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"LOCOMOTIVE PROPORTION AND PERFORMANCE."

BY

Mr. W. H. PEARCE, (Member).

From an engineering point of view the governing factor that makes for efficiency in the design of locomotives is the relative proportions of various parts that have to function together when under working conditions.

Several of these proportions can only be determined by practical applications, from which deductions can be made to form a rule that may be recognised as embodying the elements that will make for maximum efficiency according to the existing knowledge and anticipations of the designer at that period.

These notes do not profess to go outside the range of design exhibited on the Great Western Railway, and a few only can be embraced in the limits of this paper.

The magnitude of the present-day trains, i.e., weight, length and capacity, relative to the stock of only a few years ago, is often remarked upon by those interested in railways. Then it is realised that to move these about and maintain such a service, the locomotive must be an ingenious arrangement of mechanical ideas. A few of the more or less standardised items, which determine other details which make the efficient locomotive, will now be considered.

Under the heading of "Proportions," in any proposed modification, there should be a serious consideration that the nett result will be a decrease in dead weight, increased acceleration, decreased disturbing force on the rails, and minimum annual cost. The "Performance" of locomotives embraces the consideration in detail of the combined proportions that function together and give a nett result of a definite draw-bar pull when running conditions demand it.

It may be admitted that the cylinders and valve gear complete rate as the main functioning guide to all-round efficiency. The cylinder diameter relative to stroke (19in. diameter to 30in. strokes, or diameter only 63 % of stroke) has created a new ratio that has developed a confidence and a standard that may be taken as a well-tested limit to supersede previous ratios when the maximum power is required, within limits that would otherwise be more difficult to get. It must be considered also from the point of view of the method of producing the turning effort, that is, by the connecting-rod, since the ratio of rod length to stroke would merit a reduced stroke in some cases to obtain a reduced angular movement of the connecting rod.

Effective economical ratios in the cylinder itself need careful proportioning. For practical purposes in constructional design there is the initial limit of sufficient clearance between the piston and cylinder covers at each end of stroke. This is necessary to be $\frac{1}{4}$in., therefore a definite percentage of clearance space is defined. If this was the maximum it could soon be shown to be insufficient, due to the excessive compression that would result. To determine the limit of this percentage reference has to be made to indicator diagrams taken from an initial design where a steam port clearance volume is installed that approximates a theoretical percentage that will limit the compression to the proposed maximum boiler. pressure. In obtaining this volume an important point is the least area of steam passage, in relation to cylinder volume, to prevent or minimise any wiredrawing effects. An area of 1 square inch should be arranged for about every $\frac{1}{8}$ of a cub. ft. cylinder volume, and total clearance space at each end not more than 7 % of cylinder volume.

These proportions govern the ratio of expansion. For piston valves the full port opening- should be slightly in excess of least passage area, and this opening should be given by the valve for exhaust before the steam side of valve is open $\frac{1}{4}$ of an inch. When the valve is open to steam it should be supplied from a steam chest volume about $\frac{1}{4}$ cylinder volume, in order to maintain a reservoir action when the valve opens to steam at high speed. In two-cylinder engines rt. and lt. valves do not admit steam together up to 50 % cut off, thus it allows the steam pipes a moment of time to recover the supply from the steam chest. After 50 % they take steam together. Also when working at 75 % the opening to exhaust from one cylinder will cause a momentary back pressure in the other cylinder, which is also open to exhaust, due to both exhausting into a common blast pipe.

The exhaust passages from the valve should be nearly twice the area of least steam inlet passage, and maintained to the base of blast pipe. A gradual reduction of area can then be made until it conforms with any particular design of blast pipe top that may be adopted, this latter remaining standard without materially affecting the working of cylinder proportions.

This leads to the consideration of valve gear proportions, the next most important governor of efficiency, but reference to the author's previous papers must be made to get the necessary detailed summary.

The valve gear should be proportioned to give a valve travel in mid gear of not less than $12\frac{1}{2}$ % of piston stroke, and the lead not more than $\frac{1}{4}$in. The maximum travel should give a cut off of 77%.

In relation to these proportions the only true measure of efficiency can be ascertained by actual tests applied in a practical way to move the loads from one section of the line over unavoidable gradients, curves, &c., to any other section, where modern traffic demands it.

It is variations from these proportions on other engines that give different results in actual performance, and which have not proved to be so economical or efficient as G.W. engines.

The boiler and its proportion relative to the engine may be said to be more variable in its application. That is, for varying engine arrangements, the boiler can remain constant and still maintain highest efficiency. For instance, four types of boilers will meet the demands for twelve classes of engines. On each class of engine the necessarily varied working needs the maximum efficiency to be developed by the particular boiler applied to it.

For a range of heating surface from 1,200 to 2,000 square feet the range of tractive effort is from 18,000 to 35,000 lbs.

There are such limits as maximum working, and when this is attained each detail should be practically working at its maximum, allowing only for the standard factor of safety.

There are two distinct sections in a locomotive, each dependent on the other, the boiler and the propelling mechanism. The boiler is not the chief factor for maximum efficiency, although it may be the controller of maximum capacity. This seems to be the condition of events to-day, especially owing to the variable efficiency of the heat generating agents, for it can only be assumed that the locomotive relies entirely on the contents supplied to the tender for the firebox and boiler.

Of recent years this has been most forcibly verified, and different views are entertained on the consideration of a boiler. Adding heat to steam is a robber in some boilers of heat that should generate steam instead. To obtain superheat efficiency the heating surface of efficient non-superheater boilers should not be decreased. Maintaining pressures is the art of footplate engineers ; the training of these is as varied as the quality of fuel, consequently variability in the standard of steaming is not unlikely. Putting fuel on the fire is not difficult, but the combustion depends largely on the design of the firebox, ashpan, and smokebox. Good firing is a great asset to economy.

Considering the aspect of locomotive performance it must be understood that running conditions can be materially affected by the methods adopted prior to starting and during an average day's engine working. Modern conditions are not in all cases favourable to the men concerned for a definite booked portion of an engine's routine. This refers to the necessary preparation by other operators. This calls for good design in methods of lubrication to attain the expected results of those responsible for the preparation and control of the engine. Early experience of these items showed some men with the control of engines who were very conversant of the several items that make for maximum locomotive efficiency. A very practical and most reliable account of the actual result could be gauged, and the preparation arranged to give a very marked degree of economical working.

Some incidents have led to a general consideration of details, due to the gradual alteration from the working of one set of men to an engine, to the more recent demands of two or three sets to one engine throughout its trips in a week's work. The saving feature which permits of this is due to the fact that progress has been made in the perfect fitting of detail parts, and when adjusted or prepared by the running man from a lubricating point of view, each part or detail will automatically function to the anticipated results of the designer and to the satisfaction of the drivers, who endeavour to get the best results from the engine when they can see that the aim of all concerned has been to put into their charge practically, shall I say, a foolproof locomotive.

The methods of handling an engine on the road, even to do similar work, is unavoidably variable, due to the different drivers and engines. Then there is the class of engine that is allotted for the particular demands of any specified trains. This has apparently received every technical consideration, and to suit these varying demands it may be said that there is a design that will most effectively carry out specified requirements, and a consideration of these conditions can only fairly be given as a typical example.

Take, for instance, the Company's responsibility of a 220 mile one-stop run, starting at the outset with a load of 80 wheels, carrying $3\frac{1}{2}$ tons each, timed to do the first $6\frac{1}{4}$ miles in 12 minutes and negotiate a rising gradient of 1 in 42 for $2\frac{1}{2}$ miles, with the possibility of a signal check at the beginning of the gradient. This calls for experience in the correct manipulation of the engine power for each minute from the start. The fire has to be arranged for an immediate demand to generate steam at maximum rate, i.e., a gradual preparation of a full incandescent fire, uniformly glowing over the grate. This permits of a little and often supply of fresh fuel, which is the only method of charging the firebox to retain the heat, and which will allow the addition of coal without emitting smoke. When this condition of firing is attained, the designed proportions of the boiler will automatically maintain the requisite pressure. When tubes can be seen the fire is clean. The initial reserve of water in the boiler is usually 2in. above half glass ; this allows for small fluctuations in the supply from the injectors. The exhaust injectors are calibrated to supply a little less than this maximum demand, thus permitting of a draw on the reserve of the 2in. to maintain full pressure ; then, when maximum working can be reduced, the injector will very soon recover the normal water level and approach the reserve again for any further heavy bank working. A quicker return to normal water level is still to hand by using the restarting injector in conjunction with the exhaust, but it is understood this is done at the expense of boiler pressure, and when this occurs the driver is called upon to exercise every available chance of steam economy in the methods of handling the controlling mechanism for regulator and cylinder efficiency. This is an art that should be the ambition of all drivers, and one which our Running Inspectors endeavour to impart to those handling the engines.

The particular train mentioned forms a good test for the working of a four-cylinder engine. To start this train is not any special problem, as the load is reasonable for the reserve of tractive effort capable from the engine. Being of the four-cylinder type, with cranks set at each quarter, it is clear that the maximum starting effort from any cylinder arrangement is available, as two cranks are at nearly half-stroke leverage, with an equal fore and back force for turning, thus leaving the axlebox guide pressure at a minimum. The pressure on the crank pin is only reduced by effect of connecting rod angularity, which throws extra and unequal pressure against the motion bars in relation to the ratio between crank and connecting rod lengths. The longest connecting rod exerts the greatest pressure as turning effort, and this is a most important ratio, as all else being equal, it is a serious loss to the engine that is fitted with the shortest rod.

Referring again to the working of an engine with the quoted train. When starting after a signal stop or bad check at the bottom of the bank, it is found that 90 % of the maximum effort of the engine is required to take the train over the summit. The maximum has been required on one or two occasions due to a check. A load of 300 tons (tare) was attached, and before reaching the top, maximum cut off position was needed, with full regulator. (Average train for the bank is 240 tons, engine at 55 % cut off, average speed of 30 miles per hour.) The gradual increase in cut off position is very effectively attained by the use of the most efficient method, the screw reversing gear. By any other method a momentary acceleration is introduced that produces slipping, which is a type of set back that cannot again be fully recovered in bank working. To reduce any variables whilst negotiating the bank, the necessary regulator opening is gradually obtained before altering or increasing the cut off position ; this leaves the steam chest pressure practically constant, only varying with the boiler pressure. Blowing off should be avoided, in order to reduce any tendency to the lifting of water or priming, when any extra demand is made from the steam chest, due to the increasing cut off position, which is the only governing variable to get the gradually increased power. It may be mentioned here that priming is chiefly due to the various impurities suspended in the boiler water, rather than over-filling.

After the bank, the average load does not absorb a very high percentage of the maximum engine power, as the next bank, although 1 in 38, is very short, and the approach being more gradual, it is possible to maintain a higher speed, and the average working would be less than 40 % cut off. Therefore it will be seen that the load can be increased, consequently it is often an advantage to increase the initial load to the maximum allowed for the smaller gradients, and assist the engine over the first heavy gradient. When the ruling gradients are 1 in 80 the load can be further increased to 460 tons, and these can be negotiated with a cut off at 33 %.

The performance of engines is also largely influenced by the timing of the trains from point to point. Engines of the same class often differ with regard to their running capabilities, and when those that run best are operated by some drivers the actual running time is less than the booked time. This result is noted by other departments, with the probability that the reduced time may be required of all engines, and so absorb the overall margin of reserve that is practically necessary to combat with temporarily increased tonnage of trains, adverse weather conditions, and the indifferent steaming qualities of coal. The latter has a great influence on the running times. On some occasions, with good coal, the non-stop run of 225 miles can be run with the boiler pressure easily kept: at the maximum and firedoors only two-thirds closed. With poor quality coal it is difficult to maintain the pressure at 80 % maximum with firedoors closed and only using the injectors at every available opportunity, including the extra filling of the boiler when on any falling gradient.

The working of the four-cylinder Compounds with superheater steam shows a marked improvement compared with saturated steam, but compared with a two or four-cylinder simple engine of equal tractive effort, the Compound loses on acceleration and maintaining speed on rising gradients. Adding power in the usual way by admitting more steam per revolution does not result in the same percentage of increase of work done compared with the working of simple engines. If forced beyond a set proportion the tendency seems to result in a self-contained check. If a small percentage of booked speed is sacrificed, then the extra power applied can be utilised for the rising gradients. Normal working is to keep the low pressure cut off position practically constant about 60 %, with high pressure set at 30 %, this amount giving a Receiver pressure of 25lb. at 60 miles per hour, boiler pressure 225lbs. per square inch. For any varied working to obtain increased power, the H.P. cut off only is increased from 30 to 50 %.

A further increase would be to add live steam to the receiver to get about 50lb. per square inch for the L.P. For the same steam addition the G.W. two and four-cylinder engines maintain a higher rate of speed for the same loads. Forcing the Compounds results in a check that suggests it may be due to some arrangement of details or proportions of constructional data. Possibly the explanation is the latter.

In the L.P. Cylinder, only steam up to 80lb. can be dealt with, and at high speed, giving 10 strokes per second, the exhaust is not so free to return to atmosphere at the necessary rate without unduly absorbing units of work from the piston. With simple engines the exhaust is proportionately higher in pressure and less in volume for any increased cut off, and therefore has an initial velocity that returns itself to atmosphere without absorbing so much expulsion power from any piston. Further, the proportions of exit are not so favourable with the slide valve arrangement as with a piston valve. Maximum valve travel is much less, resulting in a decreased port opening velocity, both for the exhaust and steam inlet. The small steam lap, giving a port opening to steam of .48in. at 40 % cut off, does not give a full port to exhaust until the crank is 5 degrees over dead centre. With G.W. proportions the opening to steam would be .66 and full opening to exhaust 18 degrees before dead centre. This and a few other modifications would give other results, from which could be determined the most efficient.

Larger fireboxes require more attention from the fireman, but other details require less attention to maintain their efficiency.

Injectors have become easy to manipulate; the water pick up only requires half a minute attention for each 2,500 gallons used; coal watering can be done when either injector is in use, and modern signalling only requires intermittent attention from the fireman, more especially with train staff or single line working.

Top clacks and steam valves leaking cause the injectors to remain too hot, consequently it decreases the necessary vacuum required by the steam and water when combining in the injector, thus preventing the accumulation of energy to force water against the boiler pressure. Cooling the injector by the feed water is a temporary cure.

It has been mentioned that engines of the same class often differ. This refers to necessary alterations when undergoing repairs. The engines when new are recognised by the initial cylinder diameter and coupled wheel diameter. At each general repair these are varied, cylinder diameter increased, wheel diameter decreased. These altered proportions result in an increased tractive force, and when these engines are working similar trains. to a new engine of the same class the balance of power is in favour of the older engines. Some drivers remark that the latest new engines are not so powerful as the earliest ones in service of the same class.

It might be contended that the G.W. efficiency is solely due to the use of high pressure steam 225lbs., but can it be denied that equal efficiency is also developed even by the rail motors in proportion to their load, &c., with 180lbs. ? Also, smaller locomotives with similar proportions (4,400 class) at 180lbs. boiler pressure prove to be equally good with all general loads, whether on the level or on the banks.

A few comparisons with other, or outside designs, have been experienced by the drivers of late years, but without exception the general result has been more firmly to impress upon the drivers that the Swindon design alone is what they must have to minimise their responsibilities in getting trains of maximum load over the road comparatively easily and in accordance with the booked times.

DISCUSSION.

In opening the discussion, the Chairman (Mr. Hawksworth) said he thought that all would agree with him that the Author had put before them some very valuable information, particularly so because it was the result of some years of his own practical experience. Very rightly he did not bring in differences between different Railway Companies which bring in different conditions. His remarks generally applied to our own design of locomotives. He laid stress particularly on the design of the cylinders and valve gear, because it depended very greatly on the design of the cylinders and correct proportion of the port areas and the movement of the valve. High compression brought about in the cylinders may be reduced by suitable dimensions of the valve. For instance, high compression can be reduced by putting a negative inside lap on the valve, but by doing this expansion is lost, and consequently power to the engine. From their experience the best arrangement was to have no inside lap at all. There was another point which was very frequently overlooked by locomotive engineers, it was not only necessary to get the steam into the cylinder quickly, but also necessary to get it out quickly, especially at high speed. In other locomotives, very often due to this being overlooked, they were very sluggish at high speed. With exhaust opening at 65 % or earlier than that, it depended absolutely on long valve travel, and if a long valve travel is resorted to for that purpose it must have a long lap. That was the case with the G.W. engines, and was the reason why a long lap was adopted, to get steam out quickly at the early cut offs. The points put before them were valuable, because they went to show that a locomotive was not merely a matter of book theory, but depended to a very large extent on experience in running. The ratio of the port area to the cylinder volume depends to a great extent on practical experience of previously designed engines, and that had had to be bought. Another small point which it was practically impossible to work out by any known theory was the area of air space to a fire grate. Those were two instances which showed that it was not possible to design a locomotive from a text book, and that was why he felt the paper was especially valuable.

Mr. C. T. Cuss said it was rather interesting to note the proportion that, the Author was laying stress on, cylinder diameter to stroke, the diameter being something like 63 % of the stroke. He thought Mr. Churchward was the pioneer of the long stroke locomotive steam engine in England. Since then the petrol motor had become affected with the same features of design.

Mr. F. J. Bearman said he should like to ask, with regard to G.W. engines, what was the usual cause of failure in going up banks, the, failure of the boiler to supply steam or the wheels not being able to grip the rails properly.

Replying to Mr. Bearman, the Author said that things were so arranged that such things as failures in going up banks did not happen—not recognised failures. Given the load which was stipulated for that particular engine there was no question of failure going up a bank. It varied with the length of the bank. If the bank was three miles the load would be much lighter than if the length was only one mile.

Mr. E. H. Gooderson, speaking of simple and compound engines, said that other engineers had asked why railway engineers keep to the simple type. He would like to ask why it was not possible to get a compound or even triple expansion locomotive with high efficiency ?

Replying to Mr. Gooderson, the Author said that with reference to the working of compound engines the difficulty seemed to be a self-contained check ; and judging from the running point of view it comes back to the low pressure cylinder not doing the maximum amount of work designed for it. That would be due to not having condensers fitted. In marine work there are condensers, and that was the secret of the success, whereas in a l ocomotive, if the pressure in the low pressure cylinder is increased, additional back pressure is developed in the high pressure cylinder, and when the exhaust occurs there is no assisting vacuum. Two or three pounds reduction of back pressure to low pressure means a great increase in power.

Mr. C. Hinton said that recently the exhaust steam injectors had been removed from the 4,200 class engines when they came in for repairs and replaced by a second live steam injector. He would like to know why this had been done. He said he supposed that in the designing of engines the great difficulty was in the balancing and in calculating stresses due to inertia of reciprocating parts. Steel was a heavy metal, and in aircraft during the war, aluminium alloys were developed with very high tensile strength. He believed the alloys used in dirigible work had a tensile strength of 35 tons. Was there not a possibility of such alloys being effectively employed in locomotive work? Could they be substituted for steel in connecting rods, reducing the overall measurements of the rod, because the chief stress in the connecting rod was due to its inertia?

Replying to Mr. Hinton, the Author said that, speaking of the question of exhaust injectors on various engines, tests had been made with engines that did not work for over 15 miles per hour for 20 minutes, when it was found that the efficiency of the exhaust injectors was very greatly decreased. With engines waiting about so much the exhaust injector saving becomes very small. It had been balanced by putting restarting injectors on both sides of the engine. With regard to the balancing of engines mentioned by Mr. Hinton, he thought this was rather outside the range of the present paper. The question of expense would come in. For such a big thing he did not think aluminium would suit, though it might be used where the stresses were all in one direction.

Mr. G. BULKELEY, of Paddington, said their friends the amateurs, who write in the *Railway Magazine*, and in other papers, usually referred everything in the way of locomotive practice to miles per hour and tons behind the engine. Locomotive valve gear did not know anything about miles per hour or drawbar pull. The only thing it knew about, if it could think, was that the wheels were going round a certain number of revolutions per min., a certain position of the reversing lever, and more or less steam corning from the regulator valve. Looking at it from the point of view of the valve, cylinder pressure was affected, especially at high speeds, by more things than regulator opening and point of cut off. For a fixed cut off, say 25 %, or anything you like to get, it was easy to imagine a certain number of revolutions per min. where wire drawing would be the determining factor in steam distribution. That being so there must be a critical degree when steam will be distributed to the best advantage. At the present time, when engines having such different wheel diameters as the 4.6.0 Court class engines and 2.6.0 5ft. 8in. wheel engines, are both run on the same express trains at the same schedule speeds, it is almost impossible to use the same design of valve for the two types of engines owing to the presence of that critical speed for steam distribution, and while we can use a standard cylinder for engines, the design of the valve must vary if we are to get perfect steam distribution. He would like to know what the G.W. practice was in that respect, and what difference there was in their steam lap and the inside clearance in the valves used on the 6ft. 8in. two-cylinder and the 5ft. 8in. engines.

Replying to Mr. Bulkeley, the AUTHOR said that the steam lap and the proportions of the valve and the cylinder were the same. A general rule is to allow a maximum speed in M.P.H. equal to driving wheel diameter in inches. Time taken over specified distances with various engines should be based on wheel diameter ratio, thus keeping the piston speed constant, when each engine is working at its maximum rate. This permits the adoption of the same design of valves and cylinders, which functions correctly at the critical piston speed, although the speeds in M.P.H. are variable.

Mr. K. J. COOK said he would like to refer to one point which was mentioned, that was the actual failure on a bank ; also they had heard a lot, in conjunction with what had been said about climbing, as though that was the chief point. From London to Savernake, where there were no startling rises, was none the less a severe test to keep time. Working up a bank was more a test of the engine than the boiler. From London to Savernake was a severe test on the boiler. There was very little opportunity of cutting off the injector if the pressure started falling, whereas on a stiff but comparatively short bank it is generally possible to shut off the injector to maintain full pressure if necessary.

The AUTHOR said that on a slight rising an engine could take a 475 tons train 60 miles per hour average speed with the gear kept at 23 % cut off and a smokebox vacuum of 6in. 2.8.0 class engines could keep up 27 miles per hour with a train of 860 tons, and could be kept going on 17 % cut off on a slight rise. A 5ft. 8in., which ordinarily gives 36 miles per hour, could be kept with 800 tons still in 17 %.

Mr. H. G. KERRY said that in the paper mention was made of the difficulty of keeping the boiler pressure up to as much as 80 % of the blowing off pressure ; also, running down banks, it was possible to give the boiler an extra filling in order to get a reserve for any future heavy working. With the ordinary exhaust injectors taking water in cold, by the time it reaches the boiler he believed the temperature rose to about 200 degrees F. He did not know if the Author had had any experience with a feed water heater, and how it compared with ordinary injector working. If a feed water heater could be used, would the temperature at which this water was delivered be greater than the temperature of water delivered by the injectors? Also, is there any saving or any excess consumption of steam by using the pump by which the heated feed water is delivered to the boiler, compared with the injectors? Did injectors on condensing tank engines fail, due to the rise in temperature of the feed water?

Replying to Mr. Kerry, the AUTHOR said he could not assist him with any information with regard to the feed water heaters, only by information from books, which he never quoted in papers. The feed water from the injectors is 200 degrees. With the top feed there seemed to be an increased temperature before it actually combined with the boiler water. One or two tests had been made in some instances, when working under the maximum, and the injectors had fed too much for the boilers, whereby some water from the delivery of the injector could be taken back to combine with the feed water in the injector. You could decrease the feed water to a certain degree, with the result that the feed water temperature into the boiler is increased. This could only be done within the limits of a decrease in delivery to the boiler of about 15 % total capacity of the injector and the increase in water up to 20 degrees more, which was favourable. It meant a little extra complication, and it was onlv required under very special difficulties, and it had never been adopted, but had been shown that it could be done. Speaking of the condensing on engines working through tunnels he said the back pressure was less and the exhaust orifice from the cylinder into the tanks was more than normal. The blast pipe back pressure was therefore really less, and the men generally got a fair tank of water for the steam to condense into, and the increase in temperature was not sufficient to cause the injectors to fail.

Mr. O. Barker said he thought they ought to be greatly obliged to Mr. Pearce for the interesting paper, especially from a running point of view. It was very good of him to place the benefit of all his useful experience at the disposal of all the members of the Society. He thought that the diagram referring to gradients would be very useful if it could be made up as a chart and referred to. If given a certain type of engine, what load would go up a certain gradient could be readily ascertained. He thought it would be a very useful thing for the shed.

Mr. Cuss said that he gathered from the paper that the chief point the Author had tried to make was that the locomotive design, proportion and performance should be such that under ordinary conditions that most people imagined, a locomotive must work at reasonable efficiency between 25 and 60 miles per hour with a fair load of vehicles behind it, whereas those were not the conditions which governed the design of the locomotive at all. The locomotive had to get through, and the conditions and proportion have to be such that it will get over all the bad stops with bad gradients, signals against it, and one hundred other things. It was to meet those conditions, and it was chiefly for those reasons, that the locomotive was as it is to-day. It was very largely based on practical trials and experience rather than text-book practice, which did not take all these factors into consideration. It was built up, and hence, when you had gone from one locomotive that would take a certain range of work, it was necessary to step to the next that would take another range of work. The design of the whole was governed by the exceptional conditions existing perhaps for a quarter of an hour during the day's work. He would like the Author to confirm that that point of view was one of the chief factors on which the paper was based.

Mr. A. T. Cheesly said they found that different Railway Companies had different ideas of what the proportions should be, and no doubt each thought their own the best. An American railway engineer had recently started to build, or rather design, a locomotive on standardisation. It seemed to him that unless they could condense actual trials and experience and get real formulæ which were more or less applicable under a certain range of conditions, that the whole of the design of locomotives must be narrowed down to the peculiar conditions of each individual Railway Company. Hence, without a doubt, the day was far distant when we should see a standard locomotive. He said perhaps the author could give them some idea of the proportions of the proposed standard locomotive. At the tail end of the war everybody was talking about the locomotive that was going to be built like Ford cars to certain fixed proportions. Again, too, even on their own system there were many changes in very particular items.

The CHAIRMAN said that he would like to answer Mr. Cheesley's question about the standardisation of locomotives, as he himself had a great deal to do with it in connection with the proportion of locomotives. The Locomotive Superintendents met together and agreed upon various debatable points, and adopted the two-cylinder 2.6.0 class engine. The proportions of the cylinders were going to be $20\frac{1}{2}$ x 28. This was a compromise, as up to that time most Locomotive Superintendents were for 26in. stroke. The pressure was to be 180lbs. per square inch. It was recognised that all boiler shops were not so progressive as the G.W.R., and that it would not be possible to impose a pressure of 225 on other Railways. But the whole thing came to nothing, because to make a standard engine it had to be manufactured like Ford cars and possible to run on any railway. The limitations imposed by the smallest load gauge were so serious that it was agreed to drop the question until the engineers had come together and agreed to enlarge their bridges, &c., and to agree to the standardisation of permanent way, load gauges, &c., and until something was done in that direction it would be a long time before they had a standard locomotive.

Referring to Mr. Barker's suggestion regarding the chart on gradients, the AUTHOR said it would be an advantage to have it summarised in some form. The men who settled the loads might like such a condensed form, and run through it for any particular run in any section. With regard to the remarks made by Mr. Cuss, it was not a question of taking anything from text-books. Several of the proportions could only be judged by actual experience. The whole thing was based on actual outside practical results of modern engines based on a continuous test of 225 miles without a stop.

Mr. E. H. GOODERSON raised a question regarding the efficiency of locomotives. He said that it seemed that the speed of a locomotive was 200 revolutions per minute. Was that the most efficient speed ? If you could run the engine slower and have bigger wheels, as the case may be, would you get more efficiency? What proportion or diameter of wheels was most efficient for 60 miles per hour? With regard to motors the gear got over that. With an efficient engine running on a flat road, when a gradient is reached a gear is put in, and the engine still runs at an efficient speed.

With regard to the maximum speed rate and the diameter of the wheel, the Author said the piston speed was the same, based on the diameter of the wheel and miles per hour, whether with a big or small wheel.

Answering a question regarding the alteration of the boiler on 4,700 class engines, the Author said that the capacity of the boiler originally fitted to that particular class of engine was not quite sufficient to maintain the heavy working required.

Mr. H. G. Kerry said that on two or three occasions when he had been riding in the first and second coaches, chiefly behind a 4,700 class of engine, he found a considerable longitudinal motion, "to and fro," transferred from the engine to those coaches. Was that due to the short connecting rod on that type of engine, and could it be got rid of by balancing the engine differently? If so, would it make the engine ride "rough"? Did tight or loose couplings reduce this ?

The Author said that in investigating cases of this kind it was frequently found that loose couplings from the tender to the first or second coaches were to blame. Another cause was that perhaps the driver was working at too small a cut off with too much regulator for that particular weight of train. Other than those two things, tight couplings or the driver keeping the lever back, it would be practically nil. In some cases just before a general repair it is necessary to work at 30 % cut off with regulator reduced as far as possible. If worked with an engine just out of the shop at 18 % cut off and regulator open about half, the horizontal motion would be reduced. In the former case, if it was brought back to regulator off, the "to and fro motion" would still be excessive, largely due to the effect of compression on slightly worn bearings. Putting the lever in a later cut off position would effect a further reduction.

In closing the discussion, the Chairman said he must say that, although the paper was most valuable, the discussion was no less valuable in bringing out several very important points.