ON THE CORLISS EXPANSION VALVE-GEAR FOR STATIONARY ENGINES.

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At the present period of steam engineering it may be said that in the complete practical application of the expansive action of steam rests the only prospect of further economy, excepting that arising from improvements in the generation of the steam; and this practical application of the expansive action of steam has been, and still continues to be, a subject of great difficulty, from the fact that among the many plans of expansion gear very few answer even approximately the intended purpose. The Corliss Expansion Gear for Stationary Engines, forming the subject of the present paper, has until the last few years been little known in this country. The rapid increase of its application however, which has now taken place in this country, has warranted its being brought under the notice of the Institution.

The Corliss engine introduced by Mr. Corliss in the United States about twenty years ago, which in all except the cylinder with its valves and valve-gear is substantially the same as any ordinary steam engine, embodies in the arrangement of the cylinder and valve-gear several principles that had previously been used separately.

First, independent ports are used for admitting and for exhausting the steam at each end of the cylinder, with four separate slide-valves worked from a single eccentric.

Second, the steam is cut off from the cylinder by the main steam valves, without the employment of any supplementary valves for the purpose.

Third, the steam valves are opened against the resistance of springs, and a liberating gear is employed by which the valves are disconnected and left free to be closed by the springs.

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Fourth, after the valves are closed, the springs are brought to rest without shock by the application of the contrivance known as the "dash-pot." This consists of a small cylinder with closed bottom, in which a piston is fitted to work easily; and by a suitable arrangement of openings the air is admitted freely to the cylinder while the piston is moving, except when it approaches the bottom, at which time a certain amount of air is imprisoned, forming a cushion to prevent any shock when the piston actually reaches the bottom.

Fifth, the speed of the engine is regulated by the governor acting on the steam valves to cut off the steam earlier, instead of acting on a throttle-valve to reduce the pressure of the steam.

It is the embodiment of these several principles, and the arrangement and construction of the details in the mechanism employed, rather than the application of any new or untried principle, which constitute the special features of the Corliss valve-gear.

Cylinders with four separate passages and independent steam and exhaust slide-valves were used by Seaward previously, the valves employed being flat slides, but not worked in connection with any liberating gear; and a number of marine engines were made on this plan. In the earlier Corliss engines Seaward's cylinders and slides were used; but the valve now employed is a cylindrical slide working in the arc of a circle on its seat, and receiving a rocking motion from a central valve-spindle. Although separate valves and passages were employed previously for steam and for exhaust at each end of the cylinder, the motion imparted to the steam valves was invariable, and any expansion of the steam was effected by the lap of the valve. The speed of the engine also had to be controlled by throttling or shutting off the steam with a supplementary valve; and in this respect the first step in advance is made in the Corliss gear by the addition of the principle of liberating the steam valves. With the employment of liberating gear it became necessary that an independent force should be available for closing the valves when they were detached, and for this purpose weights were first used; but springs have since been substituted for the weights, because they are quicker in action, effecting a sharper cut-off, and are better adapted for quick working.

Liberating gear for the steam valves was indeed used by Watt, so that the principle may be considered almost as old as the steam engine itself; but in Watt's time it was more frequently for opening than for closing the valves that the weights used in that method of working were employed, and as might be expected the mechanism was not very perfect in its details. At that time the drop or poppet-valve was used for the purpose.

To Mr. Sickles of New York is due the credit of perfecting the liberating gear as applied to the poppet or the double-beat valves, in the cut-off gear which bears his name. In this valve-gear, which was introduced in 1841 in America, the dash-pot is applied direct to the valve itself, to arrest the progress of the valve and prevent it from striking on its seat. It should be observed that there is an essential and important difference between the use of drop-valves and slide-valves, in connection with liberating valve-gear; for in the one case the dash-pot is applied to arrest the valve itself and prevent it from striking on its seat, but in the other it is only required to prevent the concussion of the weight or spring that is used to close the valve. If the drop-valve, in order to prevent concussion, is made to fall slowly just as it approaches its seat, it is evident that there must be a certain amount of wire-drawing of the steam; whereas with the slide-valve the motion of the spring or weight which closes it is not arrested by the dash-pot till after the valve is closed and the steam completely cut off: hence while the cut-off with the slide-valve must be perfect, with the drop-valve it must at best be to a certain extent imperfect.

Regulating the speed of steam engines by connecting the governor to vary the degree of expansion, instead of throttling the steam, was advocated, if not practised, by Watt, and many different arrangements have been invented and applied for effecting this object. In the Corliss expansion gear the governor is connected to the clips used to liberate the steam valves, and according as the pressure of steam in the boiler or the load on the engine varies, the supply of steam to the cylinder is cut off at an earlier or later period of each stroke; so that the speed of the engine is kept uniform, without the addition of any throttle-valve in the steam pipe. While the steam valves are thus

controlled by the governor, and caused to close at an earlier or later period of the stroke to suit the varying conditions of the steam pressure or load on the engine, the exhaust valves have an invariable motion, and are opened and closed at the same point of the stroke, whatever may be the degree of expansion.

The disconnecting valve-gear for working the steam valves, as originally introduced by Watt and applied for the purpose of opening or closing poppet-valves, is shown in Fig. 1, Plate 88. It was usual in this gear to communicate motion to the valves by a rod A called a plug-tree, attached to some moving part of the engine, generally to the beam; on this rod were fitted tappets B B, to open or close the valves when moving in one direction, and when moving in the opposite direction to trip or liberate the catches and allow the weights to act for either closing or opening the valves, as might be arranged. The drawing shows the plug-tree A with its tappets B B, the valve C, the catch D, and the curved lever E for tripping the catch, the weight F for closing the valve, and the dash-pot G for bringing the weight gradually to rest when dropped. All the details are rude and clumsy, but it can be seen that there is in this arrangement the germ, so to speak, of the Corliss expansion gear.

In Fig. 2, Plate 88, is shown the arrangement of gear employed in the earlier Corliss engines in America for actuating the steam valves; and the contrivance used for tripping or liberating the catch, in connection with a governor, to produce the sudden closing of the valves. In this arrangement a weight H was used, attached to a lever on the valve-spindle I, to supply the external force for closing the valve when the catch K was liberated, the weight falling in a dash-pot similar to that in Watt's gear. This plan was improved several years ago by Mr. Corliss, who then introduced an arrangement in which the catches push the valves open instead of pulling them, and the valves are closed by long blade-springs fitted to vibrating levers. The tripping of the catch is effected by curving up the back end at K, and this end when moving forwards comes into contact with a plate L, which is acted on by a rod M connected with the governor; the rod M carries an incline, which raises or lowers the plate L

according to the changes in position of the governor balls, so that when the plate is lowered by the governor balls flying out in consequence of excess of speed, the catch K is tripped sooner, and reduces the supply of steam to the engine by cutting off the steam earlier. A few engines fitted with this arrangement of gear were made in this country some years ago, but the plan appears to have since fallen into disuse.

The present improved construction of the Corliss engine is shown in Fig. 3, Plate 89, which is a side elevation of the cylinder and valve-gear of a small horizontal engine made by Messrs. Hick Hargreaves and Co. of Bolton for the Royal Arsenal at Woolwich, from designs by the writer. This engine, which has 12 inch cylinder and 2 foot stroke, works at 100 revolutions per minute. The cylinder is shown in transverse section in Fig. 4, Plate 90, and in longitudinal section in Fig. 5. The steam valves AA are placed on the top of the cylinder, and the exhaust valves BB at the bottom, separate pipes leading from them at each end of the cylinder. The steam valves are closed by a spring dash-pot CC, which pulls upon each valve-rod as it is drawn out; and the liberating gear consists of a pair of side spring-clips DD, which are released by the rocking of a double toe-lever EE, and then allow the steam valve to be closed by the action of the spring: the spring-clips and toe-lever, and the valve-gear generally, are similar to those afterwards described in the Saltaire engines. The valves are cylindrical on the face, being similar in action to ordinary slide-valves, but working upon a cylindrical instead of a flat face; the valve face is a longitudinal segment of a cylinder, having recesses on its inner side, into which drop the projecting arms of the valve spindle, so that the valve is moved by the partial rotation of the spindle in opposite directions alternately. The pressure of the steam on the valves tends to press them up to the face, only when the ports are closed; so that when the ports are opened, the valves move with practically no friction from the steam pressure, and thus the pull required to close the steam valves is small, and is practically independent of the pressure of the steam.

The cylinder is steam-jacketted both on the body and on the ends; and an improvement in the construction of these cylinders has recently been introduced by the writer, considerable trouble having been experienced in getting the jacketted cylinders sufficiently hard when cast in one piece, on account of the risk from cracking if cast with hard metal, and also in consequence of the annealing process that takes place during the cooling of the castings. The improvement consists in making the cylinder and valve-chest in four distinct pieces, with flanged face-joints F F to connect all together, as shown in Fig. 5. The cylinder and the steam-jacket are two concentric castings, fitting one inside the other, with a flange F F upon the jacket only; and a separate casting at each end forms the valve-chests above and below the cylinder, with a ring connecting the two valve-chests; the end of the cylinder is fitted into this ring, and the cylinder cover is fixed upon it, all the fitting surfaces being turned and bored. The separate castings are thus rendered quite simple, and can be made of any degree of hardness without risk; while the flanged face-joints provide security against leakage, much better than if the inner cylinder were simply let in, with slip joints parallel to its bore. A saving of time in making can also be effected, as the work on the separate pieces can be proceeded with in several machines at the same time.

Figs. 6 and 7, Plates 91 and 92, show a front and side elevation of one of the new cylinders with the improved Corliss expansion gear that have recently been erected at Saltaire by Messrs. Hick Hargreaves and Co. from designs by the writer. The engines are beam engines coupled together, with 50 inch cylinders, and 7 foot stroke, working at 30 revolutions per minute. There are two pairs of engines to be replaced, four cylinders in all, and the new cylinders have been put in place and now completed for one pair, and are the same size; the previous cylinders had double-beat valves actuated by a cam motion. Figs. 8, 9, and 10, Plates 93 and 94, are vertical and horizontal sections of one of the cylinders, showing the valves. The cylinders and cylinder covers are steam-jacketted; and the valve chambers are cast with the cylinders. The steam

valves CC are in front and the exhaust valves DD at the back of the cylinder, and the valve-gear is placed on the sides of the cylinders between each pair of engines. The steam and exhaust passages EE are cast separate from the cylinder, and provided with expansion joints FF, shown in section in Fig. 8. The valves are cylindrical on the face, similar in construction to those of the Woolwich engine previously described. All the four valves are opened by the eccentric rod T, Fig. 7, acting on an oscillating disc U, to which the four valves are connected by rods; the exhaust valves DD are also closed by the same means, but the steam valves CC are released, and are closed by an air-spring P. The stop-valve G in the steam passage is similar in make to the steam valves, and is opened by a worm and wormwheel to regulate the supply of steam; but it can be closed suddenly on any emergency by means of the lever handle H, which is keyed upon the valve spindle and is connected to the wormwheel by a detent that can be instantly disengaged, the wormwheel being loose upon the valve spindle. A small auxiliary conical stop-valve I opened by a screw handle is employed for turning on the steam gradually at starting, to relieve the pressure on the main stop-valve G.

The construction of the liberating valve-rod introduced by Mr. Spencer and the writer, for the disengaging gear to release the steam valves, is shown in Figs. 11, 12, and 13, Plate 95. The valve-rod is divided into two portions, one sliding steadily within the other at the cylindrical part AA; and the two are held together by the pair of spring-clips BB fixed on one portion, which rest on corresponding shoulders CC on the other portion of the valve-rod. The clips are released by the double toe-lever D, which rocks upon a transverse centre pin, and is shown in its two extreme positions in Figs. 11 and 12; the outer end K of the arm of the toe-lever being held by the rod L shown in the general drawing Fig. 7, the toe-lever D is made to rock in each stroke of the valve-rod, and the particular point of the stroke at which the toe-lever reaches its extreme position and disengages the spring-clips BB is determined by the position of the end K of the toe-lever arm, which is not stationary, but is acted on direct by the governor through the rod L. By this means all changes

in position of the governor balls produce corresponding changes at the same time in the position of the fulcrum upon which the toe-lever acts, causing the release of the spring-clips to be earlier or later in the stroke according as the speed of the governor is greater or less than the correct rate, and thus regulating the engine by cutting off the steam earlier or later accordingly. The disengaging rods L L from the two steam valves are coupled together by a pair of toothed segments M M, shown in Fig. 7 and also in the enlarged drawing Fig. 14, Plate 96; and the rod N, Fig. 7, connects these with the governor. The spring-clips B B fall upon leather faces O O, to prevent any blow in closing; and the engaging edges of the clips and the shoulders are hardened steel faces let in and readily renewable.

The air-spring dash-pot P for this gear, Fig. 7, is shown enlarged in Fig. 14, Plate 96, one half in section. It consists of two cylinders, one within the other; the large cylinder has a loose-fitting piston R R, and the small cylinder a trunk piston S S fitted with metallic packing; the underside of this trunk piston is in connection with the condenser. The pressure of the atmosphere is therefore constantly pressing the small piston in, and this forms the spring for instantly closing the steam valve when liberated from the clip-rod; the large piston R is coupled to the small one S, and acts as a dash-pot to prevent concussion in closing the steam valve, as the air below the loose-fitting large piston R has to be driven out at the moment of closing the valve.

The double-clip gear, as far as experience goes, works with satisfaction, and is reliable and effective up to the speed of 100 to 120 revolutions per minute; and it could be worked at speeds considerably greater. More than sixty land engines, most of them of large size, are now at work in this country fitted with this gear, and many of these have been at work for several years, giving great satisfaction both in economy of fuel and regularity of speed; a considerable number of the engines have also been made and sent abroad. These engines have also been applied to steamers, and their use is rapidly extending for marine purposes. The arrangement of the valves and gear makes them easy of access either for inspection

or repair; and from the number of engines satisfactorily at work it has been proved that with good workmanship the valves and gear can be kept in order at a very trifling expense.

The consumption of fuel with these engines is about $2\frac{1}{2}$ lbs. of coal per indicated horse power per hour, which includes all the coal used for raising steam or banking fires. Indicator figures taken from the Saltaire engines are given in Figs. 15 and 16, Plate 97.

In conclusion the writer desires to add, with reference to the alterations of the Saltaire engines, that he was aided in the preparation of the designs by many valuable suggestions from Mr. George Salt, through whose kindness the members of the Institution will have an opportunity of seeing the engines at work on the present occasion.

Mr. INGLIS showed a specimen of the spring-clip liberating gear as used in the Corliss engines at Saltaire.

Mr. W. M. NEILSON enquired in reference to the valves of the Corliss engine, whether there was any provision for keeping them up to the face of the ports, as they worked up a curved surface; and whether any difficulty was experienced in making up the wear of the valve faces.

Mr. INGLIS replied that the valve face was simply a portion of a cylinder moving round upon a cylindrical surface a short distance backwards and forwards, and was just similar in action to an ordinary flat slide-valve moving upon a flat surface; and it was kept up to the face of the port in the same way, simply by the pressure of the steam. The valves were of cast iron, and the wear was as uniform over the face as in an ordinary flat slide-valve; and they were driven by projecting arms on the central valve-spindle, which fitted easily into a recess on the back of the valve, leaving the valve resting free upon the port face.

Mr. F. J. BRAMWELL thought that the object to be aimed at in an engine was to combine economy in working with economy and simplicity in construction and repairs, but in reference to the engine described in the paper there appeared to him a serious complication of construction which would entail increased cost both in original construction and in repairs; and it did not seem to him, judging from the indicator diagrams shown, that the result arrived at was any greater economy of working than was obtained from well made engines of simple construction. The several contrivances that were combined in the engine had been tried before, as stated in the paper, such as the dash-pot, and the separate valves for steam and exhaust; and he remembered seeing the original Sickles cut-off valve-gear working in the river steamers of America. The special novelty in the present engine appeared to be the particular mode of effecting the liberation of the valve-gear in cutting off: this however was done by a most complicated piece of machinery, and he thought the question to be considered was whether any real advantage was gained to warrant this complication; especially when it was borne in mind that non-condensing engines were now seen at the agricultural shows which had only a single slide-valve with a cut-off slide at the back, and yet showed a consumption considerably below 3 lbs. of coal per effective horse power per hour, measured by the friction break. If such a high degree of economy could be practically obtained by so simple a construction, he thought the adoption of the complicated construction of the engine now described would be a retrograde step.

In the arrangement of the air-spring and dash-pot he thought there was a practical objection to the connection with the condenser of the engine, as any leakage of the trunk piston would allow air to pass into the condenser; while the great object now aimed at in condensing engines was to prevent entrance of air by every possible means, as for instance by the use of lantern brasses in the stuffing-boxes. He enquired what was the mode of starting the engine, before a vacuum was obtained in the condenser to supply the force required to close the valves.

Mr. E. A. COWPER said he quite agreed with the remarks of the last speaker; and considered an engine was wanted to do its work

steadily, and that as good indicator figures as those now shown could be obtained with a proper slide-valve and expansion gear, without the objectionable complication of triggers and springs, which though certainly very ingenious were not in his opinion suitable for an engine.

Mr. B. WALKER thought it was not possible with any cut-off valve on the back of an ordinary slide-valve to produce so good an indicator figure as those now exhibited from the Corliss engine, which showed a decided economy in working. He thought there was a great deal of merit in the arrangement of the valve-gear, but feared the construction involved too much complication and too many loose parts to allow of its becoming generally applicable.

Mr. C. W. SIEMENS considered that the indicator figures exhibited were certainly very perfect, and that the arrangement of valve-gear shown was capable of producing an exceptionally perfect cut-off and exhaust. Such expansion figures could not be produced by the link motion, and it had to be remembered that with the back cut-off slide the figure obtained was not equally correct for all degrees of expansion; but by the valve-gear now shown a very correct figure was obtained for all degrees up to a very high point of expansion. He quite agreed however with the opinions that had been expressed about the complication of the gear, and thought that several of the mechanical details were of an objectionable kind; but it must be borne in mind that the arrangement was intended as a means for obtaining a very perfect result, and should be considered with reference to that object.

Mr. C. E. AMOS thought that in an engine which had to be kept in regular work, simplicity of construction was one of the most important considerations; and however beautiful and perfect the arrangement might be, all complications should be avoided, as complication in the working parts was liable to involve extra wear and tear and expense in working, which might practically outweigh the other advantages. The addition to the original cost of an engine, caused by complication of construction, was also a serious consideration.

Mr. T. HAWKSLEY observed that the main value of the special contrivance now shown appeared to consist in getting by the use of springs a higher velocity in the closing of the valves than

could otherwise be obtained ; and then a higher speed of engine could be employed with a sufficiently quick action of the valves to give a good expansion. But though there might be some circumstances in which a high speed of engine was desirable, such as 400 feet per minute or more, he thought those cases would be comparatively few, and that the high speed would then be accompanied by an objectionable cost and loss from friction. The indicator figures shown from the engine were not sufficient he thought for forming an opinion as to the results, because an engine working with these disadvantages might exhibit quite as good a figure of expansion within the cylinder as an engine working without them ; and consequently, though a good indicator figure was obtained from the engine, he feared the working effect would not be proportionate.

With regard to the determination of the effective horse power of an engine by means of a friction break, to which reference had been made, he thought the results obtained by that means were not to be relied upon for accuracy ; for he had known instances of a large amount of error in the results obtained by employing a friction break as the measure of the power given off by a steam engine. A remarkable case of a similar nature was the measurement of the power obtained from turbines, the performance of which had been estimated by the use of a friction break to amount to 80 per cent. of the total power in the water expended, and in one case to even as much as 90 per cent. ; but in fact the theoretical limit of the power that could be obtained from an absolutely perfect turbine was only 60 to 70 per cent., on account of the power unavoidably left in the discharged water flowing from the machine. He thought therefore that the very high results which had been stated to be obtained from agricultural engines by measurement with the friction break would be found to require a considerable correction, on account of error involved in the use of the friction break for this purpose.

Mr. C. E. Amos said he had had long experience in the use of friction breaks for measuring power transmitted, and was satisfied that when properly constructed their results were fully to be relied upon. One of the most striking illustrations of their accuracy was afforded in the laying of the Atlantic telegraph cable, where a

dynamometer was used, with a friction break on Appold's improved plan, for measuring continuously the strain upon the cable whilst paying it out from the ship; and the action of this dynamometer was so delicate and sensitive that the slightest increase in the strain upon the cable at any moment was instantly indicated. The breaks were loaded to a definite point, at which the cable should slip; and it was always found to slip directly the strain reached that point. On another occasion in the Bay of Biscay some experiments were made with a similar cable dynamometer, and the depth of water calculated from the indicated strain upon the submerged cable was found to agree closely with the actual depth measured by sounding.

Mr. C. W. SIEMENS fully agreed in the correctness of the indications afforded by the friction break, and considered there could be no better illustration of the correctness of the principle than in the laying of submarine cables, where the safe management of the operation was entirely dependent upon the use of the break dynamometer. Also in the case of measuring the power given off by a steam engine, he considered the result obtained by calculation from the load sustained by a friction break driven by a shaft or belt from the engine must give the correct measure of the power transmitted by the shaft or belt, as all required deductions were thereby made for loss of power by friction and imperfections in the engine. In regard to the other application of the friction break that had been referred to, for measuring the power obtained by a turbine from moving water, the measure given by the friction break could not exceed the power actually given out; and in the case therefore that had been mentioned, where the measurement of the power obtained by turbines had appeared to exceed the theoretical limit possible, he thought the gross power residing in the water must have been under-estimated.

Mr. T. HAWKSLEY considered that the friction breaks used for measuring the power transmitted from engines were defective in the mode in which the power to be measured was taken off by the break. They were generally constructed on the plan that might be termed "dithering" breaks, in which the action was not steady and continuous, but the break was constantly jumping up and down,

alternately biting and slipping, and was really doing no work at the moments of jumping off the wheel, although it was registering the full load throughout, and consequently indicating too high a result.

Mr. G. D. HUGHES believed that in several cases indicator figures which he had taken had as good an expansion curve as those now shown, with the steam cut off as early, and as good a vacuum line; and in these cases the engines had an ordinary slide-valve, with a cut-off slide on the back which was adjusted by the governor, controlling the speed of the engine without any throttle-valve. He thought it would be going back to adopt so complicated a construction for effecting the object as in the engine now shown; and considered the complexity would be found to involve a sacrifice in first cost and a great liability to get out of repair.

Mr. J. C. AMOS considered it was quite practicable to produce as good a diagram as those now exhibited, with a simple valve and a back cut-off slide; and the only advantage in the construction of engine now shown appeared to be the facility afforded for regulating the degree of expansion by the action of the governor, which notwithstanding the very numerous attempts that had been made could not be said to have been thoroughly accomplished yet with the ordinary slide-valve. The completeness with which this was effected in the plan now shown appeared to him the only good reason for departing from the simplicity of the ordinary double slide.

Mr. R. DOUGLAS remarked that he had had considerable experience in the manufacture and working of the Corliss engines, and could bear testimony to the fact of there not being that tendency to derangement of the working parts which seemed to be supposed; on the contrary the whole of the valve-gear was found to be very durable and satisfactory in working. He knew some of these engines had been in regular work for the last four years, running night and day, and their valves were still perfectly tight, and the steel catches of the liberating gear were now as square and sharp at their engaging edges as when first made, though they had been working the whole of the time; there was in fact only a very slight source of wear upon them, because at the moment of disengaging there was only the pull of the spring upon the catches that were released, and the valve

was then open with no pressure upon it, and requiring consequently very little power to move it. He had fixed Corliss engines in many cases in the place of other engines, and had effected by the change a saving of one third in the consumption of fuel in all instances, and in some cases even more. It was very difficult however to make correct comparisons of engines in this respect, on account of the great variations in the conditions; but in another respect, namely the undeviating uniformity of speed, there was no question as to the advantage gained with the Corliss engine. In one instance of an ordinary engine driving a flax mill, where two thirds of the mill was driven from one cog-wheel, this wheel had got stripped on one occasion previously to the change of engine, and the result of the acceleration in speed of the engine in consequence of two thirds of the work being suddenly thrown off was that the threads in all the remaining spinning frames were broken; but after the Corliss engines were substituted, although a similar accident happened from the stripping of the teeth of the same cog-wheel, not a single thread was broken in the spinning frames, as the supply of steam to the engines was instantly diminished to correspond with the diminished load. He did not know how such a regulation of the speed could be accomplished by any arrangement of a cut-off slide working on the back of another; but in the Corliss engine the steam-valves were completely thrown out of gear at every stroke, so that when the engine was making 30 revolutions per minute the steam supply was regulated 60 times in a minute, which gave a great nicety in regulating the speed of the engine.

Mr. INGLIS said that the valve-gear in the Corliss engines, although appearing complicated, did not really involve any practical objections in working, as the working parts were very durable and were subjected to very little wear. There had never been any trouble with any of these engines, although more than sixty of them were already in use in this country; and they had given such entire satisfaction in their working that there were now nearly twenty more of them in progress. A decided economy in consumption of fuel was found to be effected by these engines, where a comparison with other engines working under the same circumstances could be made. At

Woolwich Arsenal, where four of the Corliss engines were in use, a careful trial had been made during three months' working, and the result was found to be considerably in their favour in cost of working; their total average consumption during that time was $2\frac{1}{2}$ lbs. of coal per indicated horse power per hour, with a steam pressure of 45 lbs. per inch. The general working of other engines would be found he thought to average nearly 5 lbs. per indicated horse power per hour, and he believed more than half of the engines included in the Manchester Boiler Association were fully up to that amount or above it. The pair of Corliss engines at Saltaire, which had now been working about two months, would afford a good opportunity for comparison of results with the original pair of engines continuing to work alongside of them under exactly similar circumstances, the only difference being that the cylinders were not steam-jacketted in the original engines.

In reference to the enquiry about the arrangement for starting the Corliss engine, before a vacuum was obtained in the condenser for supplying the spring to close the steam valves in cutting off, the valve-gear was arranged not to be liberated at all when the governor was down in its lowest position; so that at starting the engine the valve continued connected to the gear throughout the stroke, and consequently did not require the air-spring for closing it; but by the time the speed was increased sufficiently for bringing the governor into action and liberating the valve at each stroke, a vacuum had been obtained in the condenser so as to effect the closing movement by the air-spring.

Mr. H. WOODS thought that a consumption of 5 lbs. per horse power per hour was too high a figure to be taken for general comparison, and that such a consumption could apply only to defective engines.

Mr. T. HAWKSLEY did not understand how any great difference in consumption could arise in really good engines, under the same circumstances of good condition, if the degree of cut-off were the same in both the engines compared; for when the steam was once shut into the cylinder, its expansion would be the same in both cases, and any difference in the indicator figures would be chiefly due

to condensation in the cylinder from the want of a steam jacket, which however could not amount he thought to more than an additional consumption of $\frac{1}{2}$ lb. of coal per horse power per hour. Any greater difference he thought must really be due to the two engines compared not being in equally good working condition; but if the two engines had their cylinders equally warmed by steam jackets, the same expansion curve in the indicator figure would be obtained from both, if the steam was cut off at the same point and at the same pressure in both, although one might be a good engine and the other a bad one.

Mr. INGLIS observed that the expansion curve was affected materially by the amount of clearance at the ends of the cylinder, which in some engines amounted to a considerable proportion of the contents of the cylinder; but in the Corliss engines the clearance was reduced to an unusually small proportion by the arrangement of the valves, and in the Saltaire engines it amounted to only $2\frac{1}{2}$ per cent. of the capacity of the stroke, including both the clearance and the contents of the ports, whereas in other makes of engines it was usually considerably more. The area of the exhaust passages in the Saltaire engines was 1-10th of the cylinder, and the steam passages 1-16th. The sharpness of cut-off in the Corliss valve-gear prevented the loss that was generally shown in an indicator diagram from the rounding off of the top of the figure; and the uniformity in the action of the valve-gear prevented the inequality that was generally found in other cases in the supply of steam at the two ends of the cylinder. There was also a great advantage in working entirely from the governor, so as to regulate the speed of the engine by the degree of expansion, thereby getting always the full steam pressure in the cylinder up to the point of cut-off, instead of wire-drawing the steam pressure by contracting the opening of a throttle-valve in the steam pipe.

The CHAIRMAN remarked that the subject was one of great practical interest and importance, and required close investigation, both as to the real economy in working of the new engines and as to the actual wear and tear attending the complication in their construction. There would be an unusually good opportunity for comparison

between the new engines at Saltaire and the original engines, provided one pair were retained for a few months to work against the other pair that was altered; it would then be seen what advantage, if any, was derived from the change. The original engines, which had been made at his own works, had been at work about twelve years and had given great satisfaction. They were plain single-cylinder beam engines, with double-beat valves worked by a cam motion adjustable to different degrees of expansion. Improvement in the construction of steam engines was certainly a subject of great practical importance, and it was desirable that any improvement such as the one before the meeting should be thoroughly investigated; and the members would have a good opportunity, through the kindness of Mr. Salt, of examining both the new and the old engines at work at Saltaire that afternoon.

He moved a vote of thanks to Mr. Inglis for his paper, which was passed.

The following paper was then read:—

Fig. 1.

Watt's Liberating Gear.

Fig. 2.

Corliss
Original Liberating Gear.

CORLISS ENGINE.

Woolwich.

Plate 89.

Fig. 3. *Side Elevation of Cylinder.*

(Proceedings Inst. M. E. 1868.)

Scale $\frac{1}{8}$ in.

0 5 10 15 20 25 30 Inches.

CORLISS ENGINE.

Plate 90.

Fig. 4. *Transverse Section of Cylinder.*

Woolwich.

Fig. 5. *Longitudinal Section of Cylinder.*

(Proceedings Inst. M. E. 1868.)

Scale $\frac{1}{10}^{th}$ 0 5 10 15 20 25 30 Inches.

Saltair.

Fig. 6. *Front Elevation of Cylinder:*

(*Proceedings Inst. M. E. 1868.*)

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

6 Feet.

*Saltair.*Fig. 7. *Side Elevation of Cylinder.*

(Proceedings Inst. M.E. 1868.)

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

*Saltaire.*Fig. 8. *Vertical Section of Cylinder.* *(Proceedings Inst. M. E. 1868.)*Scale $\frac{1}{30}^{th}$

6 Feet.

Saltaire.

Fig. 9. *Plan of Cylinder at AA. (Fig 8.)*

Fig. 10. *Plan of Cylinder at BB. (Fig 8.)*

(Proceedings Inst. M. E. 1868.)

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

0 1 2 3 4 5 6 Feet.

*Saltaire.**Liberating Gear for Steam Valves.*

CORLISS ENGINE.

Saltaire.

Plate 96.

Fig. 14. *Air-Spring Dash-Pot.*

(*Proceedings Inst. M.E. 1868.*)

Indicator Diagrams from Saltair Engines.

Cylinder 50 ins. diam., 7 ft. stroke.

30 Revolutions per minute.

Speed of Piston 420 feet per minute.

The fine lines show the theoretical true expansion curves.

(Proceedings Inst. M.E. 1868.)