines, with one high-pressure and one low-pressure cylinder operating each set of coupled wheels.

A few other cylinder arrangements have been proposed, and in one or two instances actually applied, but these can only be referred to in subsequent chapters incidentally.

Cylinder Ratios.—Strictly speaking, the relative diameters of the high- and low-pressure cylinders should be such that, under average conditions, the amount of work done in the respective cylinders is approximately equal; otherwise the division of the work will be unequal, and injurious strains will be set up. This is particularly important in the case of two-cylinder compound locomotives, for if the work done in one cylinder exceeds that done in the other cylinder, there will be a tendency to twist the engine laterally. But although this equal division of power is very desirable, it cannot be fully obtained in practice, for circumstances and requirements vary to so great an extent that attention has to be paid to average conditions of work, and it is never possible to adapt an engine so that it shall be equally satisfactory under all conditions. Thus, if the cylinders are suitably proportioned for a 40 per cent. cut-off in the high-pressure cylinder and an 80 per cent. cut-off in the low-pressure cylinder, the linking up of the H.P. valve to a 30 per cent. cut-off will at once throw the L.P. steam distribution out of proportion. Means have been provided in connection with some two-cylinder systems whereby the valve gears for the two cylinders can be independently adjusted, and this facility is a common feature of many four-cylinder systems now in use, but the provision of such means is only a partial solution of the difficulty, and, as a rule, a suitable medium is selected to govern design.

It therefore follows that the cylinders must be proportioned to give the most satisfactory all-round results in this respect, and the question of cylinder ratios is one to be decided more by experience than by calculation. It is therefore not surprising that the practice of different engineers presents considerable variation, and it will be most satisfactory if the cylinder ratios generally employed are specified.

For two-cylinder compound locomotives the ratio is usually about 1 : 2 or 1 : 2.25, though it is occasionally 1 : 2.5 or 1 : 2.75, or even 1 : 3.

For three-cylinder compound engines, if only one H.P. cylinder is employed, the three cylinders have about the same diameter, or the L.P. cylinders are slightly larger, so that the proportion is 1 : 2 or 1 : 2.25. For example, the Smith compound engines on the Midland Railway have a 19-in. H.P. cylinder and two 21-in. L.P. cylinders.

For engines such as the Webb three-cylinder locomotives, the diameters have been 15 in. or 16 in. and 30 in., giving the ratio of 1 : 2, or slightly less.

In the case of four-cylinder compound locomotives the cylinders are designed, according to various systems, with a wide range of ratios, from as low as 1 : 1.7 to as high as 1 : 3. When the low ratio is employed there is generally some special reason therefor, such as, in the case, for example, of Webb four-cylinder engines, the need for having H.P. cylinders sufficiently large for starting a train unaided. When three or four cylinders are employed, it is not, however, so important to have the work evenly divided between high- and low-pressure cylinders as it is in the case of two-cylinder engines.

In a few cases the H.P. and L.P. cylinders do not have the same stroke, but such instances must be regarded rather as curiosities than as examples of practice. When this occurs, the ratios have to be computed by cylinder-volume instead of by cylinder-diameter.

B.—Receivers and Receiver Capacities.—For practically all compound locomotives in which steam cannot pass directly from a H.P. to a L.P. cylinder it is necessary to employ a receiver, or an equivalent therefor, into which the exhaust steam from a high-pressure cylinder passes and remains for a short period until it can be admitted to a low-pressure cylinder. The provision of a receiver is a necessity for two-cylinder compound engines, but in most three- or four-cylinder engines it can be dispensed with, though one is employed according to many such systems.

In all systems wherein a high- and a low-pressure piston move together, as in tandem, annular and superposed cylinder arrangements, a receiver is not necessary, as steam can pass directly from one cylinder to the other; and in other four-cylinder systems it is often arranged that corresponding high- and low-pressure pistons shall always move oppositely, their cranks being 180° apart. When, however, the H.P. and L.P. cranks are 90° or 135° or an indefinite angle apart, as in Webb three-cylinder and other non-coupled engines, a receiver is necessary.

As a rule, the receiver is constituted by the piping by which a H.P. cylinder is connected with its corresponding L.P. cylinder, and the requisite volume is obtained by coiling this pipe round the interior of the smokebox. This method also possesses the advantage that the steam is slightly reheated before it enters the low-pressure cylinder or cylinders.

The receiver also acts in large measure as a reservoir, whereby any inequalities of the pressure of steam entering from the H.P. cylinder or cylinders is more or less compensated for in the receiver, which acts to some extent as a storage chamber.

Receiver capacity is usually estimated in terms of the volume of the H.P. cylinder or cylinders, but the practice of various designers shows considerable variation. The most usual proportion is three or four times the volume of the H.P. cylinder or cylinders, but it is sometimes less, especially when more than two cylinders are employed, though two and a half times is about the minimum, and some engineers recommend a capacity of five or six times.

Receiver space is sometimes provided in the castings of the cylinders, and in other cases large steam chests for the low-pressure cylinder or cylinders and large or extended H.P. exhaust ports serve the same purpose.

The study of the influence of the receiver in compound locomotives is, however, a complicated one, and for extended consideration the reader must be referred to Professor Wood's book already mentioned.

In most cases the receiver is fitted with a safety valve, which blows off in the event of the steam pressure therein rising unduly. A usual lifting pressure for such valves is about 80 lbs. per square inch, this being a very common admission pressure for use in the low-pressure cylinder or cylinders.

C.—Arrangement of Cranks, Division of Power, and Balancing.—For two-cylinder and two-crank compound engines the cranks are always arranged at angles of 90° , this corresponding with ordinary non-compound practice; but when there are more than two cranks, various crank dispositions are used.

The usual arrangement for three-cylinder compound engines is to place the two L.P. cranks (for Webb three-cylinder engines it is the two H.P. cranks) at right angles, and the other crank bisects the obtuse angle between them, being at 135° with respect to each of the other cranks. Mr Riekie, in his system, however, advocates the arrangement of the three cranks at angles of 120° .

For four-cylinder four-crank systems the most common arrangement is to dispose the cylinders in pairs, there being a high- and a low-pressure cylinder on either side of the longitudinal centre-line of the engine, the cranks of which are 180° apart, so that the respective pistons are always moving oppositely, while the cranks of one pair of cylinders are placed at right angles to those of the other pair of cylinders. Consequently there are four cranks, driving at angles of 90° around the circle of revolution, or, as it is sometimes expressed, "four cranks quartering."

Occasionally this practice is departed from, such angles as 165° being employed between the cranks of each pair of cylinders, so that the cranks are unevenly disposed. This is, however, unusual; and where it has been employed, this method has, so far as the writer is aware, been discontinued.

In systems such as the Webb three-cylinder non-coupled and the Mallet and Meyer-Lindner articulated systems, according to which the high- and low-pressure cylinders drive separate non-connected wheels or sets of wheels, the two sections of the engine can operate for a few revolutions independently, but it is found that they quickly adjust themselves, owing to the excess or shortage of steam from the H.P. cylinder or cylinders, and when the engine is well under weigh they work practically synchronously.

With three or four cylinders it becomes possible to divide the work over two separate axles or two sets of coupled axles, and this possibility is realised according to several systems, one or two cylinders driving one axle and the other cylinder or cylinders

actuating the other axle. According to several systems, now discontinued, two pairs of uncoupled driving wheels are driven by independent cylinders, H.P. or L.P. as the case may be; but in present practice it is universal to couple them, so that the various cylinders always operate in fixed relation, and if there is a tendency for one pair of wheels to slip, or there is a loss of power for some reason, that pair of wheels is assisted or kept in proper relation by means of the coupling rods. When there are more coupled wheels than the coupled driving wheels, they receive power from both H.P. and L.P. cylinders.

When the power is thus divided between the cylinders, the parts can often be made of lighter construction than when all the work is transmitted through one axle.

An important advantage that results from three- or four-crank compounding is the fact that balancing is greatly assisted because of the multiplicity of cranks distributed fairly equally round the circle of revolution, the moving parts of one set of motion being largely counterbalanced by the moving parts of another set of motion. With three cranks, arranged more or less evenly apart, the turning-moment is very regular; and the same occurs when there are four cranks on one axle, or two each on coupled axles, arranged "quartering" or nearly so.

D.—Slide Valves, number of Sets of Valve-Gear, relative Adjustability of High- and Low-pressure Valve Gears, character of Steam-Distribution.—With two cylinders only the question of valve gears does not require extended consideration, for, as a rule, the gears employed correspond generally to ordinary practice, except that they will usually be adjusted to give proportionately corresponding cut-off ratios in the two cylinders, instead of the same ratio in each cylinder. According to a few systems, however, means are provided whereby the two valve gears can be adjusted together or independently, or the low-pressure valve gear maintains a fixed expansion ratio.

With four cylinders, however, practice may be divided into two main classes:—

- (a) Having separate valve gears for every cylinder; and
- (b) Having two valve gears, each governing the steam distribution of two cylinders.

All three-cylinder compound engines have separate valve gears, and, as a rule, they are each complete, though in a few cases—some of the Webb three-cylinder compound engines for example—one of the valve gears is of a simple type, and is dependent for its operation on the working of other valve gears.

Four-cylinder compound locomotives are about equally divided between the two classes.

When four cranks are employed, as in balanced, divided and balanced, and articulated engines, it appears to be preferable to fit each cylinder with its complete valve gear, although such practice introduces complication and adds to first cost, as by so doing the

valve gears can be independently adjusted, and in the hands of a capable driver this facility allows of the steam distribution being regulated proportionately in the high- and low-pressure cylinders, according to varying conditions of work and requirements. In some instances, however, especially those of recent date, although both sets of valve gear can be operated together for reversal, it is only the high-pressure gear that can be varied, the low-pressure gear providing a fixed expansion ratio.

When two sets of valve gear only are employed, the cut-off ratios are necessarily varied in fixed relation, as two valves, one for a high-pressure cylinder and one for a low-pressure cylinder, have to be operated from one set of valve motion. Usually, one valve is operated directly in the usual way, and the other is operated either directly or through a lever of the first order, whereby the valve is moved in opposite phase from the first-mentioned valve. In a few instances the motion comprises special elements, whereby provision is made for adjusting the relative cut-off ratios of the two valves, although the movements of both are derived from the same gear.

In some designs the steam distribution of a high- and a low-pressure cylinder is controlled by one valve working over specially arranged ports.

In the case of four-cylinder two-crank compound engines it is usually possible to employ one valve for controlling the steam distribution of a H.P. and a L.P. cylinder, or to arrange two valves on one valve spindle.

Instead of providing independently adjustable valve gears, it has been also proposed to provide means whereby the admission steam pressure for the low-pressure cylinder can be varied according to working requirements by means of an adjustable safety valve fitted upon the receiver, or by providing for a supply of boiler steam at variable reduced pressure to the receiver for reinforcing the low-pressure steam when necessary.

In most cases the cut-off ratios of high- and low-pressure cylinders differ considerably, and as a rule the variations of cut-off permissible are less than those possible in non-compound locomotives.

It may be stated as fairly descriptive of general practice that the H.P. cut-off can be varied between 25 and 75 per cent. of the stroke, while the L.P. cut-off can be varied only between 50 and 90 per cent. of the stroke. As mentioned, in many systems the L.P. cut-off cannot be varied, and in such cases it will usually be fixed at about 75 or sometimes 80 per cent. of the stroke.

E.—Starting and Intercepting Valves.—The last division necessarily entails detailed technical description, and therefore it will not receive consideration in this chapter, as most of the succeeding chapters relate to its subject-matter in large measure. Sufficient has already been said in the way of classification of starting and intercepting arrangements for present purposes.

CHAPTER IV.

THE HISTORY AND DEVELOPMENT OF THE COMPOUND LOCOMOTIVE.

CONTENTS :—The earliest Suggestions—The Nicholson-Samuel “Continuous-Expansion” System—The Sutcliffe and Salmon Proposals—E. Kemp’s Tandem Single-acting System—Joy’s Four-cylinder Suggestion—Morandière’s suggested Three-cylinder Engine—Weir’s Three-cylinder System—Fairlie Double-bogie Type—Dawes’ suggested Four-cylinder Arrangements—Hudson’s proposed Arrangement—Mallet’s first Engines—Andrade’s Three-cylinder Design—Holt’s Designs for Compound Tramway Engines—The Struwe Three-cylinder Design—Mallet’s suggested Schemes—Von Borries’ first Engines—Worsdell’s first Engines—Webb’s first Three-cylinder Engines—Sandiford’s Experiments in India—The Du Bousquet Tandem System in France—The Dunbar Tandem System—The Nisbet and Great Western Tandem Experiments—Mallet’s Articulated System—Brief Review to Date.

The earliest Suggestions. The Nicholson-Samuel Continuous-expansion System.—Strictly speaking, the building in 1877 of three two-cylinder compound tank engines according to Monsieur Anatole Mallet’s designs, for use on the Bayonne and Biarritz Railway, a small line in the South of France, marked the commencement of the history and development of the compound locomotive, for before that date no compound locomotives for railway use had been actually tried, though reference is made below to the Nicholson-Samuel “continuous-expansion” system of 1850–2, and it is possible that two or three compound tramway locomotives antedate the first Mallet engines by two or three years (the writer has been unable to confirm this); but particulars had been published concerning a number of schemes for compounding locomotives, and many patents granted in connection therewith, for at least twenty-five years previously, some of which published schemes and patents require to be briefly noticed, partly for completeness and because of their interest, but principally in order that development may be correctly traced.

It is sometimes stated that the first suggestion for applying compounding to locomotives can be dated as far back as 1834, but the writer has been unable to ascertain the correctness or otherwise of this. According to a proposal published about 1845, a four-cylinder system was proposed having two high-pressure and two

low-pressure cylinders, one of each being arranged on either side of the engine, one cylinder above the other, the connecting rods of each pair driving on to the same crank pin.

In 1850 Mr J. Nicholson, an employee of the Eastern Counties (now Great Eastern) Railway, devised a scheme which is closely related to compounding, though it is generally described as a "continuous-expansion" system, and two engines were experimentally adapted by Mr J. Samuel, the Locomotive Superintendent of that railway, in 1852, one engine being a passenger and the other a goods engine. This system had for its object to utilise the expansive power of steam to an extent that was unknown at the period when steam pressures were low and points of cut-off late in the stroke, but it can hardly be called a compound system, though closely allied thereto.

According to this system, steam was admitted to one cylinder for half the stroke, and communication was then opened between the two cylinders so that the steam could expand, not only for the remaining half of the stroke in the first cylinder, but also for the whole of the stroke in the second cylinder, the piston of which would, of course, be just commencing its stroke at the time of admission. It therefore followed that for half a stroke one piston was subjected to full pressure, and for the remainder of the stroke to a diminishing expansion pressure; and in the second cylinder steam at correspondingly diminishing pressure would act on the piston for half of its stroke, after which the first cylinder would be cut-off, and the steam then expanded still further for the remaining half of the stroke. The two cylinders, which were of equal size, operated alternately as first and second cylinders for the above-described cycle of operations.

To enable the required steam distribution to be obtained, there were two slide valves for each cylinder, four in all.

The general arrangement is shown by fig. 20, reproduced from a diagrammatic drawing published by Monsieur Mallet many years ago for comparison with his system. As will be seen, steam admission has just been cut off in the left-hand cylinder, and communication has just opened to allow steam to pass also into the right-hand cylinder.

It was stated at the time that this curious method of working proved very satisfactory, but after extended trial the engines were converted back to their original condition. It is believed that an engine was also adapted according to this system on the then London and Brighton Railway.

The Sutcliffe and Salmon Proposals.—In 1853 a Mr J. Sutcliffe patented a curious three-cylinder compound system, according to which two outside high-pressure cylinders operated the driving axle directly, and a single inside low-pressure cylinder actuated an axle which was geared by 2 to 1 gearing with the driving axle. The low-pressure cylinder was supplied from both the high-pressure cylinders, the low-pressure piston working at double the speed of the

high-pressure piston, so as to use the exhaust steam from both of them alternately. Owing to this peculiarity, the system fails to be an anticipation of the well-known Webb three-cylinder system, for it is really the equivalent of a four-cylinder system, the one low-pressure cylinder serving the purpose of two.

In 1859 a four-cylinder system was patented by Mr P. Salmon, of Glasgow, in which the two high-pressure cylinders were arranged at the firebox end of the engine and adapted to drive the leading pair of wheels, while the two low-pressure cylinders were located at the smokebox end and drove the rear pair of driving wheels, so that the respective connecting rods crossed one another, of course in separate planes.

According to a modification, it was proposed that a high- and a low-pressure cylinder should be placed one over the other at about the centre of the engine, the pistons of the respective cylinders driving

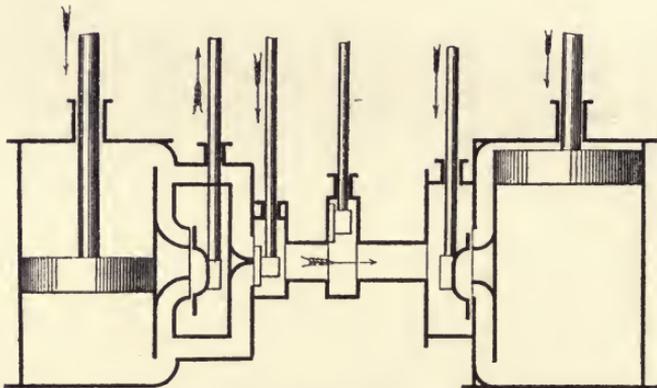


FIG. 20.—Arrangement of Cylinders and Valves—Nicholson-Samuel
“Continuous expansion” System, 1850-2.

in the one case to the front of the engine, and in the other case to the rear of the engine.

Other modifications suggest (1) the use of four cylinders placed in line, the low-pressure cylinders being between the frames and all connecting rods driving on to one axle; (2) the fitting of the cylinders in pairs outside the frames, the connecting rods at either side driving on to the same crank pins; (3) the use of one high-pressure cylinder and two low-pressure cylinders, all acting on the same axle; and (4) what is practically the ordinary two-cylinder system, with inside cylinders.

No details are given as to special starting arrangements, and it is rather curious that the two-cylinder system is placed last, being referred to almost as an afterthought, for the inventor evidently believed three or four cylinders to be really necessary for compounding, and this opinion seems to have been held by a number of the early inventors who dealt with compounding for locomotives.

E. Kemp's Tandem Single-acting System.—A strange four-cylinder system was proposed somewhere about 1860, and this may have been actually tried, though very few particulars are available. It represents a suggestion by Mr Ebenezer Kemp, and fig. 21 shows the proposed cylinder arrangement. In this case the cylinders were to be single-acting,—the steam acting first upon the plunger piston to force it in one direction, and then passing to the low-

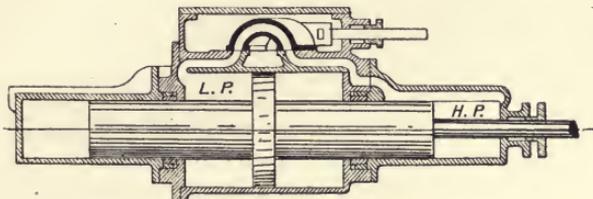


FIG. 21.—A Single-acting Four-cylinder Scheme, suggested about 1860.

pressure cylinder for acting upon the annular piston therein for the return stroke.

Joy's Four-cylinder Suggestion.—In 1866 provisional protection was granted to the late Mr David Joy for a scheme according to which the high-pressure cylinders were to actuate a pair of small wheels and the low-pressure cylinders to drive a pair of larger wheels, the different speeds of the two sets of driving wheels compensating for the difference in working pressure of the steam in each case.

Morandière's suggested Three-cylinder Engine.—At the period when the design of suitable locomotives for working traffic on the

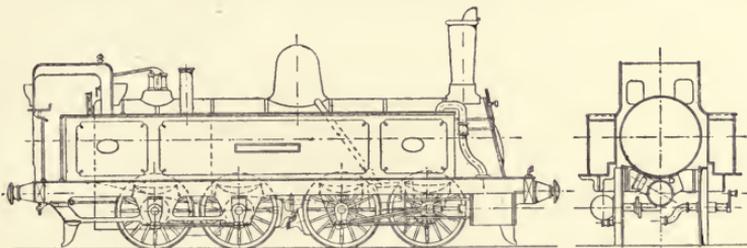


FIG. 22.—Three-cylinder System, suggested in 1866 by Monsieur Jules Morandière.

London Underground railways was attracting considerable attention, Monsieur Jules Morandière, of the Northern Railway of France, proposed a three-cylinder compound design, in which a single high-pressure cylinder drove one set of four-coupled wheels and two low-pressure cylinders drove another set of four-coupled wheels. The general arrangement, as published in *Engineering*, is shown in fig. 22.

About 1870 several tandem arrangements were proposed in England and in America, but none of them possess sufficient interest for detailed reference.

Weir's Three-cylinder System.—In 1871 a Mr J. Weir patented a three-cylinder system, comprising the use of one high-pressure and two low-pressure cylinders, all, however, operating upon the same axle; but though it is believed that the system has been actually employed for stationary engines, there is no record of its use for locomotives.

Fairlie's Double-bogie Type.—In 1872 four patents were granted in this country for compound locomotives, but only two of these are worthy of notice. In Mr Fairlie's scheme an articulated locomotive of the well-known Fairlie double-bogie type is fitted with tandem compound single-acting cylinders.

Dawes' suggested Four-cylinder Arrangements.—The other patent mentioned (No. 1857, of 1872, granted to William Dawes) is by far the most important of any before the actual commencement of the practical era of the compound locomotive, for it discloses the general features of most of the four-cylinder compound systems which have been since employed, and also includes one or two which have never gone beyond the suggestion stage.

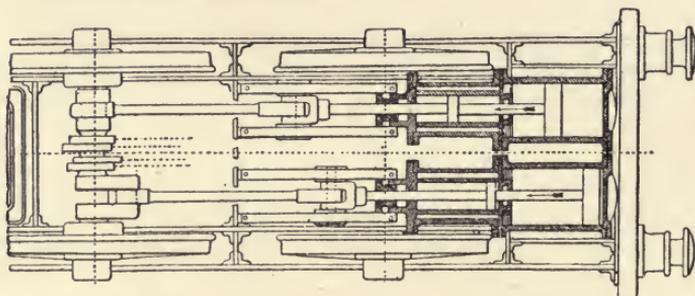


FIG. 23.—Four-cylinder Tandem System, suggested 1872.

Fig. 23 shows a tandem arrangement with the cylinders inside the frames, the low-pressure cylinders being in front, two sets of valve gear only being employed to control the steam distribution of the four cylinders. A four-cylinder arrangement, wherein the high-pressure cylinders are outside the frames and the low-pressure cylinders between the frames, is shown in fig. 24. The four cranks are 90° apart, and two sets of valve gear only are provided. This arrangement is characteristic of a good many of the systems now in use.

The arrangement shown in fig. 25 is somewhat notable, except that the cylinders are of the oscillating type, because it sets forth the division of work over two axles which are uncoupled, though this feature also occurs in several proposals already referred to.

The specification does not describe any particular construction of starting valve, but it is suggested that live steam can be admitted to the low-pressure cylinders for starting or when required by valves which can only be operated through the reversing gear when in the extreme positions of full-forward or full-backward gear; this feature is comprised in several later systems which have been actually employed.

Mr Hudson's proposed Arrangement.—In 1873 Mr Hudson, then Chief Engineer of the well-known Rogers Locomotive Works (U.S.A.), patented a two-cylinder compound system for American locomotives. A simple valve provides for admitting live steam to the low-pressure cylinder at starting. This also was never carried into practice, and it was many years before this firm commenced building two-cylinder compound locomotives according to their now well-known system, described later.

A British patent of this year suggests the fitting of a low-pressure

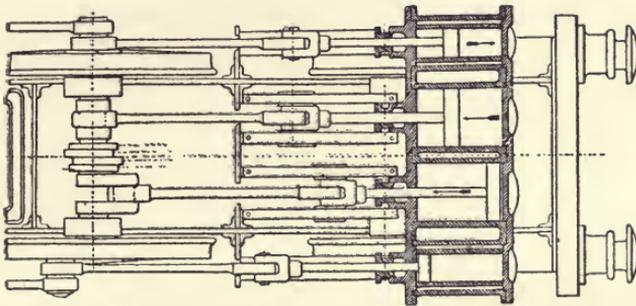


FIG. 24.—Four-cylinder Four-crank System, suggested 1872.

engine upon the tender of a locomotive; and a patent of 1874 granted to an American engineer is notable for the fact that, besides compounding, it also sets forth the use of superheated steam.

Mallet's first Engines.—It was in 1874 that Monsieur Anatole Mallet patented his two-cylinder system in France, though it was not until 1876 that it was actually realised; and a few notes concerning the early work of this gentleman, which entitles him to be described as "the father of the compound locomotive," will be in place at this

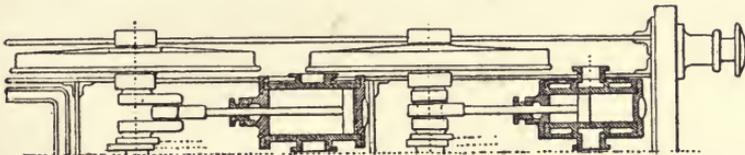


FIG. 25.—Four-cylinder System with Oscillating Cylinders, suggested 1872.

junction, for the Mallet system is one of the two main systems from which all the two-cylinder systems since introduced may be considered to be derived.

The Mallet system is the original of the now extensive list of systems according to which the driver is given complete control over the use of boiler steam in the low-pressure cylinder, the Worsdell-von Borries system (introduced 1880–1885) being correspondingly the original of systems by which, after starting, an engine is automatically converted to compound working.

Monsieur Mallet believed that the driver should be able to work

non-compound for as long as he deemed necessary at starting, and not merely for a few strokes as in automatic systems; and that, if required, the driver should be able to work non-compound at other times to overcome temporary difficulties.

The Bayonne and Biarritz Railway, a short line in the South of France, opened in 1877, and depending largely on pleasure traffic for its business, was the scene of work of the original Mallet compound locomotives. For the opening of this railway three small six-wheeled tank engines were designed by Monsieur Mallet, and built in 1876 by Messrs Schneider & Co. of the well-known Creusot Works. In designing these engines provision was made for their easy conversion,

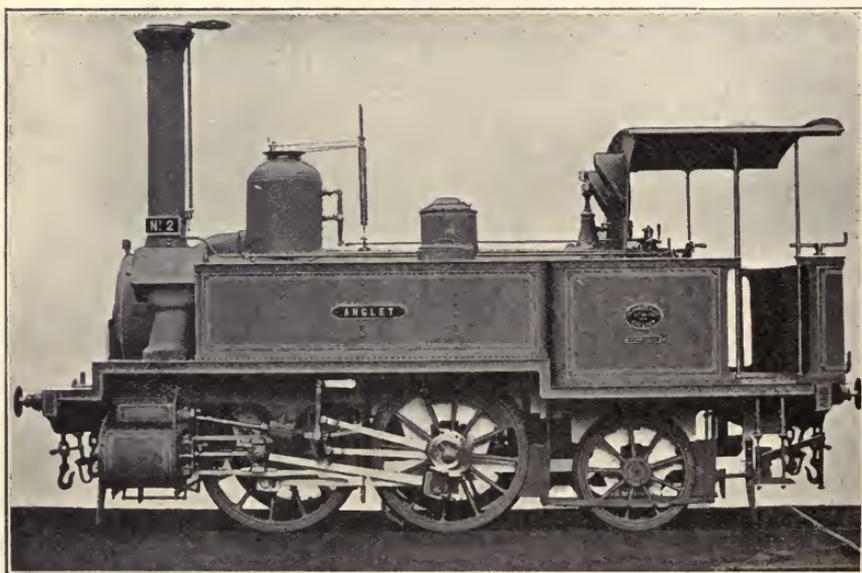


FIG. 26.—One of the first three Compound Locomotives—Mallet System.

if necessary, to non-compound, but their record was so satisfactory that the need never arose; and although other engines were added in succeeding years, this railway had the distinction of being the only line in the world possessing none but compound locomotives, which distinction was, it is believed, retained until the railway lost its identity and became merged in one of the large railway systems of France.

Fig. 26 illustrates one of the three original engines for this line, and fig. 27 is a cross section thereof.

In 1878 several six-coupled engines were added, one of which was exhibited at the Paris Exhibition of that year.

It may be mentioned that all these engines had very long chimneys, owing to the fact that the carriages then in use were largely of the

"double-decker" type, and the extended chimney carried the smoke and steam sufficiently high to clear the upper storeys to a great extent.

As some recognition of his services to locomotive engineering, Monsieur Mallet was awarded in 1877 the Fourneyron Prize for Mechanics by the Institute of France; and he has also since received several other prizes and decorations of considerable value and importance in the engineering world.

Andrade's Three-cylinder Design.—In 1875 a French patent was granted to Monsieur Andrade, with which scheme it is believed that Monsieur Mallet had something to do, setting forth the use of three cylinders, one high-pressure and two low-pressure.

Holt's Designs for Compound Tramway Engines.—Two patents were granted in 1876 to Mr H. P. Holt, a well-known British engineer, concerned largely with tramway engineering, for a two-cylinder compound system intended for tramway locomotives. It is believed that compound tramway locomotives were actually built according to this system.

The Struwe Three-cylinder Design.—In 1879 particulars were published of a three-cylinder design prepared by Monsieur Struwe, of the Kolomna Engine Works (Russia). In this arrangement an open-work piston-rod framing had to be employed for the inside high-pressure cylinder, in order to operate past the leading coupled axle, the second coupled axle being driven by all cylinders.

A curious scheme is covered by a patent of 1881. This suggests the use of an injector between the high- and low-pressure cylinders for the purpose of relieving the back pressure upon the H.P. piston when specially great power is required. Whether this would prove satisfactory in practice is a moot question.

Mallet's suggested Schemes.—In 1879 Monsieur Mallet published particulars of several suggested schemes for compounding locomotives with four cylinders arranged in various ways. One of the proposals related to a tandem arrangement of cylinders, and this was carried into practice in 1891 on the South-Western Railway of Russia, according to the instructions of Monsieur Borodine, one of the chief locomotive officials of the Russian railways, and formed the com-

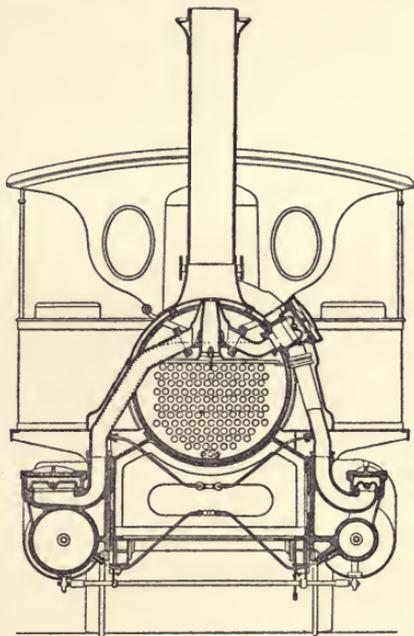


FIG. 27.—Cross Section of Mallet's first Compound Locomotives.

mencement of a long series of tandem compound locomotives employed in Russia, Monsieur Mallet being associated with Monsieur de Glehn in the design of these engines.

Monsieur Mallet also proposed a three-cylinder system wherein two low-pressure cylinders are superposed at one side of the engine, their piston rods being connected to the same crosshead, as shown by fig. 28. This system, which had for its object to allow of large low-pressure cylinder volume being employed without the cylinder projecting unduly from the frames, and which is, therefore, strictly the equivalent of a two-cylinder system, has never been carried out. It was also proposed by Mr Lapage in 1889 in connection with another scheme.

The von Borries first Engines.—The Worsdell-von Borries-Lapage system, with its variations according to the individual practices of the three engineers whose names are generally placed together in referring thereto, is the principal and original of two-cylinder automatic systems wherein the starting valve allows of the use of

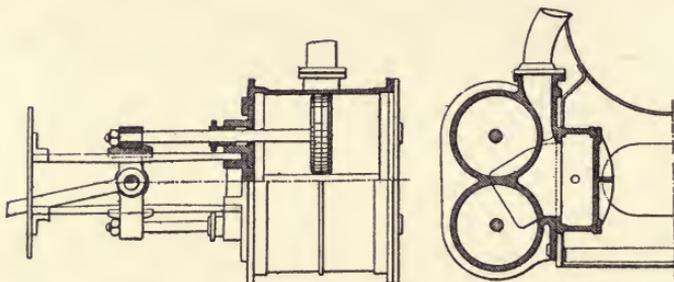


FIG. 28.—Proposed Three-cylinder or Double Low-pressure System (1879).

boiler steam in the low-pressure cylinder only until the high-pressure exhaust attains sufficient pressure for working in the low-pressure cylinder, which occurs usually after three or four strokes.

The first work was done by Herr von Borries, then in charge of the locomotives of the Hanover section of the Prussian State Railways, and was originally applied in 1880 to two small tank engines. Fig. 29 is a line engraving showing one of these engines. After extended trial, the system was applied to several other small engines, and in 1882 to two large goods engines; and during succeeding years the system was applied to engines of other railways, since which date locomotives compounded according to the von Borries system have been applied extensively on the Continent.

Worsdell's first Engines.—In 1884-5 Mr T. W. Worsdell applied his system, which corresponds in main features to that of Herr von Borries, to express locomotives of the Great Eastern Railway, of which line he was then Locomotive Superintendent. An outline engraving of one of these engines, which had inside cylinders 18 and 26 in. in diameter, is shown in fig. 30. In the latter year Mr Worsdell transferred his services to the North-Eastern Railway, on

which line these compound locomotives were introduced in large numbers, eventually to a total of several hundreds of various types—single-driving and four-coupled express engines, six-coupled goods engines, and six-coupled goods tank engines. At a later date the Worsdell system was also applied to locomotives of the Belfast

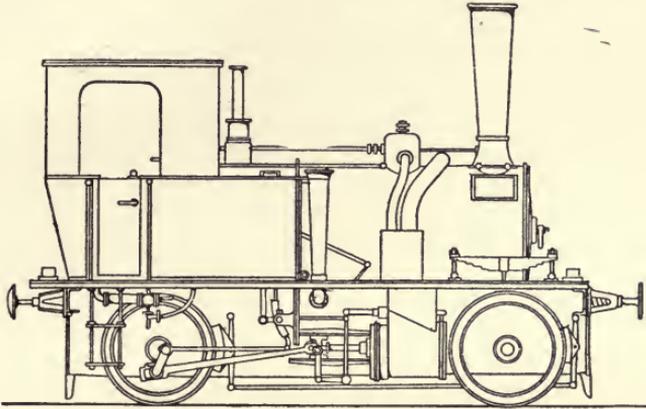


FIG. 29.—First von Borries Two-cylinder Compound Engine (1880-1).
Reproduced from *Verein Deutsche Ingenieure*.

and Northern Counties Railway of Ireland, and it is curious to note that Worsdell compound locomotives on this line are among the last to be introduced in Great Britain, some of them within the last two or three years.

After a few years of independent work the two gentlemen named

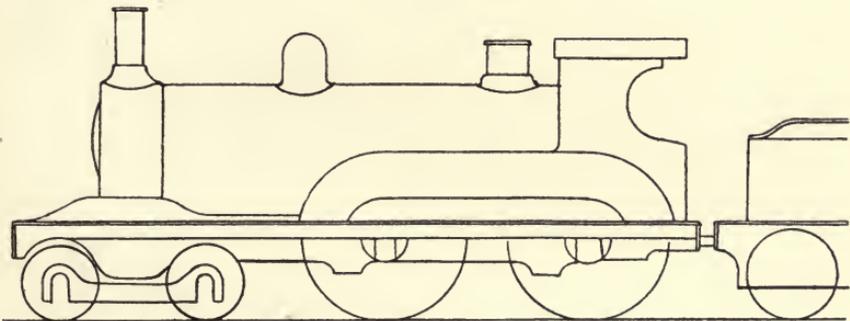


FIG. 30.—Diagram of first Worsdell Two-cylinder Compound Locomotive,
Great Eastern Railway (1884).

joined forces, as their individual systems corresponded so closely; and as Mr Lapage, a Westminster consulting engineer, largely concerned with the design of locomotives for Colonial and South American railways, was also introducing the Worsdell-von Borries system, with modifications of his own, the later arrangements have been patented jointly in the three names, and, except for the early

work, the system requires to be described as the Worsdell-von Borries-Lapage system, in which form it has been applied to many thousands of locomotives in all parts of the world.

The extremely divergent ways in which the system is estimated is, however, a fit subject for a few remarks.

On the Great Eastern Railway the whole of the compound locomotives were converted to non-compound by Mr J. Holden, who succeeded Mr Worsdell as Locomotive Superintendent, but not until that gentleman had conducted further experiments by adapting a goods engine according to the Worsdell system.

On the North-Eastern Railway, Mr Wilson Worsdell, brother and successor to Mr T. W. Worsdell, has converted the majority of the compound engines to non-compound.

In Continental countries, however, the Worsdell-von Borries engines are still in use in very large numbers, and there have been only a few instances of their conversion; in this respect Continental practice contrasts strikingly with the fate of British engines. For Colonial and South American railways the system is represented by many hundreds of engines; and although in many cases compound engines are not now built, there are other instances of new engines according to this system which have been quite recently supplied, many of them designed and built in this country.

The system has also been applied to many engines for use in India, United States, and other countries, quite independently of any of the engineers named; but, as a rule, and in the United States particularly, the two-cylinder systems employed of an automatic character are really developments or variations of the Worsdell-von Borries-Lapage system.

Webb's First Three-cylinder Engines.—The late Mr F. W. Webb, for so many years the well-known Chief Mechanical Engineer of the London and North-Western Railway, commenced experimenting in connection with the compounding of locomotives in 1878 by converting an old engine to a two-cylinder compound engine according to Monsieur Mallet's system, and in 1881 the first of his own three-cylinder compound engines was placed in service. It will therefore be seen that to Mr Webb must be credited the honour of being one of the pioneers of locomotive compounding.

In the original engine, appropriately named "Experiment," as well as for over a hundred subsequent engines, the peculiar plan was employed of using two comparatively small high-pressure cylinders driving by cranks at right angles one pair of driving wheels, there being a single large low-pressure cylinder actuating another driving axle, the two pairs of driving wheels being uncoupled. Moreover, Mr Webb did not provide any means for admitting boiler steam to the low-pressure cylinder at starting, the small high-pressure cylinders being forced to start a train unaided until the low-pressure cylinder could receive steam from them. This engine is shown in fig. 31, which has been reproduced from *Engineering*.

As might be expected, the appearance of the first of these engines

not only attracted attention from engineers all over the world, but provided material for one of the most heated controversies which have ever appeared in the pages of an engineering journal, for letters from amateur and practical engineers appeared week after week for several months in the pages of *Engineering*, the writers endeavouring to prove and disprove that Mr Webb was altogether wrong, both as regards his system and as regards the design of the engine. It must be remembered that in those early days there were very few engineers who would admit that locomotive compounding could be satisfactory at all, and the opposition to Monsieur Mallet and to Mr Webb was in some quarters of an extreme character.

However, Mr Webb disposed of his opponents, who said in effect that "he did not know his business," by building more and more of his three-cylinder compound engines, and showing their capabilities in working the express traffic of the London and North-Western Railway; and although the building of these engines has for some

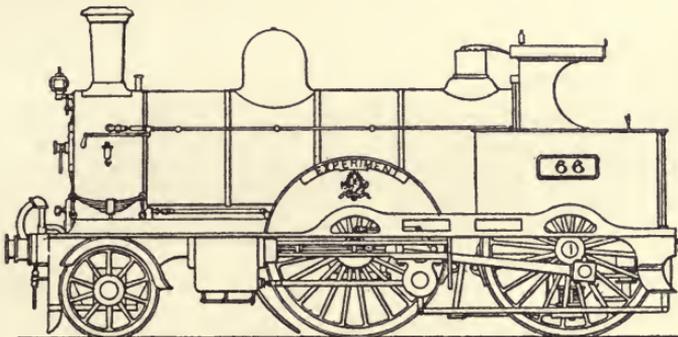


FIG. 31.—First Webb Three-cylinder Compound Engine for London and North-Western Railway (1881). Reproduced from *Engineering*.

years been discontinued in favour of four-cylinder coupled compound engines, and Mr Webb's successor, Mr G. Whale, has discontinued the building of compound locomotives at all, yet the record of the three-cylinder engines is one of which no railway need be ashamed. That they might have been improved most engineers will agree, especially now that the course of years has produced so many other compound systems, and it may be admitted that the greatest progress has been made with systems differing radically from Mr Webb's in nearly all essential particulars; but the disposition to belittle the work of Mr Webb, which has been very apparent in engineering journalism since his retirement under circumstances which preclude any reply on his part, is both discourteous and unfair. Mr Webb died in June 1906.

Nearly all the Webb three-cylinder compound passenger engines have been "scrapped" during 1905-6.

Sandiford's Experiments in India.—In 1883 Mr C. Sandiford, Locomotive Superintendent of the Scinde, Punjab, and Delhi Railway

of India, experimentally converted two engines, one as a two-cylinder compound engine and the other as a four-cylinder compound engine. A simple valve was provided to admit steam to the low-pressure cylinder in the case of the two-cylinder engine when the high-pressure crank was on a dead centre, but otherwise no special starting device was fitted. In neither case were the engines sufficiently satisfactory to warrant an extension of compounding, though they did as well as a non-compound engine, and in some cases better.

The Dunbar Tandem System.—About the same time an engine for the Baltimore and Ohio Railroad in America was fitted as a

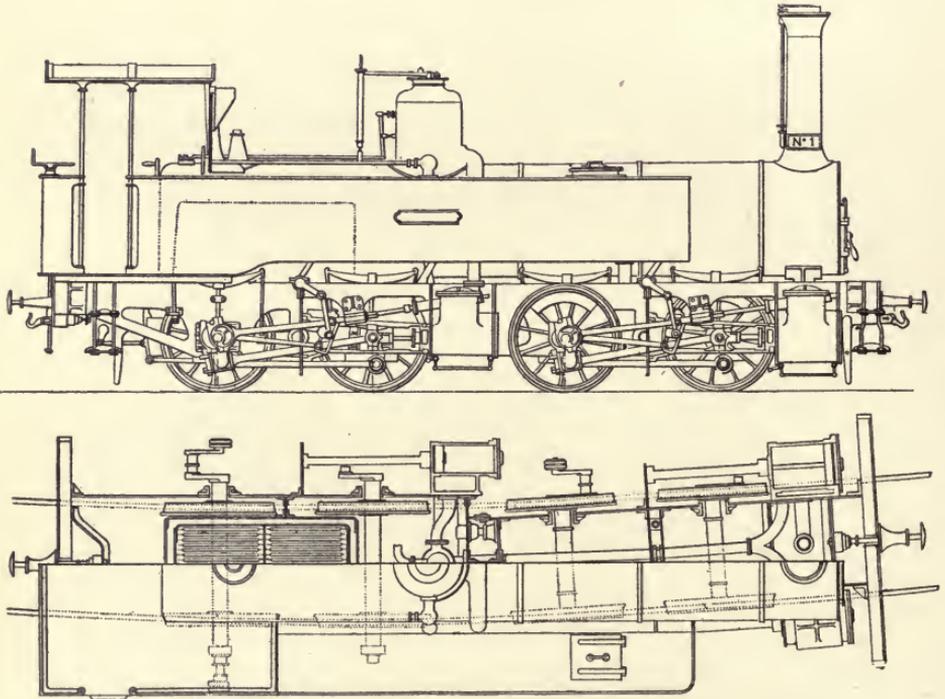


FIG. 32.—First Design of Mallet Articulated Compound Engine (1885).

tandem compound engine according to the Dunbar system, but it did not prove very satisfactory. It is, however, only fair to note that at the time of the trials the inventor was ill, and could not give his personal attention.

The Bousquet Tandem System in France.—In 1882–3 Monsieur du Bousquet introduced a class of tandem compound heavy goods engines on the Northern Railway of France, which engines have always done good work, and are still at work, it is believed, unaltered. This system is described in detail in Chapter IX.

About 1886 or 1887 an engine of the North British Railway was converted as a tandem compound engine, with all cylinders between

the frames, according to the Nisbet system. The engine selected was No. 224, the engine which fell with the Tay Bridge during the terrible storm of Christmas Eve, 1879. It was stated that the engine did not give results as a compound sufficiently notable to warrant extended use of the system, and it was soon after converted again as a simple engine.

At about the same time two engines were experimentally converted on the Great Western Railway, one engine having ordinary tandem inside cylinders, the high-pressure cylinders being placed in front of the low-pressure cylinders, and in the other case the low-pressure cylinders were in front, and their pistons had two piston rods which worked on either side of the high-pressure cylinders, so that each crosshead had three piston rods connected to it, substantially in the manner indicated by fig. 15. These experiments again did not result in further compound locomotives, and the engines were soon afterwards rebuilt as non-compounds.

Mallet's Articulated System.—The Mallet articulated or double-bogie system was introduced first in 1887, as described in detail in Chapter XIII. Fig. 32 is a reproduction of a design prepared by Monsieur Mallet in 1885.

Brief Review to Date.—This period also produced the first de Glehn four-cylinder compound engine, the Landsée "Asynometric" system, the Henri four-cylinder system, the Lindner system, the Sauvage three-cylinder system, and the Swiss three-cylinder system; and in 1889–1893 most of the American systems were introduced, together with various Continental systems, such as the Gölsdorf, Maffei, and others, most of which are specifically referred to in appropriate chapters.

It is impossible and unnecessary to maintain the subsequent chronology of locomotive compounding, and the practical developments (other than schemes not actually employed) are considered in the following chapters, which relate almost entirely to the modern compound locomotive.

CHAPTER V.

TWO-CYLINDER NON-AUTOMATIC SYSTEMS.

CONTENTS :—The Mallet System—Worsdell-von Borries-Lapage Non-automatic System—Batchellor System—Colvin System—Worsdell-von Borries-Lapage latest System—Landsee Asynometric System—Mallet Two-cylinder Tandem System—Brunner System—Starting Arrangements on Eastern Railway of France—Rogers Non-automatic System—Two-cylinder Compound Locomotives (Non-automatic) on the Hungarian State Railway—Schenectady Non-automatic System—Vauclain Two-cylinder System—The Cooke System—Nadal System—The Dultz System—Two-cylinder Compound Engines in Italy.

THE systems of this class are the most numerous of those concerned with the use of two-cylinders only for compound locomotives, and it is therefore fitting that these should be dealt with first, more especially as the earliest compound engines—those designed by Monsieur Mallet for the Bayonne and Biarritz Railway in 1876-7—belong to this class. According to all such systems, it is possible to continue non-compound working after starting, whereas in automatic systems, after two or three strokes, the engine commences to work compound, quite irrespective of any action on the part of the driver.

The original work of Monsieur Mallet has already been briefly reviewed, and the technical details of his work will now be considered.

The Mallet System.—In the first engines a valve of the slide valve type was located in a casing arranged outside the upper part of the smokebox, and could be operated from the engine cab by the driver. This valve covered or uncovered ports which allowed the high-pressure exhaust to pass either to the low-pressure cylinder or to the chimney. With it was combined an automatic piston valve, which, when the slide valve uncovered the port leading to the low-pressure cylinder, allowed steam to pass at a reduced pressure to that cylinder.

In engines built immediately afterwards for the Haironville system of light railways in France, Monsieur Mallet also provided for the independent adjustment of the valve gears of the two cylinders, so that the point of cut-off in each could be relatively

varied to balance or adjust the work being done in each cylinder under varying circumstances.

In applying the system to other engines, which was done to a notable extent during the next three or four years on the Northern Railway of Spain, in Russia on the South-Western Railway, and in a few other instances, the starting valves were slightly modified, but not to any appreciable extent. In one construction, very similar to that described in other respects, the slide valve was itself employed to control the live steam admission to the low-pressure cylinder, its upper surface controlling an admission port connected with a small steam-pipe, the required reduction of pressure resulting in this case from wiredrawing.

In these later engines the connecting pipe between the high- and low-pressure cylinders, which constituted the receiver, was lengthened by being carried round the smokebox, so that the steam became reheated somewhat before being used in the low-pressure cylinder.

In other engines the starting and intercepting valves were separated, one valve being placed on either side of the smokebox.

The starting valve comprises a small slide valve covering two ports leading to the receiver, and on the top of this valve another slide valve is formed controlling two ports, one leading to the atmosphere and the other to a small pipe connected with the intercepting valve on the other side of the smokebox. The valve casing is connected with the live steam supply to the intercepting valve, for a purpose explained in the next paragraph.

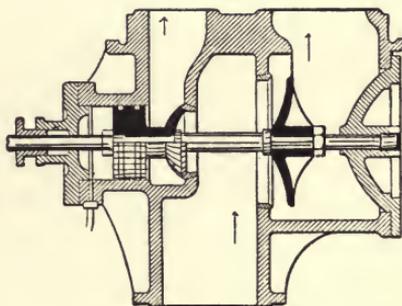


FIG. 33.—One Form of Mallet Intersecting Valve.

When the starting valve is moved by the driver, a port is uncovered so that boiler steam can pass to the receiver, and at the same time other ports are connected so that the small pipe mentioned is opened to the atmosphere.

The intercepting valve (fig. 33) consists of two circular valves and a piston mounted on one spindle. As shown, the valve is in the position for compound working. Steam enters from the starting valve by means of the small steam-pipe above mentioned behind the piston, and by its pressure closes the left-hand valve, which shuts off communication with the chimney and opens the other valve, so that steam from the high-pressure exhaust can pass to the receiver, and thence to the low-pressure cylinder. When the starting valve is operated for non-compound working, the space behind the piston is connected with atmosphere as described and the steam supply is cut off; at the same time boiler steam has been admitted to the receiver by the starting valve and the right-hand valve therefore closes, the left-hand valve simultaneously opening to the chimney.

It will thus be seen that, whereas in the earlier construction it was the intercepting valve that was controlled directly by the driver, in the later construction the starting valve was so adapted, the intercepting valve working automatically.

In another construction a starting cock was employed instead of a slide valve.

In some cases engines fitted with arrangements for non-compound working of the kind described were fitted with ordinary pressure-reducing valves between the starting valve and the receiver. Also, in some instances, the intercepting valve was adapted to be operated by the driver simultaneously with the starting valve.

In later years the Mallet types of starting and intercepting valves have lost their identity in a large measure in the newer designs

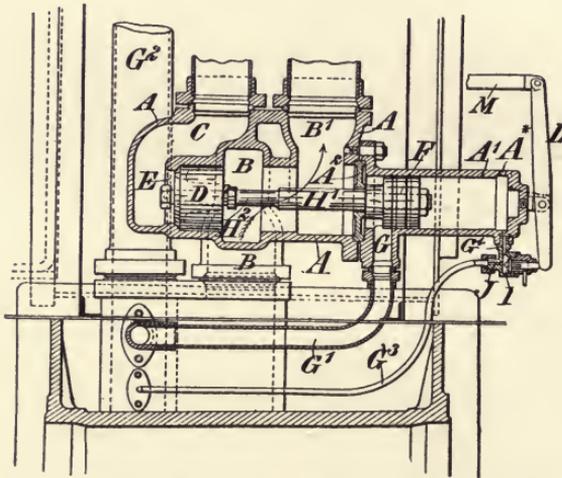


FIG. 34.—Worsdell-von Borries-Lapage Non-automatic Starting and Intercepting Valve (Compound Position).

introduced by various locomotive engineers and locomotive building firms, but they are mostly based on Monsieur Mallet's original designs.

The Worsdell-von Borries-Lapage Non-automatic System.—After a good many years' employment of compound locomotives having automatic starting arrangements, as will be described in detail in Chapter VI., these gentlemen patented in 1892 a construction of automatic starting valve which allowed of an engine being worked non-compound for a longer period than two or three strokes; and this valve, one construction of which is shown in fig. 34, has been employed for later two-cylinder compound locomotives.

The valve case A is formed with a high-pressure exhaust passage B B¹ adapted to form part of the receiver pipe, and with another passage C which forms part of the low-pressure exhaust passage. The piston valve D controls the passage E which connects the passages B¹ and C; and the piston valve F, which works in an

extension A^1 of the valve casing, controls a boiler steam inlet G . This inlet may be controlled by a cock or valve operated by hand or from the reversing gear, or a special regulator valve may be employed for the purpose, as will be described later. The port A^* connects with atmosphere in order to remove resistance to the movement of the valve F . The valves D and F are mounted on a rod H having two diameters as shown, the part H^1 working through a partition A^2 so that live steam cannot flow freely to the low-pressure cylinder until the valve D is fully opened, at which time the smaller part H^2 of the rod H has passed into the opening in the partition A^2 .

When live steam is admitted through G so as to act upon the inner end of the valve F , the two valves will be moved automatically into a position which causes the valve D to close the passage B^1 and open the passage E so that the cylinders can exhaust separately to the chimney, and the valve F occupies a position such that the rod H has moved sufficiently to open an annular passage through the partition A^2 around the smaller part H^2 of the rod, thus allowing boiler steam to pass to the low-pressure cylinder for non-compound working. When the supply of steam to the inlet G is cut off, the valves D F return automatically to the normal positions shown, by reason of the greater pressure on the valve D on the side nearest to the receiver passage B^1 .

To allow of the inlet G being in constant connection with boiler steam the air-hole A^* is dispensed with, and the front end of the extension A^1 is connected by a pipe G^3 with the steam supply controlled by a valve I , which can be opened or closed by the driver through the lever L , and there is also communication with atmosphere, so that by closing the valve I to steam and opening a passage from A^1 to atmosphere, steam acts on one side only of the valve F , and by opening the valve I to steam the equilibrium of pressure on the valves D F is destroyed, and the said valves move automatically into the compound position. The arrangement illustrated also provides for a reduction of the live steam pressure for supply to the low-pressure cylinder.

Generally, when the inlet G is only connected with steam when working non-compound, the ordinary regulator valve is provided with a special port, so that when fully opened, as at starting or when working hard, steam passes to G and the engine works non-compound, whereas on partially closing the regulator the steam is cut off from G and compound working commences. It therefore follows that with such an arrangement an engine only works non-compound with the steam regulator fully open or nearly so, whereas when the valve I is employed non-compound working results entirely at the will of the driver.

Batchellor System.—This system has been largely employed in past years for engines built by the Rhode Island Locomotive Works, U.S.A., though, since the amalgamation of this firm into the American Locomotive Company, it has only been used, if at all, when specially ordered.

The intercepting valve (shown in figs. 35 and 36) is of the piston type, having three pistons *a b c* mounted on one rod, the movement of which is controlled by a dashpot *d*, these valves operating automatically according to whether the starting valve *e*, which is controlled by the driver through an arm *f* and rod extending into the cab, is in position for compound or non-compound working. The pipe *i*

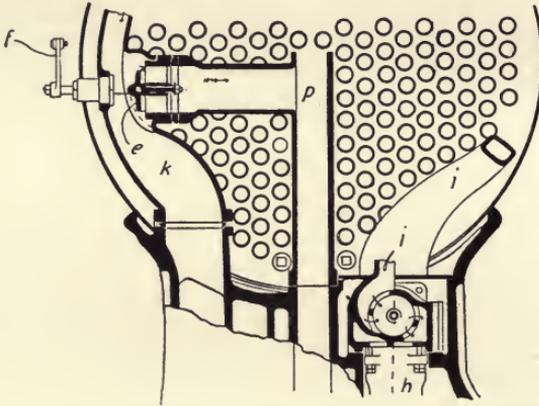


FIG. 35.—General Arrangement—Rhode Island (Batchellor) System.

serves for the main steam supply to the intercepting valve ; the pipe *k* constitutes the receiver ; the port *m* connects the steam pipe *i* with the interior of the valve ; the port *n* connects the interior of the valve with the pipe *h* wherein the reducing valve is situated ; and the port *o* connects with the low-pressure steam chest. The

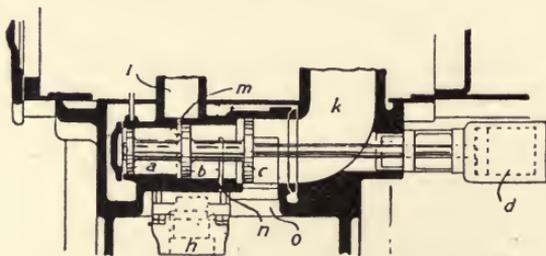


FIG. 36.—Intercepting Valve—Rhode Island (Batchellor) System.

starting valve *e* connects, when open, the receiver pipe *k* with the blast pipe *p*, and thence with atmosphere for working non-compound.

In operation at starting, the valve *e* being closed and the regulator being opened, steam passes, in addition to its direct passage to the high-pressure cylinder, along the pipe *i* and into the intercepting valve through the port *m*, where it acts on the piston *b*, which is slightly larger than *a*, moving the whole to the right, and opening a passage for steam from *m* through the port *n* to the reducing valve *h*,

and thence to the low-pressure steam chest, the steam being proportionally reduced in pressure before use in the low-pressure cylinder. As soon, however, as the pressure in the receiver becomes sufficient for compound working, the greater pressure on the receiver face of the piston *c* causes the valves to be moved to the positions shown, cutting off the live steam supply to the low-pressure cylinder, and opening the port *o*, connecting receiver and low-pressure steam chest.

Thus far it will be seen that the intercepting valve operates automatically, and were no starting valve employed the system would be an automatic one, not allowing of extended non-compound working.

By opening the starting valve *e*, which is of the "hit-and-miss" type, the high-pressure exhaust is allowed to pass to the blast pipe, and as long as this is permitted, the absence of pressure in the receiver causes the intercepting valve to remain in position for non-compound working. Consequently, although an engine fitted according to this system always starts non-compound, the driver can also continue non-compound working as long as desired.

The system has been applied without the starting valve, and it then belongs to the automatic class, but in most cases the starting valve is employed. Engines fitted according to this system (with the starting valve) have been used for service on the Brooklyn Elevated Railway (New York), than which it would be difficult to find a more arduous task, for such work entails very frequent stopping and starting, and rapid accelerative power is absolutely necessary.

The Mellin System.—This system has been principally employed for engines built by the Richmond Locomotive Works (U.S.A.), another firm now embodied in the American Locomotive Company; but it has also been fitted for some Continental locomotives, and this system stands almost alone among American compound systems in having been employed for engines outside of America, and not of American design and build.

In general operation the Mellin system is very similar to the Batchellor system already described, though it also corresponds to a great extent with some of Monsieur Mallet's valves. A general construction as used in America is shown in fig. 37.

The space *f* connects with the high-pressure exhaust and constitutes part of the receiver, and its communication with the passage *h* to the low-pressure cylinder is controlled by the main intercepting valve *g*, which valve is automatically closed at starting by boiler steam from *o* acting on the small annular area at the right-hand end of the piston *l* mounted as a sleeve upon the valve spindle. Live steam at a reduced pressure then passes from *o* through the annular passage opened when the piston *l* moves to the left with the valve *g*. As soon as the pressure in the receiver becomes sufficient, the valve *g* opens, cutting off the live steam supply from *o*, and the engine works compound.

Thus far the valve is automatic in its operation, but to allow of

compound working being maintained a spring valve *b* is fitted, which valve may be operated by levers and rods from the cab, or, as shown, by steam admitted at *d* behind the small piston *c*. When the valve *b* is opened the H.P. exhaust from *f* can pass away via *a* to the blast pipe, and as there is then no receiver pressure the valve *g* remains closed. For the purpose of ensuring prompt closing of the

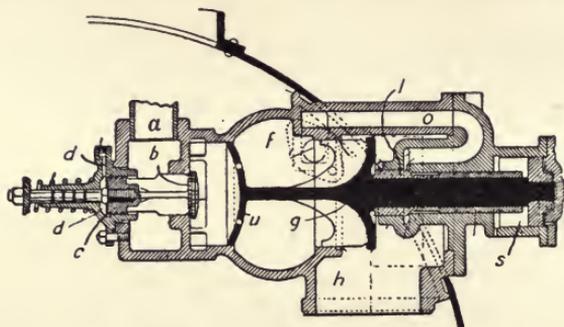


FIG. 37.—Mellin Starting and Intercepting Valve.

valve *g* it is provided with a perforated piston *u*. Communication with exhaust is allowed through the perforations in *u* until that valve has moved to the left, when passage around the valve is also permitted. A dashpot cylinder is fitted at *s*.

The Colvin System.—This system, again, is one introduced and employed by an American firm (the Pittsburgh Locomotive Works), which is now absorbed in the American Locomotive Company. In

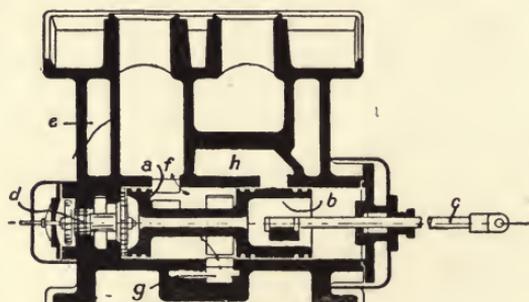


FIG. 38.—Colvin Starting and Intercepting Valve (Pittsburgh Locomotive Works).

this case (fig. 38) the controlling pistons *a b* are moved directly by the driver through the rod *c*, there being, however, an automatically acting live steam admission valve *d*. Boiler steam is admitted through the passage *e*, controlled by the valve *d*. The passage *f* communicates with the receiver, *g* is the passage from the high-pressure cylinder, and *h* the passage for the high-pressure exhaust when the engine is working non-compound. When the valve is moved to the right, boiler steam enters from *e* past the valve *d*,

which opens of itself to the receiver, and thence to the low-pressure cylinder. At the same time the high-pressure exhaust passes from *g* to *h*.

On moving the valves *ab* to the left, so that the parts occupy the positions shown, the high-pressure exhaust is diverted to the receiver, and thence to the low-pressure cylinder, and the live steam supply through *d* is cut off, that valve being forced on to its seating by the valve *a*. The valve *d* is of differential construction, so that it acts as a reducing valve whereby the boiler steam for use in the low-pressure cylinder is appropriately reduced in pressure.

Ivatt's Starting and Intercepting Valve.—In 1896 Mr H. A. Ivatt, now Locomotive Superintendent of the English Great Northern Railway, but then occupying a similar position on the Great Southern and Western Railway of Ireland, experimented with an engine having a combined starting and intercepting valve of the

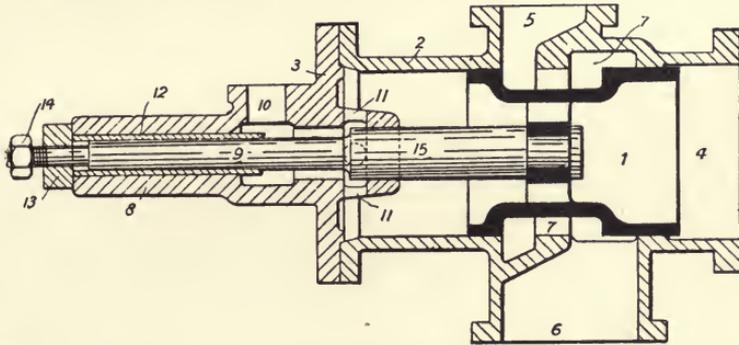


FIG. 39.—Improved Non-automatic Starting Valve—Worsdell-von Borries-Lapage System.

composite piston type, but nothing further was done with this system.

Messrs Worsdell, von Borries, and Lapage's latest form of Starting and Intercepting Valve.—The valve shown in fig. 39 represents the latest form of starting and intercepting valve introduced by these gentlemen since 1900. As can be seen, it is very similar in general character to many others of the valves which have been described, but it is somewhat notable for embodying almost the acme of simplicity in connection with such valves, especially as it combines the purposes of a starting, intercepting, and reducing valve.

The hollow piston valve 1 works within a casing having ports and openings connecting as follows:—

At 4 with the receiver, and thence with the low-pressure cylinder; at 5 with the blast-pipe or atmosphere; at 6 with the exhaust port of the high-pressure cylinder; and at 10 with the main steam supply. The spindle of the valve 1 has an enlarged portion 15, part of which constitutes a second valve co-acting with the valve 1.

With the ports in the position shown the high-pressure exhaust from 6 is connected with the blast pipe or atmosphere through 7, communication with the low-pressure cylinder through 4 being cut off, and boiler steam from 10 is allowed to enter through the annular passage round the spindle 9, as permitted by the position then occupied by the part 15, the arrangement being such that the purpose of a reducing valve is served, and passes through the openings 11 to the hollow of the valve 1, and thence to the low-pressure cylinder.

When there is no pressure in the receiver the boiler steam entering forces the valves to the positions shown if they do not already occupy those positions, but as soon as the receiver pressure becomes sufficient they move, if permitted otherwise, to the left, so that the high-pressure exhaust is connected with the receiver, and the live steam supply cut off owing to the excess of pressure of the receiver steam on the end of the spindle 15; but this may be prevented when a lever, of which the end is shown in section at 13, is so operated from the engine cab that the spindle 9, 15 is held in the position represented, and therefore the engine works non-compound until the lever 13 is moved to allow the spindle 9, 15 to move to the left so that compound working commences. It will therefore be seen that the driver has full control of compound or non-compound working, and the change from non-compound to compound is assisted when there is a working pressure in the receiver.

This construction of valve has been also applied by Herr von Borries for four-cylinder compound locomotives.

The Landsée Asynometric System.—This system is one of the very few two-cylinder systems noted here that present features of difference other than those due to variations in the construction and arrangement of starting and intercepting valves, but which otherwise relate to systems which belong to one or other of the three main classes, which may be described as the Mallet, the Worsdell-von Borries-Lapage, and the Lindner systems. The system under notice has for object to enable an engine having two cylinders of equal size to be worked either as an ordinary simple engine or as a compound engine. It was experimentally tried on the Northern Railway of France in 1885, as applied to a small tank engine, and afterwards to four engines belonging to the Dutch State Railways, but the writer has no information of further use.

As the cylinders were of equal diameter, the inventor arranged that the reduction of pressure for low-pressure use when working compound should be compensated for by so adjusting the valve gears, which were independently adjustable, that the steam was cut off early in the stroke in the high-pressure cylinder and late in the low-pressure cylinder, so that the total work done in each cylinder should be approximately equal. In the case of one of the Dutch engines, however, though both the cylinders had the same diameter, the low-pressure piston had a stroke double that of the high-pressure piston.

A Mallet Two-cylinder Tandem System.—This system, though never carried into practice, is a somewhat curious project designed by Monsieur A. Mallet and Herr A. Brunner, Chief Engineer of the well-known firm of I. A. Maffei of Munich. As will be seen from

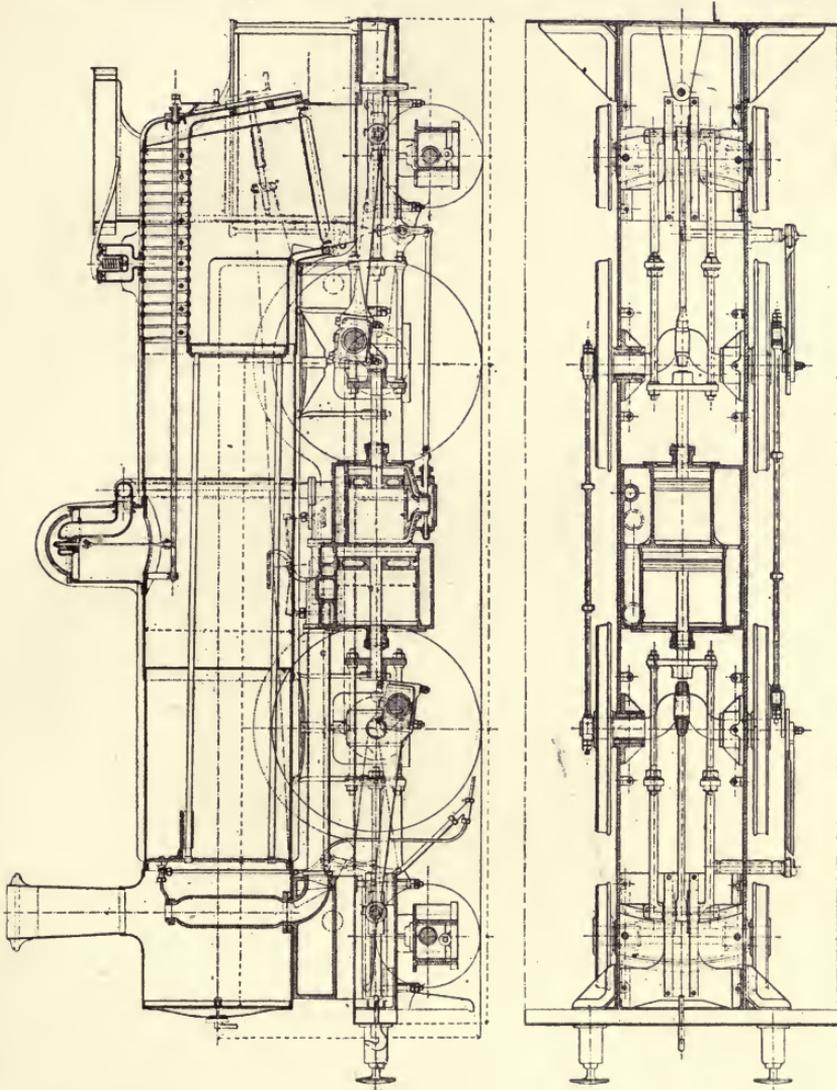


FIG. 40.—Mallet-Brunner Two-cylinder Tandem System, proposed 1889, but never used.

fig. 40, a high-pressure and a low-pressure cylinder are arranged tandem fashion between the frames, and the two piston rods (which are quadrupled outside the cylinders) drive in opposite directions, the connecting rods operating backwards on to separate cranked axles, the two pairs of driving wheels being coupled by outside rods. For

this scheme one or other of the various starting valves already described would be employed.

The Brunner System.—This system, though never carried out, was originally schemed out by Herr Brunner about 1889 as the result of

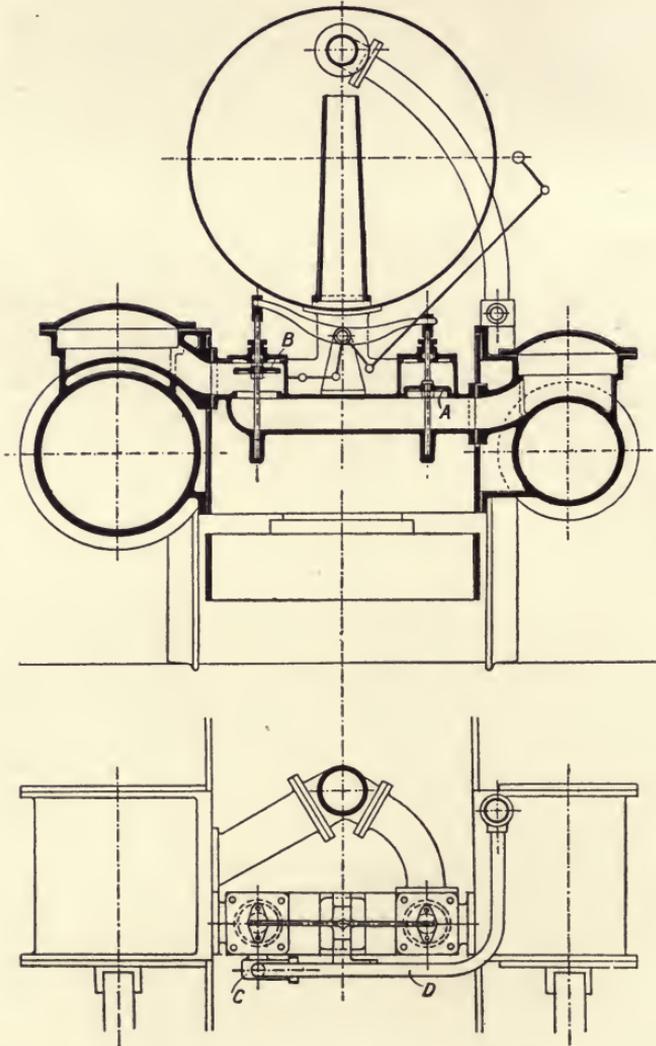


FIG. 41. —Starting Mechanism for Brunner System.

extensive experience with other engineers' (notably Monsieur Mallet's) systems; and, so far as the writer is aware, it has never hitherto been made public, though it possesses features of interest.

The two cylinders (fig. 41) are connected by a pipe having two valves adapted to be operated together, so that when one is open the

other is closed, and *vice versa*, by means of a rocking lever, which is rocked through the levers shown from a rod extending into the cab, where it can be operated by the driver; one of these valves (A) controls connection from the high-pressure exhaust to the blast pipe, and the other (B) controls the connection of the low-pressure cylinder with the receiver pipe. Alongside the valve B is a valve C, operated simultaneously with the rocking lever, and therefore correspondingly with the valves A B, whereby, when B is closed to receiver, boiler steam can pass from the pipe D to the low-pressure cylinder. In connection with this system it has been recently proposed to adapt the valve C so that, under the control of the reversing gear, it will act as a variable pressure-reducing valve, whereby the pressure of boiler steam supplied to the low-pressure cylinder is so regulated as to equalise the work done in the two cylinders according to the cut-off ratio employed for the high-pressure valve gear.

Starting Arrangements employed on the Eastern Railway of France.—About ten years ago several two-cylinder compound locomotives were fitted on the Eastern Railway of France, with starting mechanism which comprised three valves arranged side by side in different transverse planes, all three valves being operated by the oscillation of a single spindle connected by levers with an operating handle in the driver's cab. One of these valves was a spring valve for allowing boiler steam to pass from the high-pressure steam chest to the low-pressure cylinder. The second valve, of the flap type, was operated through a slotted curved link, which permitted it to open irrespectively of the operating mechanism if the high-pressure exhaust pressure exceeded that in the receiver, and its purpose was to separate the high-pressure exhaust from the receiver when working non-compound. The third valve controlled the passage of the high-pressure exhaust steam to the blast pipe or to the low-pressure cylinder.

The Rogers Non-automatic Starting Mechanism.—This mechanism has been applied to a large number of locomotives built by the Rogers Locomotive Works for various American railways. The general arrangement is shown by fig. 42, the parts being shown in position for non-compound working as at starting.

The starting valve casing contains a small slide valve *a* adapted for operation by means of levers extending into the driver's cab, and when in the position shown, live steam can pass from the pipe *b* through *c*, and then by the small pipe *d* to the intercepting valve casing *e*, where it forces the piston *f* to the right so that the port *g* is uncovered and steam can pass from *b* into the interior of the piston *f*, and thence, as shown, to the receiver, for use in the low-pressure cylinder. At the same time the piston *h* is moved on to its seating *i*, to close communication between the exhaust of the high-pressure cylinder and the receiver; and the exhaust pressure causes the valve *k* to move to the right, to open communication with the blast pipe or atmosphere.

To change to compound working, the valve *a* is moved so that

steam can pass from *c* round the outside of the valve to the pipe *m* leading to the further side of the valve *k*. At the same time the space *e* is placed in communication with atmosphere through the interior of the valve *a* and the pipe *n*, and as the pressure upon the valve *f* is removed, the intercepting valve *h* moves to the left, and with it the valve *f*, closing the port *g* and opening communication between the exhaust of the high-pressure cylinder and atmosphere, while the pressure of the steam through *m* moves the valve *k* to close the passage to the blast pipe or atmosphere.

The valve *f* acts as a reducing valve, whereby the pressure of steam

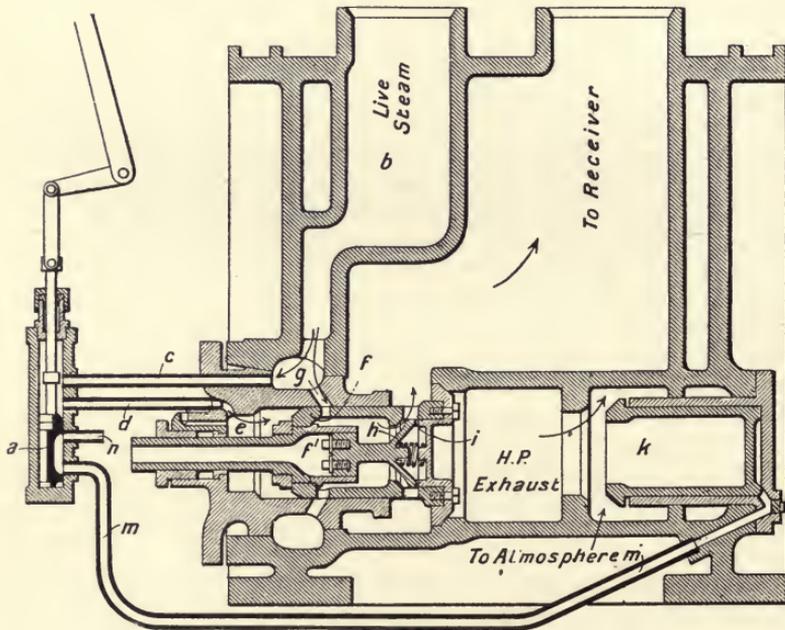


FIG. 42.—Rogers Non-automatic Starting Mechanism.

entering through the port *g* when working non-compound is reduced in pressure before it passes to the receiver as above described.

Two-cylinder Compound Locomotives (Non-automatic) on the Hungarian State Railways.—On the Hungarian State Railways compound locomotives are fairly numerous both with two cylinders and with four cylinders arranged tandem (see Chapter IX.), but comparatively little is known generally concerning the systems employed, and therefore particular interest attaches to this section of our subject, more especially as many of the two-cylinder engines concerned are among the latest built of this character, and are, moreover, notable machines from the point of view of dimensions, power, and general design.

The starting valves employed for some of these engines are of the non-automatic type, thus following the practice initiated by Monsieur

Mallet, but in other cases they are of the automatic type, wherein non-compound working results only at the moment of starting. The automatic valves are considered in Chapter VI.

According to the arrangement shown in fig. 43, the parts being represented in the positions they occupy during compound working, and the non-compound positions being indicated by dot-and-dash lines, at starting or at times when great power is required the driver moves the lever *a* so that the piston valve *b* uncovers a port whereby boiler steam passes from the pipe *c* to the pipe *d* leading to

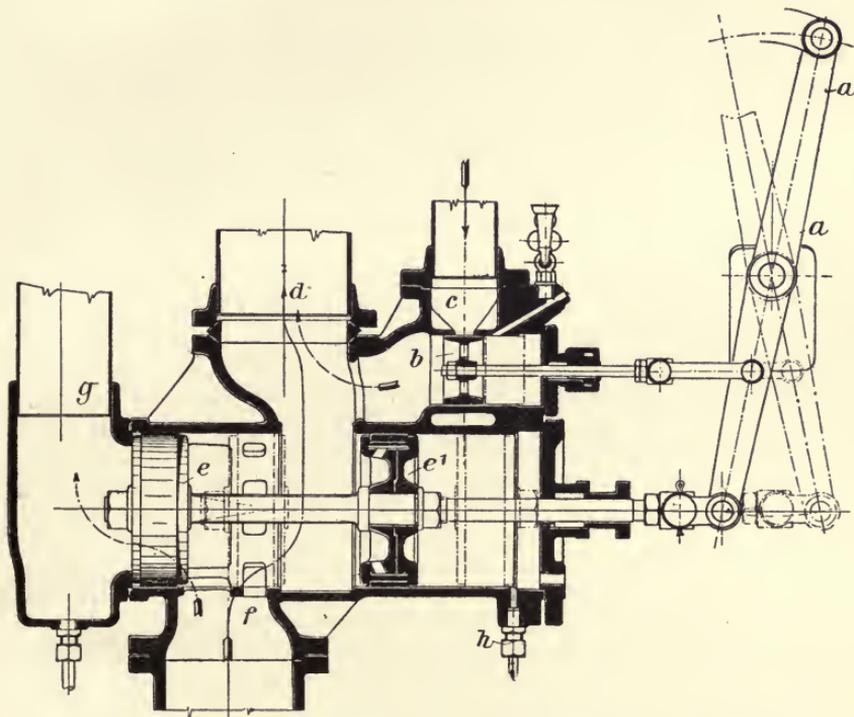


FIG. 43.—Non-automatic Starting and Intercepting Valve—Hungarian State Railways.

the receiver, and thence to the low-pressure cylinder, and at the same time the double (and consequently balanced) pistons *ee*¹ are moved so that steam is prevented from passing from the high-pressure cylinder through the pipe *f*, and is directed to the pipe *g* leading to the blast pipe. For the purpose of returning the parts to the compound positions, live steam can be admitted at *h* by a small cock so as to act on the piston *e*¹ and force it and the piston *e* to the left.

The New Schenectady Non-automatic System.—This system is now the standard for locomotives built by the American Locomotive Company, and has largely superseded the various systems already dealt with, which were associated with particular firms now

incorporated in this company. As will be seen, it corresponds in many respects with the original Schenectady (Pitkin) automatic system referred to in the next chapter. Fig. 44 shows the construction of starting and intercepting valve now employed, and fig. 45 shows the location of that valve and the smokebox arrangement.

For starting non-compound, as shown in fig. 44, the handle of the three-way cock in the cab is moved by the driver so as to admit pressure through the pipe D against the piston A, forcing it and the valves B and C to the position shown. As the regulator is opened, steam is admitted directly from the boiler into the passage E, forcing the intercepting valve into the position shown; thence the steam passes through the intercepting valve, by the ports K and the passage G, through the reducing valve to the low-pressure steam chest; at the same time steam from the boiler is admitted directly by means of the steam pipe to the high-pressure steam chest. The exhaust from the high-pressure cylinder passes to the atmosphere by means of the receiver passage H and the separate exhaust valve B. Steam from the low-pressure cylinder is exhausted directly to the atmosphere.

Having started simple, to change to compound the handle of the three-way cock in cab is turned so that pressure is released from the piston A. The separate exhaust valve will then be closed by the spring I. The pressure in the receiver, due to the exhaust from the high-pressure cylinder, will rise and force the intercepting valve to the left, thereby opening the passage for the exhaust steam from the high-pressure cylinder, through the receiver, to low-pressure steam chest. The movement of the intercepting valve to the left also closes the passage G, thereby shutting off the admission of steam directly from the boiler to the low-pressure steam chest.

When starting compound the separate exhaust valve is left closed, and as the regulator is opened, the steam pressure in the passage E will force the intercepting valve to the right or to the closed position; at the same time steam directly from the boiler will be admitted to low-pressure steam chest through ports K and passage G. The high-pressure cylinder will exhaust into the receiver until the pressure is sufficient to force the intercepting valve to the left, when the engine will work compound. The change to compound working takes place at from one-half to three-quarters of a revolution of the driving wheels.

With the engine working compound, if the engineer wishes to run the engine simple to prevent stalling on a heavy grade, the handle of the three-way cock should be placed in same position as for starting simple. This opens first the small valve C, and then the separate exhaust valve. The valve C relieves the pressure, and thus permits the main valve B to be operated more easily. As soon as the separate exhaust valve is open, the pressure in the receiver drops and the intercepting valve is forced against the seat to the right by means of the pressure in chamber E, and the engine works simple as before.

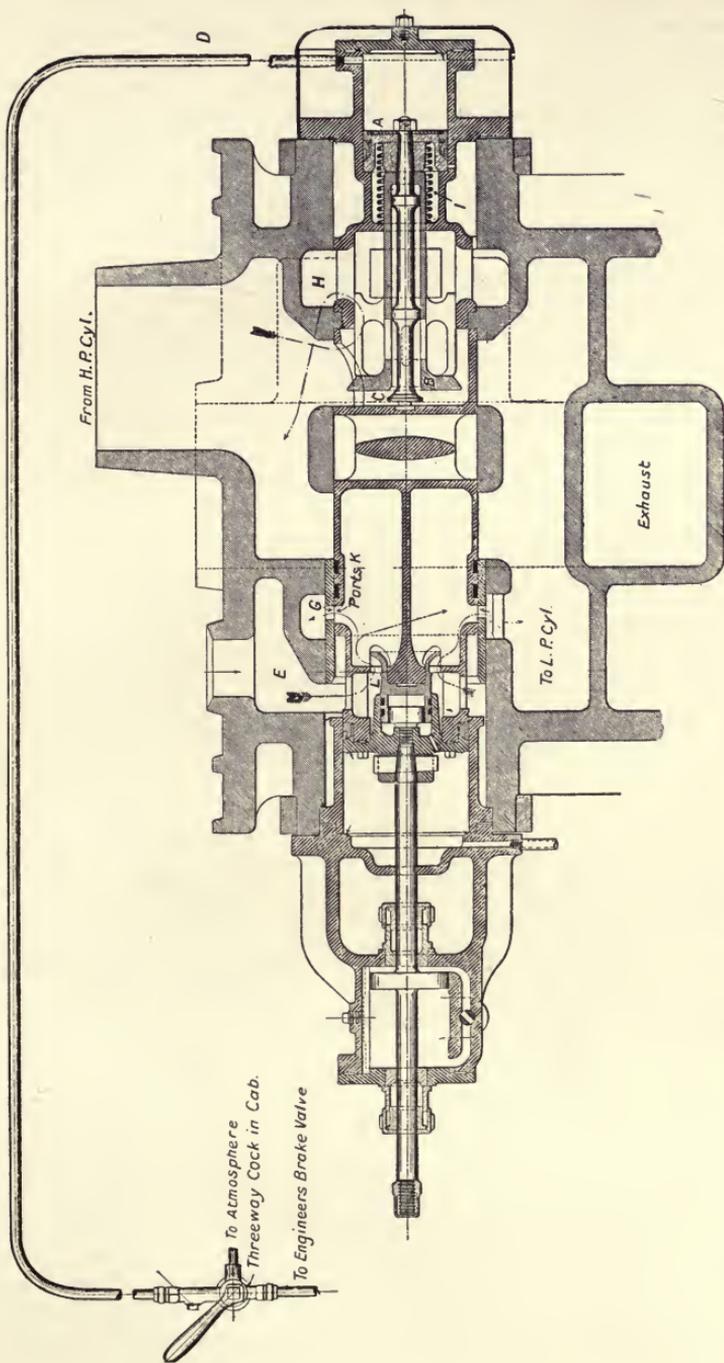


FIG. 44.—New Schenectady (Pitkin) Starting and Intercepting Valves

Some recently built compound locomotives are equipped with by-pass valves connecting the ends of the cylinders to allow free air passage when running with steam off.

The Vaucain Two-cylinder System.—The system under notice is a development of the earlier Vaucain two-cylinder system considered in Chapter VI. Figs. 46 and 47 indicate the principal features of the starting arrangements employed, the figures showing

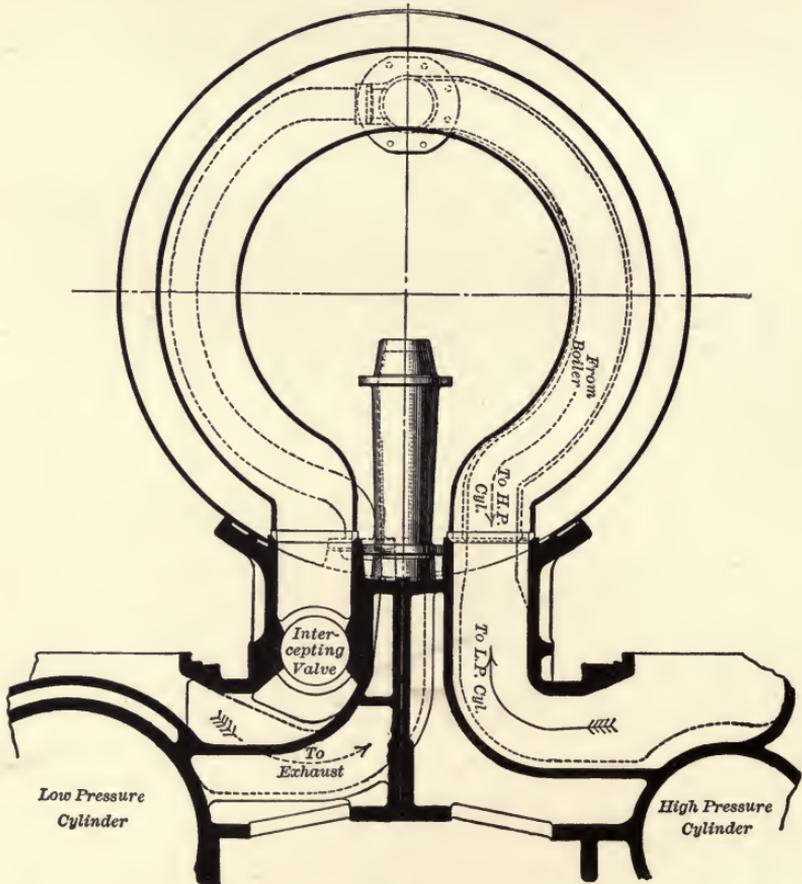


FIG. 45.—General Arrangement—New Schenectady Non-automatic System.

respectively the non-compound and the compound positions of the ports. Fig. 48 shows the cylinder and smokebox arrangements.

A is a double-piston intercepting valve, located in the cylinder casting of the high-pressure cylinder, the movement in one direction being controlled by a spring, and in the other direction by the steam pressure; C is a reducing valve, similarly operated by a spring and by the steam pressure. This valve serves to admit live steam to the receiver at a reduced pressure when the engine is working

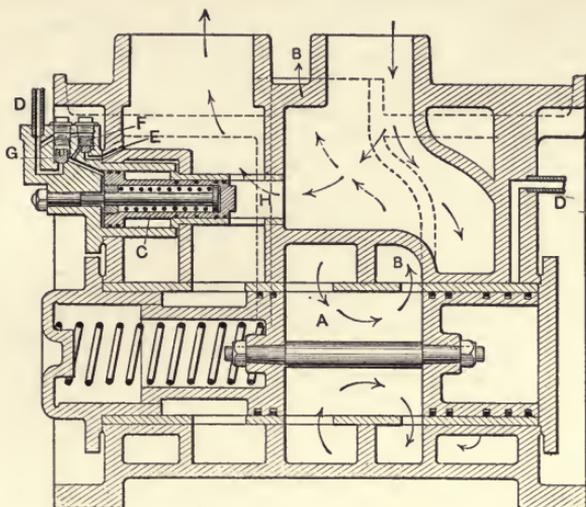


FIG. 46.—Vaclain Two-cylinder Compound. Position of Valves when working Single Expansion.

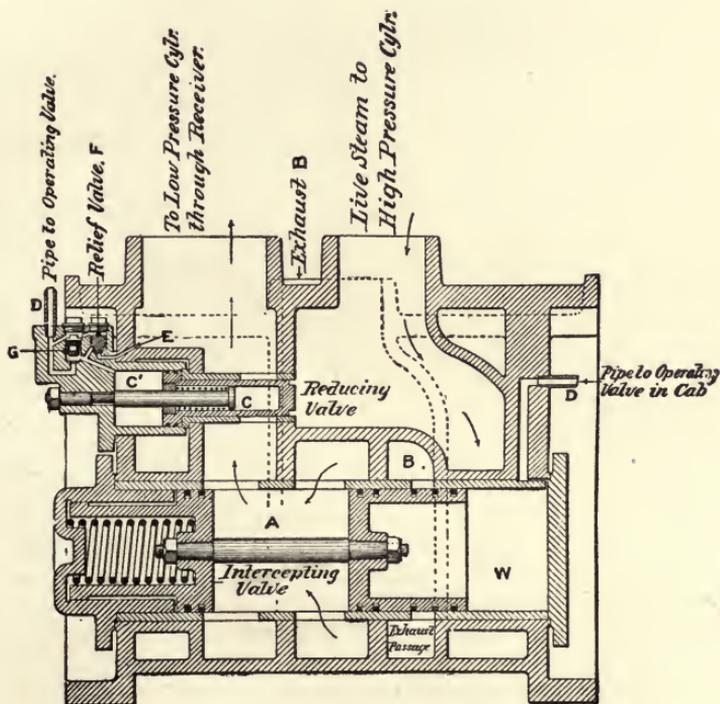


FIG. 47.—Vaclain Two-cylinder Compound. Position of Valves when working Compound.

non-compound. When working compound this valve automatically closes. The steam for controlling both these valves is supplied through the pipe D from an operating valve in the engine cab.

When not permanently closed by pressure in the pipes D, the reducing valve C is operated automatically by the pressure in the receiver. To this end the port E is provided, communicating with the receiver and the space in front of the reducing valve; as the

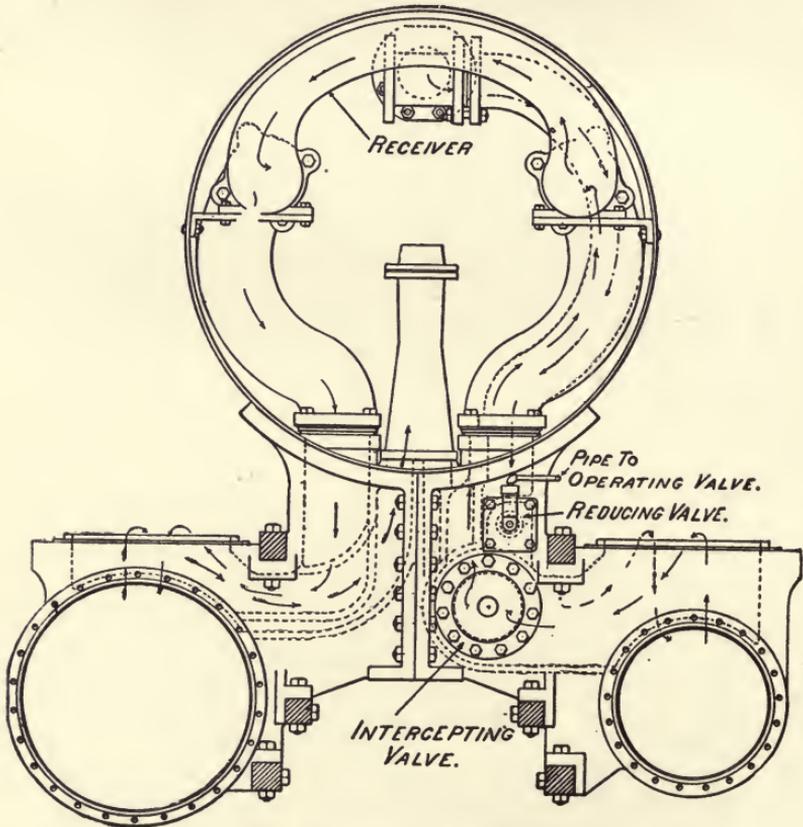


FIG. 48.—Cylinder and Smokebox Arrangement—Vaclain Two-cylinder System.

pressure rises, the steam acts on the large end of the reducing valve, causing it to move backward and close the passage H, through which steam enters the receiver, and thus prevent an excess pressure of steam in the low-pressure cylinder. Poppet valves F and G are placed in connection with the port E, one to prevent the escape of steam from the receiver to the pipe D when the locomotive is working single expansion, and the other to close the passage from pipe D to the receiver when working compound.

Normally the lever of the operating valve in the cab is in the

position marked "simple." In this position no steam is allowed to enter the pipes D, and no pressure will be exerted on the intercepting and reducing valves in opposition to the springs, and they will assume the positions shown in fig. 46. The ports of the intercepting valve A stand open to receive the exhaust steam from the H.P. cylinder and deliver it through the passage B to atmosphere. The reducing valve C is open, admitting live steam through passage H to the receiver, and thence to the L.P. cylinder.

For working compound, steam is admitted by operating the driver's valve to the pipes D to the valve chambers W and C', changing the valves A and C to the positions shown in fig. 47. The H.P. exhaust is then diverted to the receiver, and the admission of live steam to the receiver is stopped.

This system has been employed for a large number of locomotives built at the world-famed Baldwin Works, Philadelphia, though it

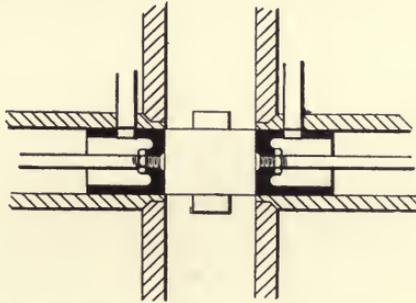


FIG. 49.—Cooke Starting and Intercepting Valve (Compound Position).

has now been largely superseded by four-cylinder systems introduced by the same firm.

The Cooke System.—This system has been associated with the Cooke Locomotive Works, but has been discontinued, unless specially ordered, since the amalgamation of this firm in the American Locomotive Company. However, as a good many quite modern engines have been equipped with the Cooke starting mechanism, brief reference is necessary.

Figs. 49 and 50 are diagrammatic views showing the main features of the Cooke intercepting valve, one figure representing the position when the engine is working compound, and the other figure showing the non-compound positions.

The two piston valves shown are adapted to be closed together, as shown in fig. 50, for starting, by the admission of boiler steam through a reducing valve controlled by the driver to the spaces (small cylinders) on their outer sides through the pipes shown. This movement brings the ports in the pistons in communication with the main pipe leading to the receiver, so that the reduced pressure steam is enabled to pass into the receiver for working in the low-pressure cylinder. Usually the driver's valve is connected

with the reversing gear, so that it is only when full forward or backward gear is being employed that steam can pass to operate the intercepting valves, and consequently, as soon as the engine is under weigh and the reversing gear is "linked up," the intercepting valve is moved to the compound position (fig. 50). In other cases the auxiliary steam valve is controlled by the driver independently of the reversing mechanism.

For engines equipped according to this system a cut-off lever is usually fitted in the driver's cab, whereby the travel of the low-pressure slide valve can be varied independently of the high-pressure slide valve travel to equalise the work on the two sides of the engine.

The Nadal System on the State Railways of France.—

Although France is essentially a country of four-cylinder compound locomotives, there are a few two-cylinder engines on several railways, notably the Eastern and Southern (Midi) lines; but the only very recent development of this method of compounding is found in the

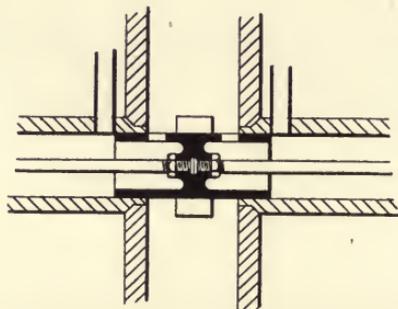


FIG. 50.—Cooke Starting and Intercepting Valve (Non-compound Position).

conversion of some engines of the State Railways into two-cylinder compound engines, according to designs prepared by Monsieur Nadal.

These engines are fitted with double piston valves to each cylinder, one for controlling admission and the other for controlling exhaust, the two piston valves being located side by side above each cylinder, and operated by the same valve motion.

Figs. 51 and 52 show respectively the arrangement of valves and steam connections on the two sides of the engine.

To enable the engine to be operated with boiler steam in the low-pressure cylinder, a slide valve working in a casing *a*, fixed upon the side of the smokebox (fig. 53), is adapted to be operated by the driver so as to admit steam to one end or the other of a small cylinder *b*, the piston of which operates by its movement a valve *c*, which diverts the high-pressure exhaust steam to the blast pipe instead of to the receiver pipe when working non-compound. At the same time boiler steam is admitted through a reducing valve to the receiver on the low-pressure side of the engine, so that the reduced pressure steam can work in the low-pressure cylinder.

It is stated that this system has proved very satisfactory in practice, and a number of engines are now in use according thereto. One of these engines was exhibited at the Liège Exhibition of 1905.

The Dultz System.—This system is a development of the earlier work of Monsieur Mallet in connection with Russian locomotives;

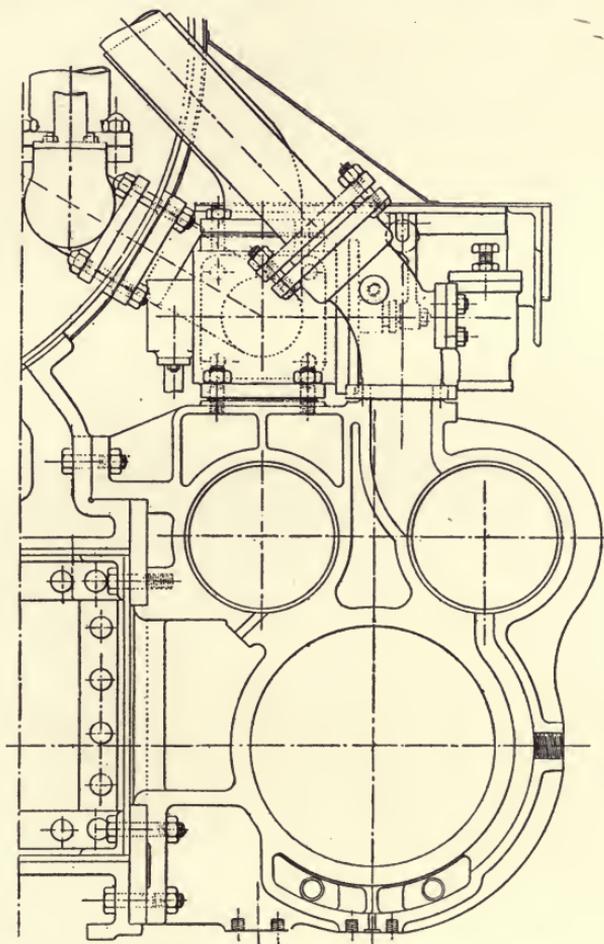


FIG. 51.—High-pressure Cylinder and Connections—Nadal System.

it is employed somewhat extensively in Russia, and to a limited extent in Germany and the Scandinavian countries.

Fig. 54 illustrates the starting and intercepting arrangements employed for such engines.

The intercepting valve consists of three pistons governing the passage of the high-pressure exhaust steam to the receiver, or to

the blast pipe, for compound or non-compound working as the case may be. As shown, the H.P. exhaust can pass from *a* to the pipe *b* leading to the blast pipe, while boiler steam, admitted by

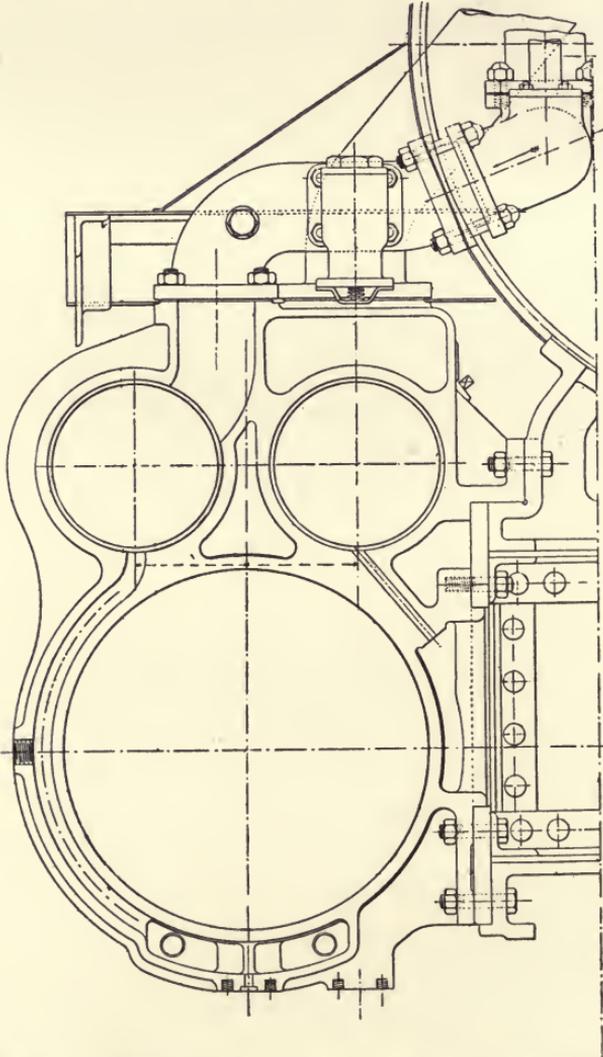


FIG. 52.—Low-pressure Cylinder and Connections—Nadal System.

the valve *c* under the driver's control, enters at *d* and passes by the passage *e* to the receiver, and thence to the low-pressure cylinder. For working compound the piston valves are moved (by the pressure of the H.P. exhaust upon the slightly larger area upon one side of the middle piston) as soon as boiler steam is shut off at *c* and the

passage *b* closed, and a passage opened from *a* to *e* so that the H.P. exhaust can pass to the receiver. It will be seen that the intercepting valve is automatic in action, the pistons occupying one position or the other according to whether steam is admitted through the valve *c* or not.

Two-cylinder Compound Engines in Italy.—In Italy there is a considerable number of two-cylinder compound engines of various

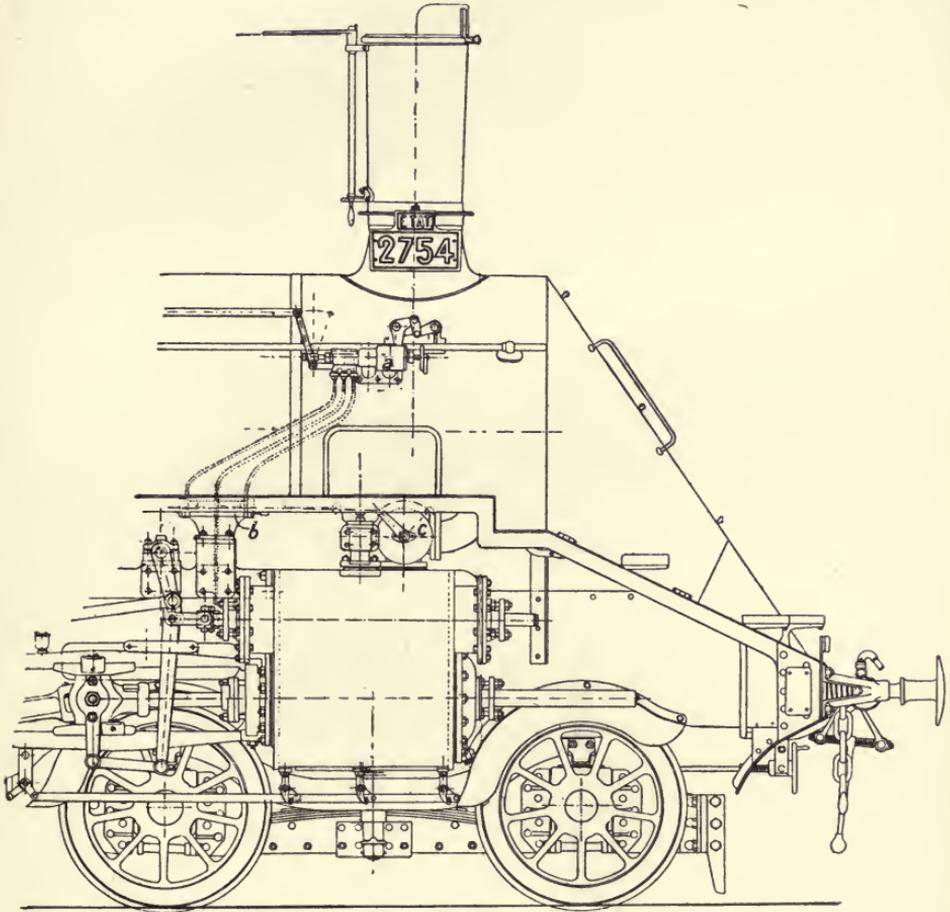


FIG. 53.—General Arrangement—Nadal System.

types, some of them being notable engines both as regards express passenger and heavy mountain service.

The starting mechanism usually employed comprises a long rotatory, cylindrical, hollow valve, mounted in a casing above the high-pressure cylinder, this valve having ports whereby the high-pressure exhaust is diverted to the blast pipe for starting, and boiler steam is supplied to the pipe connecting the two cylinders, which

also constitutes the receiver for working in the low-pressure cylinder. The arrangement is somewhat similar to that employed by Monsieur

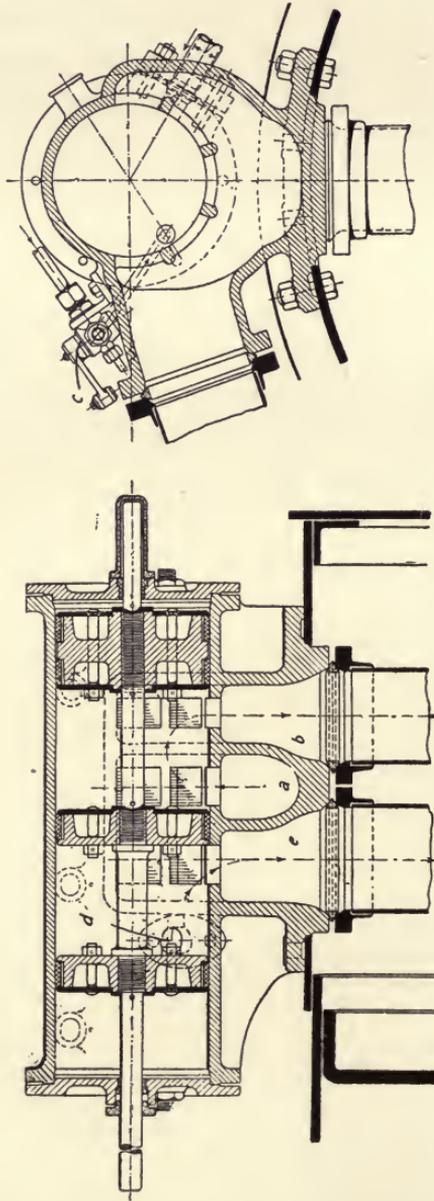


FIG. 54.—Dultz Starting and Intercepting Valve.

de Glehn, as described in Chapter XII, in reference to four-cylinder engines.

CHAPTER VI.

TWO-CYLINDER AUTOMATIC SYSTEMS.

CONTENTS :—The Worsdell-von Borries-Lapage Systems—Mr Worsdell's Practice — Herr von Borries' Practice — Joint Practice — Automatic Starting and Reducing Valves for Hungarian State Railway Systems—The Schenectady (Pitkin) System—The Vaucrain Automatic System—The Dean System—The Player System—The Rogers Automatic System.

As already explained, most of the systems of this class are related to or constitute developments of the original designs of starting mechanism first introduced by Herr von Borries in Germany in 1880, by Mr T. W. Worsdell in England in 1884-5, and by these gentlemen in conjunction with Mr Lapage in later years. It will therefore be in order that the arrangements associated with their work shall first receive consideration.

The Worsdell - von Borries - Lapage System.—The early work of each of these engineers possesses a strong family likeness, and as they have been associated to a great extent in their later designs, it will be convenient to consider the various types of starting mechanism introduced by them, either in conjunction or individually, at the same time.

Mr Worsdell's Practice.—Fig. 55 is a cross section through the smokebox of an early Worsdell engine, and fig. 56 shows the arrangement and construction of starting mechanism. *a* is the steam pipe leading to the H.P. steam chest; *b* the pipe leading from the H.P. exhaust to the L.P. steam chest, which constitutes the receiver and is carried round the smokebox to provide the required receiver capacity and for slight reheating of the steam; *c* is the blast pipe; *d* an intercepting valve casing interposed in the length of the receiver pipe; *e* the starting valve; and *f* the boiler steam supply pipe for the starting valve.

The starting valve *f* comprises a small spring-loaded piston, which can be moved off its seating by the rod *g*, which extends into the driver's cab so that the driver can operate it to open or close a port which leads to the pipe *h* connecting with the intercepting valve chamber *d*.

The intercepting valve is a flap valve mounted on a spindle, which

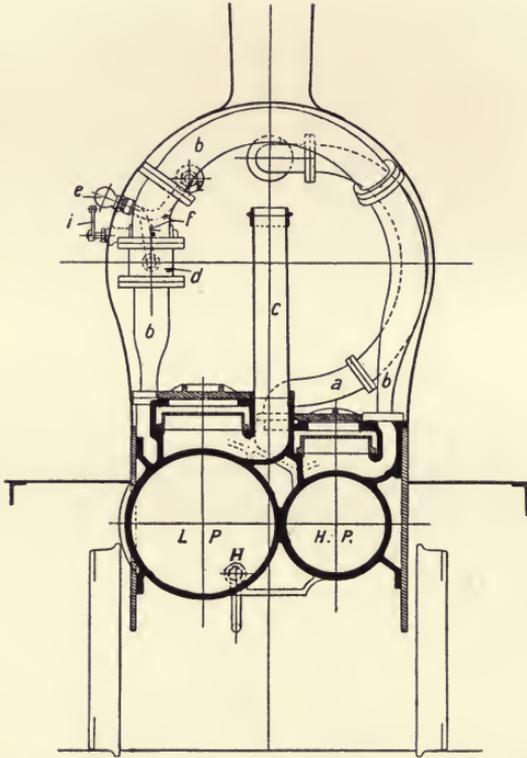


FIG. 55.—General Arrangement first employed—Worsdell System.

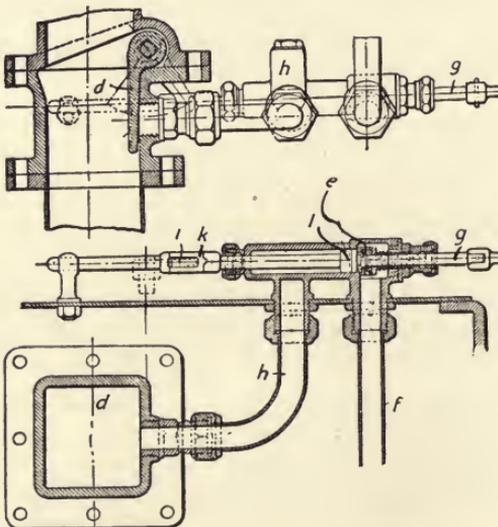


FIG. 56.—Starting and Intercepting Valves—Worsdell System (early Form).

extends outside the smokebox, where it is fitted with an arm *i* engaging in the slotted end *h* of a rod connected to the small piston *l*.

The arrangement is such that when the driver opens the starting valve, steam at boiler pressure acts upon the small piston *l* and moves it, thereby lifting the intercepting valve and closing the passage between the H.P. and L.P. cylinders. At the same time, by the uncovering of the small port before mentioned, steam is admitted to the pipe *h* and thence to the pipe *p* below the intercepting valve, thus allowing boiler steam to pass to the low-pressure cylinder. After two or three exhausts from the H.P. cylinder the pressure in the receiver becomes sufficient to open the intercepting valve; consequently the small piston *l* is moved to cut off the live steam to the L.P. cylinder, and the engine works compound thereafter. It therefore follows that, with this arrangement, although the driver can operate the starting valve at any time, its operation is of very

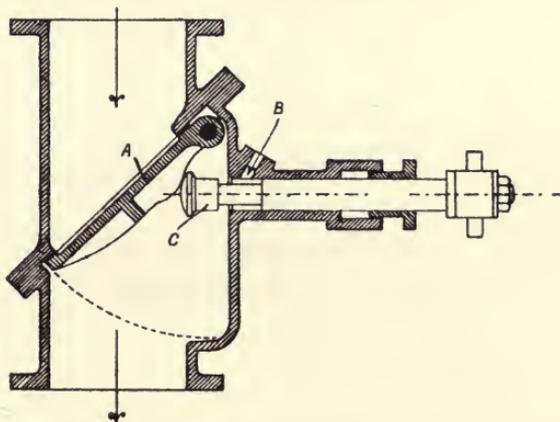


FIG. 57.—Early Form of Starting and Intercepting Valves—Von Borries System (early Form).

short duration, and non-compound working can only result when the pressure in the receiver is less than that resulting from the use of boiler steam (at a reduced pressure owing to wiredrawing) in the low-pressure cylinder.

Herr von Borries' Practice.—Fig. 57 shows a contemporary style of starting and intercepting valves introduced by Herr von Borries; the strong family likeness between the two valves will be apparent on inspection. The valve *A*, placed in the passage between the receiver pipe and the low-pressure cylinder, is closed before starting by means of a rod extending to the driver's cab, thus closing communication between the two cylinders. At the same time the valve *C* has moved from off its seating, so that boiler steam entering at *B* from a small pipe connected thereat passes through the annular space formed by the reduced portion of the valve spindle, and can pass to the low-pressure cylinder. As soon, however, as the pressure in the receiver due to a few exhausts from the H.P. cylinder rises

sufficiently, the valve A opens automatically against the pressure of steam behind it, and as, at the same time, the valve C closes on to its seating, the engine is forced to work compound.

In many of the von Borries arrangements the intercepting valve is of the disc type.

Fig. 58 shows a further form of von Borries valve as employed in the earlier years, but which has also been used more recently. In this case boiler steam is supplied by the pipe *a* to the chamber *b*, from which it passes by means of a passage (not shown) into the annular space formed by the reduced portion of the valve spindle *c*. When the intercepting valve *d* is closed the small ports *ee* are uncovered so that the steam can pass to the low-pressure cylinder, but as soon as the valve *d* opens automatically in the manner already described the ports *ee* are closed and the engine works compound. The auxiliary piston *f* works in a cylinder *g*, to which live steam is

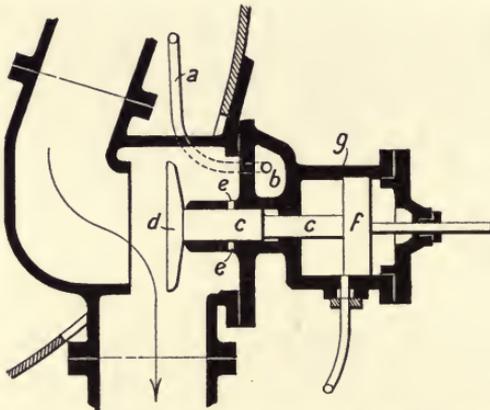


FIG. 58.—Early Form of Starting and Intercepting Valve—Von Borries System.

supplied, and operates to ensure that the valve *d* is either fully open or fully closed. When the valve *d* is closed steam acts on one side of the piston *f* so that it tends to press the valve against its seating, but when the valve *d* is opened the piston moves past the steam admission pipe so that the pressure comes upon its other face.

A further construction of the von Borries valve is shown in fig. 59. A small piston *f* is fitted which works in a cylinder *g*, and the top side of the piston is connected by the small passage shown with the receiver space; a live steam pipe *h* leads to a small cylinder *i*, wherein the end of the valve spindle *k* forms a piston. The object of this arrangement is to ensure the starting of the engine when the high-pressure crank is on a dead centre. The live steam then lifts the intercepting valve *d*, and as the spindle *k* rises high enough to uncover the small passages *ll* steam can pass to the low-pressure cylinder. When the receiver pressure becomes sufficient the valve *d* tends to open, and this is assisted by the pressure of receiver steam on the piston *f*, which has a greater area than the end of the valve

spindle *k*, which is subjected to boiler steam pressure, so that the opening of the valve *d* is ensured.

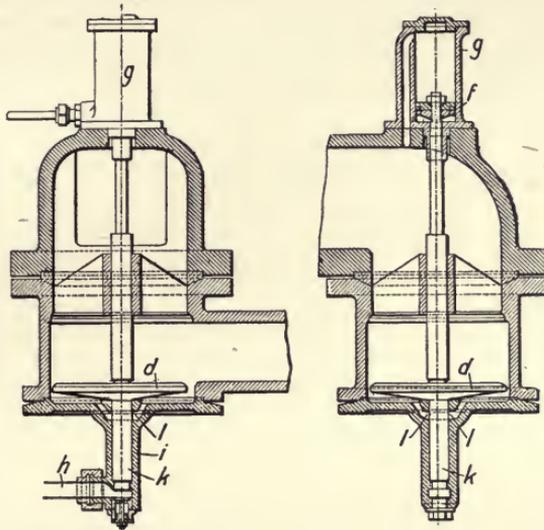


FIG. 59.—Von Borries System—Further Construction of Valve.

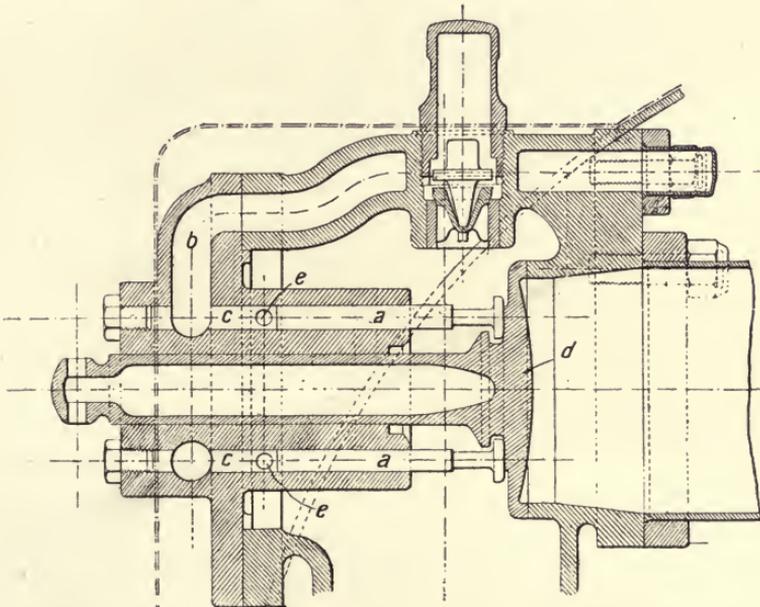


FIG. 60.—Recent Design of Starting and Intercepting Valves—Worsdell-von Borries-Lapage System.

Joint Practice.—A form of valve which is illustrative of Worsdell-von Borries-Lapage's recent practice is represented in fig. 60, this

design being employed for engines supplied for service in the Argentine Republic in 1889.

The two small plungers *aa* constitute together the starting valve. Boiler steam passes by the pipe *b* to the passages *cc*, where it acts upon the ends of the plungers *aa* to cause the intercepting valve *d* to close against its seating. At the same time

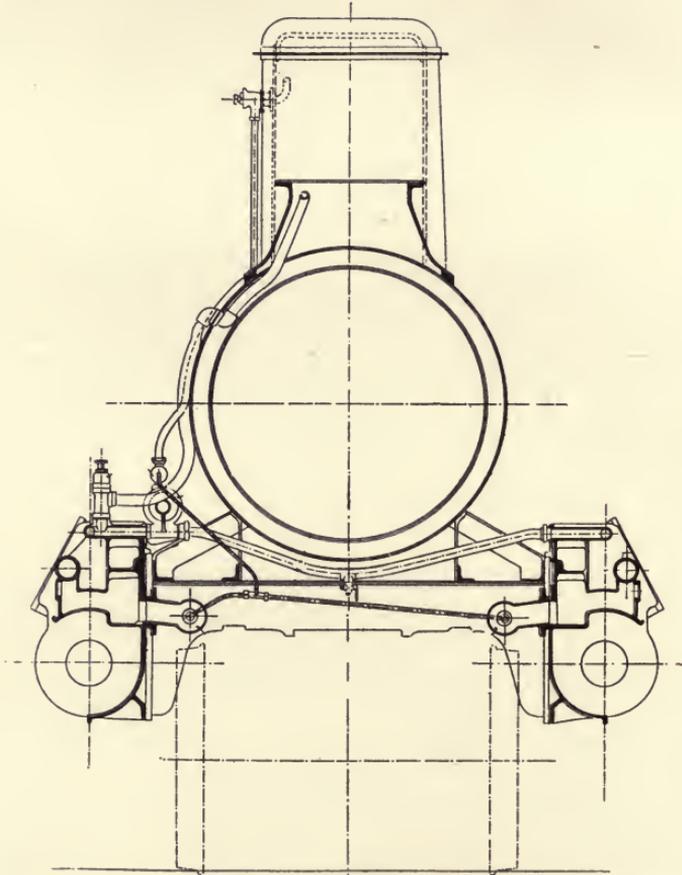


FIG. 61.—General Arrangement of Starting Mechanism—Hungarian State Railways.

the ports *ee* are uncovered by the plungers *aa* so that boiler steam can pass into the pipe connecting with the low-pressure cylinder, but as soon as the receiver pressure becomes sufficient the valve *d* is moved back and the ports *ee* are closed so that the engine works compound.

It will be noticed that in the various constructions of starting valves described in the foregoing paragraphs two classes are included, for the valves in some cases require to be operated originally by the

driver, though compound working results automatically after a few strokes, while in other cases the valves work wholly automatically.

The admission of steam to the auxiliary passages, by the pressure of which the intercepting valve is closed and boiler steam allowed to pass to the low-pressure cylinder, is effected by means

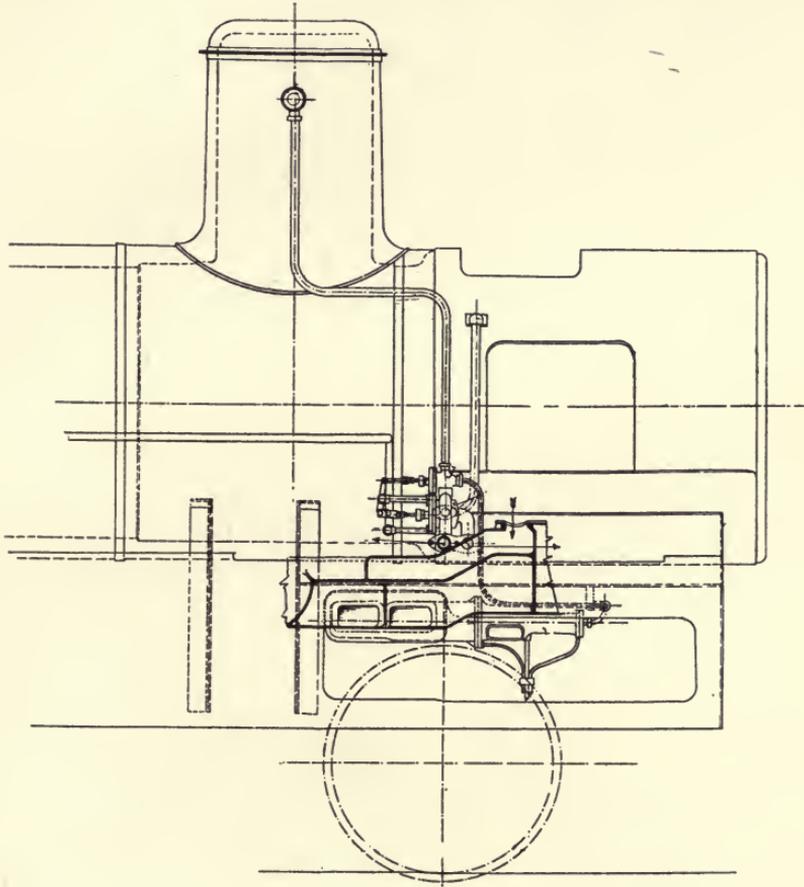


FIG. 62.—General Arrangement of Starting Mechanism—Hungarian State Railways.

of an auxiliary steam passage opened when the ordinary regulator is opened.

Owing to the larger diameter of the low-pressure cylinder, it is advisable, in supplying boiler steam thereto for starting, to reduce its pressure somewhat; with the arrangements above described it is found that in passing through the small passages it becomes wire-drawn sufficiently to obtain this result.

Automatic Starting and Reducing Valves for Locomotives of the Hungarian State Railway.—As already mentioned, two-cylinder

compound engines are fairly numerous on the Hungarian State Railways, and we now describe the various types of automatic

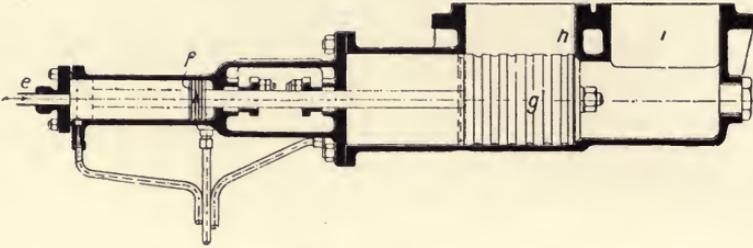


FIG. 63.—Intercepting Valve—Hungarian State Railways.

starting valves employed for these engines, the non-automatic valves having been dealt with in Chapter V.

Figs. 61 and 62 indicate the general arrangement of the starting apparatus employed for engines of one class, and figs. 63 and 64 show the two component parts thereof on a larger scale.

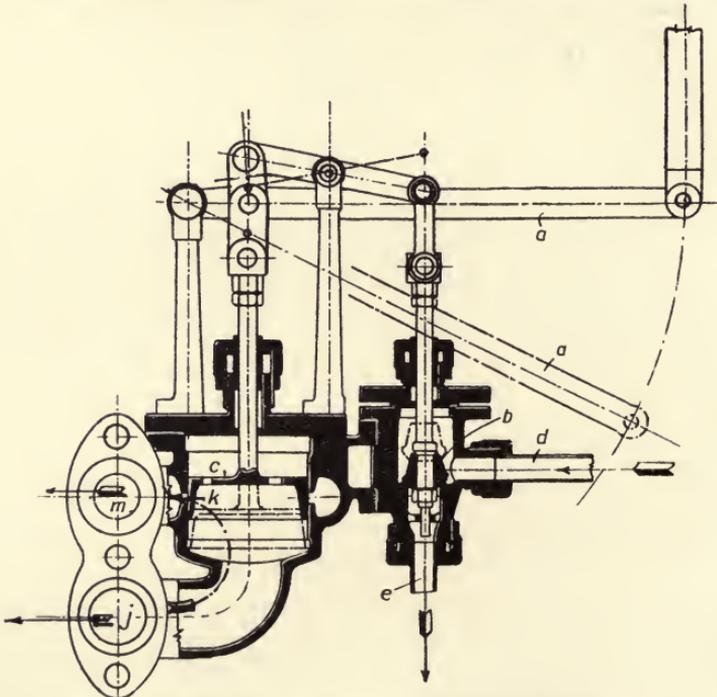


FIG. 64.—Starting Valve—Hungarian State Railways.

At starting, the driver moves the lever *a* (fig. 64) through a long rod extending into the cab so that it occupies the position shown in dot-and-dash lines. This movement causes the two valves *b c* to

move so that, in the one case, the valve *b* opens communication between the live steam supply and the starting apparatus shown in fig. 63, where it acts on the piston *f* and forces it to the position shown in full lines. As a result, the large piston *g* mounted on the same spindle is moved so that it closes the port *h* leading to the receiver, and thence to the low-pressure cylinder. As soon, however, as steam arrives through *i* from the high-pressure cylinder the piston *g* is forced to the left, thus opening communication from the H.P. to the L.P. cylinder.

In the other case, the valve *c* at starting opens communication between a live steam supply pipe *j* connected with the steam dome through small openings in the valve *c*, and thence through the small port *k* to the receiver through *m*, the steam being reduced in pressure by wiredrawing.

This apparatus is only intended to be operated for about half a revolution of the wheels, but as the valves *b c* have to be closed by the driver, the admission of boiler steam to the receiver through *m* can take place for a somewhat longer time, though it is not usually desirable to allow this to continue for more than a few strokes. The starting apparatus just described is also employed for tandem compound engines (see Chapter IX.).

Figs. 65, 66, 67, and 68 represent the construction of starting apparatus employed for other two-cylinder engines.

The valve *a* is operated by the driver through a rod extending along the boiler and having a crank connected to the valve rod, and this valve allows boiler steam to pass to the combined intercepting and reducing valve *b*. The live steam thus admitted enters below the valve *b*, which is of the disc type and lifts it so that it closes communication between the two cylinders, and the boiler steam, reduced in pressure, passes to the receiver. As soon, however, as there is exhaust pressure from the H.P. cylinder, the valve *b* is forced down and the engine works compound. The driver closes the valve *a* soon after starting.

The arrangement shown in fig. 68 is employed when there are two low-pressure cylinders, as in 'articulated' Mallet engines (see Chapter XIII.).

The Schenectady (Pitkin) System.—This system is one of the principal of the American automatic systems, and has been applied to many engines built by the well-known Schenectady Locomotive Works, though it is now largely superseded by a new Schenectady system which is not automatic, the latter system being now the standard for engines built by the American Locomotive Company, unless one of the other automatic or non-automatic systems connected with the various works of this important amalgamation firm are specially ordered. We are concerned, however, with the older automatic system, the more recent non-automatic system being described in Chapter V. In fig. 69 the valve is shown in the non-compound starting position.

As shown, the piston valves *ab* close the passages *cd* so that

communication is closed between the receiver and the low-pressure cylinder, though a small passage *e* permits boiler steam to pass through a port formed in the piston *a* to the low-pressure steam chest. The small port *f* is connected past a reducing valve with

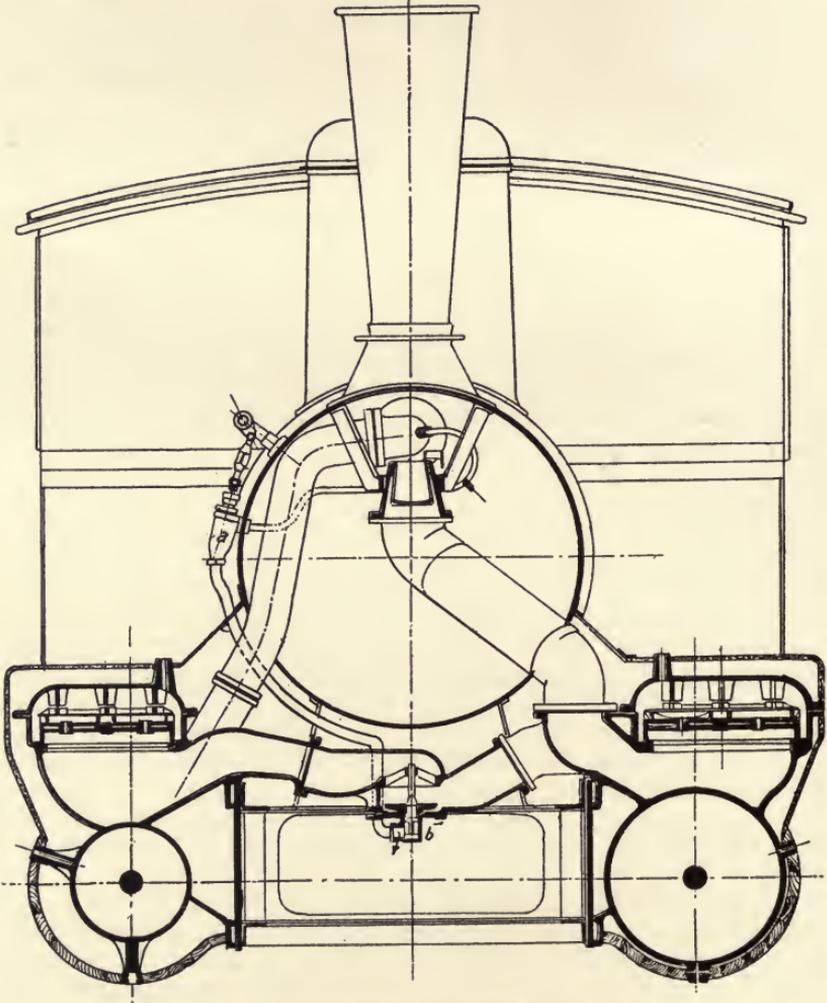


FIG. 65.—Starting Mechanism—Hungarian State Railways.

a live steam supply, whereby steam enters the space *g*, and thence passes through the passage *e* as already mentioned.

At the right-hand end of the piston *b* the receiver pressure is able to press upon the piston so that as soon as there is pressure in the receiver from the high-pressure exhaust the valves *a b* are forced to the left, thus opening communication between the receiver and the low-pressure cylinder, while the valve *a* at the same time closes

the port *f* so that the live steam supply is cut off. A dashpot cylinder *i* is fitted to regulate the speed of movement.

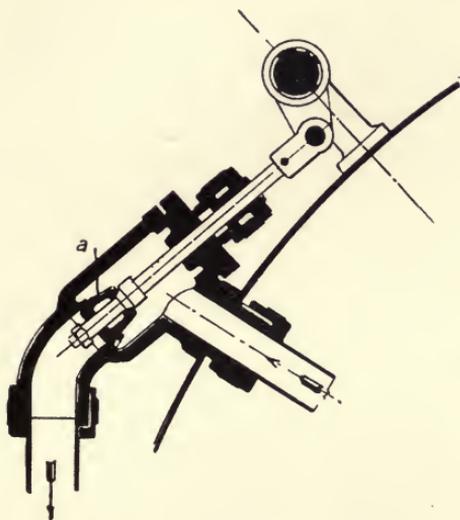


FIG. 66.—Driver's Starting Valve—
Hungarian State Railways.

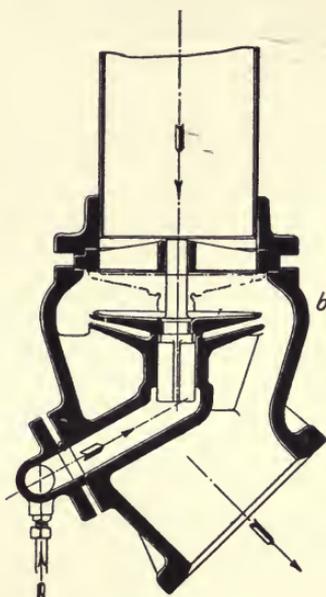


FIG. 67.—Intercepting Valve—
Hungarian State Railways.

The Vaucain Automatic System.—This system, introduced by the well-known Baldwin Works of Philadelphia, U.S.A., has also

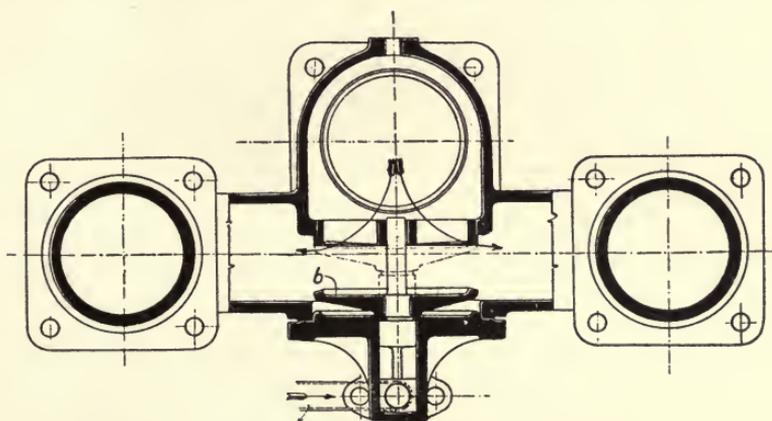


FIG. 68.—Intercepting Valve—Hungarian State Railways.

been superseded for present practice by a non-automatic system, but it has been employed for a number of locomotives, many of which are still in service.

The starting valve, fig. 70, is located close to the high-pressure cylinder, and comprises a reducing valve, which, when the pressure in the receiver is less than that on the live steam side of the valve (which is exposed to the steam pressure in the high-pressure steam

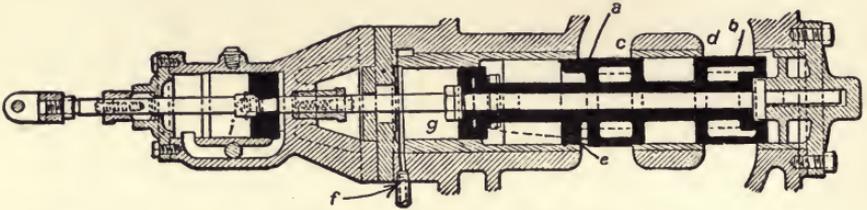


FIG. 69.—Starting and Intercepting Valves (early Form)—Schenectady (Pitkin) System.

chest), automatically opens to allow steam to pass to the receiver for starting, or when the pressure in the receiver falls below that required for work in the low-pressure cylinder.

In the smokebox is an automatic intercepting valve, comprising a

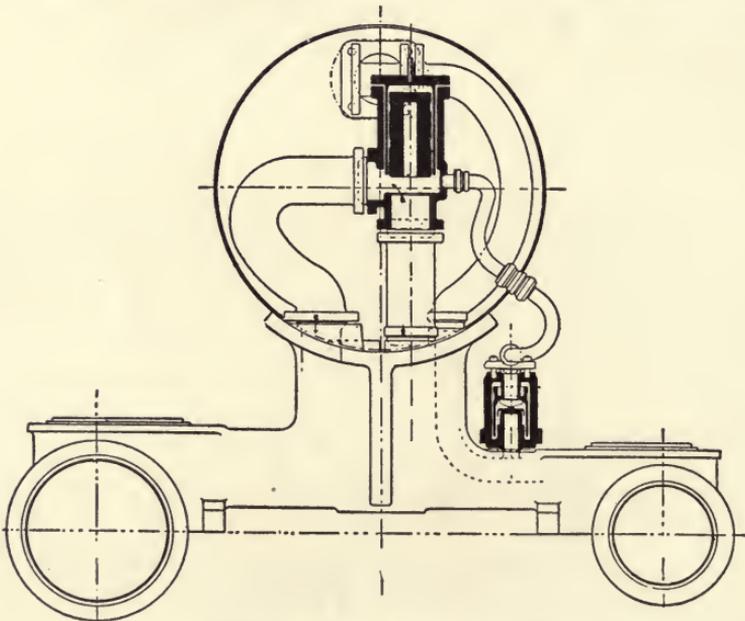


FIG. 70.—Vaclain (Baldwin Works) Automatic System.

vertically moving hollow piston working in a casing, the upper part of which, above the piston, communicates with the atmosphere, while the lower portion of the hollow piston closes the receiver passage, unless there is sufficient pressure from the high-pressure exhaust to lift the piston, which is of considerable weight.

When the intercepting valve closes the receiver passage, the boiler steam from the starting valve reaches the receiver beyond the intercepting valve by means of the annular space round the piston valve.

The Dean System.—This somewhat complicated system has been employed for a number of American two-cylinder compound locomotives. The main features are shown in fig. 71.

The high-pressure slide valve is open at the top, so that the high-pressure exhaust steam passes through it and through a port *a* above it into the space *b* which communicates with the receiver. The passage through *a* can, however, be closed by the descent of a disc

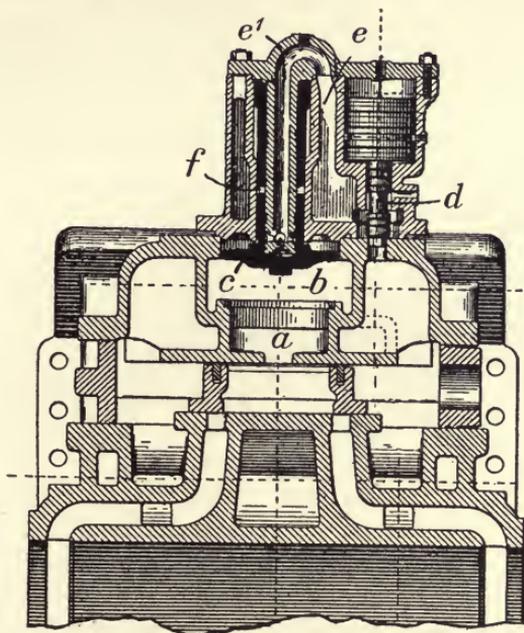


FIG. 71.—Dean Starting and Intercepting Valves.

valve *c* when there is no steam arriving from the high-pressure cylinder, thus closing the passage between the two cylinders, but as soon as the high-pressure cylinder exhausts, the valve *c* is lifted to restore communication.

A reducing valve is provided at *d* whereby boiler steam can pass from the high-pressure steam chest at a reduced pressure to the passage *e*, but the steam is checked at the end thereof adjacent to the valve *c*, except when the valve *c* is lowered, so that it is only when the passage *a* is closed that boiler steam can pass to the low-pressure cylinder. To the valve *c* is attached a long sliding sleeve; when the valve is lowered, ports *f* in this sleeve co-operate with ports at the lower end of the passage *e*¹, which constitutes a continuation of the passage *e* to allow steam to pass to the space *b*.

The Player System.—This system is associated with another of the American locomotive building firms—the Brooks Locomotive Works, which is now embodied in the American Locomotive Company.

In this arrangement (fig. 72) the live steam supply valve *a*, which also acts as a reducing valve, is combined in the same casing with the intercepting valve *b*. The passages *cde* are connected respectively with the high-pressure exhaust, with the receiver, and with the live steam supply. When steam is admitted to *e*, the valve *a* is forced to the left, so that steam can pass from *e* past the small end of the valve *a* and through the ports *a*¹ to its interior, and thence to the receiver, the movement of the valve *a* to the left forcing the intercepting valve *b*, which movement is assisted by the pressure of the steam, against its seating, so as to close the passage *c* connecting with the high-pressure cylinder. As soon as there is exhaust

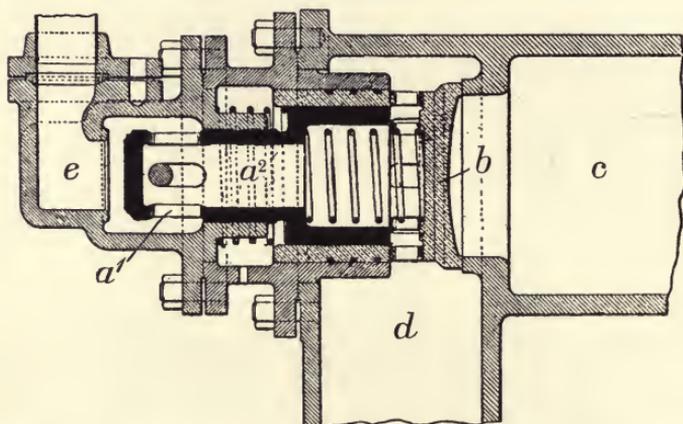


FIG. 72.—Starting and Intercepting Valves—Brooks Locomotive Works
—Player System.

from the high-pressure cylinder the intercepting valve *b* is forced to the right, thereby closing the valve *a*, and the engine works compound.

The Rogers Automatic System.—This system, introduced by the Rogers Locomotive Works (U.S.A.), has now been superseded by a non-automatic system, but the old system is of sufficient importance for inclusion in this chapter.

The combined starting and reducing valve (fig. 73) is located at *a*, and comprises a valve *a*¹ and a piston *a*² mounted on a stem, live steam being admitted for starting to the space between them, and the lower side of the large valve being exposed to any pressure within a pipe *b* leading to the intercepting apparatus. When there is no pressure in the pipe *b* the live steam pressure admitted between the valve *a*¹ and the piston *a*² opens the valve *a*¹ so that the steam can pass to the pipe *b*, but as soon as there is sufficient pressure in the pipe *b* the valve *a*¹ is lifted on to its seating and the live steam

supply is cut off. The combined valves $a^1 a^2$ serve the purpose of a reducing valve.

The presence of the reduced pressure boiler steam in the pipe b causes the closing of the intercepting valve c , the steam first passing through the small passage d to the back of a plunger d^1 , which is operated to move a hollow piston valve e to the right, closing the valve c , and thereby cutting off communication between the high- and low-pressure cylinders; at the same time the movement of the piston e places the ports f and g in communication, so that steam from the

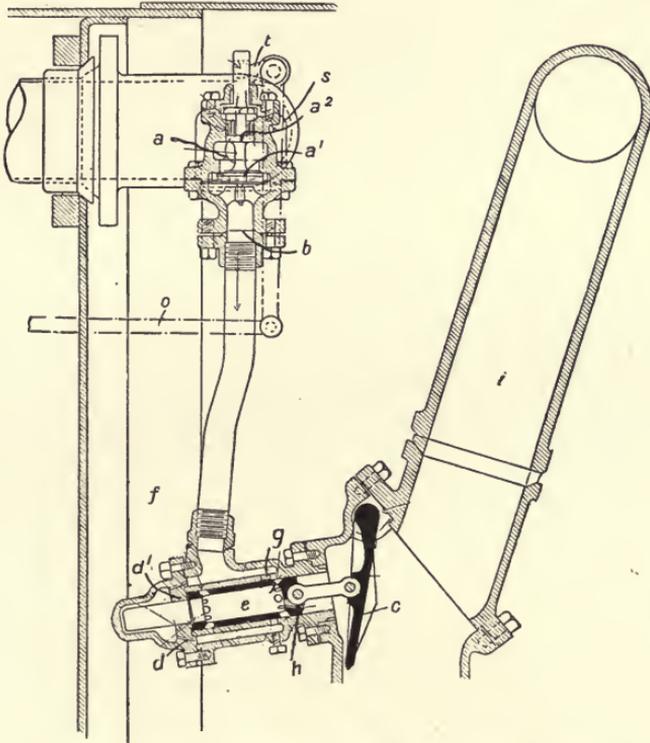


FIG. 73.—Rogers Locomotive Works (Automatic) System.

pipe b can enter the hollow of the piston e directly, and escape therefrom through the port h to the receiver. As soon as the high-pressure cylinder supplies exhaust steam to i the valve c is forced open, and the piston e and the plunger d^1 are consequently moved back, cutting off the supply of steam from the pipe b ; the consequent accumulation of pressure in the pipe b causes the closing of the starting valve $a^1 a^2$, so that the engine then works compound.

Usually this system has been applied so that the starting gear cannot act except when the reversing gear is placed in full forward and backward gear, and this result is obtained by means of the device shown in fig. 74.

The cam plate *m* is connected by the rod *n* with the reversing gear, so that when full, or nearly full, gear is employed, the non-concentric portions of the cam groove *m'* act to move the reach rod *o* a short distance to the right, the rod *o* being unaffected in intermediate positions of the cam plate *m*. The link *p* holds the roller fitted to the end of the rod *o*, and which engages in the cam groove *m'* in its working position.

The rod *o* extends to the smokebox, where it is connected to the

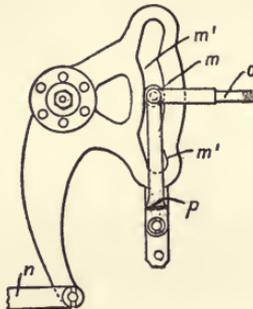


FIG. 74.—Detail View—Rogers Locomotive Works (Automatic) System.

arm *s*, secured on the end of a spindle supported within the smoke box adjacent to the starting valve; this carries a short arm *t*, which engages in the slotted end of the spindle which carries the valves $a^1 a^2$. Unless the rod *o* is operated, the arm *t* prevents the movement of the valves $a^1 a^2$ for allowing a non-compound start of the engine, but when full gear is employed and the rod *o* is operated by the cam-plate *m*, the arm *t* is lifted sufficiently to enable the starting valve to operate.

CHAPTER VII.

SEMI-AUTOMATIC SYSTEMS (LINDNER TYPE).

CONTENTS :—The Lindner System—Modifications of the Lindner System—The Maffei System—Two-cylinder Swiss System—The Cooke Starting Mechanism—Gölsdorf System.

THE third division into which two-cylinder systems of compounding may be classified is that of which the Lindner apparatus may be considered the prototype. In many respects the arrangements employed are far simpler than those necessary for even the simplest apparatus described in Chapters V. and VI., for in most cases intercepting valves are dispensed with and the starting valve is little more than a plain steam admission valve or device. The main characteristic of the systems of this class is, that non-compound working results from the placing of the reversing mechanism in nearly full gear, the apparatus being otherwise automatic as soon as the engine has been linked up for expansive working.

In several instances, as in the case of the Lindner system, the desired result is obtained by so simplifying the starting arrangements that no intercepting valve is required, the only valve provided being one connected with the reversing gear, whereby boiler steam can be directly supplied to the low-pressure cylinder. In some cases there is also provided means connected with the regulator in the steam dome so that steam can be cut off entirely from this valve, to ensure that boiler steam cannot pass to the low-pressure cylinder in the event of the reversing gear being placed in full gear before steam is admitted by the regulator to the high-pressure cylinder, and to enable the live steam supply to the low-pressure cylinder to be cut off by partially closing the regulator, even although full gear is employed.

The Lindner System.—Fig. 75 shows the arrangement first employed by Herr Lindner; and although various improvements have been incorporated in recent years, the system has not been changed in important particulars.

In the steam pipe casing of the regulator an auxiliary steam pipe *a* is fitted, and this is connected with a four-way plug cock *b*, which is connected with the reach rod of the reversing gear, so that it is

only in the extreme positions that a through way is provided for the steam. After passing this valve the steam enters the receiver pipe *c*, so that it can operate in the low-pressure cylinder.

The high-pressure slide valve (fig. 76) is formed with small auxiliary ports so that both ends of the cylinder are placed in communication with the receiver, and the high-pressure piston is therefore balanced so that when the low-pressure piston is being operated, as at starting, with boiler steam, the back pressure on the H.P. piston is minimised. As soon as the engine is "linked up," the slide valve travel becomes such that the auxiliary ports do not operate.

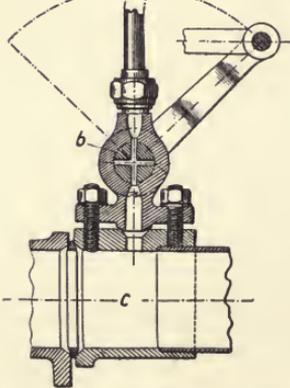
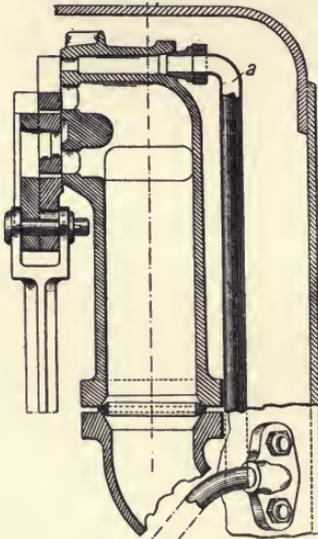


FIG. 75.—Regulator and Starting Valve
—Lindner System (original Design).

Usually the regulator valve is so arranged that, when partially closed, steam is cut off from the pipe *a*.

Modifications of the Lindner System.—According to another arrangement, specially suitable for goods engines, the steam pipe *a* is led, beyond the valve *b*, to the side of the high-pressure cylinder, where it opens into the cylinder at about half stroke, so that boiler steam enters on one side or other of the H.P. piston, according to its position, and passes thence, either through one of the auxiliary ports of the H.P. slide valve or through the exhaust, to the receiver, and so to the low-pressure cylinder, the high-pressure piston being balanced as above described. This arrangement is really only useful so far as it enables the low-pressure piston to be operated when the high-pressure crank is on a dead centre, and is not suitable for continued non-compound working.

According to another arrangement, a small piston valve is connected to the yoke of the low-pressure slide valve so as to move correspondingly therewith, and this piston valve works in a small cylinder attached to the steam chest so as to govern ports whereby

boiler steam is admitted to the low-pressure steam chest when the slide valve has full travel.

One such arrangement is shown applied to a locomotive in fig. 77, and a further arrangement, suitable more particularly for passenger locomotives, is shown in fig. 78. The live steam supply for the low-pressure cylinder is obtained from the ordinary steam pipe, so that a special regulator is not required, and the entry of boiler steam to the low-pressure steam chest is controlled by a valve surface formed on the back of the low-pressure slide valve.

The Maffei System.—This system was first introduced in 1894. Figs. 79 and 80 show the arrangement employed at that time for engines supplied by the firm of J. A. Maffei to the Bavarian State Railways.

The intercepting valve *a* is directly connected with the reversing gear through the intermediation of the peculiar gear shown, the arrangement being such that when the reversing gear is in either of the extreme positions the valve *a*, and, indirectly, the live steam valve *b*, are operated so that the engine works non-compound; and, as soon as the gear is linked up somewhat, the valves are so moved that compound working occurs. As shown, the valves are in position for non-compound working.

The intercepting valve *a* governs the steam distribution of the high- and low-pressure cylinders as shown, connecting the high-pressure cylinder with the receiver or with the blast pipe as may be necessary. The live steam valve *b* allows boiler steam to pass to the receiver, and thence to the low-pressure cylinder when necessary, the steam being withdrawn when necessary, the steam being wire-drawn to reduce its pressure; and this valve is operated by the engagement of the sleeve *c* with the bell crank lever *d* when the spindle *e* is moved, the spring *f* returning it to the non-compound position, as soon as permitted, for the purpose of closing the valve *b*. It will be seen that, whether the engine is in forward or backward gear, the longitudinal movement of the spindle *e* is very short, and is the same in either case. Fig. 80 shows the position of the operating mechanism when working compound.

Two-cylinder Swiss System.—A two-cylinder system has been fitted to a number of Swiss locomotives, having inside cylinders and fitted with a special starting valve designed by the builders, "The Swiss Locomotive Works" of Winterthur. This valve provides for the admission of live steam to the L.P. cylinder when the reversing lever is in a position giving an admission of more than 70 per cent.

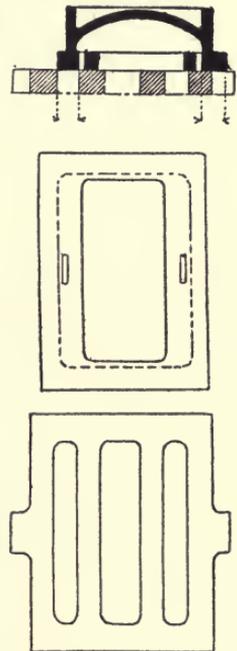


FIG. 76.—Slide Valve and Steam Ports — Lindner System.

of the stroke, but directly the valve gear is linked up to less than this the mechanism automatically changes the connections, and the engine then works compound.

The Cooke Starting Mechanism.—This system has in past years been employed for a number of engines built by the Cooke Locomotive

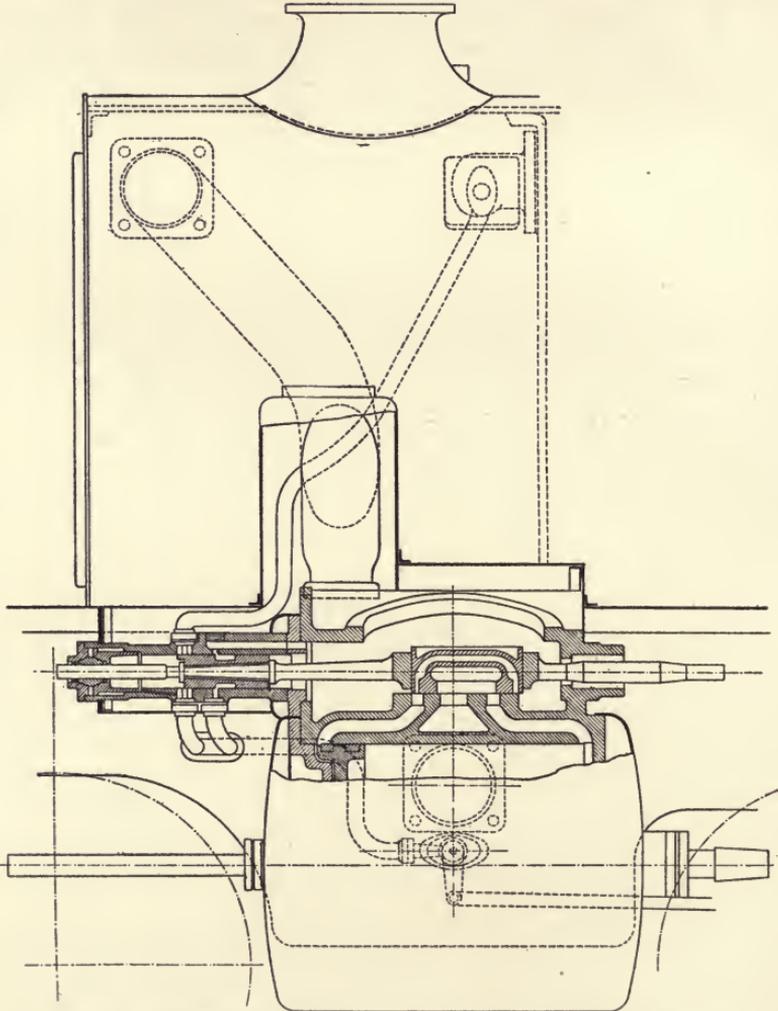


FIG. 77.—Starting Mechanism—Lindner System (improved Form).

Works (U.S.A.), though its use has been practically discontinued since the amalgamation of this firm into the American Locomotive Company.

For starting, steam is admitted from the steam dome by a pipe under the control of a cock controlled from the regulator lever or handle, the arrangement being such that, by a special mechanical

connection, the cock can only be opened when the regulator is closed.

Should an engine fitted with this mechanism be unable to start in the ordinary way owing to the fact that both steam ports of the high-pressure cylinder are closed, the driver closes the regulator again and opens the cock by the auxiliary device. Steam can then pass by the pipe past a reducing valve to the low-pressure steam chest, so that the low-pressure cylinder starts the engine. Immedi-

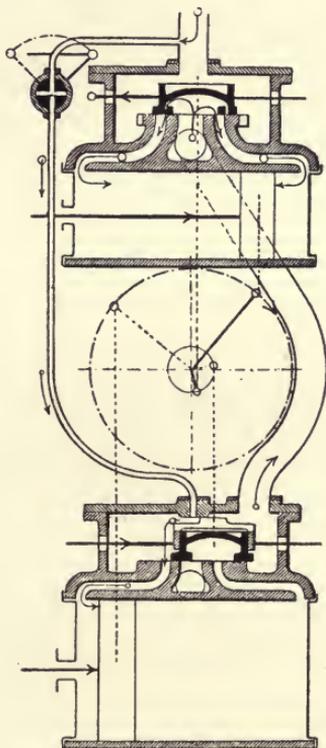


FIG. 78.—Diagrammatic Arrangement—modified Lindner System.

ately this takes place, the driver opens the regulator and the cock is consequently closed, the engine working thereafter as a compound.

The Gölsdorf System.—This system shares with the Lindner system the distinction of being the most frequently employed of systems of the character under notice, and although of somewhat later date than the Lindner system, it is probable that the engines fitted with the Gölsdorf starting apparatus are more numerous than those fitted according to Herr Lindner's methods. In fact, Gölsdorf compound engines, besides being the standards for the Austrian State Railways, are also to be found on some of the German railways, or the railways of the Balkan States, and in Hungary, Russia, Sweden, and in a few cases in the United States and elsewhere.

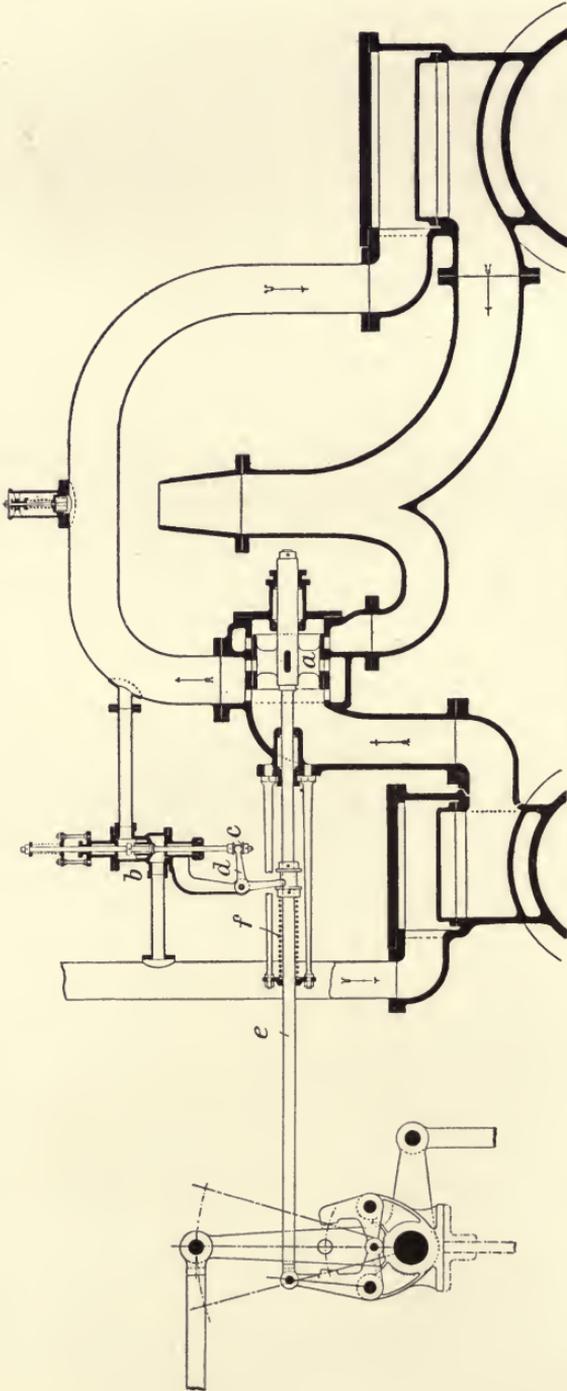


FIG. 79.—Starting Mechanism—Maffei System.

The arrangement employed by Herr von Gölsdorf is simplicity exemplified, for it consists merely in providing two small ports *aa* (figs. 81 and 82), formed through bridges placed across the steam

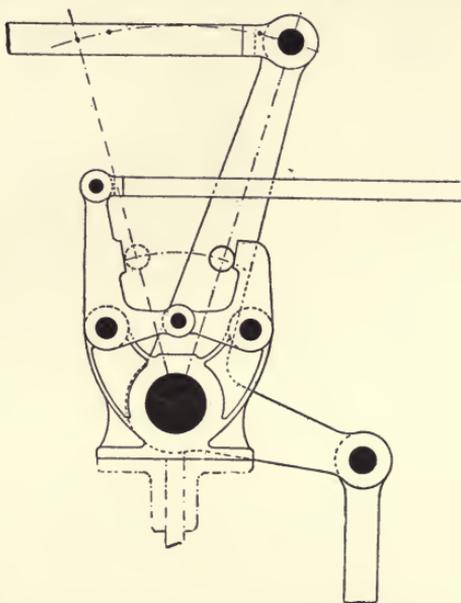


FIG. 80.—Detail of Mechanism—Maffei System.

admission ports of the low-pressure cylinder, to which auxiliary ports live steam is supplied, the slide valve having ribs working over these bridges, the arrangement being such that it is only when the slide valve has maximum travel, owing to the reversing gear being in full forward or backward gear, that the auxiliary ports are uncovered.

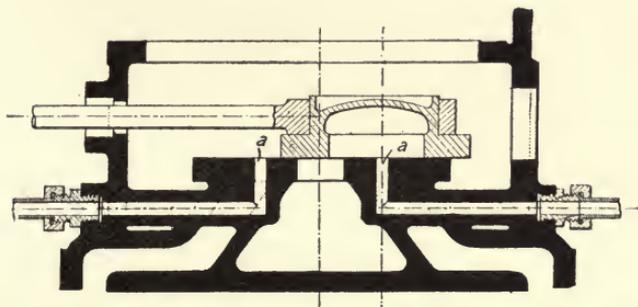


FIG. 81.—Slide Valve and Auxiliary Steam Ports—Gölsdorf System.

By this means, by placing the reversing mechanism in full gear, boiler steam can enter the low-pressure cylinder although there is no high-pressure exhaust steam available, thus enabling the engine to start in any position. If at any other time full gear is employed,

the live steam admission necessarily takes place also, but this only occurs exceptionally, and in some cases a small valve is fitted, whereby, after the engine is started, the driver can cut off the supply of steam

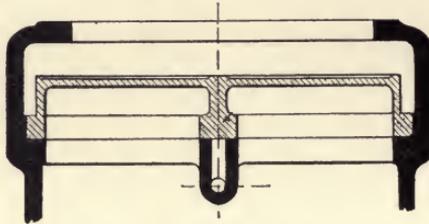


FIG. 82.—Slide Valve and Auxiliary Steam Ports (Cross Section)
—Gölsdorf System.

to the auxiliary ports. As soon as the reversing gear is linked up, the slide valve travel becomes such that the auxiliary ports are never uncovered.

In some cases the auxiliary ports are placed to one side of the

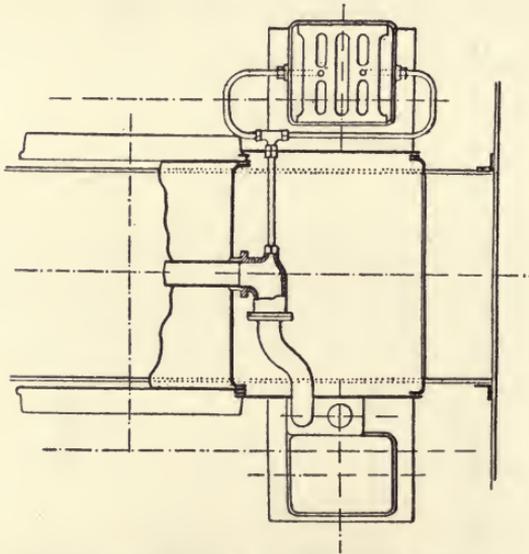


FIG. 83.—General Arrangement—Gölsdorf System.

steam chest, and the slide valve has a small side extension for controlling them.

Fig. 83 shows in diagrammatic plan the general arrangement employed.

Since about the year 1900 the system has also been applied to four-cylinder compound locomotives in which all four cylinders drive the same axle, the cranks being 90° apart round the circle of revolution.

CHAPTER VIII.

THREE-CYLINDER COMPOUND SYSTEMS.

CONTENTS :—General Remarks—Methods of Compounding with Three Cylinders—Webb Three-cylinder System for Passenger and Tank Engines—The Webb System as applied to Goods Engines—The Riekie Three-cylinder System—The Sauvage System—The Swiss System—The Smith System.

General Remarks.—In its simplest form three-cylinder compound systems for locomotives must be considered as being directly derived from two-cylinder systems by the division of the large low-pressure cylinder into two low-pressure cylinders of about the same diameter (or less) as the high-pressure cylinder.

Methods of Compounding with three Cylinders.—Thus, the proposition of Monsieur Jules Morandière in 1866 referred to in Chapter IV. supposes the use of three cylinders, all of about the same size, one of them using boiler steam, while the other two divide the exhaust steam from the high-pressure cylinder between them, their compound volumes being together equal to one large cylinder, as would be employed for a two-cylinder system.

In other propositions it was suggested that three cylinders should be employed in a manner which approximates even closer to the two-cylinder engine, and a general arrangement of this kind which was proposed by Monsieur Mallet in 1879, and patented in this country by Mr Lapage in 1889, is shown in fig. 35.

In true three-cylinder systems it is intended that some mechanical advantage shall be obtained as well as direct economy through compounding, and therefore in all practical systems each of the cylinders has complete driving gear, there being three cranks, disposed in one way or another; as a rule, too, arrangements are provided to enable increased power to be exerted when necessary.

During the whole history of locomotive compounding it is believed that only five three-cylinder systems have been actually employed in practice, and these naturally divide into two divisions, (*a*) having one high-pressure cylinder and two low-pressure cylinders, and (*b*) having two high-pressure cylinders and one low-pressure cylinder.

The first of these divisions is a direct development of the ordinary two-cylinder compound locomotive, with the added advantage that

three driving cranks can be arranged for, as well as other advantages obtained.

In the other division the systems comprise an ordinary two-cylinder high-pressure engine, and the steam, after use in these cylinders, is re-used to obtain further work before the steam is exhausted up the chimney. Two systems only come within this division, and only one of them (the Riekie system) strictly conforms to this statement, the sole object of the low-pressure cylinder being to enable work to be utilised which in a two-cylinder high-pressure engine would be wasted; whereas the other (the Webb system) only partially satisfies this statement, for it also includes the important feature of compounding, that the expansion of steam from boiler pressure to final exhaust is carried out in two more or less equal stages.

It will be most convenient to deal with the second of our divisions first.

The Webb Three-cylinder System for Express and Tank Engines.

—Reference to figs. 5 and 31 will indicate the main features which characterised these engines.

As will be seen, the two high-pressure cylinders are set back on the frames and drive the rear pair of driving wheels, while the large low-pressure cylinder is placed between the frames under the smoke-box so as to actuate the other driving axle. As no coupling rods are fitted, it is possible for the two pairs of wheels to rotate independently, and after starting it generally requires a few revolutions to enable the two sets of mechanism to "get into step." Occasionally this renders a start somewhat jerky, and in the case of the tank engines this provided a primary reason for their removal from London local traffic, which entailed stopping and starting every half-mile or so.

As already stated, no special provision is made for starting, so that all the work for the first one or two strokes has to be done in the high-pressure cylinders, but this fact, although occasionally causing trouble with very heavy loads, has not proved so serious as it may appear to be. A device has, however, been fitted whereby, before starting, boiler steam can be admitted to the low-pressure cylinder on both sides of the piston for warming up the cylinder walls before the working steam enters.

In Mr Webb's patent of 1881 means were described whereby boiler steam could be admitted to the low-pressure cylinder and the high-pressure exhaust diverted to the chimney, but it is not believed that such devices were ever fitted, unless experimentally to the first engine.

At starting, if slipping occurs, there may be an accumulation of exhaust steam from the high-pressure cylinders before it can be used in the low-pressure cylinder, and to accommodate this, fairly large receiver space is provided by means of pipes extending from the high-pressure cylinders into the smokebox, round the inside of which the pipes are curved, one from either side, so that the steam is reheated somewhat before use in the low-pressure cylinder.

In some classes of three-cylinder compound engines of Mr Webb's design, means were provided whereby the cut-off ratios of the respective cylinders could be relatively varied, firstly by fitting two reversing levers in the engine cab (this arrangement was discarded after a time), and secondly by means of a special wheel and-screw gear by which the reversing rods of the high-pressure and low-pressure valve gears could be worked together or independently adjusted. In later engines, however, the necessity for this was obviated by arranging the low-pressure valve to work with an invariable cut-off ratio, the driver being concerned only with the reversing gear of the high-pressure cylinders. This was effected by employing a single eccentric gear for the low-pressure slide valve, which, as the engine started moving, automatically took up a position for forward or backward working according to the direction of motion initiated by the high-pressure cylinders.

Several other special features were patented by Mr Webb from time to time, but the main features were unaffected, and in very few instances were special devices introduced into practice.

Fig. 31 represents the first three-cylinder engine, "Experiment," which started work in 1882. In the next two years twenty-nine more of the same class were introduced. These engines had 6 ft. 9 in. driving wheels, 150 lbs. steam pressure, high-pressure cylinders 13 in. diameter (the first engine had cylinders only 11½ in. diameter when built), low-pressure cylinder 26 in. diameter, and a stroke of 24 in.

Following these came a series of forty engines having considerably greater power, the new class being generally referred to as the "Dreadnought" class. They had bigger boilers, 175 lbs. pressure, 14-in. and 30-in. cylinders, and 6 ft. 3 in. wheels.

All of the engines of these two classes have been scrapped during 1905-6.

In 1889 and 1890 ten larger engines were built, known as the "Teutonic" class; and, somewhat curiously, these engines, though differing only in dimensions and minor particulars from their predecessors and their successors, have always had a most exemplary character, though it is difficult to say why this should be so. Whereas the earlier engines were somewhat erratic and undependable at times, the "Teutonic" class have always enjoyed a good reputation for satisfactoriness and for uniformly good work. These engines have 14-in. and 30-in. cylinders, and 7-ft. driving wheels. Some of these engines have recently been scrapped.

In the years 1891-4 ten large eight-wheeled engines were built. These engines, known as the "Greater Britain" class, had very long boilers, but, as regards their compound features, corresponded generally with the class previously described, except that the high-pressure cylinders were 15 in. diameter, and that the single-eccentric gear above referred to was fitted to them.

The final series of three-cylinder compound express engines built in 1894-8 consists of ten engines, referred to generally as the "John

Hick" class, corresponding to the "Greater Britain" class, but intended for use between Crewe and Carlisle, where severe gradients occur, and therefore having driving wheels only 6 ft. 3 in. diameter.

During the years 1884-7 four tank engines were converted or built as three-cylinder compound engines, but these were not multiplied, and the writer has Mr Webb's own authority for stating that they were never considered as other than experimental engines, which experiments were not sufficiently satisfactory to warrant further work on the same lines.

Webb System as applied to Goods Engines.—Mr Webb's three-cylinder compound system has also been applied to upwards of a hundred eight-coupled mineral engines, dated between the years 1893 and 1899. These engines necessarily do not include the use of non-coupled driving wheels, and all three cylinders drive the same axle, the second from the front. These powerful engines have always done very good work, but Mr Whale, the present Locomotive Chief, is now converting them to two-cylinder non-compound engines with larger boilers as they go into the shops for heavy repairs and rebuilding.

During the years 1883-1890 about seventeen Webb compound engines were built for service in France, South America, India, and the United States (Pennsylvania Railroad), and although in no case were other engines built, the reports of their work were fairly satisfactory.

The Riekie Three-cylinder System.—This system shares with that just described the peculiarity of employing two high-pressure cylinders and only one low-pressure cylinder, but in other respects it comprises several features which differentiate it from Mr Webb's system.

In introducing this system, Mr Riekie, who in 1894 converted one of the Webb compound engines belonging to the North-Western Railway of India according thereto, had for his object to employ the high-pressure cylinders as nearly as possible in the same manner as they are employed in an ordinary non-compound engine, cutting off at an early point in the stroke in the usual manner for engines which are not compound, except when the stress of work requires a late cut-off, the purpose of the low-pressure cylinder being to enable further work to be obtained from the steam before it passes up the chimney. Coupled with this feature is the employment of three driving cranks 120° apart, whereby an even and regular turning moment is obtained. As the high-pressure cylinders are designed to operate as the cylinders of an ordinary engine, they are made of a size equal to, or only slightly less than, those which would be employed were no other cylinders fitted, instead of being smaller and the valve gear adapted for a late cut-off, as usual in all other compound locomotives. It therefore follows that the low-pressure cylinder is additional, and, owing to the relative crank angles, it is designed to receive the exhaust steam from one high-pressure cylinder for one-third of a stroke, and from the other high-pressure cylinder for the next third of the stroke, the remaining third con-

stituting the expansion portion of the stroke. In practice, Mr Riekie is able to cut off in the high-pressure cylinders at 25 per cent. of the stroke or less; and under ordinary circumstances steam can be expanded down from 180 lbs. to 20 lbs. per square inch, or, under special circumstances, to as low as 5 lbs. per square inch.

In one of his patents Mr Riekie provided an arrangement whereby at starting the reversing gear of the high-pressure cylinders can be arranged for an 80 per cent. cut-off, but immediately the engine is in motion the gear is automatically changed to a 40 per cent. cut-off, after which it can be linked up as desired by the driver for proper compound working. Other than this device (if employed), no special starting valve or apparatus is required to enable the engine to start a heavy train.

It was mentioned in Chapter IV., in the course of our historical survey, that several suggestions were made in the early days of locomotive compounding for the employment of three cylinders, one high-pressure and two low-pressure cylinders, but only three systems of this class require more detailed consideration in this chapter, and of these only two may be considered as really belonging to modern practice, though the other system is also included for completeness.

The Sauvage System.—An engine of the "Mogul" (2-6-0) type was built in 1886 for the Northern Railway of France, to designs prepared by Monsieur A. Sauvage.

The low-pressure cylinders are placed outside the frames and drive on to cranks at right angles, and the high-pressure cylinder actuated a crank on the same axle, which crank bisected the obtuse angle between the low-pressure cranks.

The valve arrangements employed for this engine are very peculiar and unusual, but as nothing further has been done with this system, it is hardly necessary to describe them specially, though the original engine is still at work.

The Swiss System.—This system is associated almost exclusively with the Swiss Engine Works of Winterthur, Switzerland, though a considerable number of locomotives have been fitted according to it, principally for use on Swiss railways.

The two low-pressure cylinders are arranged outside the frames, the single high-pressure cylinder being placed inside, and in most cases two separate coupled axles are driven.

A double piston valve controls the passage of steam from the high-pressure cylinder to the blast pipe or to the receiver. A small pipe supplies boiler steam to the steam chests of the low-pressure cylinders, and steam is admitted to them by means of a small regulator valve.

By suitably operating the double piston valves and the small regulator, the driver can operate the engine (1) as a compound, (2) with three high-pressure cylinders exhausting to the blast pipe, (3) with the low-pressure cylinders only working with boiler steam, and (4) with the high-pressure cylinder only.

The first engine fitted according to this system was built in 1894

for use on the St Gothard Railway, for trial against a four-cylinder engine fitted with very nearly the same valve arrangements. The four-cylinder design was considered preferable, but for several years three-cylinder engines of the same kind were supplied to other Swiss railways, though now four-cylinder engines, compounded according to the de Glehn system, are principally introduced in supersession of the older system. Means are also provided whereby the high- and low-pressure valve gears can be independently adjusted.

The Smith System.—This system is one of the few introduced during the last few years which comprise features which render it correct to describe the peculiar valve arrangements employed as pertaining to a system, whereas most other recently introduced so-called systems are really developments of older systems, or are only differentiated one from another by the construction of starting mechanism or by features of design.

The arrangement of cylinders employed by Mr Smith is the same as that used in the last-described engines, viz. with one H.P. cylinder and two L.P. cylinders. In most cases all three cylinders drive one axle with the L.P. cranks 90° apart and the H.P. crank dividing the obtuse angle; but two engines have just been placed in service wherein the H.P. cylinder drives one axle and the L.P. cylinders drive another, the two axles being coupled.

The first engine fitted according to this system was a four-coupled bogie engine of the North-Eastern Railway, originally a Worsdell two-cylinder compound engine, which was adapted in 1899 by Mr Wilson Worsdell, according to Mr Smith's arrangement. The system has never been applied to other North-Eastern engines, though it is understood that the record of No. 1619 has been a good one; but two new four-cylinder compound locomotives of a very powerful type have just been constructed (see frontispiece) which embody a four-cylinder development of Mr Smith's system.

In 1901 two four-coupled bogie engines for the Midland Railway were built by Mr S. W. Johnson immediately before his retirement from the position of locomotive superintendent, and the record of these two engines, and of three others built in 1904 by Mr R. M. Deeley, has been so satisfactory that a number of other engines, having somewhat larger dimensions, have just been placed in service on this line.

The two engines referred to above, wherein two axles are employed for driving, are large Atlantic type engines for the Great Central Railway, designed by Mr J. G. Robinson, the Locomotive Superintendent.

The main object of Mr Smith's system is not so much to obtain direct economy by compounding pure and simple, but rather, while obtaining some advantage in this way, to produce an engine which can be adapted in a very considerable degree to the work required of it, so that it can work trains single-handed, which, owing to difficulties occurring on one section only of a journey, would otherwise require an assisting engine, and it can at other times deal with

its train in a way which would be difficult or well-nigh impossible for a non-compound engine of corresponding or greater power.

On the Midland Railway the record of the compound engines is very notable, and they are great favourites among both the engineers and the high officials of the line.

The starting arrangements introduced by Mr Smith comprise a duplex valve, one part of which is of an automatic character, whereby an engine, after starting non-compound, is automatically changed to compound as soon as there is sufficient pressure in the receiver from the exhaust of the high-pressure cylinder for operation in the low-pressure cylinder, this automatic valve automatically reintroducing non-compound working should the receiver pressure fall below the required (but variable) pressure for non-compound working; the second portion of the mechanism comprises a reducing steam admission valve, which can be regulated by the driver to admit boiler steam at any desired pressure to the receiver, so as to cause the automatic valve to reintroduce non-compound working, and to supply steam at a pressure suitable for variable requirements to the low-pressure cylinders, or to reinforce the receiver steam with live steam to assist work in the low-pressure cylinders.

By this means the mechanism allows of working as follows:—

(a) Three-cylinder non-compound, for starting with three large cylinders (in engines built the H.P. cylinder is 19 in. diameter, and the L.P. cylinders 21 in. diameter).

(b) Three-cylinder compound.

(c) As compound, the low-pressure steam being reinforced in a variable degree with live steam.

(d) As a two-cylinder non-compound engine with large cylinders, larger than could be well supplied with steam did the engine always have to work in this way.

The last-mentioned method of working results when the steam-reducing valve is adjusted so that full or nearly full pressure steam is admitted to the receiver, in which case the high-pressure piston is nearly balanced, and therefore floats, while the two L.P. pistons (21 in. diameter) work with steam at full or nearly full boiler pressure.

It will readily be seen that, with such facilities for adapting an engine to its work, a driver operating his engine intelligently can obtain very great power or adjusted power according to load of train and gradient, thus enabling the engine to maintain speed under circumstances when the speed would fall considerably in the case of an ordinary engine. The engines can accelerate quickly, and on a very steep gradient or under exceptional difficulties can work temporarily as a very powerful non-compound engine, whereby the difficulty can be surmounted before the large consumption of steam required for the time being has seriously strained the steaming capacity of the boiler.

Strictly speaking, economy as ordinarily understood when compound locomotives are in question, is not sought for, though for the major portion of any journey such an engine effects economy

in a greater or less degree by working compound, but the real economy arises from the fact that almost any difficulty within reason can be surmounted by working as a semi-compound or as a simple engine, and economy of engine power can therefore be effected as mentioned above. In some cases means are provided whereby the adjustable valve cannot be adapted for the full boiler pressure of steam.

At starting, it may occur that the high-pressure slide valve closes both of the steam ports, and under these circumstances the reduced boiler steam admitted to the receiver would enter one end of the cylinder through the exhaust port and tend to reverse the engine ;

this is prevented by fitting a non-return valve in a passage connecting the two ends of the high-pressure cylinder and the receiver, so that receiver steam is admitted to both ends of the H.P. cylinder, the piston of which is therefore balanced. Under these circumstances, the low-pressure cylinders start the train until the high-pressure slide valve has moved sufficiently to open one or other of the steam ports to steam, when the non-return valves automatically close.

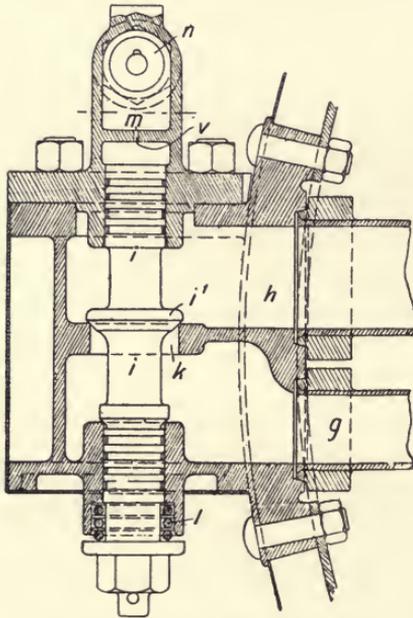


FIG. 84.—Starting Valve—Smith Three-cylinder System.

Figs. 84 and 85 show the arrangement of parts and the construction of duplex valve generally employed in carrying the Smith system into practice.

Fig. 86 is a general view showing the smokebox and cylinder arrangements. *a* is the high-pressure cylinder, the steam distribution of which is controlled

by piston valves at *a*¹ (these valves are of Mr Smith's special design, but do not concern us here); *b b* are the low-pressure cylinders, whose steam distribution is controlled by ordinary slide valves working over vertical port faces; *c* is the receiver space; *d* the casing of one of the non-return valves connecting the receiver space with the respective ends of the high-pressure cylinder; *ee* the exhaust valve; *f* the casing of the duplex valve; *g* the boiler steam supply pipe to *f*; and *h* the pipe connecting the duplex valve with the receiver.

The large spindle *i* carries a valve *i*¹ which opens or closes the opening *k*, whereby communication is opened or closed between the pipes *g* and *h*; and the two ends of this spindle work steam-tight in the casing as shown, a spring *l* being fitted to assist the closing movement, and to give the valve the character of a reducing valve.

The passage *m* communicates with the live steam supply pipe *g*, so that boiler steam presses upon the spring loaded valve *n*. The spindle *o* has a screwed portion *o*¹ engaging in screw threads formed in the casing, whereby, when the spindle *o* is rotated through the rod *p*, which extends into the driver's cab, where a wheel or handle is fitted for rotating it, the spindle is moved longitudinally, and the collar *s* compresses the spring *t*, more or less, so as to adjust the pressure at which the valve *n* will open. After passing the valve *n*, steam leaks through the small opening *v* to the space above the end of the spindle *i*.

At starting, there being no pressure in the receiver, the valve *i* lifts and allows steam to pass from the pipe *g* to the pipe *h* for use

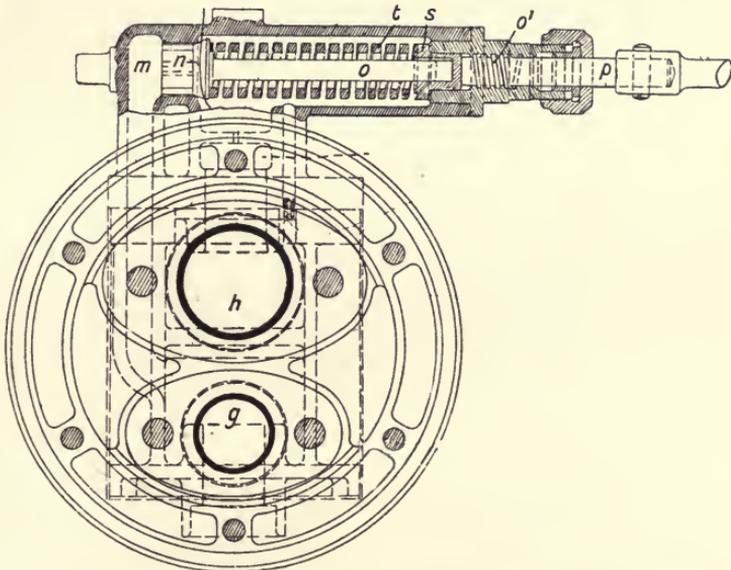


FIG. 85.—Pressure-Regulating Valve—Smith Three-cylinder System.

in the low-pressure cylinders, and the engine starts as a two- or three cylinder non-compound. As soon as there is sufficient receiver pressure the valve *i*¹ automatically closes, and the live steam supply is cut off, the engine then working compound.

If at any time the pressure in the receiver falls below that required for low-pressure working, the valve *i*¹ opens to admit boiler steam from *g* to *h*, but the pressure at which this will occur is adjusted by the driver operating the rod *p* so that the spring *t* is more or less compressed, and at the desired pressure, or a proportionate pressure, boiler steam enters by the valve *m*, leaks through the hole *k* to the space above the end of the spindle *i*, and presses the valve *i*¹ upon its seat with such force that the boiler steam has to overcome this pressure as well as that in the receiver before it can pass to *h*.

Thus, for ordinary compound working, the pressure above the spindle *i* is such that the valve *i*¹ lifts immediately the pressure in

the receiver falls below, say, 80 lbs. per square inch, admitting boiler steam at the requisite reduced pressure. If additional power is required in the low-pressure cylinders, the valve *n* is adjusted so that the closing pressure on the valve *i*¹ is increased, and it therefore results that boiler steam will be admitted to the receiver immedi-

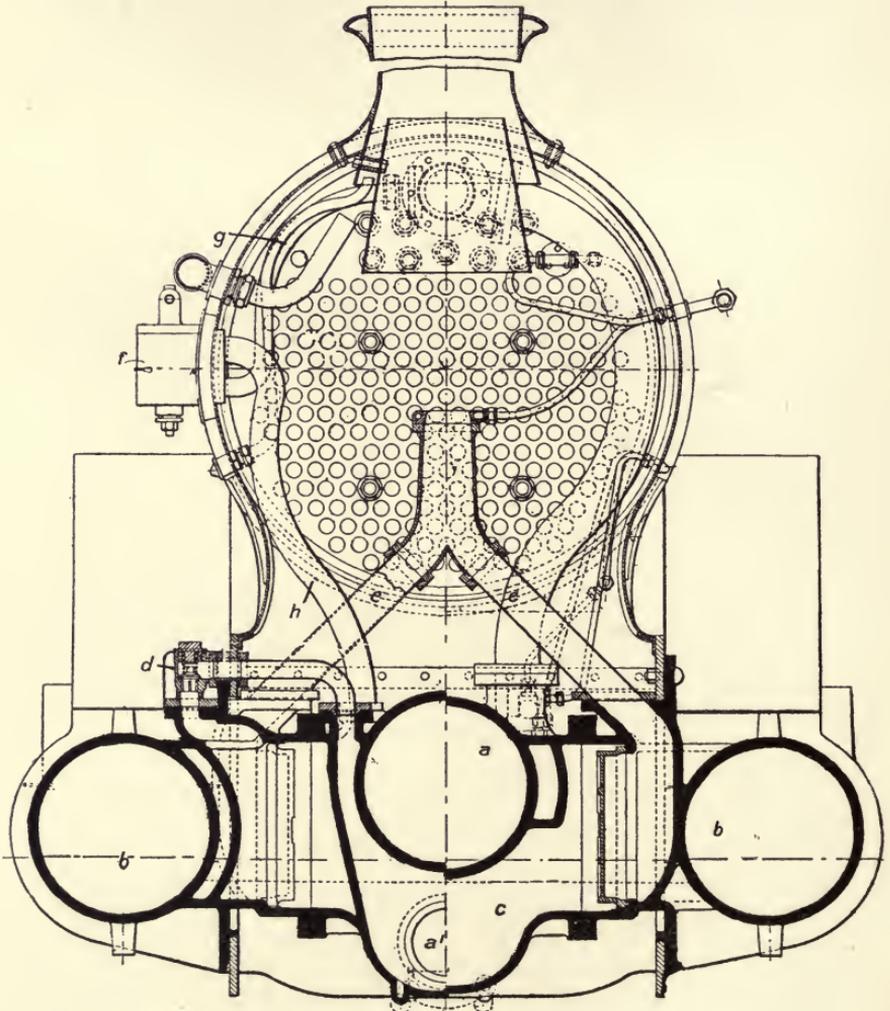


FIG. 86.—General Arrangement—Smith Three-cylinder System.

ately the pressure falls below, say, 120 lbs. per square inch, the result being that the receiver receives both H.P. exhaust and reduced boiler steam for reinforced or semi-compound working.

Several other constructional features, such as cushioning and leakage-preventing means, are also employed, but these need not be dealt with here.

CHAPTER IX.

FOUR-CYLINDER TWO-CRANK SYSTEMS (TANDEM CLASS).

CONTENTS:—General Remarks—The Du Bousquet “Woolf” System—The Brooks System—The Vaucrain Tandem System—The American Locomotive Company’s System—The Sondermann System—Mallet Tandem System in Russia—Tandem Compounds for Hungarian State Railways—The new Du Bousquet Tandem System.

General Remarks.—The tandem system of compounding is probably the simplest method of adapting compounding to the locomotive engine, for it admits of the adaptation of an ordinary two-cylinder non-compound engine for compound working by the mere addition of two small cylinders for high-pressure steam, the original cylinders serving as low-pressure cylinders; beyond this there is very little complication, and very few additional parts are required. In fact, in the case of some experimental engines the foregoing statement represents what has actually been done.

In practice, however, it is of course preferable to properly design the cylinders and mechanism, but beyond the fact that two additional cylinders are required, each having a piston and a piston rod (an extension of the ordinary piston rod in most cases), and fitted with slide or steam controlling valves, and that a few connecting pipes may be necessary, the engine is no more complicated than an ordinary non-compound engine. Owing to the fact that the cylinders are similar on either side of the longitudinal centre-line of the engine, starting arrangements, such as are necessary with a compound engine having two unequal cylinders, may be very considerably simplified, or may be dispensed with altogether.

Remarks of a corresponding nature also apply to a great extent in the case of other four-cylinder two-crank systems, as described in the next chapter.

Tandem compound engines may be divided into two main divisions: (1) those wherein the two cylinders of each tandem pair are formed together in one casting or very closely connected, this section being further capable of classification according to whether one slide valve or two is or are employed at each side of the engine, and according to whether the steam passes direct from one cylinder to the other

without the intermediation of a "receiver" (referred to as the "Woolf" method), or whether a "receiver" is employed; and (2) those wherein the cylinders are separated and distinct, though both pistons at either side are mounted on the same piston rod or connected to the same crosshead, and the two slide valves (each cylinder necessarily has its own slide valve in this case) are mounted on the same valve rod, or the respective valve rods are connected to work together.

In Chapter IV. some early attempts at tandem compounding for locomotives have been mentioned and others referred to, and now the most important of the systems which have been actually employed

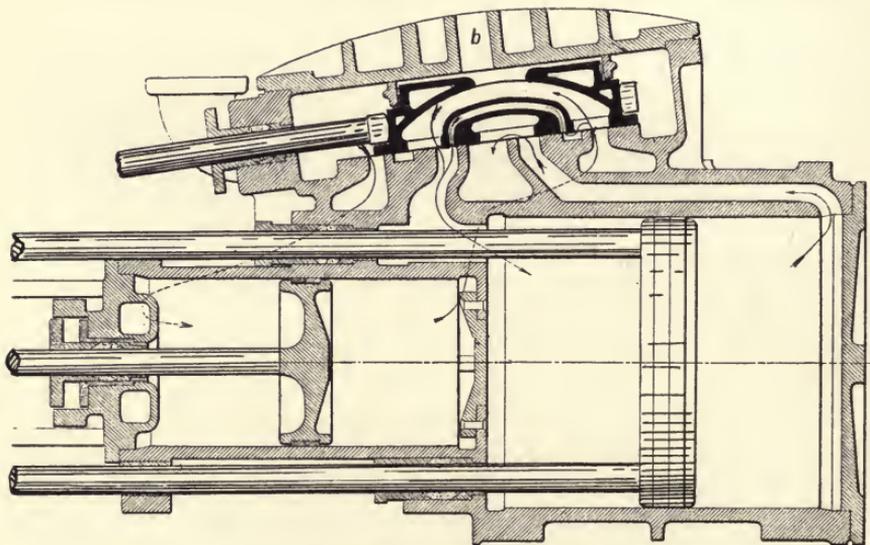


FIG. 87.—Du Bousquet (Woolf) Tandem System.

will be referred to in detail, systems of the first class above referred to first receiving attention.

The Du Bousquet "Woolf" System.—To Monsieur G. du Bousquet, Chief Locomotive Engineer of the Northern Railway of France, must be credited the first notable introduction of tandem compound locomotives into service; and, rather curiously, he is also responsible for the latest successful introduction of such engines, though on a different system.

In 1882 this well-known engineer converted three eight-coupled outside cylinder goods engines by fitting at each side a high-pressure and a low-pressure cylinder end to end. In 1890 extended trials with these engines having proved very satisfactory, twenty new engines of the same class were built, and it is believed that all of these twenty-three engines are still at work, though superseded to some extent by new engines of other classes.

Fig. 87 is a section of a pair of cylinders for one of these engines.

As will be seen, the two cylinders are cast together, and the low-pressure cylinder has two piston rods which pass outside the high-pressure cylinder, all three rods being connected to the same crosshead. A single slide valve of special construction controls the steam distribution of both cylinders, the arrangement of ports and the path of the steam for one position of the pistons being indicated. To all intents and purposes, the slide valve consists of two slide valves, one inside the other, and rigidly connected therewith.

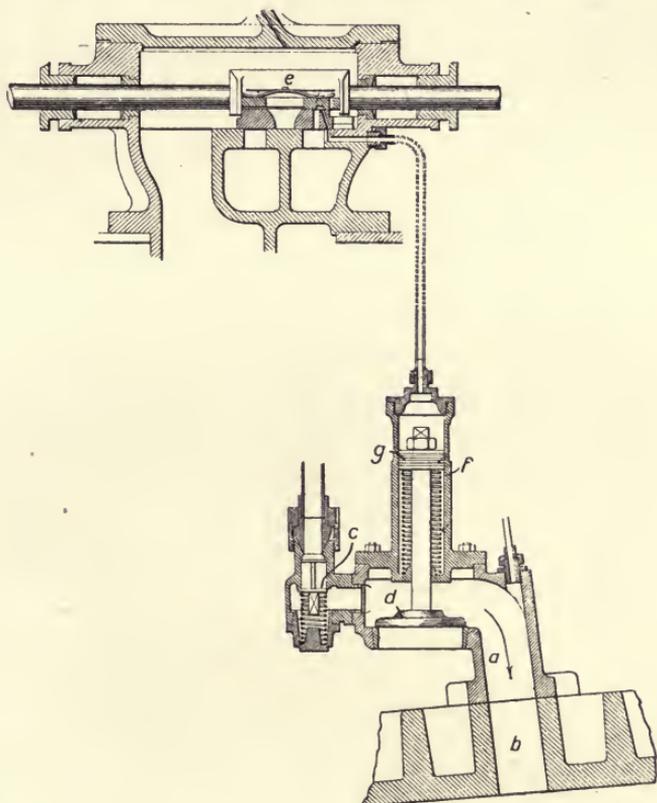


FIG. 88.—Starting Mechanism—Du Bousquet (Woolf) Tandem System.

An important feature of this arrangement is that the cylinders are placed as close together as it is possible for them to be, and that no stuffing boxes are required between them, thus obviating one of the great disadvantages of many tandem systems, *i.e.* the difficulty of obtaining access to stuffing boxes between the cylinders of each pair.

To facilitate starting, the valves shown in fig. 88 are fitted.

The passage *a* communicates with the passage *b* (fig. 87) formed through the valve chest cover, and through the opening in the top of the duplex slide valve, with the internal passages of the slide valve,

and so to the ports of the low-pressure cylinder. The spring valve *c* governs the passage of boiler steam at a reduced pressure to the passage *a*, and closes automatically as soon as the high-pressure cylinder supplies exhaust steam of a sufficient pressure. The valve *d* allows air to enter the cylinders when the engine is running with steam shut off. The valve *e* is a special type of steam regulator, and it is provided with a small port, as shown, whereby, when steam is allowed to pass to the cylinders, a small supply passes to the cylinder *f* and presses on the small piston *g*, thereby ensuring the closing of the air valve *d*.

The Brooks System.—A tandem compound engine was built in 1892 by the Brooks Locomotive Works for the Great Northern Railway (U.S.A.), and this engine, of the Consolidation (2-8-0) type,

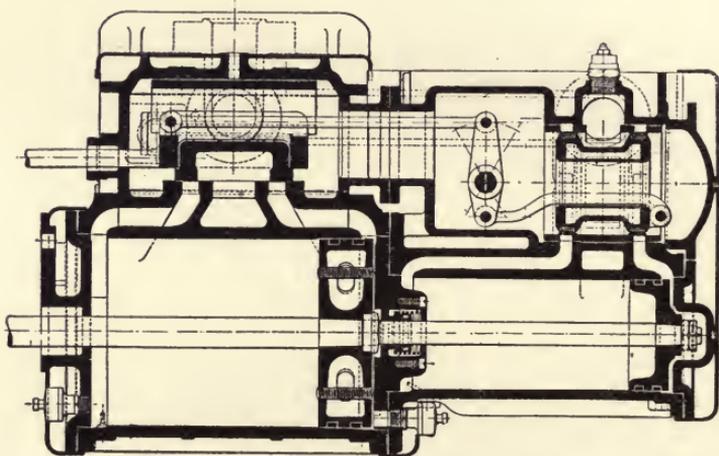


FIG. 89.—Section of Cylinders and Slide Valves—Brooks Locomotive Works (Player) System.

has been followed by several other tandem engines, though such engines (or any tandem compound engines) have never become very common in American practice, notwithstanding that many of them are notable machines. Fig. 89 shows the construction and arrangement of cylinders, slide valves, and other parts.

As can be seen, the two cylinders of each pair are closely connected, but the two slide valves are moved oppositely to one another through a rocking lever located in the receiver, the H.P. slide valve being of hollow piston design, while the L.P. slide valve is of ordinary D-construction. The bearing of the rocker arm, which is of course inaccessible during work, is oiled through a hole bored through the centre of the spindle.

A reducing starting valve, which operates only when the reversing gear is placed in full forward gear, to admit boiler steam at a reduced pressure to each low-pressure cylinder, is shown in fig. 90. The operating rod *a*, which is connected with the reversing lever, has

an inclined face formed upon it at a^1 , whereby, when the lever is moved fully over in forward gear, the reducing valve is opened to allow steam to pass to the low-pressure cylinders.

The Vauclain Tandem System.—This system has been employed for a number of American compound engines in recent years (some of them among the largest and most remarkable engines in the world); and as it also comprises the close juxtaposition of a high- and a low-pressure cylinder, and the use of a single slide valve (or rather two valves working in one steam chest) for two cylinders, it requires consideration at this stage, though other tandem compound systems antedate its use by several years.

Fig. 91 is a section of a pair of cylinders and valves according to this system.

Each cylinder, with its valve chest, is cast separately, and is separate from the saddle. The steam connections are made by a

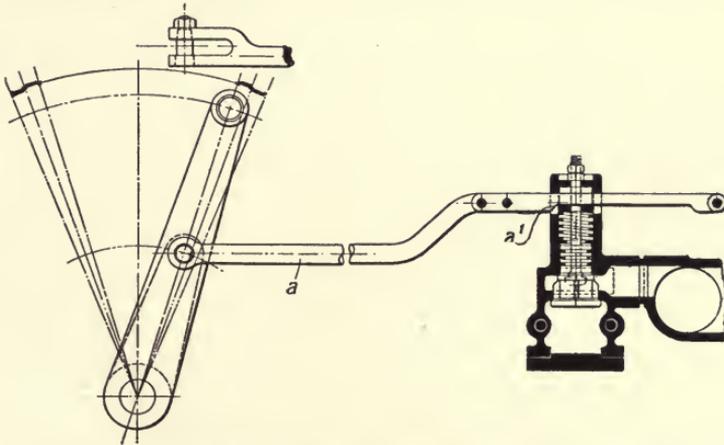


FIG. 90.—Starting Mechanism—Brooks Locomotive Works (Player) Tandem System.

pipe from the saddle to the high-pressure valve chest, and the final exhaust takes place through an adjustable connection between the low-pressure cylinder and the saddle casting. The valve, which is double and hollow, admits steam to the high-pressure cylinder, and at the same time distributes the high-pressure exhaust from the front end of the high-pressure cylinder to the back end of the low-pressure cylinder, or *vice versa*, as the case may be, without the necessity of crossed ports. As shown, A is the high-pressure valve by which steam is conducted from the live steam openings through external cavities B and B to the high-pressure cylinder. The exhaust from the high-pressure cylinder passes through the opening C to the steam chest, which acts as a receiver; D is the low-pressure valve connected to the high-pressure valve by valve rod E. This valve in its operation is similar to the ordinary slide valve. The outside edges control the admission, and the exhaust takes place

through the external cavity F. The starting valve connects the live steam ports of the high-pressure cylinder.

The system has been employed for a large class of ten-coupled (2-10-2 type) engines recently supplied to the Atchison, Topeka, and Santa Fe Railroad (United States). The cylinder diameters are 19 in. and 32 in., with a stroke of 32 in. The engines weigh in working order (without tender) 129 English tons.

The American Locomotive Company's System.—This company has also been responsible for the introduction of tandem compound engines in the United States; and such engines have been built at various times in connection with the various firms which are now amalgamated into the American Locomotive Company. Fig. 92

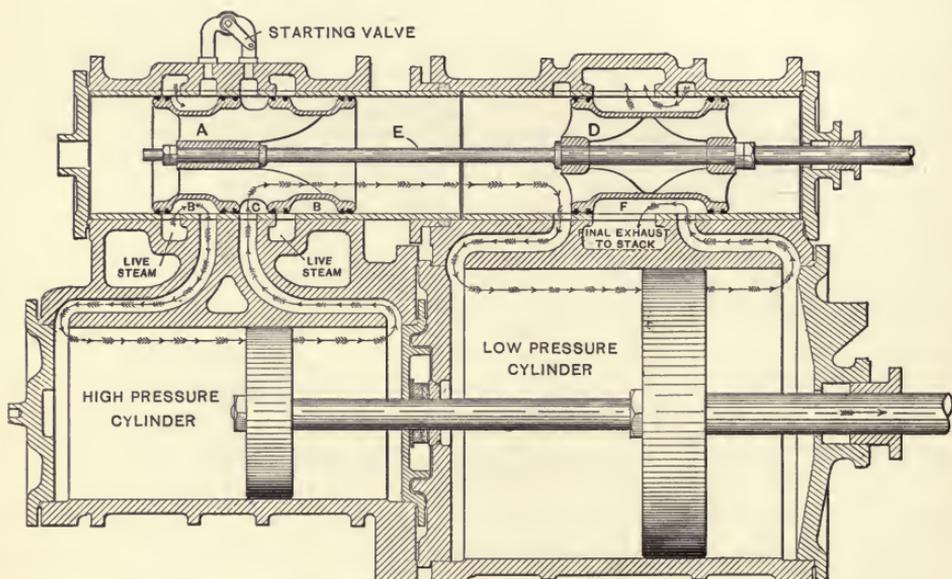


FIG. 91.—Section of Cylinders for Vaclain Tandem Compound Engine.

is a section of cylinders as now employed for engines of this class. In several cases the engines correspond very closely with those built by the Baldwin Works; and on the Atchison, Topeka, and Santa Fe Railroad there are "decapod" (2-10-0) engines built by both firms, these engines being the immediate predecessors of the engines just described, and being but little smaller.

The hollow piston valves are mounted on the same valve rod in a common steam chest, that for the H.P. cylinder being arranged for internal admission, and that for the L.P. cylinder for external admission. The design is such that steam can be admitted to the same side of each piston by means of the crossed ports of the high-pressure cylinder. As shown, steam is being admitted to the left of each piston.

Fig. 93 shows the starting valve employed. This valve is secured

to the side of the steam chest over the high-pressure cylinder, and connects directly with the steam passages of that cylinder. A by-pass valve for the high-pressure cylinder is also contained in the

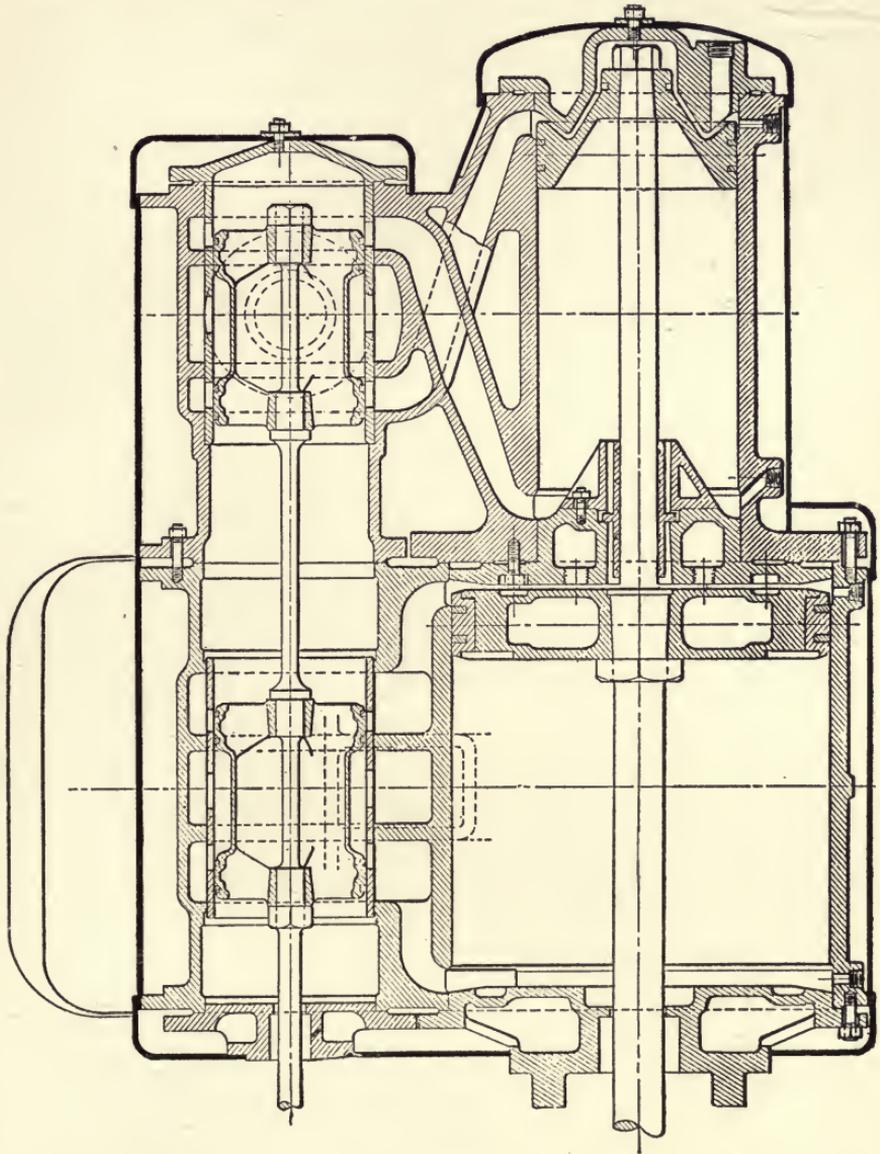


FIG. 92.—Section of Tandem Cylinders—American Locomotive Company's System.

casing of the starting valve. The low-pressure cylinder is also provided with a by-pass valve for relieving excessive steam pressure, or for freeing from back pressure when running with steam shut off.

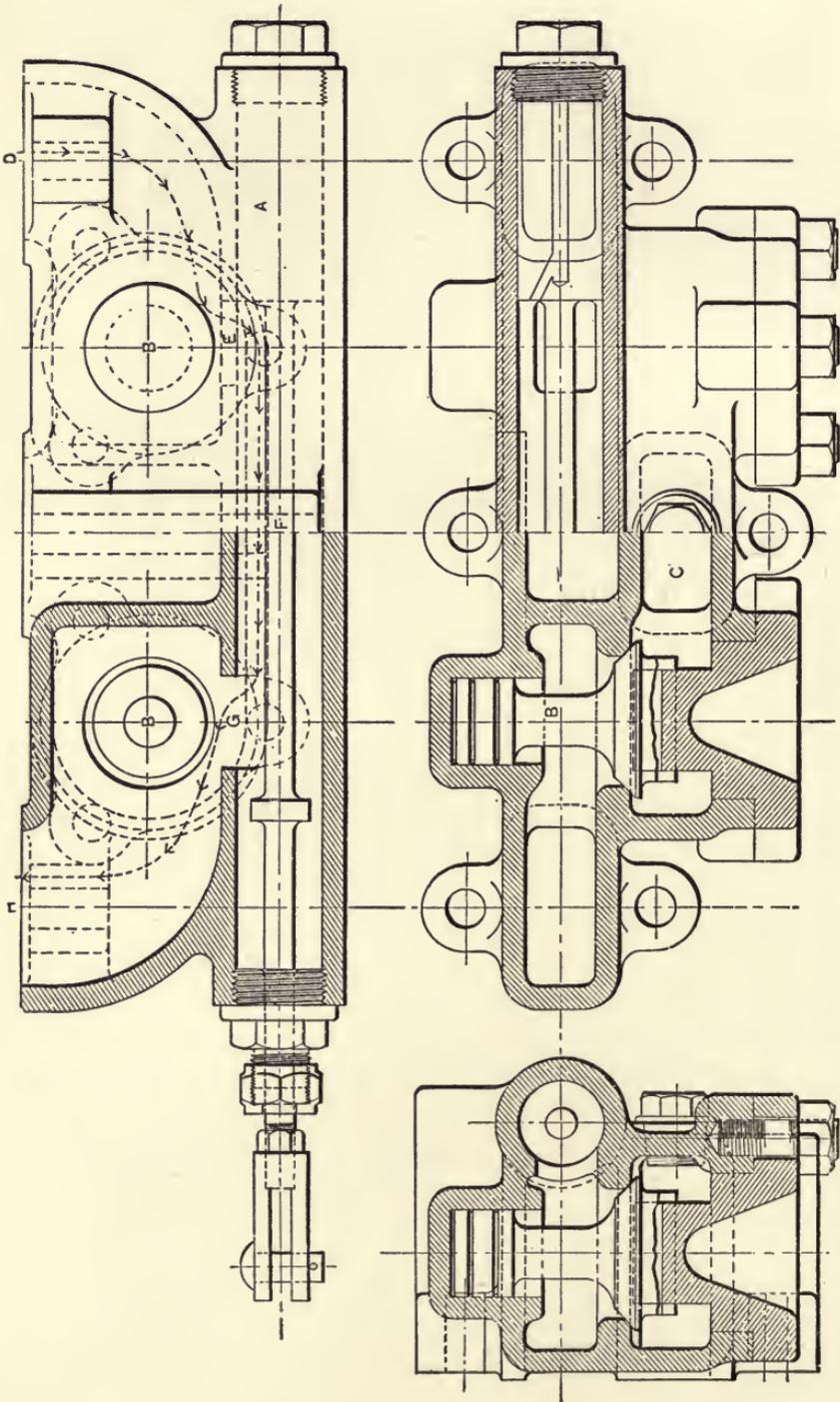


Fig. 93.—Starting Valve—American Locomotive Company's System.

At starting, the starting valve is placed by the driver in the position shown by means of a lever in the cab, and steam then passes to the H.P. steam chest through a short steam pipe, and thence through the ports D and H, which register with the H.P. steam ports in the steam chest. From D the steam passes by the ports E and G and thence by the by-pass valves BB to the port H, the valves BB being held up to their seats by pressure from below through the port C, which opens directly into the steam chest. The steam thus has access to both H.P. steam ports, and passes through both piston valves to the low-pressure cylinder, which thus works with high-pressure steam.

For working compound, the starting valve A is moved so that it closes the port E, shutting off high-pressure steam from the low-pressure end of the steam chest.

A difficulty attending the use of tandem compound locomotives is, that the packing of the piston rod between the high- and low-pressure cylinders is so located that it cannot be seen, and it is difficult to ascertain whether it leaks or is tight. Another difficulty is, that it is extremely hard to get at the low-pressure cylinder packing, and it sometimes takes several hours to make a complete inspection of this packing.

It is such difficulties as these which militate against the general introduction of tandem compounding for locomotives, but in a large measure these are overcome or considerably reduced in recent practice.

Sondermann System.—Some years ago (about 1894-5) four engines were equipped by the firm of Krauss & Co. of Munich with Sondermann's tandem cylinders, but the engines were afterwards converted to ordinary design, as they did not show any noticeable advantage.

Fig. 94 is a section of the cylinders then employed, from which it will be seen that a peculiar construction was employed. The two pistons were connected, and at one side worked over a boss formed on the cylinder cover, in which one of the high-pressure steam ports was formed. One slide valve controlled the steam distribution of the two cylinders, being formed to work over five ports instead of three.

A few systems which have been employed to some extent, wherein each cylinder is complete in itself, will now be considered.

Mallet Tandem Compound Engines.—Although Monsieur Mallet published designs for a tandem system of compounding in 1879, it was not until 1891 that any engines were built, but in that year a passenger engine was built at the Alsatian Works for the South-Western Railway of Russia, to the designs of Messrs Mallet, de Glehn, and Borodine.

Fig. 95 is a section through the cylinders showing the valve arrangement.

In this case the high- and low-pressure cylinders are cast separately, the low-pressure cylinder being nearest to the driving wheels. The arrangements for operating the two slide valves together, and the

general features of cylinder construction and arrangement, are shown in the figure.

To facilitate starting, a modification of the Mallet starting valve, as introduced for two-cylinder compound engines, is employed, whereby steam is admitted to the low-pressure cylinders whenever the reversing gear is placed in full forward or backward gear.

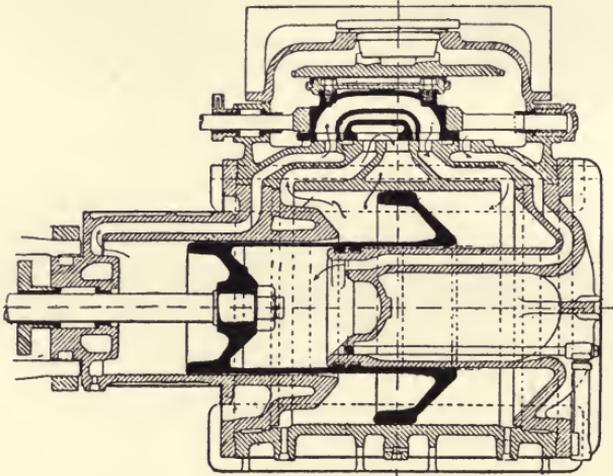


FIG. 94.—Section of Cylinders—Sonderrmann System.

Since the introduction of this engine, tandem compound locomotives have been introduced in considerable numbers for the Russian railways, the engines being of various classes, and in some cases being of notable dimensions.

Tandem Compound Engines for Hungarian State Railways.—It is somewhat strange that Hungary and Russia should be the only

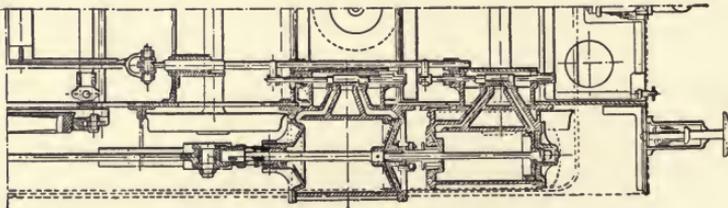


FIG. 95.—Section of Cylinders—Mallet Tandem System.

countries where tandem compound engines have been seriously employed for express service. In both cases each of the cylinders is complete in itself, having its own steam chest and slide valve, the two valves being operated from the same valve rod at each side of the engine.

Fig. 96 is a sectional view showing the arrangement and construction of cylinders and valves employed for the Hungarian State

Railways in 1891, the engines being of the four-coupled bogie type.

In these engines both of the high-pressure cylinders exhaust into the same receiver from which both of the low-pressure cylinders are supplied. At starting, live steam is admitted to the receiver for use in the low-pressure cylinders by means of a starting valve which is opened by the reversing gear when in full gear forward or backward. This starting valve is the same as that described in Chapter V. in reference to Hungarian two-cylinder compound locomotives. The two-cylinders of each pair are cast together, though each is largely independent as regards access to stuffing boxes, etc.

The new Du Bousquet Tandem System.—In 1901 Monsieur du Bousquet introduced upon the Northern Railway of France a series of fifteen tandem compound tank engines for working Northern traffic over the "Ceinture" Railway, a joint railway connecting the

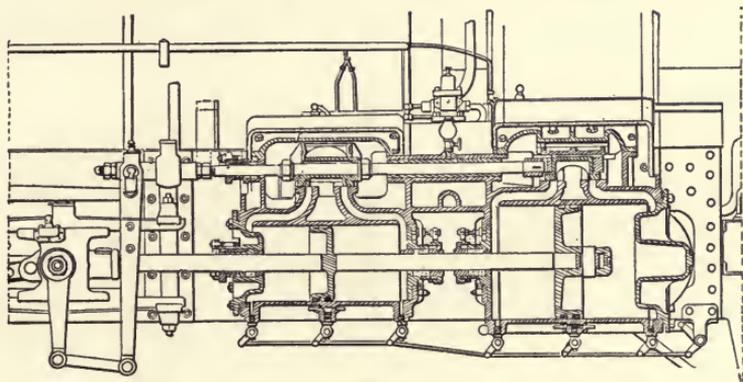


FIG. 96.—Section of Tandem Cylinders—Hungarian State Railways.

various termini in Paris, and used largely for the interchange of traffic.

The design differs radically from that of the engines described earlier in this chapter, the low-pressure cylinders being placed in front, and being entirely separated from the high-pressure cylinders, and the piston and valve rods for each cylinder being separate, and connected by coupling sleeves.

Fig. 97 is a schematic view showing the starting valves and mechanism.

For actuating the mechanism for changing from non-compound to compound working compressed air is employed, controlled by the small valve *a* operated in conjunction with the regulator; this valve allows air to pass by one or other of the pipes *b c* to the top or the bottom end respectively of the cylinder *d* so as to raise or lower its piston, and thereby to rotate through the mechanism shown the rotary valve *e*, which in one position (non-compound) opens communication between the pipe *f*, connected with the steam supply pipe *g*, for the high-pressure cylinder, and the low-pressure steam chest,

another part of this valve at the same time closing communication

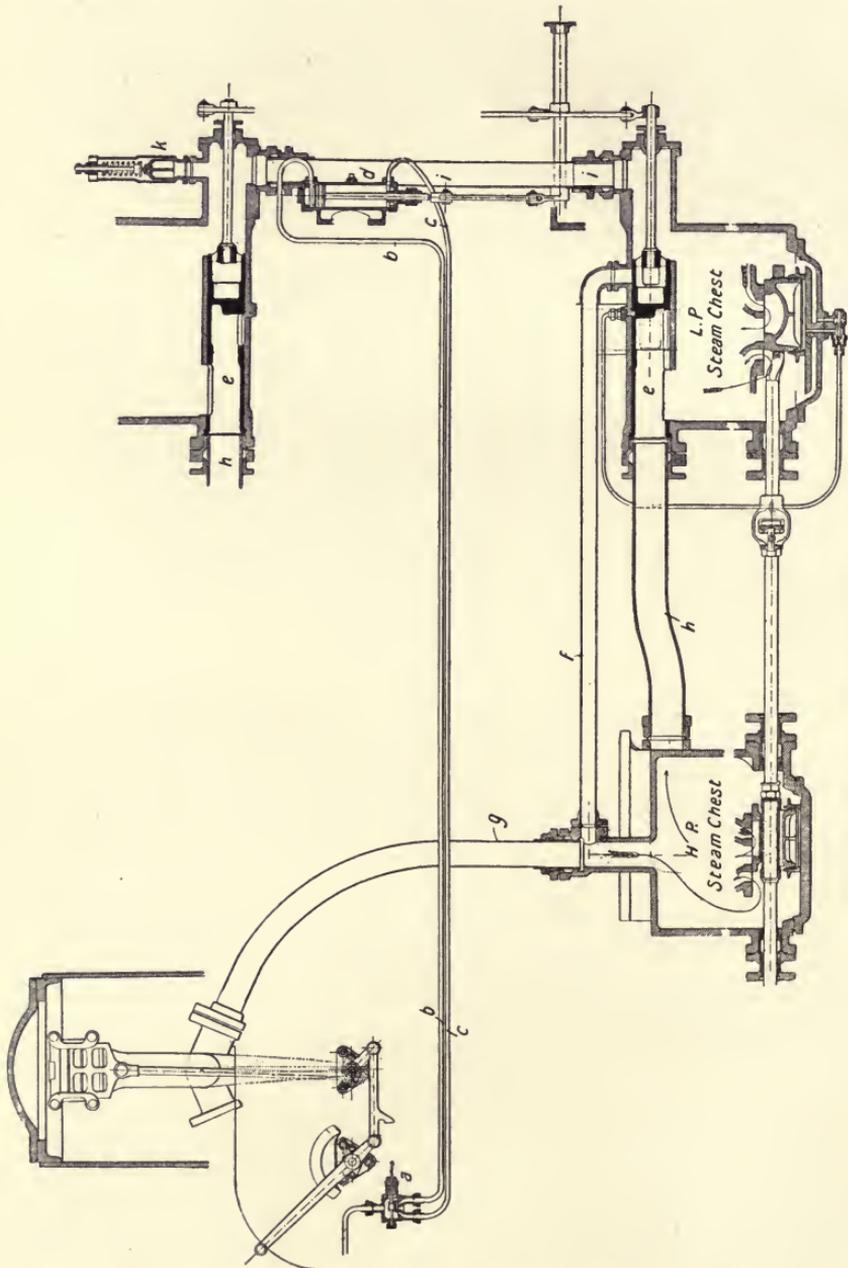


FIG. 97.—Starting Mechanism—Du Bousquet (New) Tandem System.

between the H.P. and L.P. cylinders through the pipe *h*. As represented, the parts are in the compound position. This valve also

controls communication between the pipe *h* and a pipe connecting with the blast pipe through *i*, so that when cut off from the L.P. steam chest the H.P. exhaust can pass away.

At the upper part of the figure is shown the rotary valve *ee* for the cylinders at the other side of the engine. Both these valves are operated by the movement of the piston of the one air cylinder *d*. A relief valve is fitted at *k* to regulate the pressure in the pipe *i*.

Besides the foregoing, a number of patents have been taken out in connection with tandem compounding; but as none of them have been actually used, and the constructions are, as a rule, complicated, detailed reference is hardly required.

CHAPTER X.

FOUR-CYLINDER TWO-CRANK SYSTEMS (OTHER THAN TANDEM).

CONTENTS :—The Vaucrain Superposed Cylinder System—The Johnstone Annular Cylinder System.

SYSTEMS of this class may be classed in two main divisions. In the one case the two cylinders at each side are more or less independent, yet drive on to the same crank pin; in the other case they are in conjunction, but arranged in such a manner that they cannot be classed as tandem compound engines, though corresponding thereto in large measure.

As regards the first class, several schemes were mentioned in Chapter IV., and a number of other like schemes have been patented or published in the technical press from time to time, but none of them have been employed in practice.

The Vaucrain System.—As regards four-cylinder two-crank systems wherein the two cylinders at each side are in close connection, so that the two pistons work together and one crosshead serves for the two, by far the most important is the Vaucrain, introduced by the well-known Baldwin Works of Philadelphia, and this system, though now superseded to some extent by a four-cylinder balanced system (see Chapter XII.), has been used for some thousands of engines.

The Vaucrain system consists in superposing a high- and a low-pressure cylinder at each side of the engine, the two piston rods in each case being attached to one large crosshead with a single connecting rod, so that only one set of motion and a single valve (of the piston type) are required.

Anticipatory schemes have at one time and another been unearthed from the patent records and from technical journals, and it may be said that the Mallet-Lapage double low-pressure cylinder system contains the germ of the idea; but in practice, the Vaucrain system stands alone, for no other builders than the Baldwin Works turn out engines thus compounded, and yet the system has probably as many representatives, widely scattered, as any other system.

The first engine on this system was an otherwise ordinary four-coupled bogie (American type) locomotive for the Baltimore and Ohio

Railroad,—a railway historically famous as the scene of many locomotive triumphs and daring experimental innovations in the early railway days of America,—the engine being put in service in 1889. The cylinder ratio generally employed by Mr Vaucrain is about 3 : 1. Since its introduction the Vaucrain system has been applied to thousands of locomotives of all types, and these engines have been supplied, outside the United States and other American States, to Russia, China, Japan, France, India, Italy, Egypt, Australia, and New Zealand.

Some of the Vaucrain engines have wonderful records, and there are few engines better known in Great Britain than these, although this country does not possess a single representative of its own.

This system has been applied to locomotives of practically every type now in use, and also to compressed-air locomotives for mine

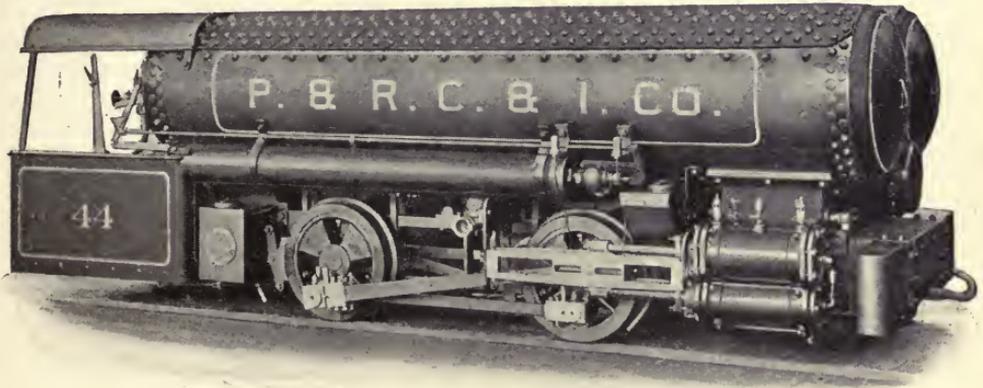


FIG. 98.—Vaucrain Compound Compressed-air Mine Locomotive.

and elevated railway service, and to rack, and combined rack and adhesion, locomotives.

Fig. 98 illustrates the application of this system to a compressed-air mine locomotive for the Philadelphia and Reading Coal and Iron Company. It is believed that the Vaucrain is the only compound system which has ever been employed for such engines, or for very small engines such as four-wheeled shunting engines, while examples of compound tramway engines of other systems are very rare.

Fig. 99 is an interesting front view of a large Vaucrain compound engine, and well indicates the arrangement of cylinders and valve chests.

Figs. 100, 101 comprise two views showing cylinder and valve chest castings formed in one with a half saddle for supporting the engine smokebox. With the low-pressure cylinder below, the engine is for passenger service; when the high-pressure cylinder is below, the engines are adapted for freight traffic, or have small coupled wheels.

Fig. 102 shows a pair of cylinders fitted up for use.

The principal objects which Mr Vaucrain had in view when introducing this system are best set forth in the following statement furnished by the Baldwin Works, of which Mr Vaucrain is Chief Engineer :—

1. To produce a compound locomotive of the greatest efficiency, with the utmost simplicity of parts and the least possible deviation from



FIG. 99.—Front View of Vaucrain Compound Locomotive.

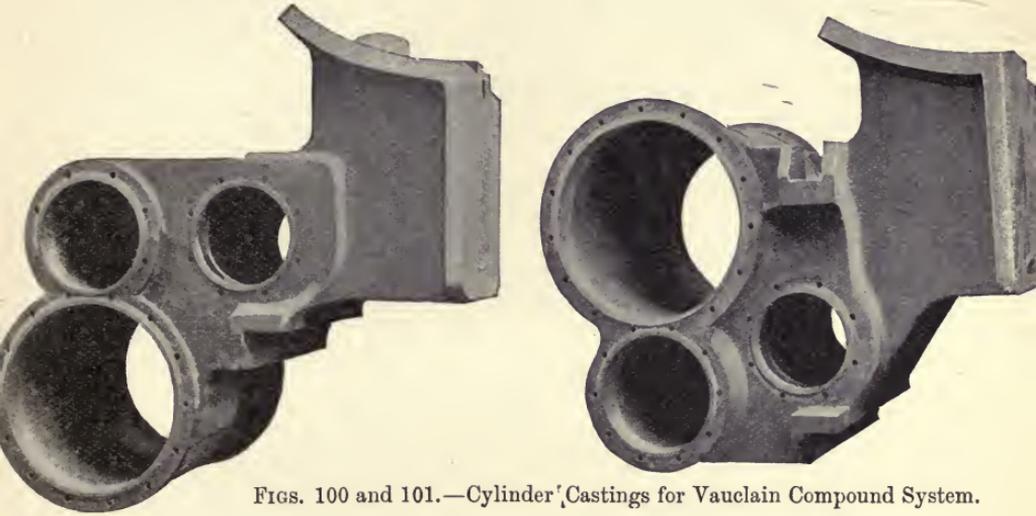
existing practice. To realise the maximum economy of fuel and water.

2. To develop the same amount of power on each side of the locomotive, and avoid the racking of machinery resulting from unequal distribution of power.

3. To ensure at least as great efficiency in every respect as in a single-expansion locomotive of similar weight and type.

4. To ensure the least possible difference in cost of repairs.

5. To ensure the least possible departure from the method of handling single-expansion locomotives; to apply equally to passenger or freight locomotives for all gauges of track, and to withstand the rough usage incidental to ordinary railroad service.



FIGS. 100 and 101.—Cylinder Castings for Vaclain Compound System.

Fig. 103 is a diagrammatic drawing showing the arrangement of cylinders, slide valve, and steam ports, a specimen route for the steam being traced by arrows.

The valve employed for controlling the steam distribution of each pair of cylinders is of the piston type, working in a cylindrical

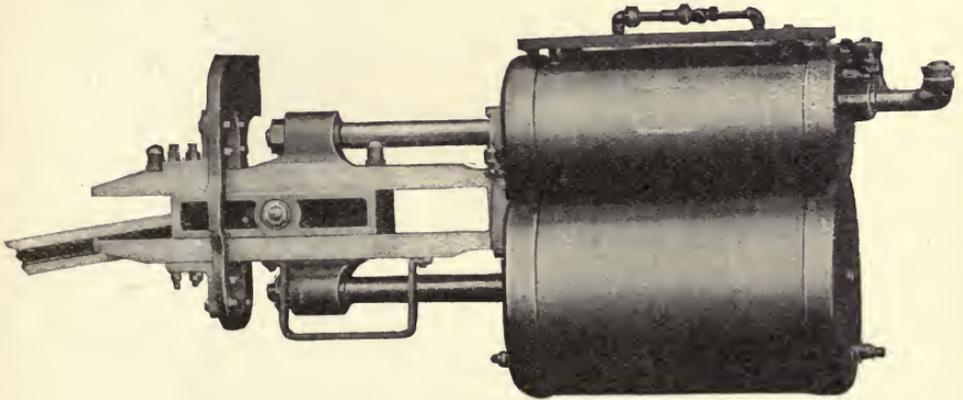


FIG. 102.—Cylinders and Fittings for Vaclain Compound System.

steam chest formed in the saddle of the cylinder casting between the cylinders and the smokebox, and arranged as close to the cylinders as possible.

The valve, which is of the piston type, is double and hollow, and

is so formed that it controls the steam distribution of both cylinders ; and as the supply of steam for the high-pressure cylinder enters the steam chest at both ends, the valve is perfectly balanced, except for the slight variation caused by the area of the valve stem at the back end. It is claimed that this variation is an advantage in case the valve or its connection to the valve rod should be broken, as it holds

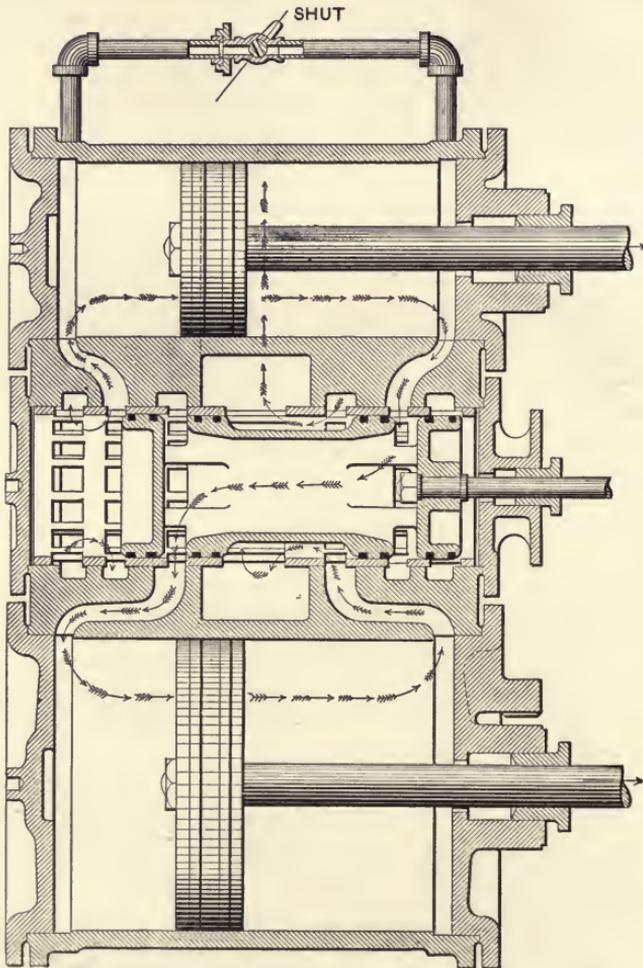


FIG. 103.—Diagram of Steam Distribution in Vaucain Four-cylinder Compound.

them together ; and cases are reported where compound locomotives of this type have hauled passenger trains long distances with broken valve stems and broken valves, the parts being kept in their proper relation while running by the compression due to the variation mentioned. To avoid the possibility of breaking, it is the present practice, however, to pass the valve stem through the valve and secure it by a nut on the front end.

Cast-iron packing rings are fitted to the valve and constitute the edges of the valve. They are prevented from entering the steam ports when the valve is in motion by the narrow bridge pieces across the steam ports of the bushing.

When the low-pressure cylinder is on top it is usually necessary to fit direct valve motion, but when the high-pressure cylinder occupies that position a rocking lever and indirect valve motion are employed, as usual in American practice.

It is obvious that to enable a Vauclain compound engine to start a heavy train it is necessary to admit boiler steam to the low-

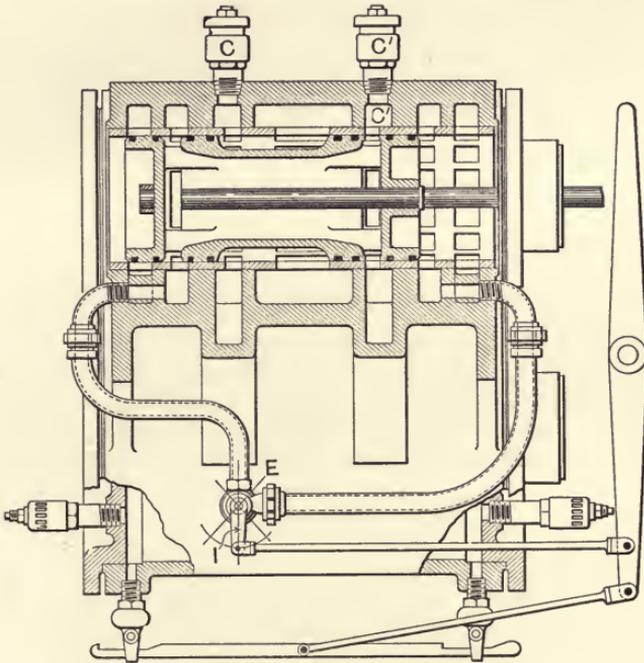


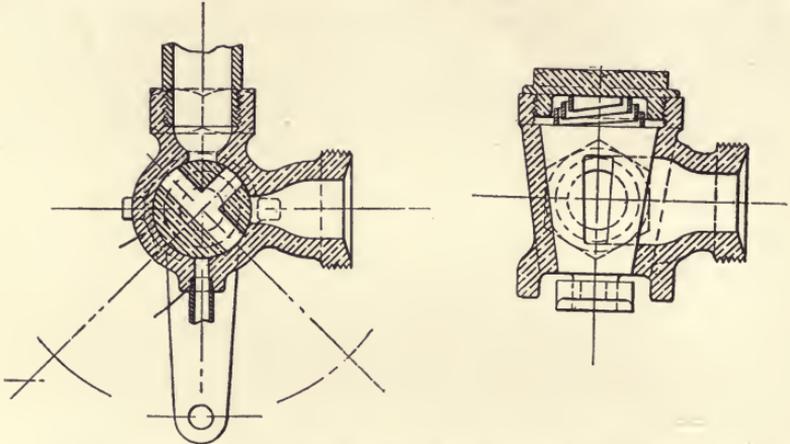
FIG. 104.—Starting Valve for Vauclain Compound System.

pressure cylinder as well as to the high-pressure cylinder, and this is provided for by the valve shown in figs. 104, 105, and 106. It is merely a by-pass valve, which is opened to allow steam to pass from one end of the high-pressure cylinder to the other end, and thence through the exhaust to the low-pressure cylinder. This is more clearly shown in figs. 105 and 106. The same cock acts as a cylinder cock for the high-pressure cylinder, and is operated by the same lever that operates the ordinary cylinder cocks, thus making a simple and efficient device, and one that need not become disarranged.

The air valves C and C' are placed in the steam passages of the low-pressure cylinders to supply air for preventing the formation of a vacuum when running with steam shut off.

The hollow valve stem shown in fig. 107, which represents a

modified arrangement, accomplishes the same result, but with a more direct action, and is preferable for fast service. The check valve at the end of the hollow stem outside the steam chest is closed by the pressure of the steam, but stands open when the pressure



FIGS. 105 and 106.—Starting Cock for Vaclain Compound System.

is relieved and air is allowed to pass into the valve through the perforation in the hollow stem. This arrangement also prevents the accidental starting of an engine because of a leaky regulator valve. In such a case slowly escaping steam will pass through the hollow stem to the open air without creating pressure in the cylinders.

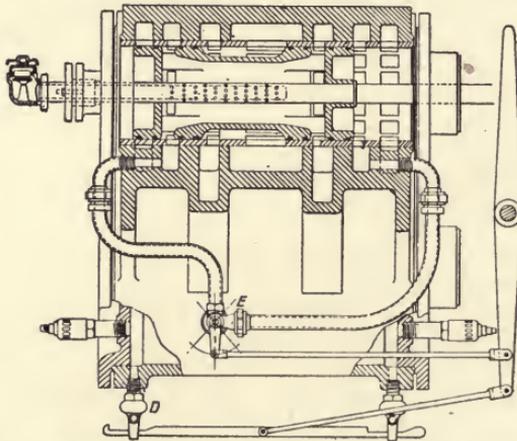


FIG. 107.—Modified Starting Valve for Vaclain Compound System.

Water relief valves are fitted at each end of the low-pressure cylinder.

The Johnstone Annular Cylinder System.—In this section must also be included the annular cylinder system of Mr F. W. Johnstone

on the Mexican Central Railway. According to this arrangement, each high-pressure cylinder is placed within a large low-pressure cylinder, so that the latter is annular, as shown in fig. 108. On the Mexican Central Railway there are very heavy grades, and powerful engines are needed. The first annular cylinder engine was a Rogers locomotive of the Consolidation type, converted about 1890.

The low-pressure piston had two piston rods which were connected, with the high-pressure piston rod, to one crosshead. The tests were very satisfactory, and it was claimed for the engine—No. 66—that an all-round increase in economy of 20 per cent. was effected.

In 1891 ten engines of the ten-wheel type,—six-coupled with leading bogie,—and compounded according to this system, were ordered from the Rhode Island Locomotive Works. Three more of these compound engines, but of a special and unique design (see Chapter XIV.), were afterwards built, making fourteen in all, and

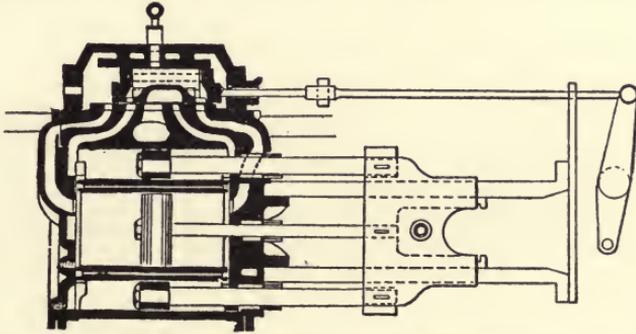


FIG. 108.—Section of Cylinders—Johnstone Annular System.

these represent the total number of annular compound locomotives on that or any other line.

The steam ports are so arranged that a single slide valve having an internal passage controls the steam distribution of each pair of cylinders. The slide valve is really of duplex construction, though both portions are mounted on the same rod, but the inner portion has independent play of about an inch along the rod, for the purpose of giving a later cut-off in the low-pressure cylinder and relieving compression in the high-pressure cylinder. The inner valve is cushioned to prevent knocking by two springs, one on either side.

To assist starting, a three-way cock is fitted in the driver's cab, whereby boiler steam can be admitted by a small pipe to the steam chest, so as to reach the low-pressure cylinder. Steam for use in the low-pressure cylinder reaches the interior of the outer portion of the slide valve by a pipe attached to the centre of the steam chest cover, a corresponding opening being formed in the valve to allow steam to pass.

CHAPTER XI.

FOUR-CYLINDER BALANCED SYSTEMS.

CONTENTS:—Introductory Remarks—The Webb Four-cylinder System—The Gölsdorf Four-cylinder System—Four-cylinder Italian System—Smith Four-cylinder System—Von Borries Four-cylinder System—Maffei Compound Engines—Compound Locomotives on the Lancashire and Yorkshire Railway—Balanced Compound Locomotives on the Hungarian State Railways.

Introductory Remarks.—As already mentioned, four-cylinder four-crank systems (other than articulated engines) may be divided into two main divisions: (1) wherein all four cylinders actuate the same axle, and (2) wherein two cylinders drive one axle and two another, the two sets of coupled wheels being in most cases coupled.

Strictly speaking, systems of the one class can be adapted, with practically no change other than constructional, from one division to the other, and in a few instances this has been done, but for convenience the present chapter deals with systems which have been applied only according to the first class. Where a system has been employed in both ways, description is reserved until the following chapter, as in nearly every instance the “divided” engines are the most important.

The four-cylinder “balanced” systems derive their name because of the fact that as the four cylinders drive separate cranks, the cranks can be distributed round the circle of revolution, at or about angles of 90° apart, and are so arranged that one crank is opposite another; consequently, the moving parts are very largely balanced, and as there are eight impulses per revolution, fairly evenly distributed, the turning moment can be made very regular, and the engines made very efficient.

That this is so appears to be becoming extensively realised, for four-cylinder balanced compound engines are becoming well-nigh universal, either with the cranks all on one axle, or with two driving axles according to the “divided and balanced” system. In fact, almost all recently designed compound engines belong to one or other of these classifications. It is true that four cylinders operating separate cranks necessitate the use of four sets of motion, and in many cases four sets of valve gear, but it is realised nowadays that

the additional first cost and apparent complication is more than justified by the advantages attending the use of such engines, and some engineers are even designing four-cylinder non-compound engines on similar lines for the sake of improved balancing and the division of work over two axles.

The Webb Four-cylinder System.—In 1898 Mr F. W. Webb introduced the first of a class of four-cylinder compound engines for express service on the London and North-Western Railway. In these engines, not only had they four cylinders, but instead of dividing the work done over two axles, as in the case of the three-cylinder locomotives (see Chapter VIII.), all four cylinders were arranged to drive one axle by cranks 90° apart, this axle being coupled with another axle, the wheel type being that known as the 4-4-0, or four-coupled bogie type. Strictly, the bogie is a double radial truck, as there is no centre pivot pin.

At first two engines were built to the same design, except that one was a compound with two high-pressure cylinders outside the

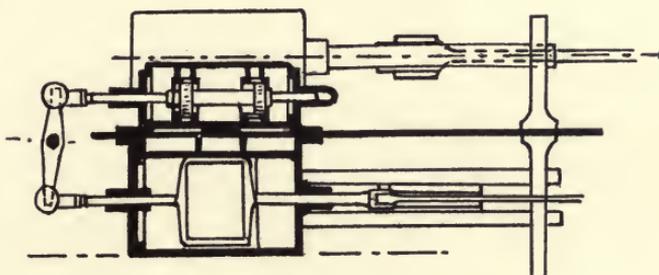


FIG. 109.—Slide Valves.—Webb Four-cylinder System.

frames and two low-pressure cylinders inside the frames, and the other had four cylinders all receiving boiler steam. After extended trial, the non-compound engine was altered to compound, and thirty-eight further compound engines were built. In 1900-2 another series of forty engines were built, having slightly larger high-pressure cylinders and augmented boiler power, the steam pressure being also raised in some cases. In 1901-2 the system was applied for eight-coupled mineral engines, otherwise similar to the three-cylinder engines already described, and in 1903-4 a class of small-wheeled six-coupled bogie engines were introduced for mixed traffic purposes.

A feature of Mr Webb's four-cylinder system is the fact that only two sets of valve gear are employed for four cylinders, and fig. 109 shows the mechanism used for transferring the movement of the directly operated low-pressure valve spindle to the corresponding high-pressure valve spindle in opposite degree as required, as the pistons of adjacent low- and high-pressure cylinders are always moving oppositely, and the slide valves therefore require to be correspondingly operated.

It has been maintained by many engineers that these engines

were not designed in a way to give really effective results, principally in respect of the apparently inaccurately proportioned cylinders, the non-provision of means for admitting boiler steam to the low-pressure cylinders at starting, and the impossibility of independently adjusting the valve operation of the high- and low-pressure cylinders respectively. As no means for non-compound starting are provided, the high-pressure cylinders are necessarily somewhat larger than they should be in proper proportion to the low-pressure cylinders. According to generally accepted ideas, the cylinder diameters should be about 13 and 22 in. diameter, but in order that the H.P. cylinders should be able to start a train alone, Mr Webb employed the diameters of 15 or 16 in. and 22 in.

In practice, however, notwithstanding the many adverse criticisms which were advanced, and the general inclination which has been shown since Mr Webb's retirement to describe them as failures and unsatisfactory engines, it cannot be denied that they have done much splendid work; and their everyday performances, if not altogether such as are required for dealing with average requirements on the London and North-Western Railway, compare very favourably with work done on other lines with apparently more powerful engines, where the duties are not so systematically onerous.

Since the accession of Mr Whale to the position of Chief Mechanical Engineer of the London and North-Western Railway, most of the larger series of four-cylinder compound express locomotives have been fitted with additional valve gear for the high-pressure cylinders, means being provided whereby the high- and low-pressure valve gears can be adjusted independently if desired; and it is stated that the result has been a remarkable improvement in the working of these engines.

Gölsdorf Four-cylinder System.—Since about 1900 Herr K. von Gölsdorf has been adapting his well-known two-cylinder system to four-cylinder engines, and fig. 110 is a cross section through the cylinders of one of his large Atlantic type express engines for the Austrian State Railways. Since these were built the system has also been applied to some large six-coupled express engines, with leading and trailing pairs of carrying wheels (2-6-2 type).

The starting arrangements are similar to those employed for two-cylinder engines as described in Chapter VII.

Four-cylinder Italian System.—The year 1900 saw the construction of the first engine of a four-cylinder compound class of express engine for the Adriatic system of Italian railways, which comprises several notable features.

These engines are six-coupled bogie engines, but are adapted to run in a reversed direction, the engine being of the trailing bogie tank engine type, but arranged to travel with the footplate end in front and the chimney behind, a cylindrical tank tender being employed for water, and the coal being carried in the engine bunkers.

This arrangement has a special advantage that the driver has an

uninterrupted view ahead, and that a very steady-running engine is produced.

Fig. 111 is an interesting photograph showing the cylinders and valve chests (for piston valves).

The cylinder arrangement employed for these engines is very peculiar, there being two high-pressure cylinders on one side of the longitudinal centre line, and two low-pressure cylinders on

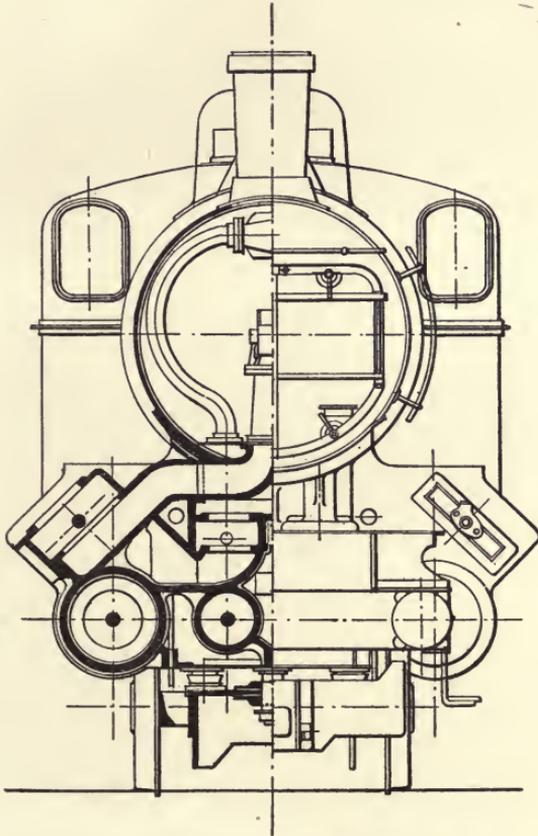


FIG. 110.—Gölsdorf Four-cylinder System—Cross Section.

the other side. The cylinder arrangement is therefore H.P., H.P., L.P., L.P.

The steam distribution is controlled by a special piston valve located over each outside cylinder, and controlling the steam passages of each pair of cylinders, one valve serving for both high-pressure cylinders, and the other for both low-pressure cylinders, the ports being crossed in some cases to allow of this. Two valves only are employed, so that two sets of valve gear are sufficient.

The inside cylinders (one H.P. and one L.P.) are higher than the outside cylinders, their piston rods being inclined to clear the

coupled axle under the smokebox, so that all cylinders operate the middle coupled axle.

It is difficult to understand why an arrangement involving such complicated cylinder castings should be employed, but it is stated that these engines, which are now fairly numerous, are doing very good work. Practically, the arrangement is that of a two-cylinder

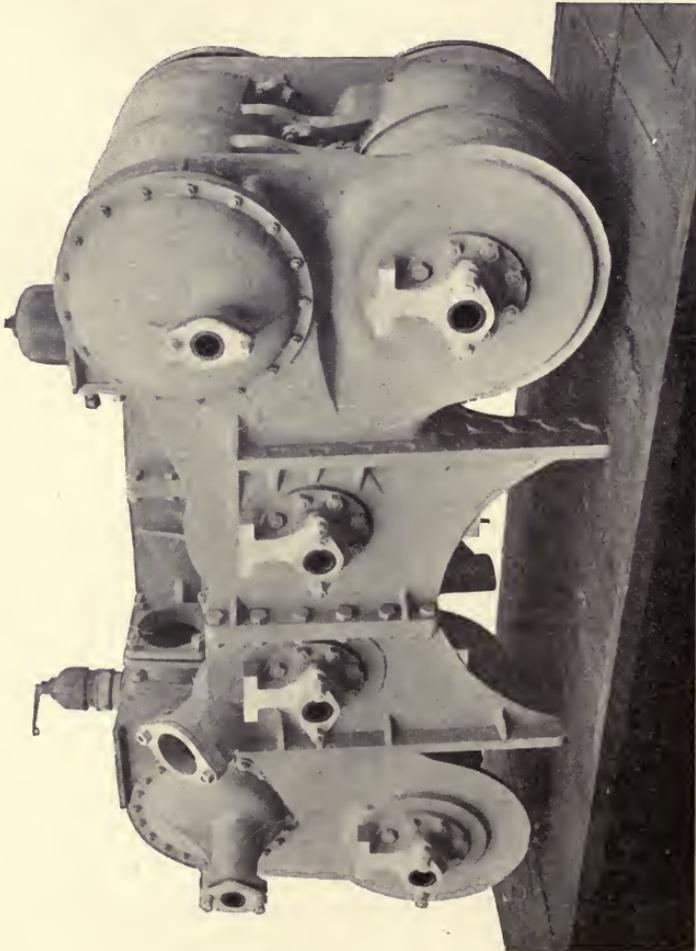


FIG. 111.—Cylinders and Valve Chests for Italian Four-cylinder Compound Engine.

compound engine with each cylinder duplicated, one piston of each pair always working oppositely to the other, and driving cranks 180° apart.

For starting, a small slide valve is connected to the H.P. valve rod and works over ports admitting boiler steam to the receiver, but the steam pipe for this admission is connected to the regulator valve, so that it is only when the regulator is opened to a certain degree

(about one-sixth open) that steam can pass to the receiver by this means, the engine working compound when the regulator is opened further. This design was prepared by Signor Planchar of the Southern Railway of Italy.

Smith Four-cylinder System.—The Smith three-cylinder system has already been described in Chapter VIII. During 1906, however, the system has also been adapted to four-cylinder engines, designed by Mr Worsdell for the North-Eastern Railway, and one of these engines is illustrated in the frontispiece.

Von Borries Four-cylinder System.—In 1903 a notable engine was built by the Hanover Engine Works, primarily for exhibition at St Louis in 1904, but also for participation in official trials of steam locomotives held in Germany at the beginning of the same year, the engine being a four-cylinder compound engine designed by Herr von Borries. Since that date a number (about fifty) of similar engines, which are also fitted with the Pielock superheater (see Chapter XV.), have been supplied for service on German Railways.

The two high-pressure cylinders are placed between the frames, the low-pressure cylinders being outside. Each pair of high- and low-pressure cylinders is cast in one piece, with their corresponding steam chests. The two groups of cylinders are bolted together and carry the smokebox. The valves of the H.P. cylinders are piston valves with inside admission, those of the L.P. cylinders balanced Trick valves.

The cranks of the H.P. and L.P. cylinders upon the same side of the engine are set at an angle of 180° with each other, the cranks of the two sides being at right angles to each other.

The valve gear is of the Heusinger-Walchaert type, and both valves on one side of the engine are driven by a single gearing. The two valves are controlled by a single link, which receives its motion from one eccentric, but the stem of each valve is coupled to an advance lever, which receives its motion from the crosshead of the corresponding piston.

For the outside valve the link movement is transmitted by a lever with arms of different length, so proportioned that the ratio of steam admission is 55 : 30 for L.P. and H.P. cylinders in forward and backward gear.

The starting is effected smoothly and without any difficulty by a direct admission of live steam into the steam chests of the low-pressure cylinders. Fig. 112 is a horizontal section showing the valve chests and starting valves for a high- and a low-pressure cylinder. The hollow intercepting valve is shown in position for non-compound working. The high-pressure exhaust passes by the passage *a* through the interior of the valve *b* to the opening *c*, and thence to the passage *d* leading to the exhaust. At the same time boiler steam is admitted by the passage *e* and by the recess *f* of the valve *b* to the passage *g*, by which it enters the low-pressure steam chest. For compound working the valve *b* is rotated so that a

passage-way is opened for the H.P. exhaust steam to pass from the interior of the valve *b* through the opening *h* to the low-pressure steam chest, and the boiler steam supply is cut off.

There are two valves *b*, one at each side of the engine, but they are operated together by mechanism under the driver's control.

Maffei Compound Engines, Bavaria and Baden State Railways.— These engines, of the Atlantic (4-4-2) type, were first introduced in 1903, and were also designed to some extent in connection with the official steam locomotive trials conducted in Germany. They are now employed in considerable numbers on the Bavarian and Baden State Railways, together with some engines differing only in the fact that a third pair of coupled wheels are substituted for the trailing carrying wheels. The system has also been applied to some

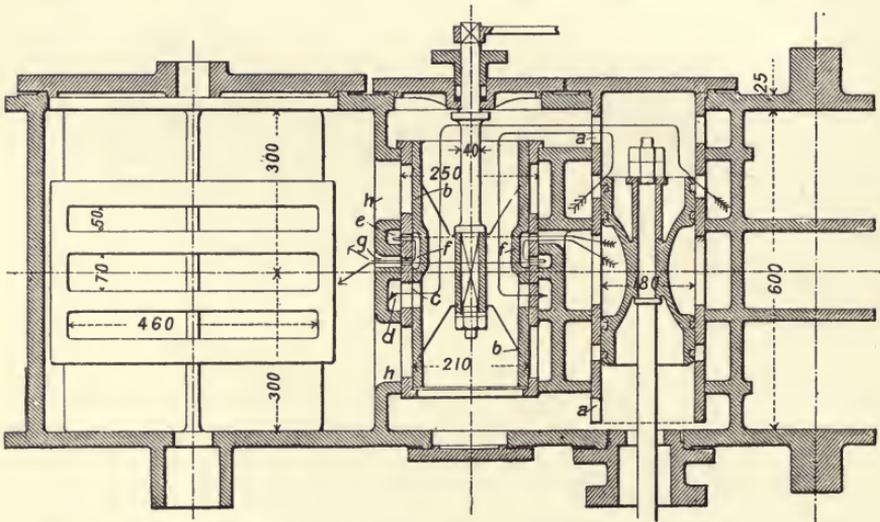


FIG. 112.—Von Borries Four-cylinder System—Valve Chests and Starting Valves.

large engines of the 4-4-4 type, having a bogie under the firebox as well as at the leading end, and four coupled wheels.

Fig. 113 is a cross section of one of these engines for the Bavarian State Railways. All four cylinders are in line underneath the smoke-box. The H.P. cylinders are fitted with piston valves. The outside low-pressure cylinders are provided with balanced slide valves having double admission and exhaust ports.

The low-pressure cylinders are each connected with the high-pressure cylinders by short double pipes. The valve motion is outside and actuates the low-pressure valves directly, the high-pressure valves being operated from the same motion by means of a rocking lever.

To ensure economical working of steam, the proportion between the high- and low-pressure piston areas has been made 1 : 2·9.

For starting the engine there is a valve worked from the reversing

gear and admitting live steam up to a pressure of 9 atmospheres into the receiver, which is fitted with a safety valve corresponding to that pressure. The arrangement is very similar to that described in Chap. VII.

In order to prevent a vacuum in the cylinders when running with the regulator closed, automatic vacuum valves are provided,

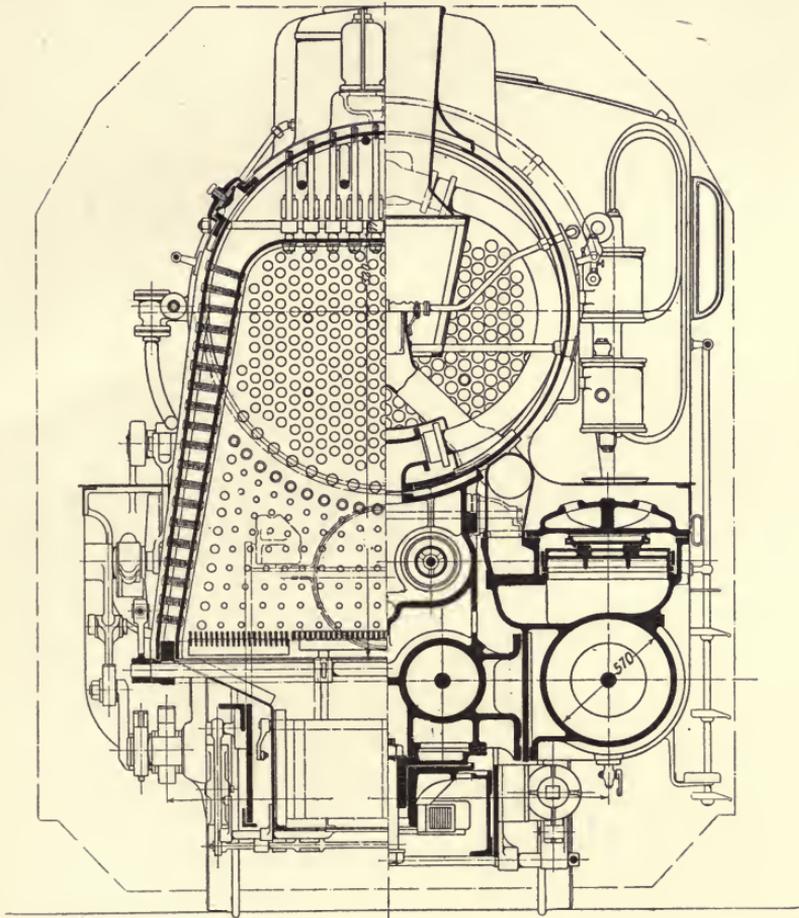


Fig. 113.—Cross Section—Maffei Four-cylinder Compound Locomotive.

and these actuate smaller valves, which admit steam at low-pressure to the cylinders for lubrication. In the front and back covers of the high-pressure cylinders there are safety valves, which prevent damage to the cylinders through condensed water.

Compound Locomotives on the Lancashire and Yorkshire Railway.—On this railway an engine was adapted a few years ago as a four-cylinder compound engine, the arrangement being similar to that employed by Mr Webb on the L.N.W.R., but the cylinder

diameters being 14 and 22 inches. Quite recently an eight-coupled engine has been adapted as a four-cylinder compound engine by Mr G. Hughes, Locomotive Superintendent. All cylinders operate one pair of wheels.

For starting, a small slide valve is employed controlling ports whereby boiler steam can be admitted to the L.P. steam chests.

Four-Cylinder Compound Locomotives for the Hungarian State Railways.—Towards the close of 1906 a series of powerful express locomotives was placed in service on the Hungarian State Railways. They are of the Atlantic type, with the four cylinders all actuating the leading pair of coupled wheels. The low-pressure cylinders are outside, and all cylinders are provided with piston valves. Two sets of valve gear only are employed. The starting mechanism, permitting of non-compound working, is an adaptation of that described in Chapter V. in reference to two-cylinder compound engines, and illustrated by fig. 43.

CHAPTER XII

FOUR-CYLINDER DIVIDED AND BALANCED SYSTEMS.

CONTENTS:—General Remarks—The de Glehn System—Vulcan Foundry Engine (de Glehn System) for Great Northern Railway—De Glehn Compound Engines for Portuguese Railways, built by A. Borsig—The Henri-Baudry System—The Vaucrain Balanced System—The Cole System—Ivatt's Compound Engine for Great Northern Railway—Compound Engines in Belgium.

General Remarks.—Four-cylinder systems of this class appear to be now in greatest favour in most countries, for a large proportion of the four-cylinder compound engines introduced since the commencement of the twentieth century belong to this class.

In France, nearly all compound engines now built are four-cylinder divided and balanced engines according to the de Glehn or the Henri-Baudry systems, and, with variations introduced by the firms of A. Borsig, J. A. Maffei, and the Swiss Locomotive Works, the systems employed are very similar, these engines being found in Germany, Switzerland, Spain, and Portugal, as well as in some of the smaller European States. In Belgium compound engines are very few, but most of them can be placed in this section.

In the United States the new Vaucrain system, though first introduced as a balanced system, all cylinders driving one axle, is frequently adapted as a "divided and balanced" system, for which reason it is described in this chapter; and the Cole system, which is the other of the two American four-cylinder systems now employed, is also "divided and balanced."

Strictly speaking, there is very little difference between four-cylinder "balanced" and four-cylinder "divided and balanced," for it is only necessary to adapt the cylinders (they need not always be separated) to drive separate coupled axles to transfer a design from one class to another, though in most cases the divided system is less adaptable for the use of two sets of valve gear only.

The de Glehn System.—The first locomotive compounded according to Monsieur de Glehn's system was an engine designed in 1885 for the Northern Railway of France. It had two high-pressure cylinders inside driving the front driving axle; and two outside low-pressure cylinders, set back on the frames, driving the rear pair of

driving wheels. The axles were not coupled, in which respect de Glehn followed Mr Webb's practice ; and it is worthy of note that, although in all subsequent engines coupling rods have been employed, this engine is still at work with uncoupled wheels.

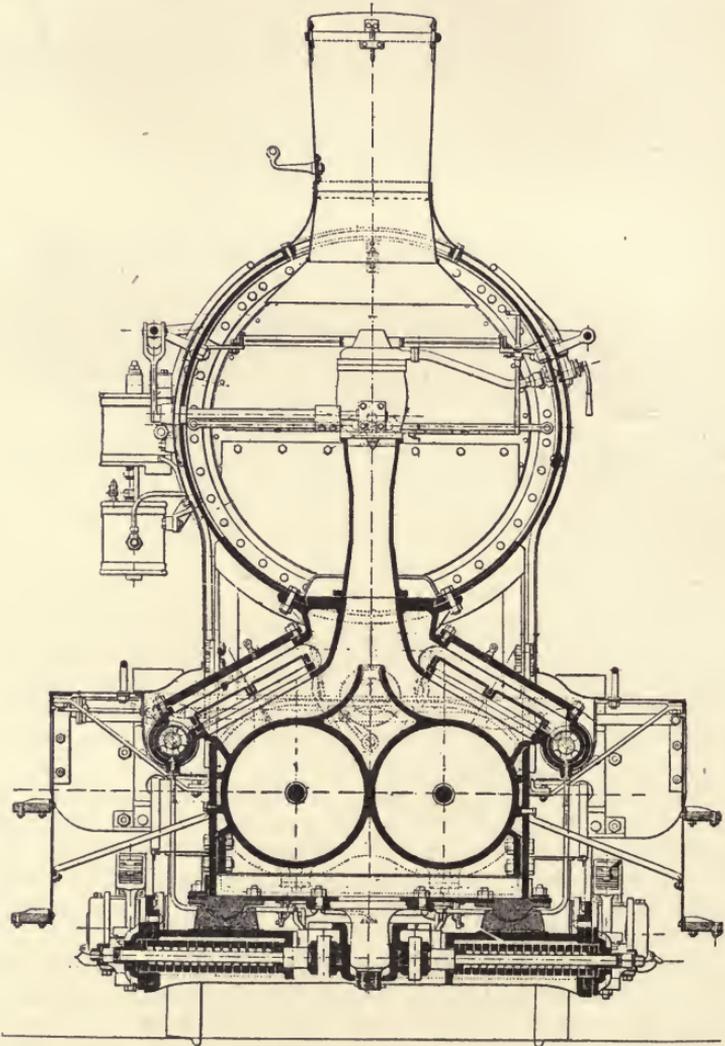


FIG. 114. — Cross Section—de Glehn Four-cylinder Compound Express Locomotive.

The engine was shown at the Paris Exhibition of 1889. A few years ago a bogie was substituted for the single leading axle ; otherwise the engine is still in its original condition, though, of course, it has long since been taken off first-class work.

It was not, however, until 1891 that Monsieur de Glehn, in collaboration with Monsieur du Bousquet, Chief Engineer of the

Northern Railway of France, really introduced the system now universally known; but from that date onwards it has been employed very extensively, first on the Northern Railway of France, and then, with but slight modification, on all the other French railways except the Paris, Lyons, and Mediterranean Railway, while the system has also been used for large numbers of engines for Germany, Switzerland, Spain, Portugal, Belgium, Alsace, some of the Balkan States, Asia Minor, etc., and a few engines in England, United States, Egypt, China, etc.

In fact, the de Glehn system is probably the most extensively used of any, and in many cases the engines have been built quite independently of Monsieur de Glehn. The total number of these engines is now considerably over 2000, of various designs.

As a rule, the cylinders are arranged in two sets, one pair outside (usually the high-pressure cylinders), set back somewhat on the frames, and actuating the second coupled axle, and the other pair inside, under the smokebox, and driving the leading coupled axle. In some cases, however, the cylinders are placed in line, though separate axles are driven, the outside piston and connecting rods being much longer than those inside, to permit of this. For some of the goods engines, the inside cylinders drive the second coupled axle, and the outside cylinders the third axle.

Fig. 114 is a cross section through the low-pressure cylinders of one of the large express engines of the Northern Railway of France, and fig. 115 is a half-sectional plan showing the cylinders, and motion thereof.

From these views it will be seen that there are four sets of valve gear of the Walschaert type, those outside employing a return crank and those inside a single eccentric. A feature of the de Glehn system is the fact that the

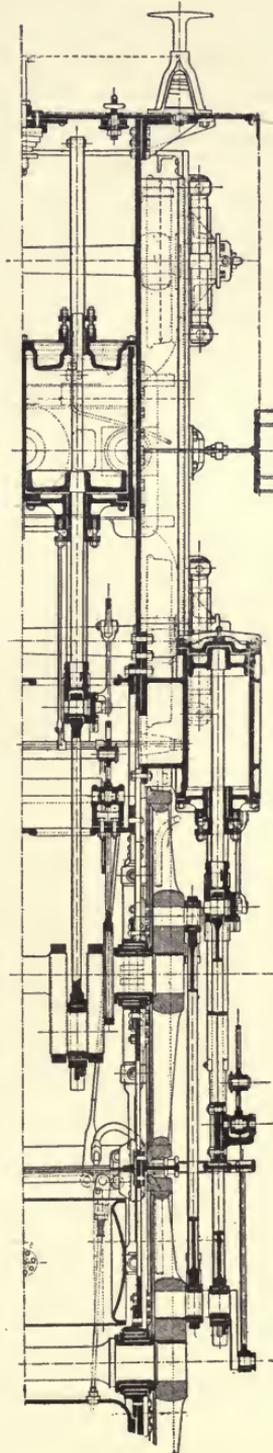


FIG. 115. — Sectional Plan—de Glehn Compound Express Locomotive.

respective valve gears can be independently adjusted to vary the relative cut-off ratios of the H.P. and L.P. cylinders.

In some of the early engines the cranks of the H.P. and L.P. cylinders at each side are placed 165° apart, but the general practice now is to place them at 180° apart, as usual, according to other systems.

To enable the engine to start with boiler steam in the low-pressure cylinders, or for working as a four-cylinder non-compound engine temporarily when very great power is required, a valve is provided by which boiler steam can be admitted, past a reducing valve, to the low-pressure cylinders, and an intercepting valve is fitted whereby the high-pressure cylinders exhaust to the blast pipe instead of to the receiver pipe when working non-compound. The intercepting valve is operated by a small steam motor ("servo"-motor) controlled by a three-way cock in the driver's cab.

Fig. 116 represents a series of diagrammatic drawings published by the *Locomotive Magazine*, and reproduced here by permission, which well indicates the principal features of this system. The locomotive shown in outline is the first of three French-built locomotives in use on the English Great Western Railway.

In the driver's cab is the three-way cock already referred to, and a steam valve by which steam is admitted to the reducing valve, and thence to the low-pressure steam chests.

The intercepting valve is in the form of a long hollow cylinder located alongside each of the low-pressure steam chests.

Diagram No. 1 shows the valves with the engine working non-compound. The valve A is operated to allow steam to pass to the reducing valve E, and the valve B allows steam to pass to a small cylinder D, where it acts on a piston which rotates the cylindrical valve C to allow H.P. exhaust steam to pass to the blast pipe. When altered for compound working the three-way cock B (diagram 2) is moved so that steam passes to the other end of the cylinder D, and causes the piston therein to rotate the valve C to a position wherein the H.P. exhaust steam is allowed to pass through the interior of the valve C to the low-pressure steam chests. The references are marked with one or two dashes for the two positions.

By means of the intercepting valve C, the driver can operate the engine with the low-pressure cylinders alone in case of accident.

In most respects the arrangement corresponds very closely to that employed for the du Bousquet tandem compound tank engines, described in Chapter IX. ; indeed, the latter is directly derived from the methods introduced by Monsieur de Glehn.

Fig. 117 is a separate enlarged view showing the construction of the cylindrical intercepting valve.

According to an earlier construction of the de Glehn intercepting valve, the valve is a short cylinder acting as an ordinary three-way cock controlling the passage of the H.P. exhaust steam either to the low-pressure steam chest or to the blast pipe.

Figs. 118 and 119 are views reproduced from a recent number of

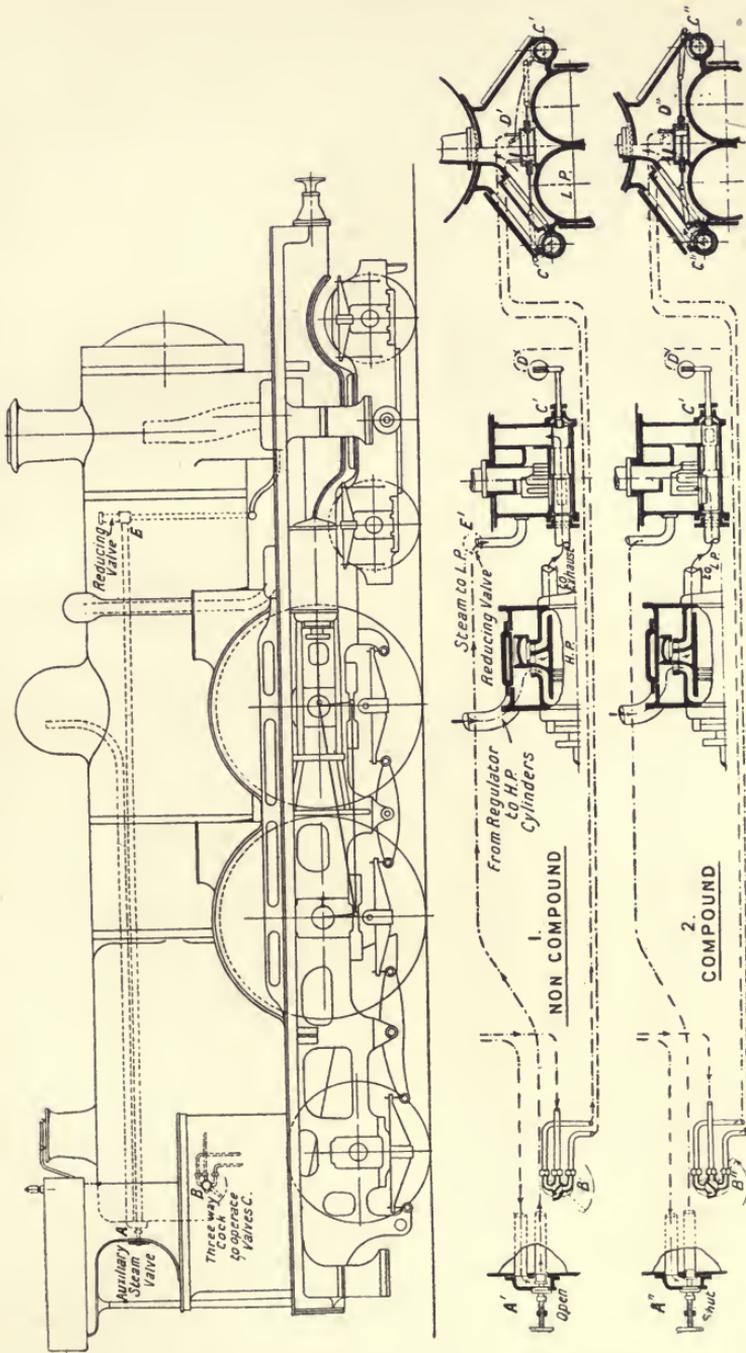


FIG. 116.—Diagram showing Features of de Glehn Compound System. Reproduced from the *Locomotive Magazine*.

Engineering, which very clearly set forth the main features of the de Glehn system as employed in recent engines of the Eastern Railway of France.

The system is not altered from that already described, but the constructive arrangements are somewhat different, though resulting mainly from the employment of piston valves, and from the use of compressed air for operating the intercepting valve instead of steam.

Vulcan Foundry Engine (de Glehn System) for Gt. Northern Railway.—During 1905 an engine was built in Great Britain by the Vulcan Foundry Company, Limited, of Newton-le-Willows, under unusual circumstances.

The Directors of the Great Northern Railway invited tenders for a powerful express locomotive for purposes of comparison with their own engines, the builders having practically a free hand as regards design, and the order was obtained by the firm mentioned.

The engine is a four-cylinder compound engine of the Atlantic type, compounded according to the de Glehn system. As regards essentials, the starting mechanism corresponds to that already described, the difference being almost entirely constructional, but the driver's lever for controlling non-compound working is so arranged that it changes automatically to compound as soon as the driver lets go of the lever.

De Glehn Compound for Portuguese Railways, built by A. Borsig.—It has already been stated that the de Glehn system has been employed by several Continental locomotive building firms, and fig. 120 is a view showing the construction of intercepting valve and operating mechanism therefor,

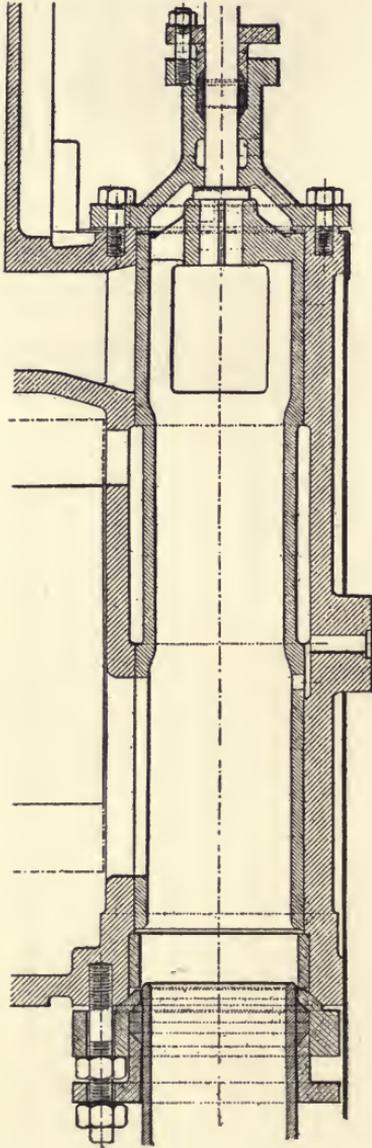


Fig. 117.—Detail View—de Glehn Intercepting Valve.

as fitted by the well-known firm of A. Borsig of Berlin to some notable six-coupled bogie engines for the Portuguese State Railways.

In this construction, the intercepting valves are of the three-way type mentioned, and the view also shows the small operating cylinder by which they are operated, and the connections.

The Henri-Baudry System.—Early in 1889 M. Henri, Locomotive Engineer of the Paris, Lyons, and Mediterranean Railway, entered the field with a compound system which developed for some years in advance of the de Glehn system, and which probably entitles M. Henri to far greater credit than is usually assigned to him.

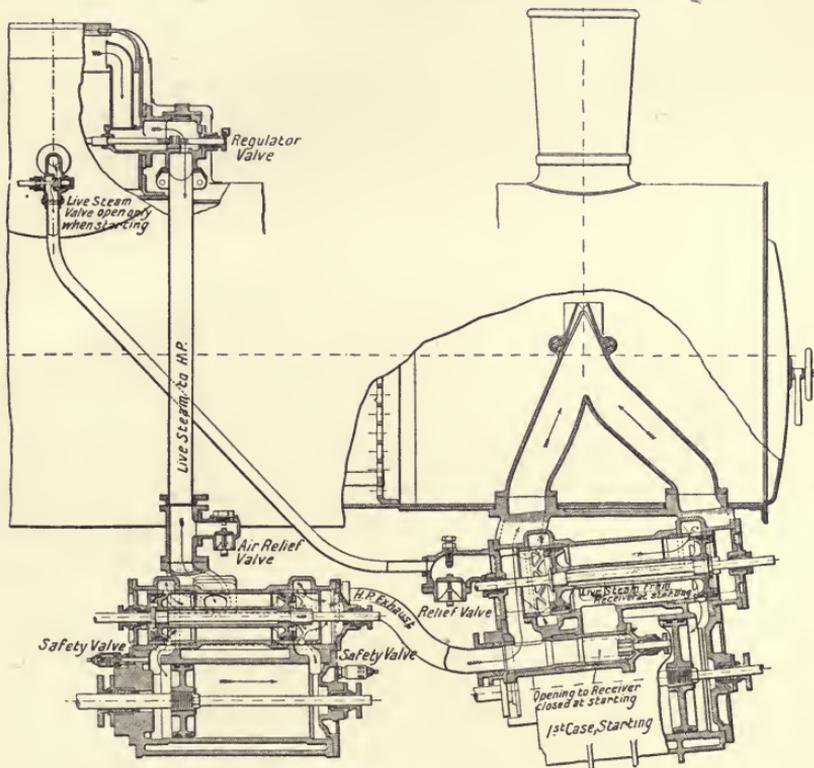


FIG. 118.—De Glehn System—Eastern Railway of France. Reproduced from *Engineering*.

Six engines were built according to this system, of three distinct types. In these engines coupling rods were employed, in which respect M. Henri was certainly ahead of M. de Glehn, and, what is most important, a high steam pressure was used—213 lbs. instead of 156 lbs. as used in de Glehn's system; but the cylinder arrangements were very unusual. Later engines for the Paris, Lyons, and Mediterranean Railway were built according to one of these arrangements, but such dispositions of the cylinders have never since been repeated elsewhere, and even the one arrangement referred to has been discontinued for some years.

The type designed for passenger use had the four cylinders

abreast, but driving on to separate axles, the inside high-pressure cylinders driving the front coupled wheels, and the outside low-pressure cylinders driving, with long piston and connecting rods, the rear coupled wheels. Two of these engines were built, and one of them was exhibited at the Paris Exhibition of 1889, forming an interesting companion to Monsieur de Glehn's engine above described.

The second type was an eight-coupled goods engine, with the outside low-pressure cylinders in the usual positions, driving the second axle, and with the inside high-pressure cylinders set back between the frames—an absolutely unique arrangement—and driving the third axle.

In the other two locomotives, also eight-coupled engines, all cylinders were under the smokebox; but the inside high-pressure cylinders were raised and inclined and drove the second axle, while

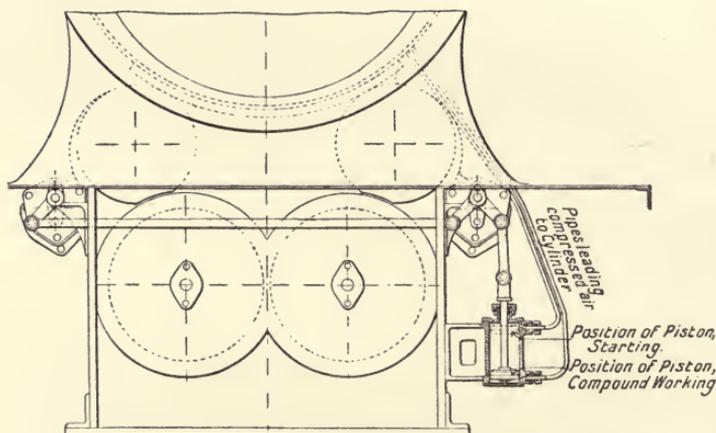


FIG. 119.—De Glehn System, as employed on the Eastern Railway of France. Reproduced from *Engineering*.

the outside low-pressure cylinders were fitted with long connecting rods to drive the third axle. These engines, according to a statement made by M. Baudry, successor to M. Henri, proved very successful, owing, it is claimed, principally to the high steam pressure employed, and paved the way for an extensive adoption of the compound system for locomotives on the Paris, Lyons, and Mediterranean Railway.

Commencing in 1893, a number of other eight-coupled engines were built having the cylinders arranged according to the second type above described. In 1892 was built the first of fifty eight-coupled engines having all cylinders driving the second axle, thus constituting a four-cylinder balanced (not divided) design.

In 1892 three engines were constructed, two of which were of the four-coupled bogie type, and the third four-coupled with a single leading axle, in which the low-pressure cylinders were inside and drove the front coupled axle, and the outside high-pressure cylinders were set back

on the frames to drive the rear coupled axle, thus conforming to the cylinder arrangement generally associated with Monsieur de Glehn.

In 1894 M. Baudry built forty more four-coupled bogie engines of the same type, and since then further engines of various types on the same lines have been built as required, the Henri and the de Glehn systems having by this time converged until the differences became those of detail design or in matters outside the present subject.

For many years these bogie four-coupled engines and a corresponding class of small wheeled six-coupled bogie engines have been employed on the Paris, Lyons, and Mediterranean Railway, but in 1904 Monsieur Baudry introduced a large-wheeled six-coupled class of engine on the same system for heavy express traffic.

The cylinders are all placed very nearly in line, but the connecting rods of the outside high-pressure cylinders are much longer than those of the inside cylinders, so as to actuate the second coupled axle.

For all these compound engines provision is made by means of a special design of reversing gear for the independent adjustment of the high-pressure valve gear, but, as a rule, according to this system the low-pressure cut-off ratio is invariable, as Monsieur Baudry considers this method of operation preferable.

For starting purposes, a simple valve is fitted whereby boiler steam can be admitted to the low-pressure cylinders at starting.

The Vauclain Balanced System.—This system, introduced by the Baldwin Works of Philadelphia, has in large measure superseded the superposed cylinder system described in Chapter IX. It admits

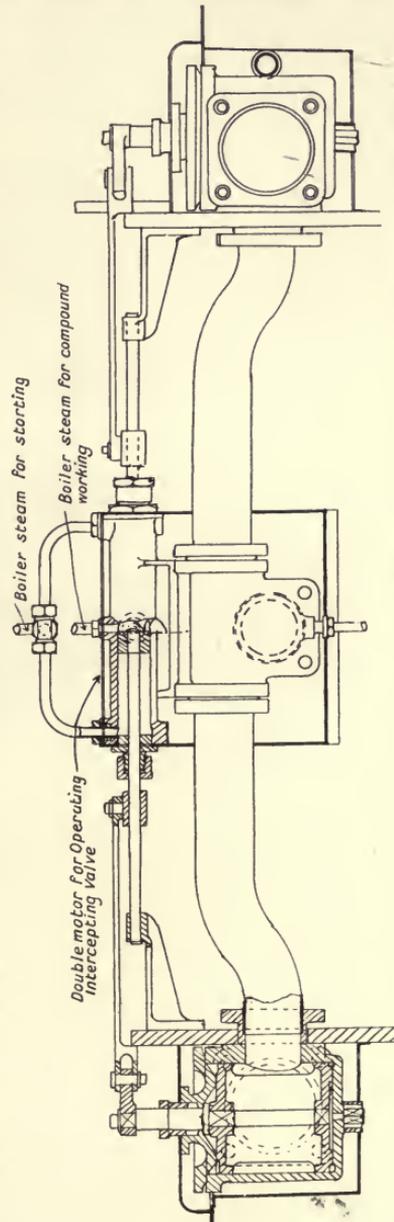


FIG. 120.—De Glehn Intersecting Valve and Operating Mechanism, as fitted by the Firm of A. Borsig.

of employment as a "balanced" system, or as a "divided and balanced" system; and although it was first introduced according to the former method, it is now as often employed in one way as in the other, and the large number of engines of this system now in use are about equally divided between the two classes. In practice, the only difference is that when "divided" the outside cylinders have long connecting rods to drive an axle behind that operated by the inside cylinders.

The first locomotive of the four-cylinder balanced compound system was built in January 1902 for the Plant System of Railroads, as the twenty-thousandth locomotive built by the Baldwin Locomotive Works after seventy years of continuous operation. This locomotive was, however, too heavy for use on the Plant System

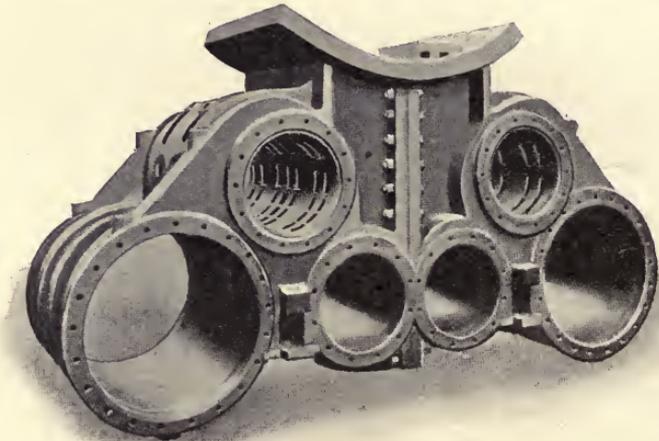


FIG. 121.—Cylinder and Valve Castings for Vaucain Balanced System.

and was sold to the Chicago Short Line. It was of the ten-wheel (4-6-0) type.

As is common to locomotives of this system, the low-pressure cylinders are placed outside the engine frames, connections being made with crank pins on the driving wheels. The high-pressure cylinders are located inside the frames in the same horizontal plane as the low-pressure, and connection is made with a cranked driving axle. In the first locomotive referred to all four connecting rods are coupled with the front axle.

The cylinder saddle is cast in two parts (fig. 121) and bolted together in the usual way, each half containing a high- and low-pressure cylinder and a single valve which controls the admission of steam to both cylinders. This admits of the use of the ordinary Stephenson type of valve motion, the same as is used in single expansion locomotives. The valve is of the piston type, with central steam admission, and slides in a machined bushing, which is forced

into the cylinder saddle. A single reverse lever in the cab is all that is required for governing the valve motions of all cylinders.

The course of the steam from its admission to the high-pressure cylinder until the final exhaust is shown by the diagram reproduced in fig. 122.

The live steam port in this design is centrally located between the induction ports of the high-pressure cylinder. Steam enters the

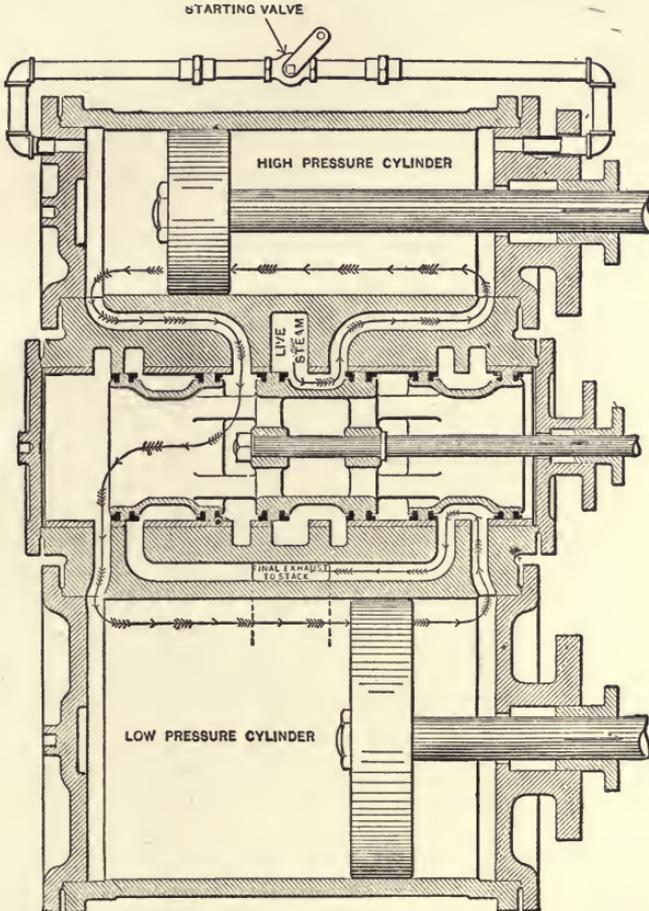


FIG. 122.—Steam Distribution in Balanced Compound Cylinders.

high-pressure cylinder through the steam port and the central external cavity in the valve. The exhaust from the high-pressure cylinders takes place through the opposite steam port to the interior of the valve, which acts as a receiver. The outer edges of the valve control the admission of steam to the low-pressure cylinder. The steam passes from the front of the high-pressure cylinder through the valve to the front of the low-pressure cylinder, or from the back of the high-pressure to the back of the low-pressure cylinder. The

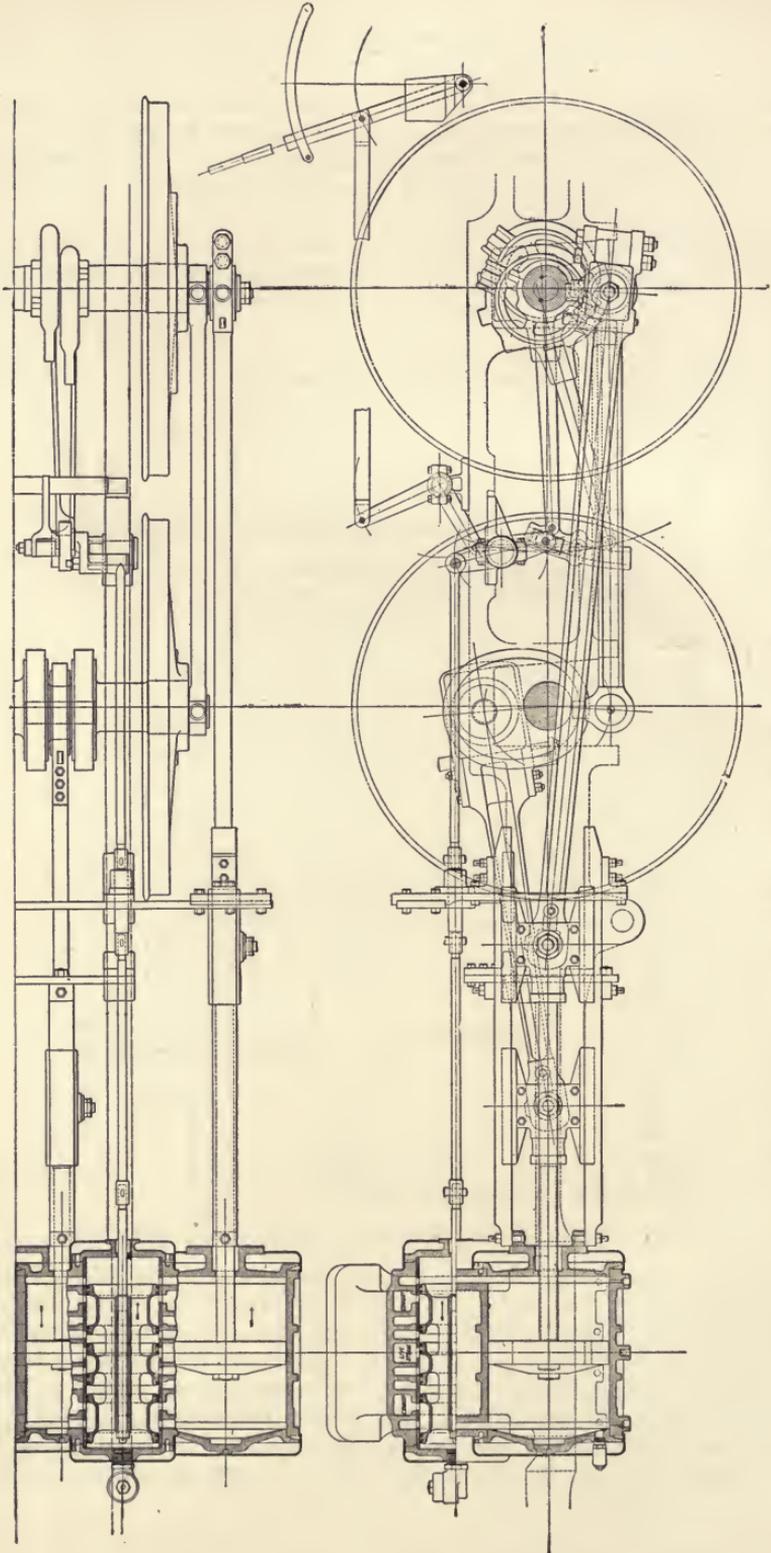


FIG. 123.—Cylinders and Motion for Vaclain Divided and Balanced System.

exhaust from the low-pressure cylinder takes place through external cavities under the front and back portion of the valve, which communicate with the final exhaust port. The starting valve connects the two live steam ports of the high-pressure cylinder to allow the steam to pass over the piston.

In many engines, although the cylinders are located in line, the piston and connecting rods are of different lengths, so that separate axles are driven by each pair of cylinders, the arrangement then being that of "divided and balanced."

In all cases the parts are so arranged that on each side of the engine, while the reciprocating parts in connection with the high-pressure cylinder are moving in one direction, those in connection with the low-pressure cylinder are moving in the opposite direction. These parts having the same rate of speed, and being practically of the same weight, exert an equivalent force in opposite directions at all points and balance each other. This leaves only the revolving parts to be compensated for in the driving wheels, and these can be exactly counterbalanced. The two pistons on each side of the locomotive, travelling in opposite directions, equalise the longitudinal strains, and prevent what is termed the "nosing" action. This relieves the track from injury, and adds to the safety of the locomotive and to the comfort of the engineer.

The crank on the axle and the crank pin in the driving wheel for the corresponding high- and low-pressure cylinders are set at an angle of 180° , the two axle cranks being set at 90° ; this brings the action of each high- and low-pressure cylinder on one side of the locomotive, quartering with those on the other side, and four points of connection are provided, equally distributed about the central axis. This arrangement to a great extent neutralises the unequal rotative moments due to the angularity of the main rods. Four sets of rods, guides, and pistons are used, but the strains are so distributed between them as to make it possible to lighten the weight of each, and still have ample strength for maximum requirements. This division of the strains decreases the wear and tear on the moving parts and compensates for the increased number.

In some engines the inside cylinders actuate the same axle (the second coupled axle) as the outside cylinders, and to enable the inside connecting rods to work past the first coupled axle, looped connecting rods are employed, the rods being adapted to embrace the leading coupled axle.

The Cole System.—During the past two years the American Locomotive Company have been introducing the "divided and balanced" four-cylinder compound system devised by Mr F. J. Cole when Locomotive Engineer of the New York Central and Hudson River Railroad.

The first of these engines is illustrated by line diagram and half-sectional plan in fig. 124. In this engine the four cylinders are so related that it has not been necessary to duplicate the valve motion, or to depart in any way from the best previous accepted practice.

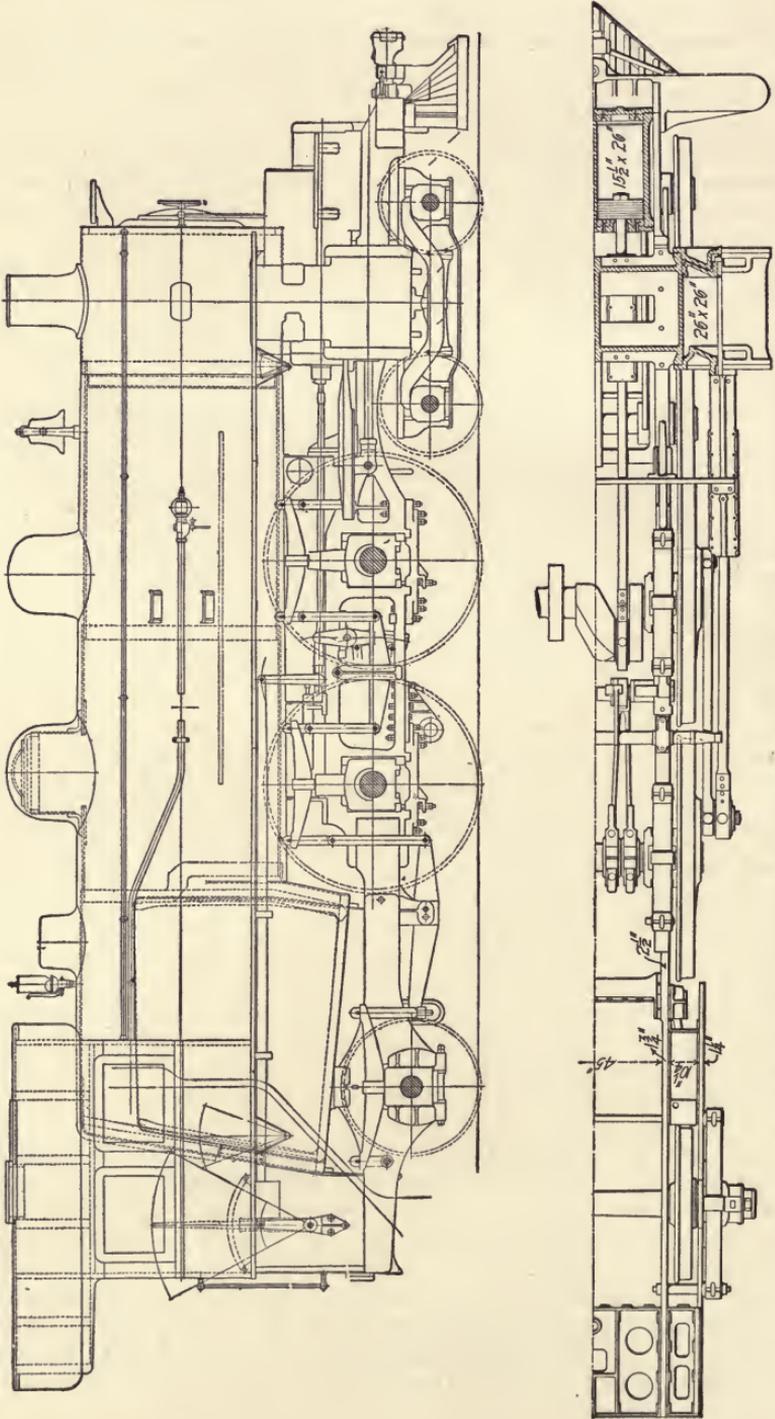


FIG. 124. — Divided and Balanced Compound Locomotive—Cole System.

The use of four cylinders, two high-pressure and two low-pressure, gives an opportunity for compounding under the most favourable conditions; and with each high-pressure piston working 180° from its low-pressure piston, and the other pair working 90° from the first pair, the successive impulses from the four cylinders produce a remarkably uniform turning moment. This results in a much more rapid rate of acceleration when starting up than has been possible with two-cylinder engines.

In order to avoid the concentration of work on a single driving axle, one pair of cylinders is connected to the forward axle and the other pair to the rear axle. The high-pressure cylinders are placed between the frames and located slightly in advance of the usual position, so as to secure the necessary length for the connections, crossheads, guides, connecting rods, etc. The forward axle is necessarily a crank axle. The low-pressure cylinders are placed outside, and connected in the usual way to crank pins on the rear drivers.

With this relative arrangement of each pair of one high-pressure and one low-pressure cylinders, both a high-pressure and a low-pressure piston valve are carried by the same valve stem, the intermediate portion of the valve chamber serving as a receiver between the two cylinders.

Ivatt Compound Engine for Great Northern Railway.—The Vulcan Foundry engine on the de Glehn system for the Great Northern Railway has already been mentioned earlier in this chapter, but, besides this engine, Mr Ivatt has himself designed a four-cylinder divided and balanced compound engine.

This engine, as regards the boiler and general dimensions, corresponds with the standard non-compound engines of this railway.

The cylinders are arranged abreast, but drive separate axles, the outside high-pressure cylinders actuating the rear coupled wheels, while the low-pressure cylinders drive the leading coupled axle. This engine also possesses the peculiarity that the stroke of the high-pressure cylinders is only 20 in. (diameter 13 in.) as compared with 26 in. (diameter 16 in.) for the low-pressure cylinders. Walschaert valve gear is employed for the outside cylinders and ordinary link motion for the inside cylinders. Two reversing levers are employed with sectors placed close together on the footplate, and the two sets of reversing gear can be operated either simultaneously or independently of one another. Each reversing shaft is fitted with a vacuum-locking device by which the gear can be locked in position. The engine can be worked either as a simple or as a compound engine by means of a change valve located over the low-pressure steam chest. The valve is worked by a small auxiliary steam cylinder in connection with a water dashpot arranged so as to lock it either in the simple or compound position.

Judging from the cylinder capacities of this engine it appears that the main object in view is to provide an engine which can be worked frequently as a non-compound, but whenever circumstances

are favourable, as when travelling on easy gradients or the level, and when the train is well under weigh, can be used as a compound engine with small steam consumption. Most four-cylinder compound locomotives if worked non-compound for long would run the boiler out of steam, whereas with the cylinder dimensions employed for this engine the non-compound steam consumption is not excessive, while compound working enables any economy that is possible to be obtained at other times. The comparative performances of the two Great Northern compound engines will therefore be peculiarly interesting whenever official data is published.

Four-cylinder Balanced Compound Engines in Belgium.—The year 1905 has seen some notable developments in Belgian locomotive practice, for, in connection with the Liège Exposition, quite a number of remarkable engines have been introduced for experimental trial, and in several cases have been introduced into ordinary service.

Almost without exception these notable engines are of the six-coupled bogie type, with comparatively small wheels, as very high speed is but seldom required in Belgium, heavy loads over severe gradients, at good though not excessive speeds, being the rule; but the engines are in every instance very large and powerful. In only

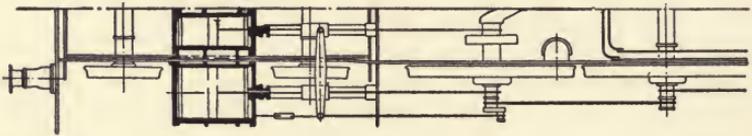


FIG. 125.—Diagrammatic Plan View of Balanced Compound Locomotive—Belgian State Railways.

a few cases are the engines compound, but several of them are fitted with superheating apparatus, as described in Chapter XV., and some of them combine both features.

Some of the compound engines are on the de Glehn divided and balanced system already described, and correspond with standard classes on French railways, but others are arranged with the four cylinders driving the leading coupled axle.

Fig. 125 is a diagrammatic plan view of one of these engines, as built by the John Cockerill Company of Seraing, and having all four cylinders driving one axle. This engine has two sets of valve gear operating the valves of four cylinders by means of a reversing rocking lever, in the manner already described in reference to the Webb four-cylinder system. The low-pressure cylinders are placed outside.

For starting, the admission of boiler steam to the receivers is automatically effected by a small differential valve which allows steam to pass only so long as the pressure in the receiver is below 88 pounds per square inch, but which closes as soon as that pressure is reached. The driver has, however, control of this valve, so that he can prevent live steam admission if desired.

Another engine built by the same firm has the cylinders arranged

to drive separate axles as shown in the diagrammatic plan view (fig. 126).

Some of the engines are fitted with superheating apparatus (see Chapter XV.), and are adapted so that part of the superheater also serves the purpose of a receiver superheater through which the steam passes between the high- and low-pressure cylinders.

Another engine, having four cylinders abreast and driving the

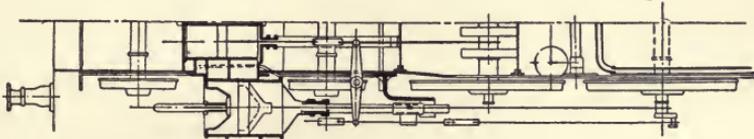


FIG. 126.—Diagrammatic Plan View of Divided and Balanced Engine—
Belgian State Railways.

same axle, has been built by the La Meuse Company, and this, though a non-compound engine, is adapted for ready conversion as a compound engine.

Besides the four-cylinder divided and balanced engines described, a few such engines have also been supplied to the Bavarian and Swiss railways, which, while not corresponding exactly with the de Glehn system, are compounded according to very similar systems.

CHAPTER XIII.

ARTICULATED COMPOUND ENGINES.

CONTENTS:—Articulated Engines—The Mallet System—Mallet Compound Engines for St Gothard Railway—Mallet Compound Engines for Russia—Mallet Compound Engines in the United States—The Meyer-Lindner System—Compound Fairlie Engines—The Johnstone Articulated Engine—The Du Bousquet Articulated System.

Articulated Engines.—By the term “articulated,” as applied to locomotives, it is understood that the engine is so fitted that some of the driving wheels can move into planes at an angle with those of other axles, and this usually entails that the engine has two distinct sets of coupled wheels, which are operated either from one set of cylinders or from distinct cylinders, the engine being thus divided into two driving sections capable of independent movement upon very curved lines, notwithstanding that the wheel base is long.

Numerous designs for such engines have been employed at various times, particularly for mountain and narrow-gauge railways on the European Continent, and they may be classified in two divisions: (1) those wherein all the wheels are coupled in somewhat the usual manner, but some of the axles are capable of the requisite independent angular movement (many of these designs are most ingenious, but very complicated); and (2) those wherein the wheels are arranged in distinct sets.

Engines of the former class have never been very numerous, and all of them, so far as the writer is aware, have been simple engines.

In the second class, however, compounding has been employed with success, and therefore extended consideration is required.

Engines of this class can be again divided into three main divisions: (1) those having cylinders all fixed upon the frame, but driving one series of coupled wheels directly and one series indirectly through more or less complicated lever mechanism which allows of the required independent angular movement of one set of wheels; (2) those having two sets of coupled wheels, one set fitted in the engine frames which carry their operating cylinders, while the other set are fitted in a bogie frame and usually carrying operating cylinders therefor; and (3) those wherein two pivoted bogie trucks, each with a set of coupled wheels and a set of cylinders, are employed.

In the first and second of these divisions one boiler only is employed, but in the last division are included engines with one boiler and also engines having a double boiler (Fairlie type).

As regards compounding, no engines of the first division have been so adapted, but the writer is aware of several designs for the adaptation of compounding to such engines.

In the second class, comprising engines having two sets of coupled wheels carried under one boiler, one set being carried in a bogie frame, and each set having an equipment of operating cylinders, compounding is now well-nigh universal, for as four cylinders are a necessity if the engine is to be really powerful and large, it becomes a matter of difficulty to supply high-pressure steam to all of them, and compounding is almost a *sine qua non*. Indeed, useful though such engines have proved themselves—for the adoption of this design of articulated engine constitutes the simplest means of providing adequate power on light, heavily-graded, and curved lines—and although many such non-compound engines have been employed for the last forty years or more, it is only since the application of compounding thereto that engines of this type have been introduced in large numbers as a really satisfactory class.

The Mallet System.—This system is by far the most generally employed for these engines. In fact, so extensively is it used that by many people the general type is referred to as the Mallet type, whereas the type is really the Meyer type (introduced in 1867), adapted for compounding by Monsieur Mallet since about 1884. It should, therefore, more correctly be referred to as the Meyer-Mallet design, in the same way that the Meyer-Lindner system (described later) is always referred to.

In the Mallet system the high-pressure cylinders are carried by the frame and drive four- or six-coupled wheels at the back part of the engine in the usual way, and the low-pressure cylinders are fitted upon a large pivoted truck and actuate a second set of four- or six-coupled wheels at the front of the engine.

The low-pressure cylinders are always fitted at the front of the engine because the pressure of the steam to be supplied is lower than that for the high-pressure cylinders, and steam-tight joints can therefore be more readily effected for the telescopic and movable connecting steam pipe that is required, and the exhaust is required to pass to the chimney.

On the Continent these engines are often referred to as duplex compound engines; but they are very correctly described as “engines having an articulated forward motor truck.”

Monsieur Mallet's designs for these engines were first prepared about 1876-7, these designs being included in Chapter IV., but it was not until 1887 that it was introduced into practice for service on the Decauville Railroad (25 in. gauge), to enable the weight of the engine to be brought to nearly 12 tons, and to enable it to pass around curves of 15 to 20 metres radius. The weight of the rail led to the use of four drivers, and the shortness of the radius of the

curves was inconsistent with the coupling of four axles in the ordinary way.

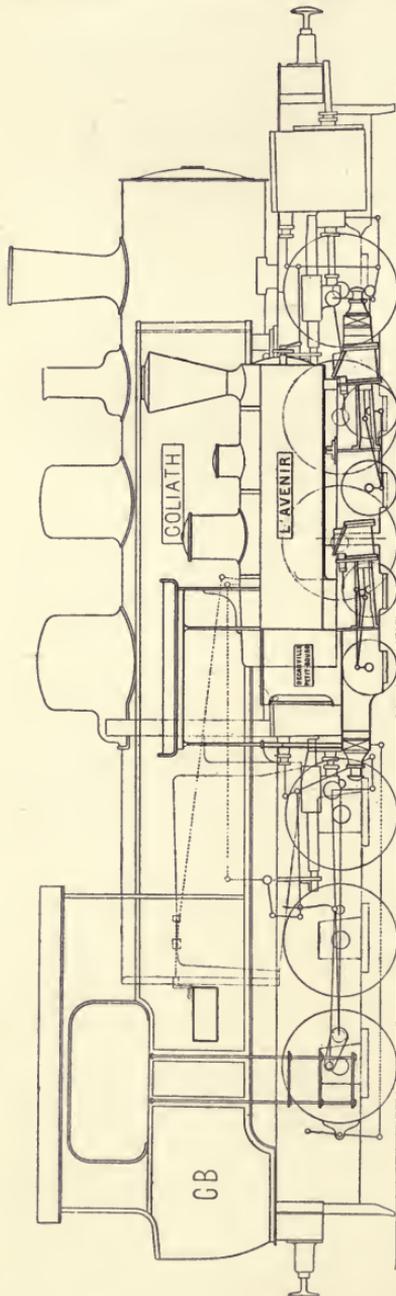


FIG. 127.—Comparison of Mallet Articulated Compound Engines.

Mallet Compound Engines for St Gothard Railway.—Fig. 127 is an interesting drawing showing the first engine "L'Avenir" in outline, compared with the largest engines of the class (for the St Gothard Railway of Switzerland) in Europe. The frame of the engine, as may be seen, is divided in two parts, united by an articulation in the form of a vertical hinge. The rear part is fixed to the boiler, and the fore part of the latter rests on the front frame by means of a curved guide, which allows the angular displacement of the fore part relatively to the rear part on curves. The cylinders at the rear are high-pressure; the pipe-work that leads the steam from the boiler to them is fixed in the same manner as in ordinary locomotives; the two groups of cylinders are united by a longitudinal tube acting as a receiver, a vertical elbow pipe fitting in a stuffing box being fitted near the hinge connecting the two frames. This articulated connection is the only one besides that of the exhaust pipe to the chimney, and, as has already been said, it has to resist comparatively low pressures only.

The transmission of motion for the reversing gear, the brakes, etc., is effected by means of jointed rods of no serious complication.

Although intended primarily for light narrow-gauge lines, the Mallet-Meyer design has been used quite as much for large engines working on standard-

gauge lines; and, as already mentioned, the largest engines in

Europe, for the St Gothard Railway, are of the same class. These were built by the firm of J. A. Maffei of Munich in 1889, and are, as will be seen from fig. 127, large tank engines, having two sets of six-coupled wheels.

The following notes concerning this engine will be of interest:—

The engine weighs 83 tons in working order. The reasons which led to the construction of this type are to be found, not so much in the desire to possess a more powerful machine than the ordinary ones with eight-coupled wheels in operation on the Gothard, but to get additional safety in traffic on Alpine lines.

The ordinary engine weighs 52 tons, and has a separate tender of 27 tons when laden. In constructing the new machine the following objects were kept in view:—

1. To haul the same trains by the same total motor weight without increasing the strain on the rails, and under more favourable conditions as to the adhesion, so as to have a guarantee against difficulty in the tunnels, which are so numerous on this line, or from bad weather.

2. To haul heavier loads under good climatic conditions.

3. To obtain a far greater speed with like loads.

4. To offer less resistance on curves of 300 metres radius.

5. To effect a saving of fuel in hauling equal loads.

How important this last requirement is will be easily understood when it is borne in mind that the engines consume over 30 kilos of fuel, which costs 33 francs per ton delivered on the spot per kilometre.

The new engine realised all the conditions, and in over two years of service not the least inconvenience occurred to counterbalance the advantages which have been obtained.

Before being sent to Switzerland, the engine was subjected to trials on the line of the State of Bavaria; and between München and Schliersee, over gradients of 16 per 1000, it hauled a train of forty-three freight-cars, weighing 400 tons, at a speed of 20 kilometres per hour. On the St Gothard lines, in fair weather, it hauls 200 tons, while the ordinary engines haul only 175 tons.

At starting, boiler steam is admitted to the high-pressure cylinders only; the exhaust steam from these cylinders then fills the receiver, exercising a certain amount of back pressure upon the high-pressure pistons as it passes to the low-pressure cylinders. The steam pressure in the receiver is limited to 70 pounds per square inch, safety valves being provided to prevent the accumulation of a higher receiver pressure. The receiver acts somewhat as a pressure regulator between the two cylinders, so that if the front engine should slip there is a corresponding decrease of pressure in the receiver, while in the case of the rear engine slipping the reverse would take place. In both cases either engine will cease slipping without the regulator being touched. If necessary, the starting of the locomotive can be assisted at certain positions of the high-pressure pistons by admitting live boiler steam to the receiver, and

this can be done automatically by connecting the auxiliary steam cock with the reversing gear.

As a rule, these locomotives are built as tank engines with all wheels available for driving, but sometimes a separate tender is employed, and many notable tender engines of this type, some with a leading pair of carrying wheels, are in use.

Mallet Compound Engines for Russia.—Fig. 128 illustrates the arrangement of steam connections as employed for some large twelve-wheeled engines for the Moscow-Kasan Railway of Russia. The chamber *a* receives the high-pressure exhaust steam from both cylinders, and to it is connected, by a vertical pivoted pipe *b*, the long pipe *c*, extending to *d*, where a spherical joint is provided. The pipe *c*, which serves the purpose of a receiver, is therefore able to freely accommodate itself to the pivotal movements of the leading pivoted frame. At *d* the steam divides into two pipes, one leading to each of the low-pressure cylinders. The low-pressure exhaust steam passes by the pipe *e*, which has spherical connections at both ends and a little endways freedom, to the blast pipe.

The low-pressure frame is not strictly a bogie, as it is pivoted at the rear, and not by a central pin. Its pivot is shown at *f*.

Such engines as these, together with corresponding eight-wheeled engines, are extensively employed on Russian railways, including the Trans-Siberian Railway.

Fig. 129 is a cross section of this engine through the high-pressure cylinders, and fig. 130 is a similar view showing the steam connections of the low-pressure cylinders.

The arrangement of steam connections varies, of course, in various designs, particularly in reference to the flexible connection between the high- and low-pressure engines. According to one arrangement, the connecting pipe includes a flexible section, and is connected to a special receiver chamber, from which the steam is distributed to the low-pressure cylinders. The exhaust pipe from the low-pressure cylinders is provided with a telescopic joint instead of a flexible connection, as in the design illustrated.

The details of starting mechanism also vary according to the practice of various builders. In one arrangement, to enable boiler steam to be used in the low-pressure cylinders at starting and when required, boiler steam passes through a small pipe, governed by a three-way cock in the cab, and to divert the high-pressure exhaust to the blast pipe under these conditions a lift valve is fitted so that the connection from the receiver pipe to the low-pressure cylinders is closed, and a passage-way opened through a pipe to the blast pipe.

This valve is adapted to be opened through a rod having a closing spring so that as soon as released the valve closes, and a trip device is fitted whereby when the reversing lever in the cab is thrown fully over either way this rod is operated, but as soon as the valve gears are linked up the valve is released. Consequently the engine can only be worked non-compound when in full or nearly full forward or backward gear. This mechanism is very similar to that employed

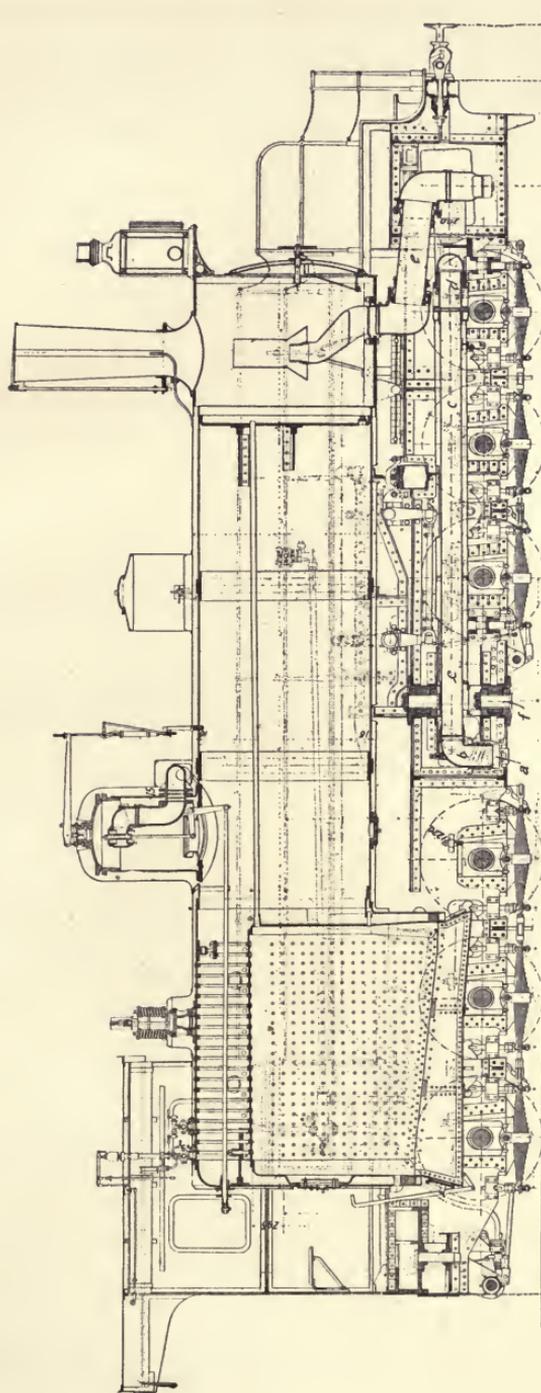


FIG. 128.—Mallet Articulated Locomotive—Moscow-Kasan Railway.

by the firm of J. A. Maffei of Munich, and described in Chapter VII. (figs. 79 and 80).

Mallet Compound Engines in the United States.—Although used so extensively all over Europe and in many other parts of the world, engines of this class are not used in Great Britain, and until 1904

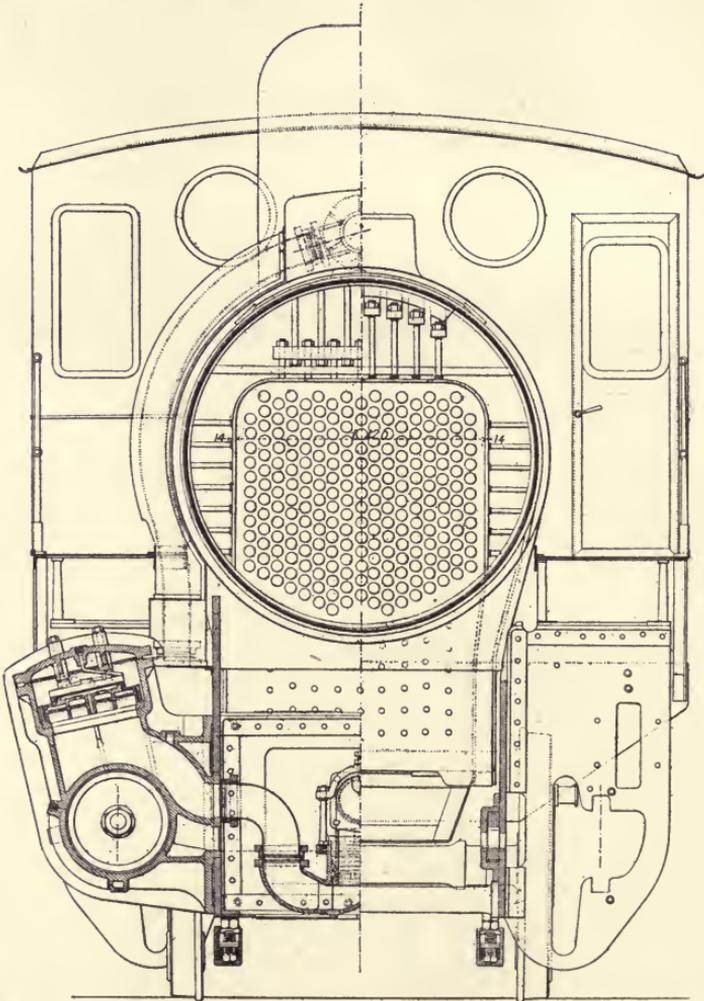


FIG. 129.—Cross Section through H. P. Cylinders—Mallet Articulated Locomotive.

they were not to be found in American practice; but in that year a large engine was built by the American Locomotive Company for the Baltimore and Ohio Railroad, which is notable as being by far the largest engine in the world.

Since this engine was built, two or three other similar but smaller engines have been supplied by the Baldwin Works for service in the

Philippines, and a large engine has just been supplied by the Baldwin Works for road service on the Great Northern Railway (U.S.A.). This latter engine has two sets of six-coupled wheels and a pair of

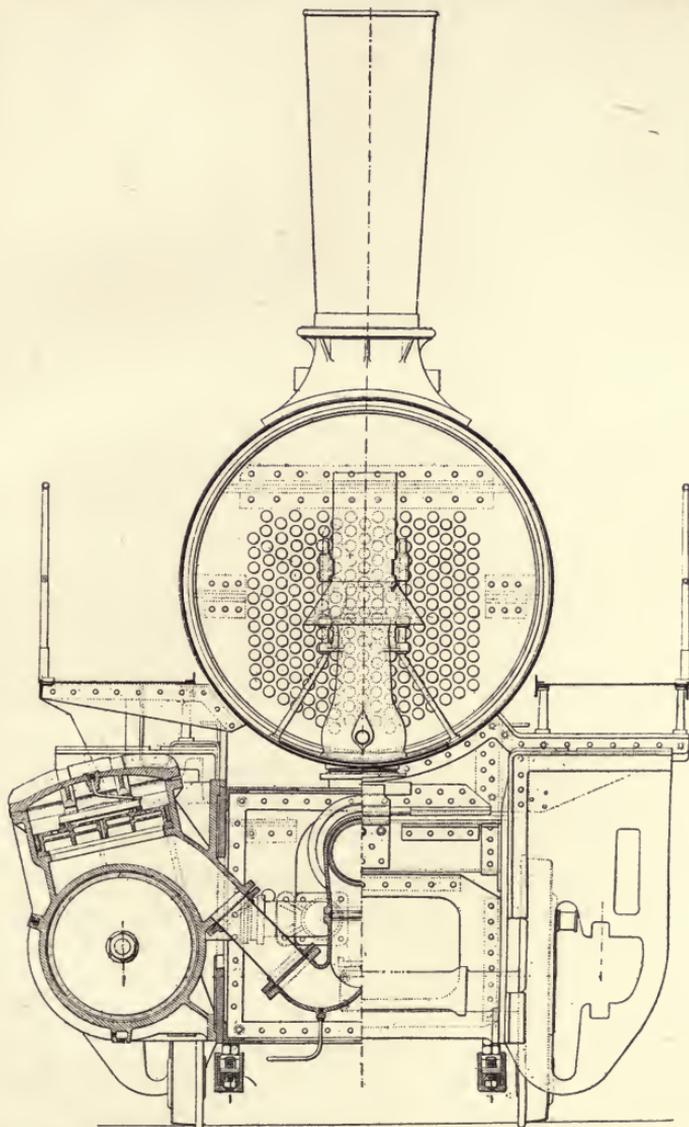


FIG. 130.—Cross Section through L.P. Cylinders—Mallet Articulated System.

carrying wheels at each end, though a tender engine. The wheel arrangement is therefore 2-6-6-2.

The Meyer-Lindner System.—In most respects this system represents the adaptation of the Lindner system of starting

mechanism, substantially as described in Chapter VII., to articulated engines, but although in most respects comprising similar constructional methods to those employed by Monsieur Mallet, it differs therefrom as regards the position of the low-pressure cylinders, which are placed at the rear of the front coupled wheels and close to the high-pressure cylinders. This arrangement has the advantage that the steam passage between high- and low-pressure cylinders is very short; and as the relative movement of the two sets of coupled wheels is very limited at this position, being close to the pivoted connection of the swivelling frame, the joints of the steam pipes can be made very simple.

Compound Fairlie Engines.—Engines having two pivoted bogies, instead of one fixed frame and one swivelling frame, belong to either of two classes: (1) having two separate boilers or one double boiler, and (2) having one ordinary boiler only.

In the first class the engines are of the Fairlie type, but the writer only knows of two instances of the adaptation of compounding thereto.

In one case each bogie has a high- and a low-pressure cylinder, so that it is really a duplex two-cylinder compound engine.

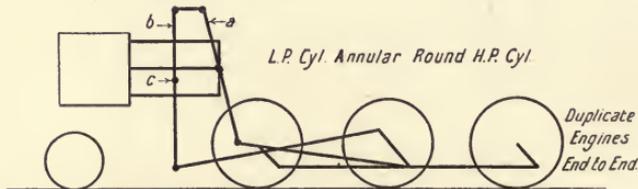


FIG. 131.—Mechanism for Annular Compound Double Locomotive—Johnstone Annular System.

In the other case, of American build, the engine is an eight-cylinder compound articulated Fairlie type engine. This engine is really a double Vaucrain compound engine with superposed cylinders, arranged as described in Chapter X.

The Johnstone Articulated Compound Engine.—Reference has been made in Chapter X. to Mr F. W. Johnstone's annular compound system, as applied to more ordinary locomotives. The system has also been applied for some extraordinary double-articulated tank engines, intended for mountain goods service over very sharp curves.

Three of these engines were built in 1892 by the Rhode Island Locomotive Works for the Mexican Central Railroad. There are two sets of six-coupled wheels set in bogie frames, leading and trailing pony trucks, and two connected boilers set on a rigid frame, water being carried in saddle tanks over the boilers, and fuel in bunkers fitted on the frame.

The cylinders are fixed upon the frame, not on the bogies, and there are eight of them, four upon each part of the engine, there being a high-pressure cylinder and an annular low-pressure cylinder

disposed round it at each side of the engine at each end. Each low-pressure piston has two piston rods, and these and the corresponding high-pressure piston rod are connected to one crosshead.

To connect with the wheels, an ingenious arrangement of mechanism is employed as shown diagrammatically in fig. 131. Each crosshead is pivoted to a lever *a*, to the lower end of which one connecting rod is attached, while to the upper end a link is pivoted by which a lever *b*, with a fulcrum at *c* on the frame, is driven, the other connecting rod being driven by the lever *b*. Thus the wheels are driven by double connecting rods, acting at angles of 180° , and the bogie wheels are driven on curves, whatever the relative positions of wheels and cylinders. By this arrangement an equable turning effect is obtained, and also any tendency for the bogie to twist upon its centre is counteracted.

In work, these engines are said to have given very good results, but no more of them have been built, nor have any locomotives compounded upon the Johnstone system been built for any railways other than the inventor's own line.

The Du Bousquet Articulated System. — In 1905 two very strange articulated engines were built to the designs of Monsieur du Bousquet for dealing with the heavy coal traffic on some sections of the Northern Railway of France, one of these engines being exhibited at the Liège Exhibition.

Fig. 132 is a line drawing which sets forth the main features of the design. As will be seen, the engine, though having only one

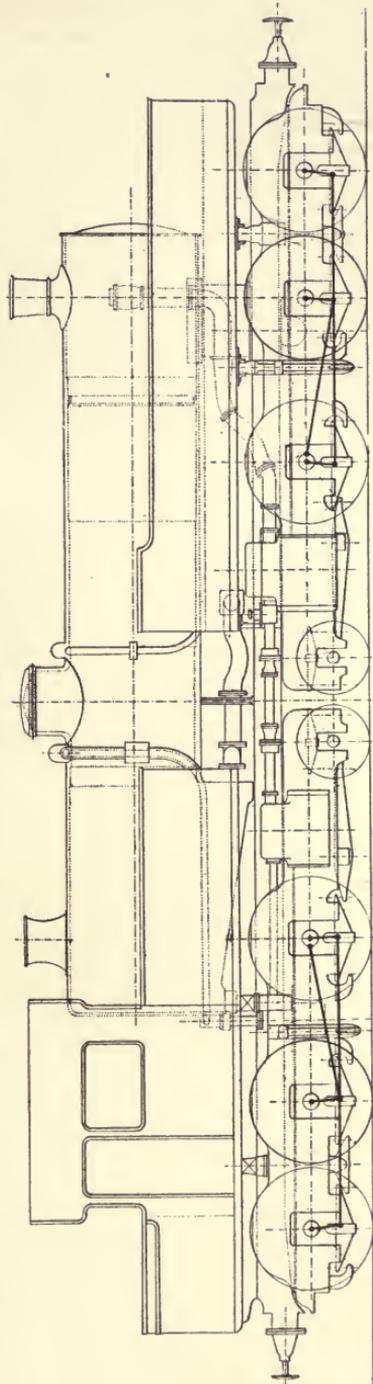


FIG. 132. — Articulated Tank Engine — Northern Railway of France.

boiler, is mounted on two pivoted bogie frames, each having six-coupled wheels and a pair of small wheels arranged towards the middle of the engine, and each having a pair of operating cylinders, in one case (the rear) using boiler steam, and in the other case using low-pressure steam supplied from the high-pressure cylinders.

The weak point of the design appears to be the multiplicity of flexible steam-pipe joints required, some of them for steam at full boiler pressure (225 pounds per square inch), but special provision has been made for this, and it is stated that no difficulty has been experienced from this cause.

The starting arrangements employed correspond very closely to those employed by Monsieur du Bousquet for the tandem compound tank engines described in Chapter IX., and according to the de Glehn system (Chapter XII.), so that extended reference is not necessary.

CHAPTER XIV.

TRIPLE-EXPANSION LOCOMOTIVES—COMPOUND RACK RAILWAY LOCOMOTIVES—CONCLUDING REMARKS CONCERNING COMPOUND LOCOMOTIVES.

CONTENTS :—Mallet's Triple-expansion Engine—Riekie's Triple-expansion Scheme—Compound Rack Locomotives with Four and Six Cylinders—Concluding Remarks concerning Compound Locomotives—The Future of Compounding for Locomotives.

Mallet's Triple-expansion Locomotives.—In marine and stationary engine practice the triple-expansion engine, not to mention the quadruple, and even the quintuple engine, is an acknowledged success; but in locomotive practice many engineers deny that even the ordinary two-stage compound engine has really been satisfactorily produced, notwithstanding the good work done by present-day two-, three-, and four-cylinder compound locomotives; and it is only the amateur inventors who airily speak of triple, quadruple, quintuple, and even sextuple expansion for locomotives.

Yet, while these schemes, none of which have ever been tried in practice, are, as a whole, worthless, when an engineer of standing deals with the question, even although only on paper, it may be worth while to consider the suggestions, and therefore it is not out of place here to describe two triple-expansion locomotive designs suggested, respectively, by M. Mallet and by Mr John Riekie.

In 1886 M. Mallet, writing to the Institution of Mechanical Engineers in reference to Mr Sandiford's four-cylinder compound engine already mentioned, outlined a suggested triple-expansion express locomotive. There were to be four-coupled driving wheels, 7 ft. in diameter, in the usual positions, and a single pair of 7-ft. wheels in a bogie frame in front with the leading wheels. The four-coupled wheels were to be driven by an 18-in. high-pressure cylinder and a 26-in. intermediate cylinder, and the single driving wheels were to be driven by two 26-in. low-pressure cylinders. The arrangement is shown in fig. 133.

Riekie's Triple-expansion Scheme.—Mr Riekie's triple-expansion scheme (fig. 134) consisted in using two outside cylinders, one high-pressure and one intermediate-pressure, and a large inside single-

acting low-pressure cylinder, all three cylinders driving on to one axle. The practical arrangement of this design depended upon the special features of the Riekie system, as described in Chapter VIII. The cylinders were to be 14, 20, and 28 in. in diameter, with a stroke of 26 in. This design also included a triple boiler and various other departures from usual practice.

The engine has been referred to and illustrated in some locomotive books, generally to be depended on, as an actual engine for the North-Western Railway of Beluchistan (India), but this is not so. It is purely a design, though an interesting one.

Compound Rack Railway Locomotives.—Rack railways are of two kinds. One is entirely separated from any other railway; the other works in connection with adhesion lines, or forms a part thereof, the same engines working, or being capable of working, on both sections.

On railways of the first class the locomotives rely wholly upon the rack, so that no adhesion cylinders are needed, and therefore, as these engines are comparatively small and draw light loads, two

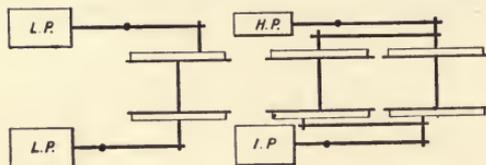


FIG. 133.—Monsieur Mallet's suggested Design for Triple-expansion Locomotive.

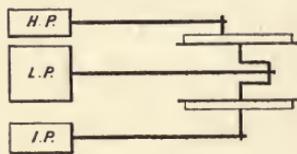


FIG. 134.—Mr Reikie's proposed Design for Triple-expansion Locomotive.

ordinary high-pressure cylinders are sufficient, and compounding is hardly required. In the second case, four cylinders are often employed, two for the rack pinions and two for the adhesion wheels, though it is a fairly usual practice, even with these engines, to use only the two cylinders and to provide clutches so that either the rack pinions or the adhesion wheels can be driven at will.

Many of these four-cylinder rack and adhesion locomotives, of various designs and dimensions, are in service, but very little has been done as regards compounding for such locomotives.

The principal system employed for these engines is the Vaucrain, already described in Chapter X. On wholly rack lines, such as the Count Telferer Railway in Italy, the Vaucrain cylinders drive the rack pinions only. In other cases the Vaucrain cylinders drive the rack pinions and can be coupled to the adhesion wheels when required.

In another design, which affords an example of a six-cylinder locomotive, there are three cylinders at each side—two Vaucrain cylinders for driving the adhesion wheels and a cylinder on top for driving the rack.

Fig. 135 illustrates in diagram the various arrangements for Vaucrain compound rack locomotives mentioned: (1) operating the

rack only; (2) operating both rack and adhesion wheels from the same cylinders; and (3) with six cylinders—two for the rack pinion and four for the adhesion wheels.

Since writing the foregoing, a combined rack and adhesion locomotive has been introduced by the Swiss Locomotive Works wherein high-pressure cylinders drive the rack pinion, and low-pressure cylinders the adhesion wheels, the engine working compound when both sets are worked simultaneously, as often occurs in this case, or either set can be operated independently with boiler steam.

Concluding Remarks concerning Compound Locomotives.—We have now reviewed every compound system of any importance

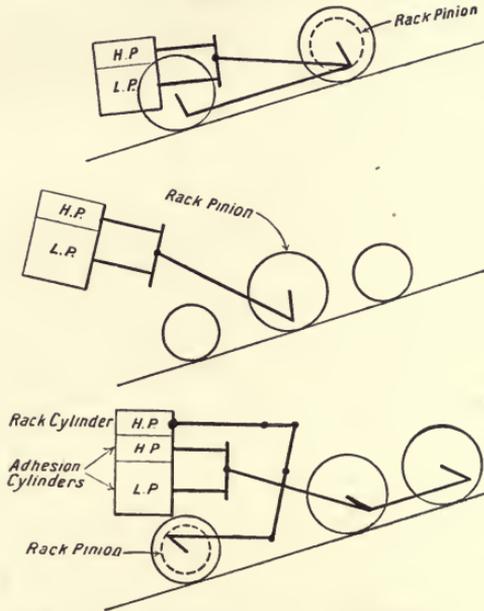


FIG. 135.—Compound Rack Locomotives.

as employed for locomotives, and, with very few omissions, have indicated nearly every system that has been employed at all, besides dealing with a few suggestions which have never been carried out; and it only remains for the writer to devote a few words to a résumé of his subject, and the future probabilities and possibilities of the compound locomotive.

The methods of applying compounding for locomotives now employed for new locomotives are almost entirely arranged with three or four cylinders; for the two-cylinder systems, with their unequal cylinders, and the necessity for comparatively complicated starting devices to enable the work in the low-pressure cylinder to be equalised with that being done in the high-pressure cylinder when working non-compound, are being superseded very largely by other systems.

At one time the increased complication and greater first cost of

engines with more than two cylinders were considered good arguments against the use of three or four cylinders ; but it is now argued with success that these factors, though important, are more than balanced by the mechanical advantages as well as the compound advantages of multi-cylinder compound locomotives. Moreover, with three or four cylinders available, the possibility of using them all with boiler steam on occasions goes far to solve the problem of providing very powerful engines of ordinary dimension, and, if only for this reason, compounding represents progress. And when the possibility of achieving advantage by the compound use of the steam at ordinary times, that is, for the largest proportion of the time the engine is working, is added to this, it will be seen that it is almost impossible for the compound locomotive, if properly designed and handled, to be other than satisfactory.

The future of Compounding for Locomotives.—It is therefore only reasonable to prophesy that the next few years will see a great extension of the use of compound engines, especially for hard passenger and goods traffic. In fact, this prophecy is even now in the early stages of its fulfilment.

It appears very doubtful whether triple-expansion engines will ever be employed for locomotive purposes, for to attempt to go beyond two-stage expansion is to invite difficulties owing to the extreme variableness of the working conditions of locomotive operation, with very little corresponding advantage.

CHAPTER XV.

THE USE OF SUPERHEATED STEAM FOR LOCOMOTIVES.

CONTENTS:—General Remarks—The Advantages and Economy of Superheating for Locomotives—A short History of the Schmidt Superheater as applied to Locomotives—The Schmidt Smokebox Superheater, Smokebox Type—The Schmidt Superheater, Smoketube Type—Schmidt Superheaters in Belgium—The Pielock Superheater—The Cole Superheater—Superheating Apparatus on the Lancashire and Yorkshire Railway—The Cockerill Superheater—The New Century Engine Company's System—Superheating Apparatus in New Zealand.

General Remarks.—The principal reasons for the employment of superheated steam in steam engines have already been set forth in Chapter I., so that it is unnecessary to do more than summarise the remarks there made as introduction to this chapter. The reasons are—(1) to provide “dry” steam at a higher temperature than that corresponding to its pressure, and thus to minimise cylinder cooling and cylinder condensation, and enable extended expansive working to be employed; (2) to increase the volume of the boiler steam before it is used in the cylinders; and (3) to utilise some of the heat remaining in the furnace gases after they have passed through the boiler tubes, and before they are passed away up the chimney.

The Advantages and Economy of Superheating for Locomotives.—In the case of locomotive engines these advantages exist to nearly the same extent as they do in the case of stationary and marine engines; for whereas compounding as applied to locomotives requires to be considered on a special basis, superheating is only differentiated in detail matters, such as the fact that most superheating apparatus for locomotives necessitate some diminution of the steam generative efficiency of the boiler (usually only slight, however), and that a special construction of slide valves, especially when of the piston type, is usually necessary owing to difficulties attending the use of high-temperature dry steam and the consequent loss of the lubricating capabilities of “saturated” or ordinary wet steam.

The principal problem attending the adaptation of superheating apparatus for locomotives has therefore consisted in the design and construction of the apparatus in such a way that it can be con-

veniently applied without detracting from the steam generative efficiency of the boiler, and without interfering with tube cleaning and repairing, though a few other minor difficulties, such as those mentioned relating to the construction of slide valves, have also required consideration before superheating for locomotives could be said to be really satisfactory.

In nearly every case the superheating apparatus employed is arranged in the smokebox, which is made somewhat larger than it would otherwise be, and tubes extend into the boiler tubes (some of these are usually larger than the ordinary tubes), the arrangement being such that the whole apparatus can be easily withdrawn when necessary. In one or two instances, however, the superheating chamber is fitted within the boiler itself.

A short History of the Schmidt Superheater as applied to Locomotives.—Some half-dozen types of superheating apparatus are now in use for locomotives, but the constructions most generally employed are those designed by Herr Wilhelm Schmidt, a well-known German engineer, principally associated with stationary engines and boilers, but who is responsible for the first successful design of superheating apparatus for locomotives. A number of constructions of superheating apparatus have, however, been patented before this, some of which would probably be satisfactory in use. As a result of the original work of Herr Schmidt, the last few years have seen experimental work either with the Schmidt or with other forms of apparatus, some of which are practically adaptations of the Schmidt superheater, on railways of nearly every country in the world.

The following is a brief history of the Schmidt superheating apparatus, which will fittingly introduce a technical description of the two constructions in use.

The first engines were built for the Prussian State Railways in 1898, so that it will be gathered that superheating for locomotives is quite a recent development of locomotive engineering; and the original application was largely due to Herr Müller, of the Prussian Ministry of Public Works, and to Herr Garbe, Member of the Berlin Board of Directors, who recognised the value of Herr Schmidt's work, and at once afforded him every facility for carrying out his object. Indeed, Mr Garbe, together with the Vulcan Engineering Company of Stettin-Bredow, Mr A. Borsig of Tegel-Berlin, Messrs Henschel & Son of Cassel, the Hohenzollern Locomotive Works of Düsseldorf, and the Union Foundry of Königsberg, are deserving of special credit for the part taken by them in introducing the Schmidt system into the Prussian State Railway service, and in adapting the apparatus to the requirements of locomotive practice.

Credit is also due to the following gentlemen: Mr George Noltein, of the Moscow-Kasan Railway Company; Mr E. A. Williams, formerly Superintendent of Rolling Stock of the Canadian Pacific Railway; Mr René Bertrand and Mr B. Flamme, of the Belgian State Railways. As early as the year 1900, both Mr Noltein and Mr Williams had

trial locomotives built on the Schmidt superheated steam system for their respective railways, while in the year 1901 the Directors of the Belgian State Railways, at the instance of Messrs Bertrand and Flamme, were the first to adopt the "smoketube" superheater described later.

The first two superheater locomotives on the Prussian State Railways were put to work in the beginning of the year 1898, and, it may be added, are still in regular express service. Although a number of obstacles were naturally encountered in the construction of these particular engines, in so far as concerned the adaptation to the somewhat complex conditions of railway operation of so essentially new a feature as highly superheated steam, Mr Schmidt soon overcame these difficulties by improving the details of the apparatus, and by designing special forms of pistons, piston valves, and stuffing boxes, which were thoroughly suited to withstand the high temperature, and which therefore ensured great efficiency and durability.

In 1899 the two original locomotives mentioned above were followed by two further superheated steam express engines, and in 1900 by two superheater passenger tank engines. These six trial engines proved conclusively that it was possible, notwithstanding the unfavourable conditions under which locomotives usually work, to generate and successfully employ highly superheated steam in such engines, the practicability of which had previously been doubted, even by leading engineers. The Administration of the Prussian State Railways have since applied the Schmidt apparatus to an increasingly greater extent year by year, as the following figures testify :—

in 1902, 24 engines were fitted with his superheating apparatus ;

in 1903, 40 engines " " "

while 123 additional superheater locomotives were ordered in 1904 (57 engines in July and 66 engines in November).

In addition to these engines, the Schmidt apparatus has been fitted to locomotives of many other countries, as the following particulars, compiled from additional information recently supplied to the writer by Mr Schmidt, will testify.

The apparatus is now employed for engines of various types to locomotives of the following railways, besides the Prussian State lines :—

Imperial Railways of Alsace-Lorraine.

Canadian Pacific Railway (a large number of engines).

Moscow-Kasan Railway.

Belgian State Railways.

Cape Government Railways.

Swedish State Railways.

Saxon State Railways.

Swiss Government Railways.

Austrian State Railways.

Hungarian State Railways.

Warsaw-Vienna Railway.

Paris-Orleans Railway.

Paris, Lyons, and Mediterranean Railway.

Western Railway of France.

Great Western Railway of England (one engine).

Besides these, there are a few other instances of one or more engines being so fitted, making a total, according to the particulars in the writer's possession, of 287 engines.

Since this list was made up a number of other engines have been fitted with the Schmidt apparatus,—notably, additional ones in Belgium, Canada, and some in the United States,—and the actual number is now probably between 400 and 500.

The Schmidt Superheater, Smokebox Type.—This system of superheating is based on the following principle: The gases of combustion issuing from the firebox are divided into two separate currents; one, the larger current, passes through the ordinary tubes in the boiler and generates steam in the usual manner, while the other and smaller current flows through a single large flue or tube which extends from the firebox and along the lower part of the boiler barrel to the superheater apparatus in the smokebox. The gases in this flue are cooled only to a comparatively small extent by the water, and the heat is consequently utilised for superheating purposes. Therefore, as the temperature of the gases entering the apparatus is comparatively high, a relatively small amount of heating surface, easily provided and accommodated, suffices to highly superheat the steam before it reaches the valve chests. Approximately, 10 per cent. of the heat developed on the grate is employed in this way. The heating surface of the boiler is but inappreciably diminished. On the other hand, the total cross-sectional tube area is increased—a fact of great importance when hard work has to be done—while the superheater sensibly increases the total heating surface, and thus secures a better use of the gases of combustion than would otherwise be possible. As a matter of fact, the efficiency and draught of the boiler are improved by the increased cross section of free passage for the gases, since the vacuum in the firebox will be greater, and more coal can therefore be burnt per hour than in an ordinary locomotive.

Referring to fig. 136, it will be seen that the large flue tube in the lower portion of the boiler conducts the hot gases from the firebox direct to the superheater, and that the latter consists of a number of small tubes arranged in three concentric rows and situated in the annular space of the extended smokebox. The inner row is so bent as to constitute an arched continuation of the flame tube. This arch, which has a gradually decreasing radius towards the front of the smokebox, thus forms a passage, which conduces to a uniform distribution of the gases in the superheater. The superheater tubes are expanded into the walls of two cast-steel headers or steam chambers, which are fixed in a longitudinal position inside the roof of the smokebox, one on each side of the chimney, and are covered on the outside

by detachable steel casings, packed with asbestos, and secured by

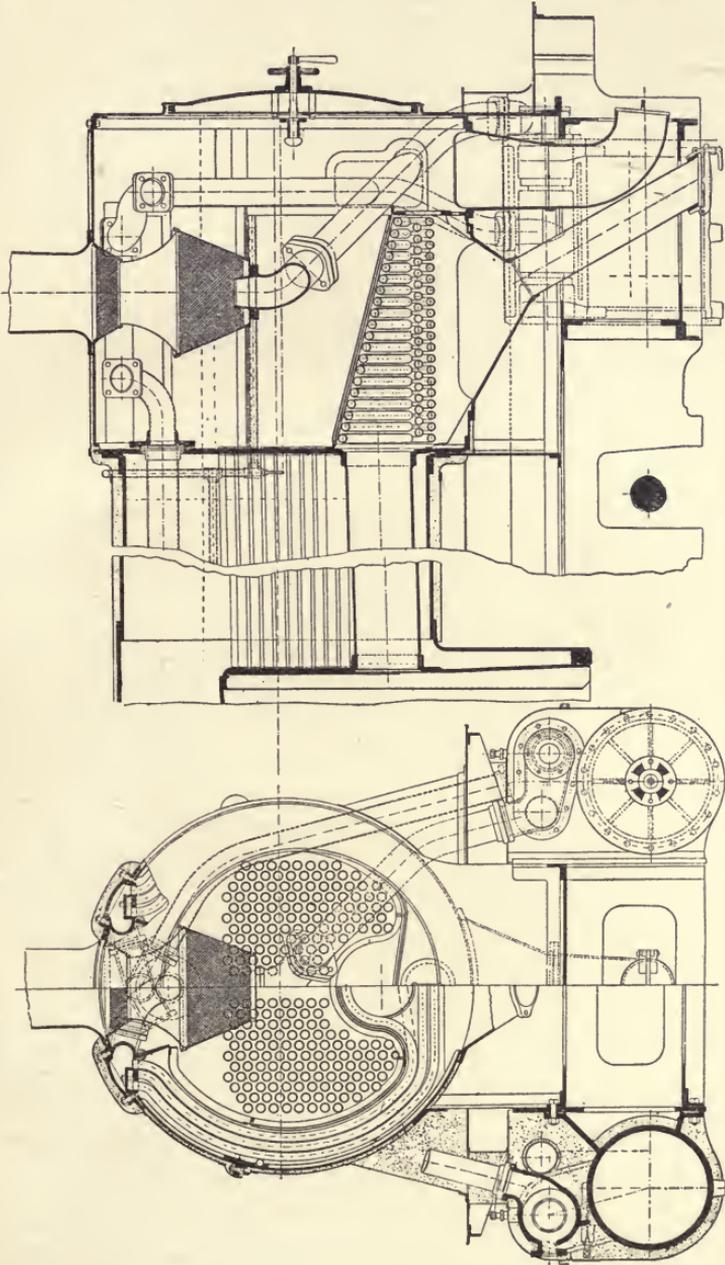


FIG. 136. — Schmidt Superheater—Smokebox Type.

screws. The space occupied by the superheater is separated from the remainder of the smokebox by a wall of removable plates which

extends almost up to the headers, and is shaped to the form of the superheater tubes, which, in turn, follow the contour of the smokebox interiorly. This wall is effectually protected from the destructive action of the high temperature of the gases in the superheater by the rows of tubes located before it, and from the abrading action of cinders in the smokebox by guardplates, which are capable of being easily and inexpensively changed. Between each header and the top of the wall on either side a long narrow opening is left through which the superheater gases pass on their way to the chimney, and each of these openings is covered by a damper operated from the footplate.

For the purpose of collecting the cinders which fall between the superheater tubes, a hopper, which can be emptied on the completion of a journey, is fitted below the apparatus. During the run, soot and ashes can be removed from the superheater coils by means of either superheated steam or compressed air, the device for effecting this operation being controlled from the cab. In order to facilitate thorough inspection and cleaning, the inner casing of the apparatus can be taken down if desired, but experience proves that this course is seldom necessary.

With a view to avoiding loss of heat by radiation, the superheater is provided with plates arranged just inside the wall of the smokebox, while it is further protected by asbestos sheeting, covered by plates, on the outside of the smokebox.

The hot gases enter the arched distributing channel, and ascend between the superheater tubes on each side of the apparatus. When the engine is at work, or when the steam blower is closed while the engine is standing, the superheater dampers are open, and the gases are then discharged into the smokebox, where they combine with those issuing from the boiler tubes, and finally escape into the atmosphere *via* the chimney.

Owing to the fact that the combustion in the firebox of a locomotive is only intense when the regulator is open, and when, therefore, the escaping steam produces a vacuum in the smokebox, the superheater possesses a very wide margin of safety and durability. When, for instance, the regulator is open, the superheater tubes are cooled by the inflowing steam; and when, on the other hand, it is closed, the gases of combustion enter the superheater at a low velocity and at a low temperature, so that the uncooled superheater coils cannot in any case become distorted. It is unnecessary, therefore, that the superheater dampers should be shut while the engine is standing, unless the steam blower is in use. For this reason, the rod controlling these dampers is so connected with the lever of the steam blower that when the latter is employed the dampers are closed.

The action of the superheater is as follows: On the regulator being opened, steam flows direct from the main steam pipe to the left-hand header, and then passes through the inner row of superheater tubes to the right-hand header. In this header a baffleplate or cover is fitted over the ends of the inner and middle rows of tubes, by means of which the steam, on leaving the former, is diverted into

the central rings, and returns through them to the left-hand header. This header also contains a baffleplate, fixed, in this case, over the openings of the middle and outer series of tubes, and so arranged that the steam is conducted from the central rings of tubes into the outermost sets, and thus finally flows back to the right-hand header, from which it passes in a highly superheated condition to the valve chests and cylinders. In this way the steam is made to traverse the superheater three times—from left- to right-hand header, and *vice versa*, and from left to right again—before reaching the cylinders. As the combustion gases, both on entering and leaving the superheater, come in contact with tubes whose surfaces are cooled by wet steam, their temperature is sufficiently reduced to prevent the tubes which contain superheated steam, and which are therefore much hotter than the others, from becoming overheated. Thus the high temperature of the gases cannot act injuriously on the walls of the superheater tubes.

As already stated, the headers are provided with detachable covers. These covers in reality form part of the outside of the smokebox, and afford direct communication with the interior of the headers. They can be readily removed for the purpose of expanding or plugging the tube ends when necessary. Since, by reason of their bent form, the tubes can expand freely, and since their extremities lie at the top of the superheater, and consequently only come in contact with gases having a temperature varying approximately from a minimum of 570° F. to a maximum of 750° F., loosening of the joints is a very remote contingency. If, however, any of the tubes should get loose in course of time, the difficulty can be temporarily and easily overcome by plugging those tubes, without necessitating the withdrawal of the engine from service. If a considerable number of tubes become so defective as to require renewing, the upper part of the smokebox, together with the complete superheater, can be removed, so that the whole apparatus is capable of being readily examined and repaired.

In a general way, regulation of the superheating by means of the dampers is wholly unnecessary, but their provision enables the driver to reduce, or to entirely stop, superheating, as the case may be, when special circumstances render either course advisable. As a rule, therefore, the driver does not have to pay any attention whatever to the superheater whilst running, so that he can devote his time entirely to his usual duties. A steel mercury pyrometer is fixed in the cab for the purpose of indicating to the driver the degree of superheating. Although this pyrometer gauge is not absolutely essential, it is extremely desirable and useful. For test runs it is indispensable. It is also of great value to the driver, inasmuch as it enables him to control the combustion and evaporation in the boiler, while a slagged grate, holes in the fire, or priming of the boiler, frequently caused by the water-level being too high, or by dirty, scummy water, are conditions which, owing to their effect on the degree of superheating, are at once made known by means of

this instrument. Priming of the boiler is indicated by a rapid fall in temperature; the driver can then, by promptly throttling by means of the regulator, prevent, or at all events diminish, this trouble. Consequently, all German superheated steam locomotives have so far been fitted with a pyrometer.

A special advantage of this type of superheater is, that as the smokebox tubeplate is always accessible, the boiler tubes can be either cleaned or renewed in the ordinary manner without difficulty.

The Schmidt Superheater, Smoketube type.—In this system, as shown by fig. 137, the upper part of the boiler barrel is fitted with two or three rows of large fire tubes or flues, which are expanded into the firebox and smokebox tubeplates. These flues are $4\frac{5}{8}$ in. in diameter, except at the extreme firebox end, where they are contracted to a diameter of $3\frac{1}{2}$ in. Inserted in each flue are four weldless steel superheating tubes, the front ends of which extend into the smokebox, where they are bent upwards and secured to a flange common to each set of four tubes. At their other ends, these steel tubes are united in pairs inside the large flues by means of cast-steel U-bends. The flanges of the several sets of superheating tubes are bolted to a common cast-iron header, arranged transversely inside the smokebox. The header is constructed in such a manner, and is so connected with the regulator pipe and with the pipe leading to the valve chests, that the steam is conducted through all the superheating tubes simultaneously on its way from the boiler to the cylinders.

A portion of the gases of combustion passes through the ordinary boiler tubes, while the other portion flows through the large flues, and its heat is partly given up to the water surrounding flues, and partly to the steam in the superheating tubes enclosed within them. The flow of gases through the large flues is controlled by a damper hinged or pivoted below the header in the smokebox. This damper is kept closed by a counterweight so long as the regulator is shut: but immediately on the opening of the regulator, it is automatically lowered by means of a piston working in a small steam cylinder and operating suitable lever gear. Thus, while getting up steam, or whenever the regulator is closed, and when, therefore, the superheating tubes are not cooled by the inflow of saturated steam, no gases of combustion pass through the large flues. The superheating tubes are consequently prevented from becoming unduly heated at any time. Only when the regulator valve is opened is steam admitted to the small steam cylinder for the purpose of lowering the damper. As the piston of this cylinder in its end position acts as a valve, which is kept closed by the steam pressure, leakages past the piston cannot cause a loss of steam. The piston can therefore be adjusted to work freely and reliably. If desired, the superheated damper can be actuated from the footplate by hand-power instead of by steam; and as it is only necessary that the damper should be closed when the steam blower is in action, the damper lever can with advantage be connected to the lever con-

trolling the blower, in such a way that the latter can only be turned on when the damper is shut.

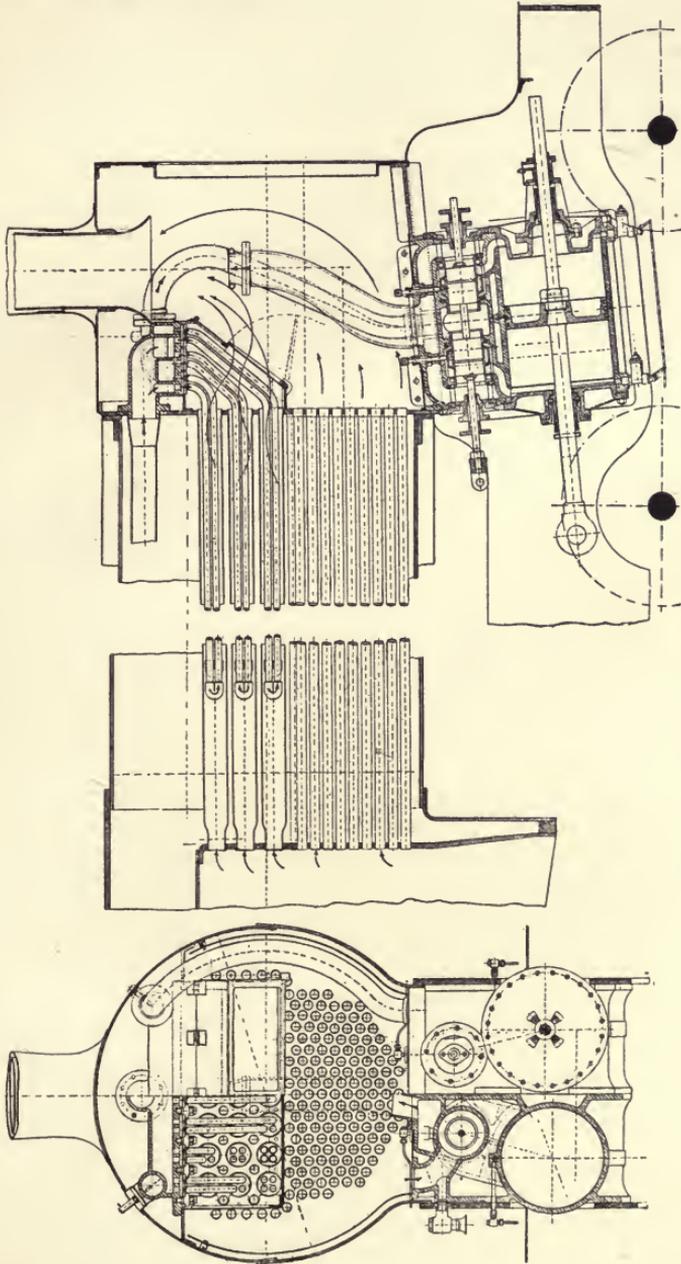


FIG. 137.—Schmidt Superheater—Smoketube Type.

Soot and ashes can be removed from the large flues and super-

heater tubes by means of either steam or compressed air, with the aid of a hose and blast pipe. This operation is preferably carried out from the firebox, but it can also be performed from the smokebox. As the cleaning can be effected by steam or compressed air much more quickly than by brushes, it will be found advantageous to clean the ordinary boiler tubes in the same manner. With this superheater, it is unnecessary to provide a special hopper to receive the cinders.

The total heating surface of the boiler is increased by about 5 per cent. by means of this pattern of superheater, while the cross-sectional area of free passage for the gases is approximately the same as when the usual boiler tubes take the place of the large flues.

The great advantages of the smoketube superheater are its extreme simplicity and thorough accessibility. Each group of tubes can be readily inspected, repaired, or renewed without the entire superheater having to be taken to pieces.

Further, it can be more easily fitted than the smokebox superheater to inside-cylinder and compound locomotives; and as the dimensions of the boiler and smokebox remain unaltered, this superheater can be easily fitted to existing engines.

In the case of the first superheated steam locomotives on the Prussian State Railways, as few alterations as possible were purposely made in such parts of the engines as the superheated steam came in contact with. Under these circumstances, it was foreseen that several changes and improvements would be requisite in the course of time. Accordingly, Mr Schmidt modified the details where necessary (designing, among other parts, the special form of piston valves mentioned), and succeeded in fully meeting the conditions imposed by superheated steam, so that the working of the engines left nothing to be desired as regards wear and tear, safety, and general efficiency.

The superheated steam locomotives in their present forms prove that all difficulties have been successfully overcome, and that the wear and tear of the valves, piston rings, cylinders, and stuffing boxes are not greater than in the case of engines using saturated steam. Even in trial runs, when, instead of the ordinary temperatures ranging from 570–660° F., the engines worked with a temperature of 720° F., no trouble whatever has been experienced.

Schmidt Superheaters in Belgium.—In concluding these notes, a short extract from a recently published report prepared by Monsieur J. B. Flamme, of the Belgian State Railway Administration, on experience with superheating apparatus for locomotives, will be of interest:—

“By superheating, the volume of steam is augmented proportionately to the rise of temperature, diminishing, however, its density. In other words, when the degree of superheat is sufficient to prevent the loss due to condensation in the cylinders, then the surplus heat contained in superheated steam is sufficient to reheat the walls of the cylinders, maintaining the temperature necessary to get rid of

the condensation and the loss of work during expansion. These trials have brought to light a valuable property of superheated steam. It was recognised as a bad conductor of heat, contrary to that which obtains when steam is in the saturated state.

"These numerous advantages, tested by many trials undertaken by most competent engineers, are specially valuable to the locomotive engine. The employment of a practical superheater augments the power of the boiler, and the utilisation of superheated steam is most economical. This is well observed in hauling heavy goods trains on sections of the line having heavy gradients; for it is then indispensable to reduce to the minimum the consumption of water and steam. For the suburban trains having frequent stoppages superheat is, again, highly recommended, because it reduces the condensation necessitated by the frequent stops. High speed is also favourable to the employment of higher superheated steam, the great fluidity of which, as well as its dryness, permit running with early cut-offs, which helps the boiler just at the time when it is most hard-pressed.

"On the other hand, the passage of saturated steam through the pipes—and steam ports—is more difficult, and entails inevitably an increase of condensation.

"At the same time another important question presented itself: Was it absolutely necessary to superheat the steam to a temperature reaching 300° to 350° Cent.—572° to 662° Fahr.? It is evident that the more the steam is superheated the more necessary it becomes to give attention to the oiling of the piston valves and cylinders and to the construction of the stuffing box. With a view to getting a clear idea of the actual amount of superheat, some trials were made with a superheater of small surface installed in the barrel of one of the locomotives. After several months of experiments, it has been recognised that the utilisation of steam slightly superheated does not offer any appreciable economy of fuel or increase of power."

The Pielock Superheater.—Next to the Schmidt superheater, the apparatus now to be considered, and which is exploited by the Hanover Engine Works, is probably the one which has been most extensively employed, though the Cole superheater, next dealt with, bids fair to be introduced more extensively in the near future.

This apparatus differs essentially from the Schmidt apparatus in that the superheater is, as shown in figs. 138, 139, and 140, fitted into the barrel of the boiler in such a manner that some of the heating surface of the boiler tubes is used, though it is located far enough from the firebox to prevent the tubes from becoming overheated.

According to the position and the dimensions, the superheater can superheat to every required degree of temperature up to 350° C.

The main part of the Pielock superheater is a box, into the end walls of which the boiler tubes are fitted. Ordinary tightness is sufficient, as the pressure inside and outside the superheater is the same.

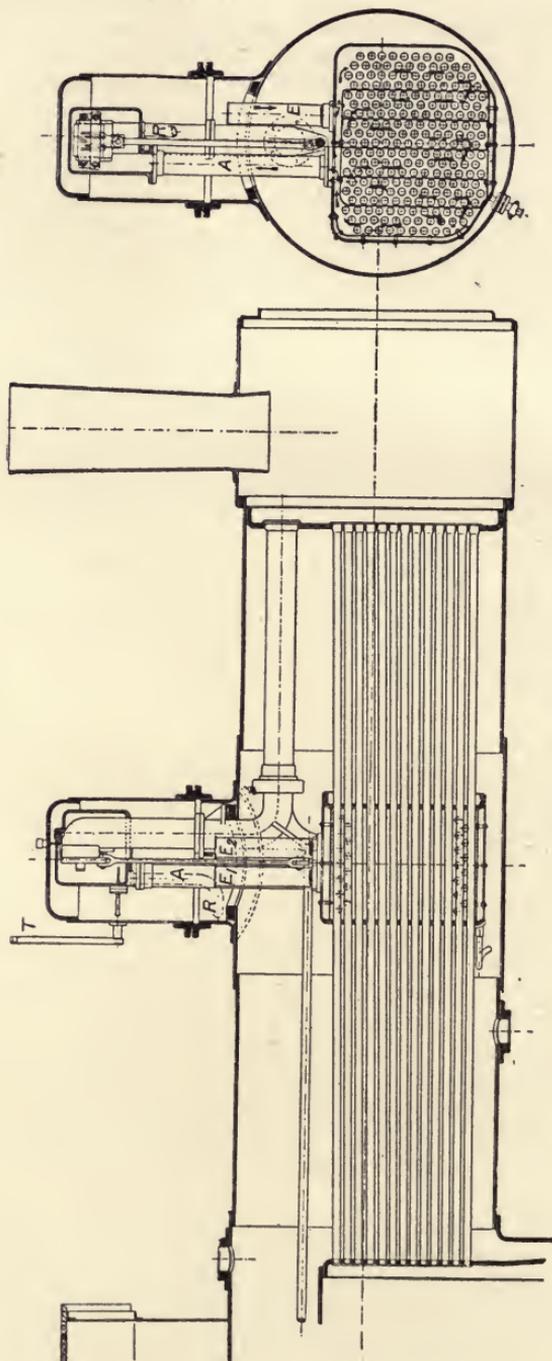


Fig. 138.—Pielock Superheater.

The superheater box is divided by plates, parallel to the boiler tubes, into several compartments, so as to get a very long contact of the steam with the boiler tubes.

The steam passes, under boiler pressure, through the pipes E_1 and

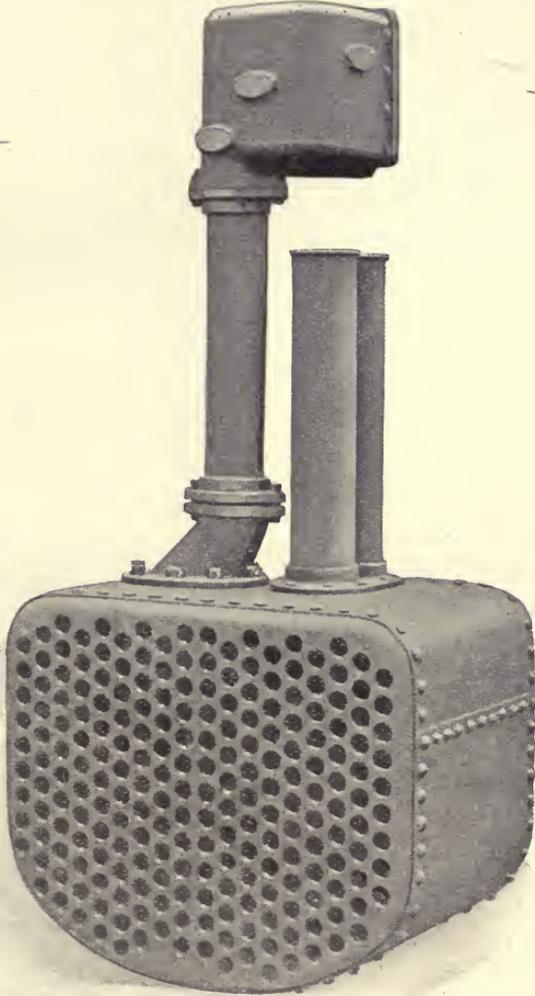


FIG. 139.—Pielock Superheater detached.

E_2 into the superheater, and is conducted through the different compartments in the direction of the arrows, and goes by the pipe A into the steam chamber which encloses the regulator head.

A tube passing through the bottom of the superheater and boiler

is fitted with a drain cock, which is used to ascertain if the superheater is watertight.

A thermometer on the dome, which is connected by a pipe with the steam chamber of the superheater, and whose scale can be clearly seen from the footplate, shows the temperature of the superheated steam.

To fit this simple superheater into its place, the main box is first put into the boiler, before the front or back tubeplate is brought into position, and is kept there by suitable means. After the tubeplates are both in position, the boiler tubes have to be tightened, first in the back tubeplate, then in the plates of the superheater, and finally in the front tubeplate.

The tightening of the tubes in the superheater plates has to be done by a specially constructed mandril. To remove the boiler tubes

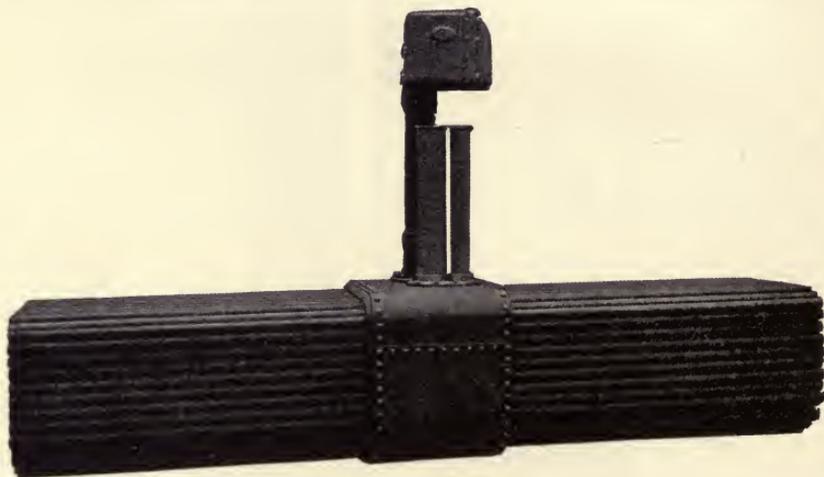


FIG. 140.—Pielock Superheater detached from Boiler and showing Boiler Tubes.

easily, it is necessary to slightly increase the diameter of the holes, from the firebox tubeplate to the smokebox tubeplate.

A special fastening of the superheater box is not necessary, because the box is floated, and the surplus weight is taken by the great number of tubes.

On locomotives with piston valves a superheating of 350° C. may be used, but on those with flat slide valves, 280° should not be exceeded. It may be pointed out that, in using superheated steam, pipes of wrought-iron or steel, stuffing boxes with metal packing rings, and oil presses should be used. For oiling purposes, only mineral oil, which boils at a high temperature, should be used.

The advantages of the Pielock superheater are as follows:—

(1) Owing to the simple construction of this superheater, it is possible to build it, not only into new, but also into old locomotives without making any changes in the boiler, and without loss of

draught. The strain on the boiler after putting in the superheater, and so lessening the heating surface, will not be increased but decreased, owing to the effect of the superheater being equal to a larger water-heating surface than that occupied by the superheater.

(2) This superheater is in some ways more economical than the smokebox superheaters, because it can be put (within certain limits) where the heating gases are at the highest temperature, and the heating power which is not used for superheating will be used for further heating of the water surrounding the tubes on its way to the smokebox.

(3) The superheater does not necessitate any alteration to the locomotive to which it is applied, as it will be built to suit the boiler.

(4) The superheater is safe for working, as the pressure inside and out is the same. The strain on the boiler tubes remains the same with or without the superheater, and overheating of the boiler tubes is impossible if the superheater is so far from the firebox that the temperature of the heating gases does not exceed 700° to 800° C. The steam, which passes round the tubes at high speed, cools them as effectually as the water which surrounds the tubes, and which has a slow motion usually.

When the locomotive is at rest, no steam is passing through the superheater, and the temperature of the heating gases in the tubes is falling so quickly that it is impossible to overheat the tubes; the superheating of the steam is, however, still going on, and on starting the locomotive there is always superheated steam. If a leakage should occur, it can be detected not only by the thermometer but also by the draincock. A small leakage does not do any harm, because a small quantity of water will be evaporated. A large leakage will not affect the working of the locomotive, but only the working of the superheater.

(5) The superheater requires very little attention, because its action is very even and no regulation is necessary. The work of the driver is not increased by the superheater.

The trials already made have been very satisfactory. The saving in coal was on an average 15 to 18 per cent., and in water about 20 per cent. It may be mentioned, that after opening the regulator the temperature of the superheated steam increases very quickly, and can be kept very even with a good fire, and that after closing the regulator the temperature decreases very slowly (per minute about $1\frac{1}{2}^{\circ}$ C.), so that on starting again there is always superheated steam.

This system of superheater is in use on several sections of the Prussian State Railways, and also in Baden, Bavaria, Italy, Hungary, and Switzerland.

It has been found in practice advisable to provide means for circulating a little steam in the apparatus when the engine is not working, and this is effected by a simple arrangement of pipes and controlling valves.

The Cole Superheater.—The firm of the American Locomotive Company and several of the Canadian and American Railways have been well to the fore in the application of superheating apparatus to locomotives, a large number of engines having been fitted with the Schmidt apparatus, but besides this Mr F. J. Cole, lately Motive Power Superintendent of the New York Central and Hudson River Railway, but now Chief Engineer of the American Locomotive Company, has introduced another design of superheater which is now employed for a large number of engines, in many cases on lines also employing the Schmidt apparatus.

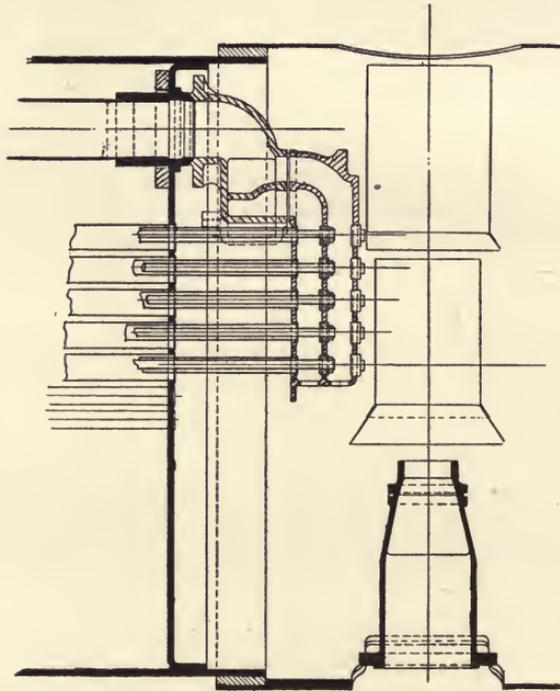


FIG. 141.—Smokebox Arrangement—Cole Superheater.

Figs. 141, 142, and 143 illustrate the arrangement first employed in 1904.

The upper rows of boiler tubes are somewhat larger than the others, and into them extend two concentric tubes, connected respectively to two chambers formed in a header casting mounted in the smokebox, the other ends of the outer tubes being closed (as shown separately in fig. 143), while the inner tubes terminate a short distance before the end is reached, so that the steam can circulate from one chamber of the header through the annular space between the two superheater tubes and return through the inner tube to the other header chamber, and thence to the cylinders. The superheater tubes are placed towards the top of the boiler tubes. The ends of

the outer superheater tubes are closed together and pressed to form arms which rest on the sides of the boiler tubes for supporting purposes (see fig. 143).

The smokebox header is built up in sections, as shown in fig. 142, connected together so that the complete apparatus can be readily fitted and removed with a minimum of trouble.

In later designs, still larger boiler tubes have been employed for the upper rows, and four sets of superheater tubes fitted in each, as shown in fig. 144. In this case a special fitting is employed to

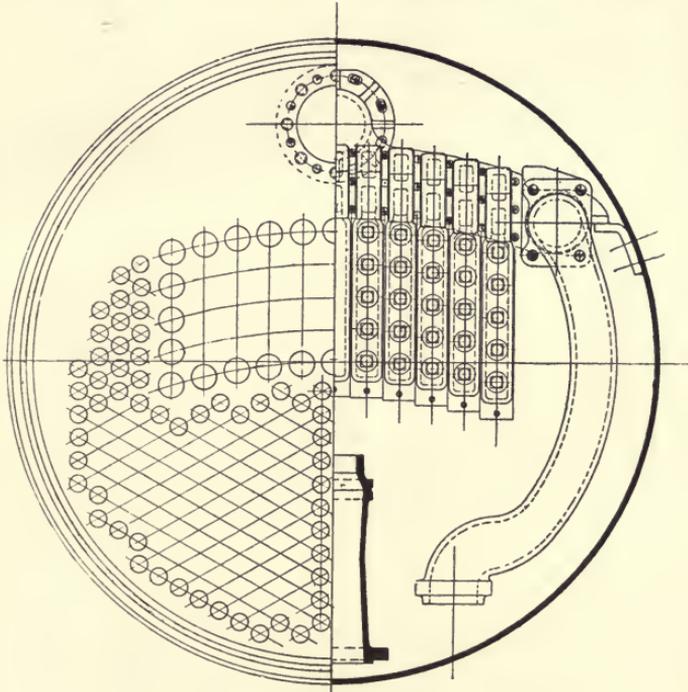


FIG 142.—Cole Superheater.

support the free ends, having legs whereby it rests on the sides of the boiler tubes.

In usual designs for large boilers, there are thirty-two large 5-in. boiler tubes, each containing four superheater double tubes, so that the heating surface available for superheating is considerable.

Superheating Apparatus on the Lancashire and Yorkshire Railway.—Two or three years ago several of the express engines of this railway were fitted with superheating apparatus arranged in a large smokebox formed by an extension into the barrel of the boiler. The superheater consists of a large drum, through which pass fire tubes slightly larger than those of the boiler, and the drum is divided up internally by diaphragms which cause the steam to pass internally up and down as it circulates through the apparatus.

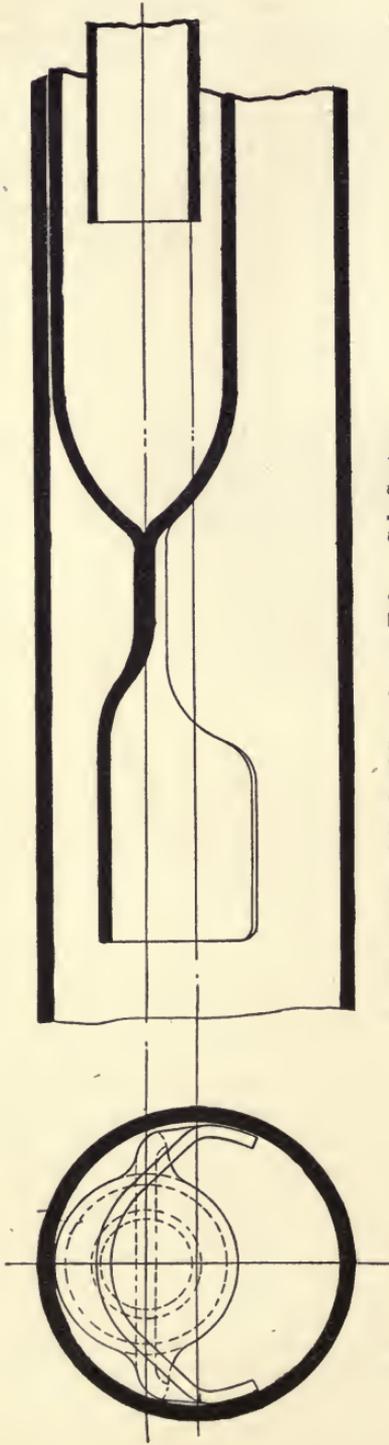
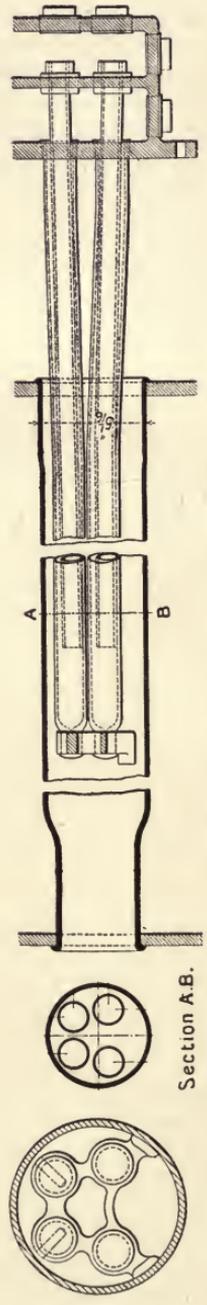


FIG. 143.—Closed Ends of Superheater Tubes—Cole System.



Section A.B.

FIG. 144.—Modified Arrangement of Superheater Tubes—Cole System.

These engines are also fitted with steam jackets to the cylinders, and in the upper part of the superheater is a coil in which the jacket steam is superheated.

The whole apparatus is so arranged that it can be bodily removed with little trouble.

With the exception of these engines, the only other British locomotive fitted with superheating apparatus is one recently equipped with the Schmidt apparatus on the Great Western Railway.

The Cockerill Superheater.—In connection with the extensive trials of superheating apparatus for locomotives carried out in Belgium already referred to, an experimental construction of apparatus has been designed by the John Cockerill Company of Seraing, Belgium, and applied to several engines, some of which were exhibited at the Liège Exhibition of 1905.

The following description is reproduced directly from Monsieur Flamme's report already referred to in connection with the Schmidt superheater.

"It was thought that a superheater placed partly in the barrel of the boiler offered some real advantages, as being lighter, less cumbersome, easy to clean and maintain, and its introduction does not necessitate any important modifications in the smokebox. Consequently it was this kind of apparatus that the Locomotive department adopted in a new type of powerful locomotive then being built in the Cockerill Works at Seraing.

"This apparatus was specially designed to enable trials to be made as to the advantages or otherwise of combining compounding and superheating, and it has been applied to a large and notable compound locomotive (described in Chapter XII.) built by the John Cockerill Company.

"The question to be settled was: Is it more economical to divide the superheater into two parts in such a manner as to raise the temperature at the entrance to both the high-pressure and the low-pressure cylinders, or, on the other hand, to devote the whole power of the apparatus to superheating the steam before it enters the low-pressure cylinders? The Cockerill Company, after numerous investigations, have just completed a superheater that will enable them to settle this question.

"This system is being tested on a series of compound engines with four cylinders and six-coupled wheels with a bogie.

"The apparatus for superheating the steam may be used in two ways. One may heat the steam near to the entrance to the high-pressure cylinder, and afterwards near to those of the low-pressure cylinders, or at the entrance of the low-pressure only. The superheater shown in fig. 145 indicates the general arrangement, comprising two series of large flame tubes containing the circulating pipes intended to superheat the steam. The rôle of the compartments C and H, placed inside the barrel, and the collectors J and D, installed in the smokebox, will be dealt with later on in connection with the explanation of the working of the apparatus. In B there

is a valve with three pistons intended to divert the steam coming from the regulator towards the compartment C, or into the tube L, according as it is required to operate the superheat to high-pressure

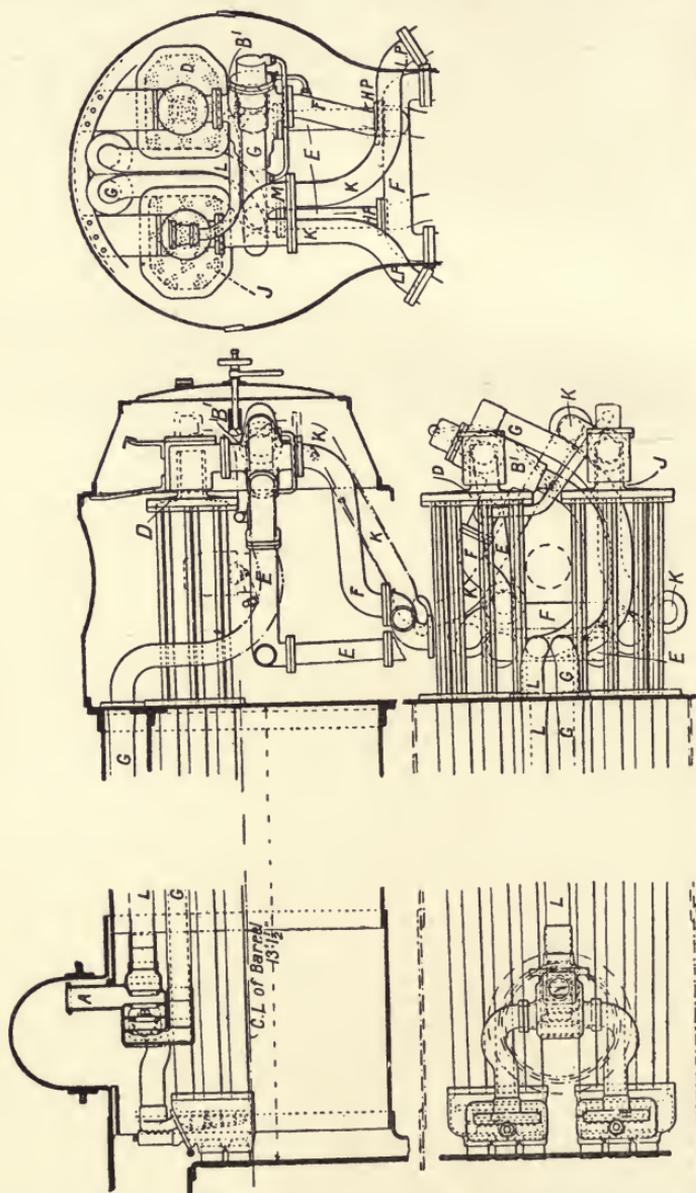


FIG. 145.—Experimenting Superheating Apparatus. Fitted by John Cockerill Company—Belgian State Railways.

and low-pressure, or to low-pressure only. The movements of the valve B are automatically repeated, owing to the presence in the tube L of an identically similar valve located within B¹. The

destinations of the different pipes is made clear by following the course of the steam as explained below.

*“First case.—Superheat at the entrance of high-pressure and low-pressure.—*The steam, on leaving the regulator A, makes its way, after passing B, towards the compartment C; from there it traverses the left set of superheater tubes and enters the collector D, whence it goes to the high-pressure cylinders by passing through the valve B' and pipe E. The superheated steam, after doing work in the high-pressure cylinders, goes out by the exhaust pipe F, and traverses the valve B', after that the pipe G, lodged in the interior of the barrel to enable it to enter the compartment H. From there the steam goes into the superheating tubes—the right set—and arrives at J, whence it passes by pipes K to the L.P. cylinders.

*“Second case.—Superheat at the entrance of the low-pressure cylinder.—*The valve B is placed by the driver in a position that diverts the direction of the steam directly from the regulator into the pipe L; from there it goes to the high-pressure cylinders after having passed through the valve B' and the delivery pipes E. On leaving the high-pressure cylinders, the steam traverses the pipes F, the valve B', and enters into the collector D. From the front it passes back through the left set of superheater tubes and arrives at the compartment C. From this it passes through the valve B into the compartment H, and traverses through the right group of superheater tubes, whence it goes into the collector J, and from there by the delivery pipes K into the low-pressure. A locomotive of type 19 bis, showing this pattern of superheater, is exhibited in the Liège Exhibition. Trials are going to be continued with a second identically similar engine to determine which is the more advantageous mode of working to adopt for the new superheater. It is manifest that if the superheat is required at the entrance of the low-pressure cylinders only, it will be possible to dispense with a certain number of parts of the superheater, and by that means remedy the obstruction in the smokebox.”

The results of these trials will be watched with great interest by locomotive engineers in all parts of the world.

The New Century Engine Company's System.—As an interesting corollary to the subject of the use of superheated steam for locomotives, a system of working which is now undergoing trial in Great Britain, and which may become a feature of locomotive engineering practice, is deserving of brief mention.

Superheating is principally intended for the purpose of preventing the condensation of moisture from steam as it falls in pressure, by providing a reserve of heat to make up to some extent for the inevitable loss of heat as the steam is used, and in the arrangements already described this is effected by heating the steam in superheating apparatus after it leaves the boiler, and before it is used in the engine cylinders. The system now under notice, however, goes further than this, and also introduces means of economical working in other ways.

According to the New Century Engine Company's system, air under pressure is mixed with the steam, both being heated before mixture, and also to a further extent after mixture. The result is that, as air is a bad conductor of heat, there is an interchange of heat units

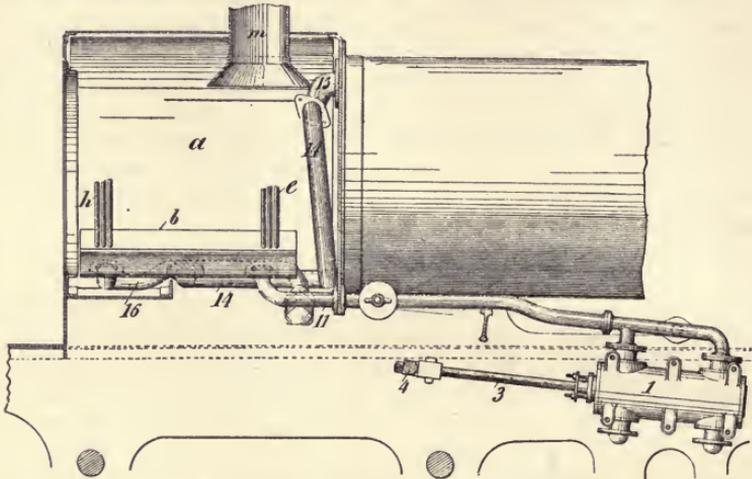


FIG. 146.—The New Century Engine Company's Steam and Compressed Air System.

between the heated air and the superheated steam, which has the effect of not only providing all the advantages attending the use of superheated steam, but also provides a motive fluid which appears from practical experience to possess peculiar advantages of its own.

The air pumps are, in the case of a locomotive, operated from the

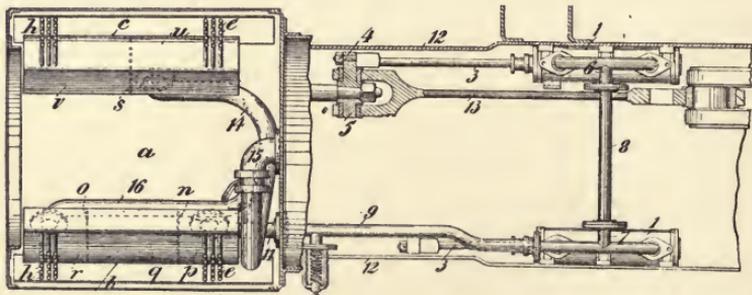


FIG. 147.—New Century Engine Company's Steam and Compressed Air System.

engine crossheads; and although this entails expenditure of work, it is returned by the working of the air in the cylinders in a large measure, owing to the expansion of air in the heater, and by the effect that the heater air has upon the superheated steam.

The heating of the air and the superheating of the steam are

obtained by utilising the heat of the escaping furnace gases, which is otherwise wasted, and absolutely no change in the boiler is required, so that there is no employment for devices which detract even in a slight degree from the heating surface of the boiler. It will therefore be seen that the advantage occurring from the heating of the air and steam is obtained without utilising any energy which would otherwise be available for direct steam generation or utilisation.

The apparatus comprises a special arrangement of heating coils and chambers in the smokebox, as shown in figs. 146, 147, 148. The air pumps are adapted to compress the air to a pressure slightly above that of the boiler steam; and when the steam and air are heated, the volume of the mixture is considerably increased, although maintained at an approximately uniform pressure. At starting, the engine works, of course, by steam alone, but as it continues working the steam is gradually and partially displaced from the apparatus by the air supplied at about the same pressure, and in working it is found that the relative proportions of air and steam become adapted very nearly to the varying requirements of work.

Air is admitted to the heating device whilst the air pumps are at work, and steam is admitted from the boiler to the heating device only when the pressure in the latter falls below the normal pressure due to consumption of the mixture by the engine. Thus the supply of air and steam to the heating device is self-regulating, the supply of compressed air depending upon the working of the air pumps, and the supply of steam upon the rate of consumption of the mixture in the engine, both supplies automatically stopping when the engine, and consequently the pumps, are stopped, and automatically recommencing when the engine is restarted. The proportions of this mixture are usually about one of air to eight of steam.

One of the chief advantages is the more complete prevention of cylinder condensation without injurious temperature, a temperature of 500° F. being more than sufficient, in the case of air and steam, to produce a high degree of economy under this head, whereas a temperature of 650° F. to 700° F. is probably required for pure steam as used in a superheater alone.

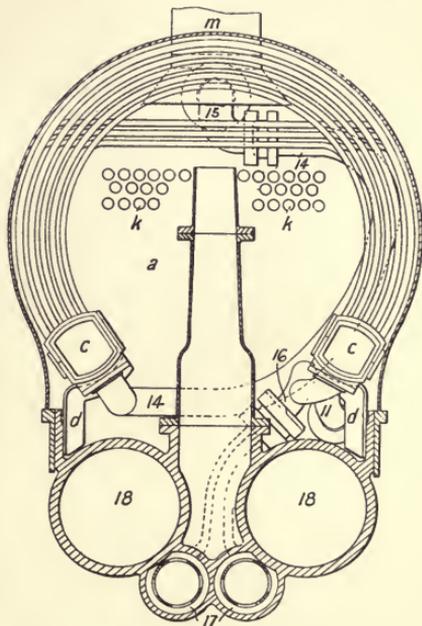


FIG. 148.—New Century Engine Company's Steam and Compressed Air System.

In the case of excessive pressure in the heater, which may occur on descending gradients, a relief valve is provided.

The apparatus comprises a system of tubes coiled round the smokebox and connecting chambers as shown, divided up so that steam is superheated in one section, air is heated in another, and the mixture is then further heated in the final section before it is sent to the engine cylinders.

This apparatus has so far been adapted to two small contractors' engines for elaborate tests, which have shown very favourable results, and it has been fitted for some time to a standard engine belonging to one of the large British railway companies.

The general system of using air and steam together under pressure is not a new one, for it forms the subject of many patents, but the system of working above briefly reviewed appears to possess advantages which may result in its extensive adoption in connection with locomotive and other steam engines.

Superheating Apparatus in New Zealand.—A type of superheating apparatus has also been adapted to a compound locomotive in New Zealand, the apparatus comprising a system of coils of piping arranged in a large smokebox.

In addition to the foregoing, a number of constructions of superheating apparatus for locomotives have been patented, but, so far as the writer is aware, no others have been actually employed.

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