ON DOUBLE CYLINDER PUMPING ENGINES.

BY MR. DAVID THOMSON, OF LONDON.

The Double Cylinder Pumping Engines referred to in the previous paper by Mr. Pole as having been erected by Messrs. Simpson at the Lambeth Water Works, Thames Ditton, were designed and executed under the superintendence of the author of the present paper, in which it is intended to give a general description of the engines, with a few practical remarks suggested by the experience of their performance.

The general arrangement of these engines is shown in Fig. 1, Plate 70. They are beam engines, having the double cylinders A B at one end of the beam, and a crank C and connecting rod at the other end; four engines of 150 horse power each are fixed side by side, arranged in two pairs, each pair working on to one shaft, with cranks at right angles, and a flywheel D between them. The strokes of the crank C and of the large cylinder A are equal; while the small cylinder B, which receives the steam direct from the boiler, has a shorter stroke, and its effective capacity is nearly one fourth that of the large cylinder. The pumps E are connected direct to the beams near the connecting rod end by means of two side rods, between which the crank C works. The pumps are of the combined plunger and bucket construction, and are thus double-acting although having only two valves: the author believes that this kind of pump, which is now in general use, was first introduced by him at the Richmond and Bristol Water Works in the year 1848. The following are the principal dimensions of the engines:—

Diameter of large cylinder	46 ins.
„ small cylinder	28 ins.
Stroke of large cylinder	8 ft. 0 ins.
„ small cylinder	5 ft. 6 $\frac{3}{4}$ ins.
Diameter of pump barrel	23 $\frac{3}{4}$ ins.
„ pump plunger	16 $\frac{1}{2}$ ins.
Stroke of pump	6 ft. 11 $\frac{3}{4}$ ins.
Length of beam between extreme centres	26 ft. 6 ins.
Height of beam centre from floor	21 ft. 4 ins.

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The principal peculiarity of these engines is in the valves and valve gear : the valves are so constructed that one valve effects the distribution of the steam in each pair of cylinders. Fig. 2, Plate 71, is a vertical section through the centres of the two cylinders and valve, which are drawn as if situated in the same straight line, for convenience of illustration ; but the correct position of the valve in connexion with the two cylinders is shown in the sectional plans, Figs. 3 and 4, Plate 72, taken through the steam ports of the large and small cylinders respectively. The valve F, of which the top end is shown enlarged in Fig. 7, Plate 73, consists of four small pistons GG, 14 inches diameter, connected together by a pipe H which forms the passage whereby the steam is conveyed from one end of the small cylinder to the opposite end of the large cylinder. The action of the valve is shown by the two diagrams, Figs. 5 and 6, Plate 73, which represent its two extreme positions at the commencement of the up and down strokes. The steam from the boiler enters the annular space I surrounding the middle of the valve ; and the communication with the condenser J, Fig. 1, is at KK, beyond the top and bottom ends of the valve. With the valve in its lowest position, as shown in Figs. 2 and 5, Plates 71 and 73, the steam from the boiler is admitted into the bottom of the small cylinder B, for making the up stroke ; and the steam from the top of the small cylinder is exhausted through the hollow pipe H of the valve into the bottom of the large cylinder A, while the top of the large cylinder exhausts direct into the condenser, beyond the top end of the valve. Figs. 6 and 7, Plate 73, show the valve in its highest position, for admitting the steam in the corresponding manner at the beginning of the down stroke.

The cylinder ports are rectangular, with inclined bars across the faces to prevent the packing rings of the valve from catching against the edges of the ports : and the bars are made inclined instead of vertical in order to avoid any tendency to grooving the valve packing. The openings of the port extend two thirds round the circumference of the valve in the ports of the large cylinder, as shown in Fig. 3, Plate 72 ; but they extend only half round in the ports of the small cylinder, as shown in Fig. 4. The packing of the valve consists of the four cast iron rings GG, Fig. 7, Plate 73, which are cut at one

side exactly as in an ordinary piston, the joint being covered by a plate inside. A considerably stronger pressure of the rings against the valve chest is required than was at first expected, because the openings of the steam ports extend so far round the valve; and for this purpose springs are placed inside the packing rings to assist their own elasticity. This construction of valve has the advantage of admitting of great simplicity in the castings of the cylinders; and also allows of the whole of the valve work being executed in the lathe, which is generally both the cheapest and most correct kind of work in an engineering workshop. These valves are worked by cams, which are not well adapted for engines working at high speed; and this led the author in the construction of some recent double cylinder engines to adopt valves and valve gear of a different construction; but he has not been able to design any which surpass or even equal these in the economical distribution of the steam.

The principal object aimed at in the construction of this piston valve was the reduction to a minimum of the loss of pressure which the steam undergoes in passing from the small cylinder to the large one. This is here accomplished by making the passage of moderate dimensions and as direct as possible; and also by preventing any communication of this passage with the condenser, so that when the steam from the small cylinder enters the passage, the latter is already filled with steam of the density that existed in the large cylinder at the termination of the previous stroke. In constructing the engines some doubt was entertained as to the best size of passage, in order on the one hand to avoid throttling the steam, and on the other to obviate as much as possible the loss of steam in filling the passage. The size adopted was a pipe 6 inches in diameter, or 1-60th of the area of the large cylinder, for a speed of piston of 230 feet per minute in the large cylinder; and this is believed to be about the best proportion, the entire cubic content of the whole passage in the valve amounting to 3944 cubic inches. The indicator diagrams, Figs. 8 to 11, Plates 74 and 75, show that with this construction of valve there is very little or no throttling of the steam; and also that there is but a very moderate drop in the pressure as the steam passes from the small cylinder into the large one. In this respect the valve completely

answered the expectations entertained of it, and left little further to be desired on this point.

The accompanying indicator diagrams, Figs. 8 to 11, Plates 74 and 75, taken from the Lambeth Water Works engines, show the action of the steam throughout the stroke.

In Fig. 8, Plate 74, the upper diagram is that taken from the bottom of the small cylinder, and the lower is the corresponding diagram from the top of the large cylinder. Fig. 10, Plate 75, is the diagram taken at the same time from the top of the small cylinder, to which however there is none corresponding from the bottom of the large cylinder; but as the diagrams from the two ends of the small cylinder so nearly correspond, it may be presumed that a diagram taken from the bottom of the large cylinder at the same time would have been very nearly the same as that from the top, shown by the lower diagram in Fig. 8.

In Fig. 9, Plate 74, the upper diagram is that taken from the top of the small cylinder, and the lower is the corresponding diagram from the bottom of the large cylinder; while Fig. 11, Plate 75, is the diagram taken at the same time from the top of the large cylinder, to which however there is no corresponding diagram from the bottom of the small cylinder. The dotted lines in Figs. 8, 9, and 10, represent the exhaust line in the small cylinder reversed, so as to show by direct measurement of the distance between this and the top line of the diagram what is the effective or working pressure on the small piston at any part of the stroke.

In order that these diagrams may be compared with theory, it is necessary to know the cubic contents of the cylinders with the given lengths of stroke, of the clearances at the ends of the cylinders, and of the different parts of the steam passages. The following are the capacities of these spaces:—

	Cub. Ins.	Cub. Ins.
Capacity of small cylinder, 5 ft. 6 $\frac{3}{4}$ ins. stroke		40870
Clearance at end of small cylinder	308	
Space in port between valve and small cylinder	805	
Total space between valve and small piston		1113
Capacity of large cylinder, 8 ft. stroke		159542
Clearance at end of large cylinder	831	
Space in port between valve and large cylinder	2844	
Total space between valve and large piston		3675
Capacity of all passages in valve		3944
Sum of last two capacities		<u>7619</u>

Hence the steam escaping from the small cylinder has to expand into an additional space of 7619 cubic inches before it reaches the large piston.

The following table shows the principal results deduced from these indicator diagrams, in the calculation of which it has been assumed that the space occupied by the steam when expanded is inversely as the pressure; and also that the valve and pistons were steam-tight when the diagrams were taken, which is believed to have been nearly the case. For the sake of simplicity also the steam enclosed in the valve passage has been neglected, and the passage is supposed to be empty when the steam from the small cylinder enters it. The effect of the clearances and steam passages has been taken into account in calculating the expansions.

These indicator diagrams show in different degrees a few results which the author has constantly observed in all the indicator diagrams he has taken from double cylinder engines. In the first place, the pressure of the steam at the end of the stroke, instead of falling short of what it ought to be by the theoretical expansion curve, always exceeds that amount. In Fig. 8, Plate 74, this excess is as much as 30 per cent., and in Fig. 9 it is 23 per cent. of the actual final pressure. This fact has been often observed before to a smaller extent in single cylinder engines, and has been said to be peculiar to cylinders without jackets or external means of keeping up their heat. But in this case both cylinders were jacketted, and the jackets were supplied with steam of a higher pressure than the maximum pressure in the cylinders. It might be supposed that the increased pressure at the end of the stroke

*Table of Results**Deduced from the Indicator Diagrams, Figs. 8 and 9, Plate 74.*

	Fig. 8.	Fig. 9.
1. Percentage of stroke at which steam is cut off in small cylinder	25 per cent.	40 per cent.
2. Total expansion at end of stroke in small cylinder, in terms of bulk before expansion	3.78	2.41
3. Amount of expansion on passing from small to large cylinder, in terms of bulk before escaping from small cylinder	1.18	1.18
4. Total expansion at end of stroke in large cylinder, in terms of original bulk	15.15	9.66
5. Total amount of efficient expansion, in terms of original bulk	12.80	8.19
6. Total pressure of steam per square inch at point of cutting off	32 lbs.	41 lbs.
7. Theoretical total pressure at end of stroke of small piston	8.4 lbs.	17.0 lbs.
8. Actual total pressure shown by diagram	10.6 lbs.	18.0 lbs.
9. Excess of actual over theoretical in percentage of actual pressure	21 per cent.	6 per cent.
10. Theoretical loss of pressure in passage from small to large cylinder	1.7 lbs.	2.6 lbs.
11. Actual loss shown by diagram	2.5 lbs.	4.5 lbs.
12. Theoretical total pressure at end of stroke of large piston	2.1 lbs.	4.2 lbs.
13. Actual total pressure shown by diagram	3.0 lbs.	5.5 lbs.
14. Excess of actual over theoretical in percentage of actual pressure	30 per cent.	23 per cent.
15. Mean pressure on crank pin from both cylinders	15240 lbs.	22400 lbs.
16. Maximum ditto	27838 lbs.	36058 lbs.
17. Ratio of maximum to mean	1.83 to 1.00	1.61 to 1.00
18. Ratio of maximum to mean pressure on crank pin in a single cylinder engine with the same total amount of efficient expansion (art. 5), the clearances and ports bearing the same proportion to working capacity of cylinder, namely 1-40th part; this ratio is calculated from the ordinary logarithmic expansion curve	4.00 to 1.00	2.75 to 1.00
19. Efficiency of steam contained in large cylinder at end of stroke, as shown by diagram, if used without expansion, taken as	1.00	1.00
20. Actual efficiency of same steam as employed in both cylinders, as shown by diagram	2.70	2.90
21. Theoretical efficiency of same steam if expanded to same degree as total amount of efficient expansion (art. 5)	3.56	3.10

was due to the heat imparted from the jackets either superheating the steam or converting the watery vapour mixed with it into true steam; and probably the latter is the cause of a small part of the observed effect: but in the author's opinion it is not likely that sufficient heat could be communicated from the jackets to produce an increase of 23 per cent. in the actual final pressure, much less of 30 per cent. This is the more unlikely because on several occasions the condensed water from the jackets has been collected and found not to exceed half a gallon per hour. The experiments made on the quantities of water passed from the boilers give uniformly the result, that a considerably larger quantity of water passes from the boilers than is accounted for by the indicator diagram, taking the quantity and pressure of the steam just before it escapes to the condenser as the basis of calculation. In some trials made within a few days of the indicator diagram Fig. 8, Plate 74, being taken, the excess of water thus disappearing from the boilers was about 37 per cent. It appears however to the author that this constant excess of the actual over the theoretical final pressure of the expanded steam is still not satisfactorily explained. To suppose that the valve was leaking might account for it; but besides great care having been taken to avoid this source of error, it can hardly be supposed that the valve was always leaking more than the pistons.

Secondly, although the pressure of the steam in the cylinders in these engines always exceeds what would be given by theory, yet the loss of pressure in passing from the small cylinder to the large one always exceeds what would be expected from theory. This fact holds as universally as the previous, in the author's experience, although by no means to a uniform extent.

Thirdly, the table shows the great practical advantage that the double cylinder engine possesses in moderating the extreme strains on the machinery which are produced when expansion is carried to a great extent in a single cylinder: the maximum pressure on the crank pin from both cylinders is here only 83 per cent. greater than the mean in the diagram Fig. 8, and only 61 per cent. greater in the diagram Fig. 9. It is indeed impossible in practice to carry expansion in one cylinder to so high a degree as is shown in these diagrams. Although

single cylinder engines are frequently said to be expanding ten times, the author has not known any instance of their being so worked continuously, but only occasionally and experimentally; and in no case that he is acquainted with has the expansion ever been more than nominally to the extent of ten times, that is the steam has been cut off at 1-10th of the stroke from the commencement. In such a case the size of the valve passages and clearance of the piston amount to so large a proportion of the steam in the working part of the cylinder at the moment of cutting off that a nominal expansion of ten times is often in reality not more than six or seven times. In the small cylinder of the double cylinder engines now described the passages and clearances are reduced to a minimum, and are much smaller than in most single cylinders of the same size; and yet if the steam were here cut off at 1-10th of the stroke these passages would amount to one fourth of the volume of the steam contained in the cylinder at the moment of cutting off, and the expansion in this cylinder instead of being ten times would be only about eight times. This is a point too generally neglected in estimating the merits of different engines or discussing the results of indicator diagrams.

To ascertain the amount of friction in these engines the author has made many experiments, and has found that, when the engines are new and working at perhaps little more than half their power, the loss in comparing the work done with the indicator diagrams amounts to as much as 25 per cent. of the indicated power; but in these cases the pistons have been too tight in the cylinders, and when this error has been corrected and the engines worked up to their regular work all the losses are brought down to from 12 to 15 per cent. of the indicated power. This includes the friction of both the engines and the pumps, the working of the air pumps, feed pumps, cold water pumps, and pumps for charging the air vessels with air.

On the whole the author is of opinion that where expansion is carried to an extent of only three or four times, the single cylinder form of engine is simpler and better than the double cylinder; but where expansion is required to a much higher degree, the double cylinder presents the only way of carrying it out successfully in practice. When the double cylinder is adopted an ordinary expansion

of not less than ten times should be effected, if it is desired to get a result corresponding with the additional complication incurred. The theory of the action of steam jackets appears still somewhat doubtful, but there can be no doubt that with high expansion in two cylinders they are absolutely essential to a favourable economical result.

With regard to the economy of fuel attained by the double cylinder engines, it may be stated that the four pumping engines at the Lambeth Water Works are fixed in one house and are employed in pumping through a main pipe 30 inches diameter and about nine miles in length; and when all the engines are working together at their ordinary speed of 14 revolutions per minute, the lift on the pumps as measured by a mercurial gauge is equal to a head of about 210 feet of water. Under these circumstances they were tested by Mr. Field soon after being finished, in a trial of 24 hours' duration without stopping. The actual work done by the pumps during this trial was equal to 97,064,894 lbs. raised one foot high for every 112 lbs. of coal consumed; in addition to which this consumption included the friction of the engines and pumps, and the power required to work the air pumps, feed and charging pumps, and the pumps raising the water for condensation. The coal used was Welsh, of good average quality.

The economy in consumption of fuel during this trial and in the subsequent regular working of these engines, together with the satisfactory performance generally of the engines and pump work, induced the Chelsea Water Works Company and also the New River Company each to erect in 1854 a set of four similar engines, which were made almost exactly the same as the Lambeth Water Works engines already described, with the exception that a jacket of high pressure steam was in these subsequent engines provided under the bottoms of the cylinders, which had not been done with the previous engines. The pumps were also different in size to suit the different lifts.

The New River engines were tested soon after being completed, and the result reported was 113 million lbs. raised one foot high by 112 lbs. of Welsh coal. But this duty was obtained from a trial of only 7 or 8 hours' duration, which is too short to obtain very

trustworthy results; and similar circumstances the author believes have given rise to the extraordinary statements that have sometimes been made regarding the duty obtained from steam engines.

The set of engines made for the Chelsea Water Works was the last finished, and on completion the engines were tested by Mr. Field in the same manner as the Lambeth engines, by a trial of 24 hours' continuous pumping. The coal used was Welsh, as before, and the duty reported was 103·9 million lbs. raised one foot high by 112 lbs. of coal. This, as in the previous instance, was the duty got from the pumps in actual work done, no allowance being made for the friction of the engines and pumps, and the power required to work the air pumps, cold water pumps, &c. At the time of these engines being tested the loss by friction and by working the air pumps, &c., averaged about 20 per cent. of the power as given by the indicator diagrams; so that if the duty had been estimated from the indicator diagrams, as is usual in marine engines, it would have been $103\cdot9 \times \frac{100}{80}$ or about 130 million lbs. raised one foot by 112 lbs. of coal, which is equivalent to a consumption of 1·7 lbs. per indicated horse power per hour.

Mr. POLE said that in the investigation of the double cylinder engine he had been desirous of entering rather fully into its history, which had previously been involved in some obscurity. Few seemed to be aware of the extent of Hornblower's connexion with the engine, which was generally called Woolf's, although it was certainly Hornblower's invention; and the principle of expansion, one of the most important principles in the steam engine, was first introduced to the world in Hornblower's engine. The revival of this same engine at a subsequent period was due to Woolf, who simply applied high pressure steam to it, as was done also about the same time by Trevithick to the single cylinder engine in Cornwall; in the latter case the circumstances were so far different from those of other engines that the single cylinder engine was here undoubtedly the best for the purpose to which it was applied.

The double cylinder engine, as now practically carried out in the manner described in the paper last read, proved a very useful arrangement, by affording the means of carrying the important principle of expansion to a much greater extent than was practically possible in the single cylinder engine. In a single cylinder engine, when applied to pumping without a crank and flywheel, it was indeed possible to make use of a considerable degree of expansion, because the blow which then inevitably came at the commencement of the stroke was immediately absorbed by the inertia of the mass: but when the piston was controlled by a crank and flywheel he thought experience proved that it was scarcely possible to expand more than four or five times without producing a very great strain on the machinery; beyond that expansion the engine could not be made strong enough, and the blow was what no engineer would like to incur. This was made clear in the three theoretical diagrams exhibited, (Plate 69,) which were all constructed for the same total amount of expansion of the steam, namely six times. The first diagram showed that in the single cylinder engine the initial blow was 2.15 times the mean pressure throughout the stroke, and the force of the blow continued undiminished during one sixth of the stroke, after which the pressure dropped according to the regular expansion curve. The second diagram gave the combined effect of the two cylinders in the double cylinder engine, when the steam was kept on at full pressure throughout the entire stroke in the small cylinder: this was the original plan in the use of two cylinders, and the plan generally followed; but the diagram showed that the initial blow was here still the same as in the single cylinder engine, namely 2.15 times the mean pressure, the steam then passing at full pressure into the large cylinder at the moment of commencing the stroke; and although the pressure immediately fell off rapidly, instead of continuing during any length of the stroke, yet the machinery had necessarily to be made as strong as before, in order to stand the same initial blow, so that no practical advantage was gained. His object however had been to show in the paper that the initial blow might be greatly reduced and its injurious effect avoided by first expanding the steam partially through a portion of the stroke in the small cylinder, and then

completing the expansion in the large cylinder; and also to show that by the adoption of this plan a point of cut off could be found at which the initial blow would be reduced to the minimum. The third diagram gave the result of cutting off the steam at the most advantageous point in the small cylinder, namely 41 per cent. of the stroke, whereby the initial blow was reduced to the minimum, being then only 1.40 times the mean pressure throughout the stroke, instead of 2.15 times as previously, and the line was much more equable throughout the stroke, approaching much more nearly to the mean pressure; but an earlier cut off would have the effect of again raising the force of the initial blow. These theoretical results were fully borne out by the practical results obtained in the double cylinder pumping engines that had been described, in which the principle of expansion was now carried to a greater extent than would be possible in a single cylinder engine with crank and flywheel, and without being attended with the disadvantages that a single cylinder would entail.

The CHAIRMAN enquired what experience there had been as to the durability of the long cylindrical slide valve between the two cylinders in the double cylinder engine.

Mr. THOMSON replied that in the case of the Chelsea and the Lambeth Water Works engines the valves had proved quite as durable as the ordinary pistons made with metal packing rings were found to be. But in the engines at the New River Water Works the valves had not been so durable, nor had the pistons, and much inconvenience was suffered from this circumstance; the reason had been found to be some peculiarity in the tallow used for lubrication, which caused the substance not only of the valves but also of the pistons to become eaten away. Now however, in place of the tallow previously used, animal fat procured in an unmanufactured state had been employed for the last twelve months, which had produced a great improvement in the durability of the valves and pistons, and the metal was now not nearly so much acted upon as it was before.

The CHAIRMAN asked what was the initial pressure of steam at the commencement of the stroke, and also the pressure in the boilers: and whether the actual final expansion of the steam was really as much as fifteen times.

Mr. THOMSON replied that in the engines from which the indicator diagrams were taken the boiler pressure was 40 lbs. per square inch above the atmosphere, and the initial pressure of the steam in the small cylinder was 35 lbs. The expansion in the first indicator diagram appeared to be 16 times, if merely the point of cut off were taken into consideration; but by including the effect of the capacity of the ports the actual expansion was 15 times, and if the useless effect of the expansion of the steam into the valve between the cylinders were also deducted, the total efficient expansion was found to be 13 times nearly; that is the volume occupied in the cylinders alone by the steam at the end of the stroke was 13 times as great as at the point of cut off. The steam would therefore be in reality expanded to that extent if its expansion followed the regular logarithmic curve; but the indicator diagram showed that the final pressure at the end of the stroke was 30 per cent. in excess of the theoretical pressure corresponding to the total expansion of 15 times, and therefore the actual expansion was proportionately less.

Mr. J. GRANTHAM enquired whether the steam was superheated in the engine from which the indicator diagrams had been taken.

Mr. THOMSON said the steam was not superheated, except by the heat obtained from the steam jacket of the cylinders which was filled with steam at the boiler pressure.

Mr. J. GRANTHAM thought that would probably account both for the pressure of steam being raised at the end of the stroke above the theoretical pressure, and also for the loss of water from the boiler, which had been stated to amount to 37 per cent. in excess of the consumption of water as calculated from the volume of steam contained in the small cylinder at the point of cut off. This extra amount of water must evidently have been carried off from the boiler mixed with the steam by priming, and then became evaporated at the end of the stroke by the heat from the steam jacket: but if the steam had been superheated immediately on leaving the boiler, before entering the cylinder, no water would have passed over with it, and there would have been no loss of water from the boiler, while the pressure would have followed the regular curve during the expansion.

The progress of the application of expansion in the steam engine, of which so interesting an account had been given, was a remarkable history, and seemed to have been divided into three distinct eras, the original idea of expansion having virtually died out after its first promulgation, until revived in 1814 by Trevithick and Woolf in connexion with a higher pressure of steam; then it again fell into neglect, and the great majority of engines were worked with little or no expansion whatever; and it was only within the last few years that the subject had now been again revived. The principle of expansion was one of such great practical importance that it required the most attentive consideration in all classes of steam engines. He remembered seeing at Stroud about twenty years ago a small double cylinder engine of about four horse power, which had been put up about thirty years previously by Woolf himself; it was employed in a brewery, and had a large cast iron boiler with some cast iron tubes through it, and the boiler was apparently as good as ever after thirty years' work, during which it had been going on without repairs. The engine was working with high pressure steam, about 60 lbs. per square inch above the atmosphere, and showed a remarkable economy in fuel, quite unequalled by any of the numerous other engines employed in the woollen manufacture in that neighbourhood: the latter however, though good engines, were all worked on the common low pressure system, and in none of them was the use of high pressure steam with expansion ever adopted for about twenty years after the erection of Woolf's small engine. A second engine on the same plan was however at length put up there, of about 30 horse power, carrying out the principle of expansion with high pressure steam; and this engine had at the time he saw it been working for nearly ten years consuming only about $2\frac{3}{4}$ lbs. of coal per horse power per hour, whereas many engines in the neighbourhood were using as much as 12 lbs.: yet no one else had at that time attempted to repeat the engine, notwithstanding the extent of steam power employed in the neighbourhood. This was an illustration of the indifference with which so important a subject had been treated, and not in that district alone, but throughout the entire country; but now that it was again revived, the question could not be discussed too frequently,

not only as regarded manufacturing purposes, but more especially in reference to marine engines.

From an examination of the various steam engines exhibited in the present International Exhibition he was confirmed in the opinion that the expansive use of steam was much more fully carried out on the continent than in this country, probably arising from the greater cost of fuel there. On the continent the double cylinder engine was in common use and had been so for many years, and in some localities he believed it was used exclusively. It was moreover curious that in most of the descriptions given of these engines Woolf's name was associated with them; and foreigners generally seemed to look upon Woolf as the originator of the double cylinder engine, which strictly he was not, although he revived its use, and thereby probably did a greater service than even the original inventor, because he brought into use what Hornblower had not succeeded in establishing.

Since the time of Woolf's revival of the double cylinder engine, so great an advance had been made in the construction of stronger boilers and the use of a higher pressure, and in the introduction of super-heating, that there was now a better prospect of extending the adoption of this engine, in which expansion could certainly be carried to a much greater extent than in a single cylinder, as shown in the paper. But there was still much to be done in respect of increasing the pressure of steam in stationary and marine engines, in which at present the common practice was to use only about 25 lbs. pressure per square inch, whereas in locomotives the pressure was frequently as high as 150 lbs., and would probably be carried higher. If this pressure could be attained in marine and stationary engines, great economy of fuel would result; but the greater expense required in the construction of the engine in the first instance was in most cases the obstacle in the way of any high degree of expansion; and even where an engine was provided with separate valves for working expansively, the expansion valves had been abandoned, and the full steam kept on through the entire stroke, involving a wasteful consumption of fuel. The papers that had been read would he thought do much towards advancing the general knowledge of the value and practicability of the double cylinder arrangement.

In pumping engines indeed, such as had been described, the slow and deliberate action, and the careful way in which such engines were generally attended to, afforded peculiar advantages for carrying out the application of the double cylinder engine ; but there were other cases, especially marine engines, in which economy of fuel was evidently of far greater importance than in pumping engines, because the weight of fuel formed a limit to the load that could be carried : and to marine engines therefore the application of a high degree of expansion was particularly desirable. It was not necessary however to adhere closely to the arrangement of the double cylinders that was adopted for the pumping engines, which in many cases would be inconvenient, since it would necessitate either four cranks for two pair of cylinders, or else the use of a beam for each pair as in the pumping engines. In the marine engines shown in the Exhibition by Mr. Humphrys, similar to those working in the "Mooltan" with Hall's surface condensers, the small cylinder was mounted on the top of the large one and the same piston rod was carried through both cylinders, requiring some alteration in the arrangement of the passages to convey the steam from the small cylinder to the large one : but the short distance that the steam had here to travel from the bottom of the small cylinder to the top of the large one compensated for the long distance it had to travel from the top of the small to the bottom of the large cylinder, so that he believed there was altogether not much difference in loss of pressure in the steam passages between these engines and the double cylinder pumping engines shown in the present paper. There was also a small horizontal engine among the Belgian machinery in the Exhibition, designed for driving the gunboats of the Swedish navy, which had a small cylinder placed within a large one, with three piston rods, one from the inner piston and the two others from the outer annular piston ; the high pressure steam was admitted to the inner cylinder, whence it was conveyed to the outer low pressure cylinder by passages through the cylinder covers, with a considerable loss of pressure in the passages in this case on account of their length. In other respects the arrangement seemed good, and it was simple and well adapted for the purpose for which it was intended.

Mr. J. SCOTT RUSSELL said the introduction of a high degree of expansion in marine engines was greatly to be desired, but the difficulty attending it was the great strain thrown upon the machinery at the commencement of the stroke compared with the mean force of the entire stroke; and it was with the view of obviating this difficulty that he had himself designed some years ago the plan which had been mentioned of putting the small cylinder inside the large one and working with three piston rods, admitting the high pressure steam to the inner cylinder and expanding into the outer. There were however several inconveniences for the practical purposes of steam navigation in any of the combinations of cylinders that he had yet seen. Working with two cylinders was attended with certain trammels in the case of marine engines, which virtually limited the expansion to a particular grade; whereas the special want in steam navigation was the means of working with a great variety of grades of expansion, and sometimes with no expansion at all, but with the full power of both cylinders. When this difficulty was surmounted, the great practical inconvenience of double cylinder engines for marine purposes would be got rid of. Another difficulty in the way of extending the degree of expansion was the want of a better class of men to attend to the engines placed in vessels; until superior men were employed it would be unwise to attempt obtaining the large economy that would result from greater expansion, higher pressure, superheating, and surface condensation, with the use of more costly engines and stronger boilers. In order to get over the difficulty of repairs, arising from the complexity of a double cylinder engine, he had arranged an engine with three separate cylinders, all working expansively and acting direct upon one crank, so as to have the free use of any degree of expansion without the disadvantage of the double cylinder arrangement. With this engine, expanding the steam about four times in each of the three cylinders, the consumption of coal in ordinary working was brought down to about $2\frac{1}{2}$ lbs. and even 2 lbs. per horse power per hour. Marine engines however had not the same advantages for great expansion as pumping engines, in which the large mass to be put in motion absorbed the excess of power at the beginning of the stroke, and served as a reservoir of power to perform the remainder of the work when the high pressure of the steam was reduced by expansion.

Mr. E. E. ALLEN observed that the alleged difficulty of obtaining a temporary increase of power had been frequently urged against the use of double cylinder expansive engines for marine purposes, but he was not able to see how the objection applied, because the steam, instead of being cut off at a third or a half of the stroke or at any other point that was desired, might be kept on for the full length of stroke in the first cylinder, when the full power of the engine was wanted. In ordinary marine engines cutting off at three quarters of the stroke there was no means of adding to the power more than about one fifth; but if a larger and more expansive engine were used, with the steam cut off at one third of the stroke in the small cylinder, which was what was generally proposed in double cylinder expansive marine engines, the power could be increased between two and three times. An important difference moreover between the application of the double cylinder expansive arrangement to marine engines and to other purposes was that, while it was quite possible in pumping engines and in most other cases to lengthen the cylinders for an increased expansion, making the length of stroke frequently three or four times the diameter, it was impossible to do so in marine engines, which were confined within very narrow limits, so that the cylinders assumed a different shape from those in other engines; in marine engines of 1200 horse power now being made the diameter of the cylinder was more than double the length of stroke, the diameter being nearly 10 feet while the stroke was only 4 feet. In cylinders of these large diameters however, not only was the initial blow of the steam very much in excess of anything that was met with in pumping engines, but there was a heavy loss in the clearance space at the end of the cylinder, bearing a large proportion to the whole steam used if the steam were cut off at an early part of the stroke. The double cylinder engine had therefore a great advantage for short strokes, by reducing the initial blow with a high degree of expansion, and he believed it afforded the only practical mode of carrying out expansion to any high degree in marine engines. He had proposed placing the cylinders horizontal, with the small cylinder at the back of the large one, instead of the vertical arrangement adopted in the "Mooltan" and other vessels, because he objected to raising the engines, especially when the cylinders were large and heavy.

The degree of expansion and point of cut off to be adopted depended upon the pressure of steam employed: with an initial pressure of 20 lbs. per square inch above the atmosphere he had proposed that the steam should be expanded 7 times, and about 10 times for 60 lbs. total pressure, and perhaps 18 times for 120 lbs., the economy obtained being greater the higher the pressure of steam used. The expansion of 7 times was the same that had been adopted by Mr. Humphrys and Messrs. Randolph and Elder with 20 lbs. steam or 35 lbs. total pressure, the object being to expand the steam down to a final pressure of about $4\frac{1}{2}$ or 5 lbs. per square inch above a vacuum.

When expansion was fully carried out in marine engines there was reason to look forwards to the consumption of fuel being reduced to less than half what it now was. At present the average consumption reached $4\frac{1}{2}$ or 5 lbs. per indicated horse power per hour, but by expanding 7 times with 20 lbs. steam he believed this would be brought down to $2\frac{3}{4}$ lbs. per horse power per hour; and if surface condensation were employed in addition, the consumption would be further reduced to $2\frac{1}{4}$ lbs. of fuel, which was the actual consumption in the engines of the "Mooltan" during a continuous sea voyage, and also in Messrs. Randolph and Elder's engines.

Mr. E. A. COWPER did not consider it was necessary to adopt the plan that had been mentioned of having three cylinders in marine engines for obtaining a high degree of expansion; nor did he think the other plan of putting the small cylinder inside the large one was altogether advisable, as it involved certain complications of construction. In the latter case, although there were two cylinders, they could act only on one crank; and the outer annular piston would be subject to a great amount of wear, by being confined between the two cylinders, instead of being left as free as possible in working, which was particularly desirable in a marine engine. The use of two cylinders of different size with cranks at right angles had been tried several times, by Mr. Zander about fourteen years ago, by Mr. Rontgen about eleven years ago on the Rhine, and by himself twelve years ago, the steam expanding out of the small cylinder into the large one: this plan required a space between the two cylinders for the steam to expand into on leaving the small cylinder, because at the end of the

stroke of the small cylinder the crank of the large cylinder was at half stroke, and therefore not in the position for taking steam, so that a steam-jacketted reservoir was required into which the steam could be exhausted from the small cylinder, and in which it could be kept without any loss of heat and be slightly superheated before being admitted into the larger cylinder. In this particular arrangement he had found that a great advantage in uniformity of power was obtained by cutting off the steam at particular points near half stroke in both cylinders : it had been proposed many years ago to cut off the steam at half stroke, with the view of obtaining uniformity of rotative power ; but the exact point of cut off had to be ascertained for each case, to produce the best result. The total variation from the average rotative power when the steam was admitted through the whole stroke in both cylinders was 31 per cent. ; but when cutting off at the most advantageous point near half stroke in each cylinder it was only 14 per cent. This was shown in the diagram, Fig. 12, Plate 75, in which the curve L represented the rotative power obtained from one cylinder throughout one revolution of the crank, as measured by the height of the curve at successive points from the base line X, which represented the path of the crank ; and the curve M represented the power obtained at the same time from the second cylinder, the steam being admitted throughout the whole stroke in each cylinder. The curve N gave the combined rotative power of the two cylinders at the successive points of the entire revolution, measured from the base line Y ; and showed an extreme variation in the power of 31 per cent. from the average line P. The curves R and S showed similarly the rotative power when the steam was cut off at the most advantageous point near half stroke in both cylinders ; and the curve T gave the combined rotative power of the two cylinders in that case, showing a variation of only 14 per cent. from the average line U, and thus giving a practical uniformity of effect. In the diagram the length of the connecting rod had been taken into account. In the case of using full steam throughout the whole stroke it had also to be observed that the variations in rotative power were not only large in amount but long continued ; for instance in the first quarter of the revolution the power was greatly in excess of the average, but in the third quarter it was

greatly below the average, as shown by the curve N in the diagram. When cutting off however at the most advantageous point, each quarter of the revolution had nearly the same rotative power, as shown by the curve T. The amount of power not obtained from the steam, owing to the drop in the expansion curve at the point of exhausting into the reservoir from the small cylinder, when cutting off at nearly half stroke in both cylinders and expanding nearly nine times, was very small in amount, and formed an insignificant portion of the whole power, as shown by the combined indicator figures taken from the two cylinders, compared with the true expansion curve or such as would be given from a single cylinder having the whole expansion performed in it. This was the result that had been obtained with a 40 horse power horizontal engine constructed on this plan by Messrs. Walter May and Co., shown at the International Exhibition. The great uniformity of rotative power obtained, together with the great economy, would prove most important advantages in the case of cotton mills, flour mills, marine and pumping engines, and indeed manufactures generally.

Mr. T. HAWKSLEY remarked that from his own experience he believed that in pumping water the single cylinder rotative engine expanding the steam not more than three or four times, with a boiler pressure not exceeding 30 lbs. per square inch above the atmosphere, was for all ordinary purposes the best kind of engine that could be adopted. Such an engine did not indeed realise all the advantages which theory assigned to the double cylinder engine, and the power of the steam might undoubtedly be utilised to a greater extent by carrying the expansion further. But practically, whether as regarded the first cost of the engine or its durability or the facility of its management, he was convinced that a single cylinder engine, worked as he had mentioned, was as a general rule the best that could be applied to pumping purposes. Where the district to be supplied was generally flat, such as the east of London, and where the water could be delivered into a stand-pipe to one uniform height, he considered the single cylinder Cornish engine with loaded plunger was eligible for pumping. Also in raising water from a deep pit, which frequently had to be done for the supply of towns as well as in draining mines,

he had found the Cornish engine was again practically the best, because it worked under a uniform steady pressure without being exposed to fluctuations from any cause, and gave due time for the rods to come to rest; and this was a case in which the expansion could be carried somewhat further than three or four times. There were cases however in which it was desirable to use the double cylinder engine, and these formed probably the great majority of all the cases that occurred in waterworks: where the water had to be pumped either direct into the town or into a remote reservoir, and where consequently the water was taken off from the mains at intermediate and irregular intervals, producing a considerable variation in the amount of pressure; and also where the height to which the water had to be raised rendered a stand-pipe unavailable. Here it was found useful to apply a flywheel; and it was then also desirable to carry out the expansion to a considerable extent, as the steam could in practice be expanded further when a flywheel was used than in the Cornish engine without flywheel. It therefore became a consideration how best to get this increased amount of expansion; and the double cylinder engine was found, as shown in the first of the two papers that had just been read, to afford the means of so limiting the initial blow of the steam as that practically there was no necessity for employing a great weight of material to obtain the requisite strength in the engine, since the strain on all the machinery could be reduced to a minimum for a given power, by properly adjusting the proportions of the two cylinders and cutting off at the proper point of the stroke in the small cylinder.

In reference to the actual extent of expansion that could be realised, very high degrees of expansion were often spoken of, with corresponding economy of fuel; but he considered the expansive power of steam at ordinary pressures could not be realised beneficially beyond a limited extent, because the passive resistance in an engine of moderate size amounted practically to something like 5 lbs. per square inch on the piston. The back pressure from defective vacuum in the cylinder was rarely less than 2 lbs. per square inch in the best constructed engines: and the working friction of the engine under its load, even in engines of considerable size, was seldom below 3 lbs. per square inch on

the piston; sometimes it was rather less, but only in large engines. Hence there was no gain in carrying the expansion so far that the pressure of the steam should at any time be reduced to less than 5 lbs. per square inch above a perfect vacuum, since every portion of the stroke that was done with a pressure below 5 lbs. per square inch was done at a loss. Pumping engines for waterworks were generally worked with steam at about 30 lbs. per square inch above the atmosphere or 45 lbs. total pressure, and consequently the steam ought not to be expanded more than nine times under those circumstances. If therefore under such circumstances steam were expanded as much as fifteen times from the same initial pressure in the engines described in the paper, as had been stated, part of the expansion must have been performed at a loss.

It had also been stated that in one trial of the double cylinder pumping engines a duty was realised of about 130 millions of lbs. raised one foot high by 112 lbs. of coal, giving a consumption of about 1.7 lbs. per horse power per hour; but by the ordinary calculation that would require an expansion of forty times, and as it was clear this could not have been the case, he could only conclude there had been some mistake in the experiment, which might readily arise from a variety of causes. It might not be theoretically impracticable to get down the consumption of coal to 1.7 lbs. per horse power per hour, but he was convinced it was altogether impossible to do so under the practical circumstances in which steam engines were placed, either in pumping or on board ship or in driving machinery. He was acquainted with the double cylinder pumping engines described in the paper, which were certainly working with extraordinary economy, and he believed the discrepancy in the account of their consumption was sufficiently explained by the further statement that 37 per cent. of water had been lost out of the boilers beyond the consumption that corresponded with the volume and pressure of steam contained in the small cylinder at the point of cutting off. That extra quantity of water was no doubt carried over into the cylinder partly in the form of water mixed with the steam, and partly as steam leaking in through the valves after the cut off: for if the steam were not superheated on leaving the boiler, it was only by passing it through a large chamber

where it could deposit the water mixed with it before entering the cylinder that the actual expansion curve in the indicator diagram could be brought into conformity with the theoretical line; but when this provision was made, and when the valves were perfectly steam-tight, he had found the actual curve coincided as nearly as possible with the theoretical. He therefore believed the loss of water that had been stated fully explained the higher pressure which was shown in the indicator diagrams at the end of the stroke, above the final pressure that would have resulted from regular expansion.

In the use of high pressure steam its effect upon the materials of the engine was a subject that required some consideration. He had had an opportunity of watching the progressive change from low pressure to high pressure steam that had taken place during the last thirty years, and in one instance that had been under his observation a low pressure pumping engine erected and set to work in 1831 had still at the present time all its working parts and even the boilers nearly as perfect as at the time when it was put up; while on the other hand engines using high pressure steam of 30 lbs. and under, subsequently erected at the same place, had had the cast iron parts and many of the wrought iron parts completely cut through in the course of ten years. This could not be due as had been supposed to the quality of the tallow, for the same quality of tallow had been used in both cases; but he believed it was entirely due to a cutting or destructive action of the high pressure steam itself. This was therefore one of the causes of expense which would limit the use of high pressure steam in all cases where durability of the machinery was an important point.

In making a trial of any engines in order to ascertain the consumption of fuel, the condition of the boiler at the time ought not to be left out of the consideration. For if the boiler were thoroughly cleaned and the flues also cleared of soot, the evaporation might be increased in an experiment to the extent of 25 or 30 per cent. beyond what was obtained in the ordinary working condition of the boiler; and hence such experimental results could not be relied upon as any sure guide for what might be expected in regular practice. It was therefore important that in all statements of the quantity of water evaporated by a given consumption of fuel the condition of the boiler should be stated as well.

Mr. POLE remarked that, in reference to the extent of expansion that could be adopted with a given pressure of steam, there was no doubt a point beyond which no further advantage could be got from expansion, because the size of cylinder would have to be increased so much that the passive resistance of the engine would become so great as to overbalance the benefit of the expansion. But he thought this certainly could not be the case in expanding up to eight or nine times with steam of 30 lbs. per square inch above the atmosphere ; and he believed that for practical purposes it was not intended to work the double cylinder engines to a greater extent of expansion with that pressure.

As regarded economy of fuel and the alleged impossibility of getting the consumption so low as 2 lbs. of coal per horse power per hour in regular practice, the reports of the Cornish engines showed that many of the best engines had been working regularly for years together with a duty of 90 millions of lbs. raised one foot high by one bushel or 94 lbs. of coal, which was equivalent to a consumption of 2 lbs. of coal per horse power per hour. The duty which had been stated to have been obtained in the trial of the double cylinder engines, 113 millions with 112 lbs. of coal, was also equivalent to the same consumption of 2 lbs. of coal per horse power per hour ; and although this might seem an exceptional duty for the double cylinder engines, he believed it would not be found so, but that in regular working they would fall very little short of the best Cornish engines.

Mr. T. HAWKSLEY observed that the engines used in Cornwall, from which so high a duty had been obtained, were an exceptional class of engines ; and even in these the duty at the present time had come down from the former amount of 90 millions to a duty now of only 56 millions on an average per bushel of coal. At the time when the engines were worked at the high duty of 90 millions, it was a common saying that a lb. of tallow was equal to a bushel of coal, and the engines all competing with one another got more than their proper allowance of tallow, so that the consumption of coal was diminished by the excessive lubrication. He was therefore satisfied that in engines of ordinary size and under ordinary circumstances it was a mistake to imagine that any such high results as had been spoken of could be

practically and economically realised in regular working, or even results within 50 per cent. of them.

Mr. POLE said it was certainly the case that the engines in Cornwall had receded from their former high duty, because when an engine was put up new it cost less in working than afterwards; and moreover as the workings in the mine were extended deeper, the engine had more work to do and the steam could not be expanded so much, so that less economy was then obtained.

Mr. J. SCOTT RUSSELL concurred in the importance of not carrying the expansion so far as that the pressure of the steam should ever be reduced below the passive resistance of the engine, in the case of marine engines and rotary engines generally where no flywheel was used; but in pumping engines with a heavy beam or flywheel he thought the limitation was not so applicable, because here the reservoir of momentum in the heavy mass in motion could be drawn upon for carrying the engine on to the end of the stroke even after the pressure of steam in the cylinder had been reduced below the resistance of the engine, when without the aid of that momentum the steam alone would be of no avail.

Mr. THOMSON said that, in reference to the annular construction of double cylinder engine that had been mentioned, he had last year made two pumping engines on that construction of 60 horse power each, and also a small double cylinder engine for a yacht which made from 300 to 330 revolutions per minute. In the latter instance the arrangement was modified by making the two pistons travel in opposite directions, in order that the engine might be balanced; and with the same object the centre piston was made heavier than in other engines, so as to be the same weight as the annular piston. The point of cut off in the small cylinder could also be varied from one quarter to three quarters of the stroke, and the expansion consequently altered between those limits. This engine had moreover a surface condenser, with a cold water pump to draw off the condensing water from it, worked at the same speed as the engine; but though the speed was so high there was no shake at all in the pipes of the pump.

With regard to the practical advantage of expanding the steam more than three or four times; and the amount of the passive

resistance of the engine, the indicator diagrams exhibited, as well as others that had frequently been taken from the double cylinder pumping engines shown in the drawings, gave a defective vacuum of only about 1 lb. per square inch; while the total dead resistance of the engine, including this defective vacuum, certainly did not amount to anything like 5 lbs. per square inch on the piston. He had also tried some experiments recently with several different degrees of expansion in one of the two 60 horse power pumping engines with annular cylinders that he had mentioned, in order to ascertain the degree to which the expansion could be advantageously carried in practice. For this purpose the evaporative duty of the boilers was entirely left out of the account, and the engine having injection condensers the quantity of injection water supplied was measured by a meter and thereby kept uniform: the load on the engine was also kept almost perfectly uniform, as the engine was employed in pumping water, and a counter was attached to ascertain that there was no variation in the speed of working; the work done by the engine was thus measured and maintained as uniform as possible. The expansion was then varied to different degrees whilst working, the initial pressure of the steam admitted to the cylinder being increased as the degree of expansion was increased, so as to keep the total power of the engine uniform throughout the experiment, to correspond with the uniform work to be done. The steam was first cut off at 7-10ths of the stroke in the small cylinder, giving an efficient expansion of 5·7 times, neglecting the expansion in the passages and clearances, since the larger or annular cylinder was four times the size of the small inner cylinder: and the temperature of the waste water in the hot well being measured was found to be 96° Fahr. The expansion was then increased by cutting off the steam 1-10th earlier in the stroke successively, and the following results were obtained:—

Point of Cut off in small cylinder.	Total Efficient Expansion.	Temperature of Water in hot well.
7-10ths of stroke	5·7 times	96 degrees Fahr.
6-10ths "	6·7 "	94½ "
5-10ths "	8·0 "	93½ "
4-10ths "	10·0 "	92 "
3-10ths "	13·3 "	91½ "
2-10ths "	20·0 "	91½ "

Hence it appeared that no improvement was effected by cutting off earlier than 3-10ths of the stroke, making the efficient expansion 13·3 times; for on increasing the expansion to 20 times with the cut off at 2-10ths of the stroke, the temperature of the waste water in the hot well was no further reduced, but remained the same as in cutting off at 3-10ths. In the temperatures obtained in these experiments the diminution indeed was certainly not so great as it ought to be by theory; for with a temperature of 96° when the steam was cut off at 7-10ths of the stroke, the diminution of temperature on cutting off at 3-10ths ought to have been something like $1\frac{1}{2}$ or $1\frac{3}{4}$ times what was actually found.

The CHAIRMAN suggested that the quantity of water lost from the boiler by priming and carried over with the steam into the engine would probably account for the higher temperature in the hot well, as well as for the increased pressure of steam at the end of the stroke. He enquired what was the initial pressure of the steam when it was expanded thirteen times.

Mr. THOMSON thought that all the heat which passed off from the engine must find its way into the condenser, and would there be shown by the temperature of the water in the hot well, which was therefore taken as the measure of the waste of heat accompanying each grade of expansion. No heat would pass into the condenser beyond that which remained in the steam at the end of the stroke after expansion, excepting of course a certain quantity of heat imparted from the steam jacket of the cylinder, which would be the same under all circumstances. The initial pressure of the steam at the time of expanding thirteen times was about 30 or 35 lbs. per square inch above the atmosphere, as shown by the indicator diagram: in ordinary working however the steam was cut off at half stroke in the small cylinder, which gave an expansion of eight times, the large cylinder being four times the size of the small one; or seven times efficient expansion, neglecting the passages and clearances.

Mr. T. HAWKSLEY considered the experiments that had been mentioned with different degrees of expansion did not furnish any proof that the higher expansions were not carried on at a loss; and he thought this would not be detected by the plan which had been

adopted of measuring the temperature in the hot well. For in an extreme case of a cylinder of excessive length, if the steam were cut off so early as to be expanded below the passive resistance of the engine long before the end of the stroke were reached, the latter part of the stroke would all be done at a loss, without the steam exerting any appreciable force on the piston; but still almost the same quantity of heat would be sent forwards into the hot well as if the stroke had been stopped at that point where the pressure of the expanded steam was just balanced by the passive resistance of the engine. It was therefore important to make sure in every case that none of the previously gained power should be afterwards wasted in merely overcoming the useless resistance.

Mr. E. E. ALLEN observed that with steam of 35 lbs. per square inch total pressure an expansion of seven times would reduce the pressure to 5 lbs. per square inch above a perfect vacuum, and he was not aware that it was ever proposed to expand further with that pressure of steam, certainly not in marine engines; since it was generally considered useless to reduce the final pressure below that amount, which usually covered the friction of the engine and the back pressure of the condenser; and therefore a higher expansion could be adopted only when a higher initial pressure of steam was used. It was accordingly impossible to fix any particular grade of expansion for all cases, but the expansion must always be proportional to the initial pressure of steam, so that with 55 lbs. total pressure the steam should be expanded ten or eleven times.

With regard to the consumption of fuel, he fully concurred in the opinion that, if the steam were only 35 lbs. per square inch total pressure, by no possible arrangement could the consumption be reduced to less than about 2 lbs. of coal per indicated horse power per hour, which was the limit even when surface condensation was adopted. But if greater economy were desired, the pressure of the steam must be raised; and then with 120 lbs. steam there would not be the slightest difficulty he believed, even in a marine engine, in reducing the consumption to about $1\frac{1}{2}$ lbs. of coal per indicated horse power per hour.

In reference to the particular form of engine best adapted for marine engines, the only objection that he knew of to the three cylinder arrangement, or the double cylinder with cranks at right angles, was the multiplication of connecting rods and piston rods; whereas by putting the small cylinder at the back of the large one, upon the same piston rod, only one connecting rod was required, and all the parts were reduced to the smallest size compatible with the initial pressure of the steam on the small piston and the pressure of the expanded steam on the large piston. If it were attempted to expand much in a marine engine with only a single cylinder of large size, such as 10 feet diameter, all the parts would have to be made strong enough to bear the full pressure of the steam on that large area at the beginning of the stroke; while for all the rest of the stroke the strength of the parts was much above what was needed. In the double cylinder arrangement however the high pressure steam admitted into the small cylinder was reduced by expansion to about a third of its initial pressure, before being let into the large cylinder, whereby the weight of the engine was reduced fully $2\frac{1}{2}$ cwts. per nominal horse power.

As regarded the back pressure of the imperfect vacuum, many experiments had been made on this point, and he believed that good marine engines would work regularly with a back pressure of about $2\frac{1}{2}$ lbs. per square inch; the friction of the engine also amounted to about $1\frac{1}{2}$ or 2 lbs. per square inch on the piston, as had been stated; and the total passive resistance of the engine was therefore about $4\frac{1}{2}$ lbs. per square inch, below which pressure the steam certainly could not be usefully expanded, whatever its initial pressure might be.

The CHAIRMAN proposed a vote of thanks to Mr. Pole and Mr. Thomson for their papers, which was passed.

The following paper, communicated through Mr. J. Scott Russell of London, was then read :—

Fig.1. Double Cylinder Pumping Engines at Lambeth Water Works.

(Proceedings Inst. M.E. 1862. Page 259.)

Scale $\frac{1}{120}^{th}$.

10

5

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10

20

30 Feet.

Fig.2. *Vertical Section of Cylinders and Valve.*

(*Proceedings Inst. M.E. 1862. Page 259.*)

Fig. 3. *Sectional Plan
through steam port of Large cylinder.*

Fig. 4. *Sectional Plan
through steam port of Small cylinder.*

Scale $\frac{1}{30}^{th}$.

10 0 10 20 30 40 50 60 70 80 90 100 Inches.

(*Proceedings Inst. M.E. 1862. Page 259.*)

DOUBLE CYLINDER ENGINES.

Plate 73.

Fig 7. Vertical Section of Valve.

(Proceedings Inst. M. E. 1862. Page 259.)

Indicator Diagrams from Lambeth Water Works Engines.

Fig. 8. Indicator Diagrams taken simultaneously from Bottom of Small cylinder and Top of Large cylinder.

Fig. 9. Indicator Diagrams taken simultaneously from Top of Small cylinder and Bottom of Large cylinder.

Fig.10. Indicator Diagram from Top of Small cylinder, taken simultaneously with Fig. 8.

Fig.11. Indicator Diagram from Top of Large cylinder, taken simultaneously with Fig. 9.

Fig.12.