

ON A NEW REVERSING AND EXPANSIVE VALVE-GEAR.

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The Reversing and Expansive Valve-Motion, which is the subject of the present paper, was originally drawn out by the writer in a crude state, but possessing all its present elements, in the year 1868-9; and has since been, at different times, the subject of frequent investigation and experiment on his part. In 1877 he made it a special study, first working it out on paper, and afterwards testing all the movements and positions by means of models. And thus, passing through innumerable forms under the correction of various errors of action, it has ended in the arrangement which is now submitted to the Institution.

In passing, the writer may call attention to the fact, that this is only one of the many instances where inventions are the result of a long course of work, followed in a given and definite direction, and with a special end in view. It thus helps to disprove the theory of opponents of the patent system, who rather characterise inventions as lucky chances, which men of scheming brains fall upon without expecting it. A few such cases do occur, just to give colour to this statement; but even these generally happen to men who have been working laboriously on some kindred subject.

In the writer's case, as an engineer, his attention has been specially directed by circumstances, and perhaps partly by taste, to the question of the movement of the valves in steam and other engines. As a pupil at the Railway Foundry, Leeds, he was thoroughly initiated into the mysteries of lead, lap, port, and travel, by the investigation and observation of John Gray's valve-motion as applied

to locomotives, the first instance in which expansion was so applied successfully. Those who are familiar with the ingenious details and perfect action of Gray's motion will not be surprised at the strong bias thus given to the writer's mind in this direction; and the conviction was gradually attained by him that the proper distribution of the steam in a steam-engine is the very life and soul of the machine, and that the mechanism for effecting this object cannot receive too careful or too minute attention.

The great complication of Gray's motion and the difficulty of keeping it in order (partly owing to the very perfection and refinement of the action), were no doubt the causes of its falling out of use, and giving place to others more simple though less perfect in their action. These were again finally superseded by the very general adoption of the "Link Motion," now employed almost universally by English and American engineers, and very widely also on the Continent, though with a greater disposition there to depart from established usage. To the link motion the writer will refer in the following paper as the most satisfactory, because the most generally known, standard of comparison; and by this standard he hopes to show that a distinct advance has been made in the valve-motion now to be described.

The link gear in its turn became the subject of very careful practical analysis by the writer, while he had the charge of the rolling stock of a railway in the Midland counties; where the high price of coke rendered necessary a careful attention to economy of fuel consumption. Here he personally superintended the setting of numbers of valves, worked by link gears of various descriptions; and arranged them in many varied positions and proportions, all with the view of obtaining an even distribution of steam together with an equal lead; but all these contributed to prove the well known fact that it is impossible to gain both, and that in setting for one the other is seriously sacrificed; and further that the inequality increases as the expansion is increased. With high grades of expansion, and with the link gear as usually constructed, the lead becomes so excessive, and the point at which steam is admitted is so considerably in advance of the beginning of the stroke, that, although the

arrangement may answer fairly for high-speed engines like locomotives, it does not give a satisfactory result for slow-running types, such as marine engines; consequently in these an additional valve and independent gear are usually employed for expansion.

Hence in later practice, having to design marine and other engines, the writer followed up the same course, and worked out many varied methods for distributing the steam, keeping in view throughout the two leading desiderata in designing all machinery—increased simplicity and increased accuracy. Among the earliest of these methods was the device of giving steam to the first piston of a compound engine in the usual manner, and then using this piston as the admission valve for the second cylinder, into which it passed the steam for expansion. Afterwards, working in an entirely different direction, he employed live steam to move the valves, instead of any mechanical connection at all. This plan, though answering very well in the case of reciprocating machines, such as steam hammers, steam pumps, etc., failed to give the exact control necessary for the valves of engines producing a rotary motion. Finally, coming back to strictly mechanical appliances, and using both the experience of the past and an increased knowledge of the action required, he laid down and worked out the valve-gear which is here described.

Perhaps this is the place to remark that, though on the whole the link motion has held its own so well and for so many years, yet, especially during the last few years, the endeavour to produce a valve-motion at once simpler than the link, and free from its inherent errors, has engaged, both here and on the Continent, the attention of several engineers whose eminence is sufficient proof of the importance attached to the subject. Prominent among these motions are, on the Continent, the Walschaert gear, and that designed by Mr. Charles Brown of Winterthur; and more recently in England, that of Mr. F. C. Marshall of Newcastle, and that of Mr. Kitson of Leeds. To give even the shortest possible description of these would be out of place here; but on examination it will easily be seen that the prominent aim in each is to avoid the complication of the double eccentrics and the link, as well as the various errors unavoidable in that system.

Referring now to the author's valve-motion, it may be premised that the original intention was to arrange a suitable valve-gear for the usual type of overhead marine engine, abandoning entirely the use of eccentrics, and taking vertical motion from the air-pump lever, in combination with transverse motion taken from the vibration of the connecting-rod. It is on this general principle that the valve-motion is arranged; in other words, the combination of two motions at right angles to each other, by the various proportions in which they are combined, and by the positions in which the moving parts are set with regard to each other, gives both the reversal of the motion and the various degrees of expansion required.

The action of the gear will at once be understood and followed by reference to the models, or to Figs. 1 to 3, Plate 57, representing an ordinary overhead marine engine; and to Figs. 4 to 6, Plate 58, representing a horizontal engine.

Referring to Fig. 4, Plate 58, from a point A in the connecting-rod—preferably about the middle—motion is imparted to a vibrating link B, constrained at its lower end to move vertically by the radius-rod C. From a point D on this vibrating link, horizontal motion is communicated to the lower end of a lever E, from the upper end of which lever the motion is transmitted to the valve spindle by the link G. The centre or fulcrum F of the lever E partakes also of the vertical movement of the connecting-rod, to an extent equal to the amount of its vibration at the point A; the centre F is for this purpose carried vertically in a slot J, which is curved to a radius equal to the length of the link G, connecting the lever E to the valve spindle. The slot itself is formed in a disc or sheave K, which is concentric with the centre F of the lever E at the moment when that lever is in the position given by the piston being at either end of the cylinder. This disc is capable of being partially rotated on its centre, so as to incline the slot over to either side of the vertical, by means of the worm and hand-wheel M, thereby causing the curved path traversed by the centre F of the lever E to cross the vertical centre line, and diverge from it on either side at will. The forward or backward motion of the engine is governed by giving the slot this inclined position on one or other side of the vertical centre line; and the

amount of expansion depends on the amount of the inclination, the exactly central or vertical position being "mid gear." In that position steam is admitted at each end of the stroke to the amount only of the lead; and this is done exactly equally on each side of the centre line, the amount of lead being constant for forward and backward motion, and for all degrees of expansion. Thus when the crank is set at the end of the stroke either way, the centre F of the valve-lever coincides with the centre of the slot, and therefore the slot may be moved over from forward to backward gear without affecting the valve at all.

It will be seen at a glance that, if the lower end D of the lever E were attached directly to the point A on the connecting-rod, there would be imparted to the centre F of that lever an unequal vibration above and below the centre of the disc K. The extent of inequality would be twice the versed sine of the arc described by the lower end D of the lever E; and this would give an unequal port and unequal cut-off for the two ends of the stroke. But this error is corrected by attaching the lower end D of the lever E to the vibrating link B: for while the point A on the connecting-rod is performing a nearly true ellipse, the point D in the vibrating link B is moving in a figure like an ellipse bulged out at one side, and this irregularity is so set as to be equal in amount to the versed sine of the arc described by the lower end of the lever E, thus correcting the above error, and giving an equal travel to the centre F of the lever above and below the centre of the slot. At the same time the error introduced by the movement of the end of the valve-link G is corrected by curving the slot J to a radius equal to the length of G. These two errors may however be set against each other, and a compromise may be made by attaching the end of the lever E direct to the connecting-rod at A, and allowing the centre F to slide in a straight slot. By a just balancing against each other of the errors so produced, and by making the centre F of the lever E, and the centre of the disc K, to coincide at varying points in the travel of the former, a fair motion may be got for the forward gear of an overhead marine engine, giving a longer cut-off for the up stroke than for the down stroke. This is of course at the sacrifice of the backward gear, in which the reverse

is the case ; and the various degrees of expansion are between the two extreme conditions.

Referring again to the equalising of the traverse of the centre *F* of the lever *E* in the slot *J*, the unequal traverse may be either under-corrected or over-corrected, by shifting the point *D* in the vibrating link *B* nearer to or further from *A* ; by this means a later point of cut-off may be given to either end of the cylinder at will, and the engine may thus have more steam admitted to one side of the piston than to the other, if required. The same thing may be done for the lead. By altering the position of the crank for which the lever-centre *F* coincides with the centre of the slot *J*, an increased or a diminished lead may be given. The central positions and exact corrections are however in all cases standard and equal.

Hitherto the centre *F* of the lever *E*, which gives motion to the valve spindle, has been described as carried in a curved slot. This plan is given as the most simple to manufacture, and for clearness sake has been adhered to throughout the description. But if preferred the centre *F* may be carried by a radius-rod, in the manner shown in Figs. 7 and 8, Plate 59, for a marine engine. Here the centre *F* is supported by a link *L*, and the other end of this link is carried by a weigh-lever *NN*, whose fixed centre takes the place of the centre of the slot *J* in the other design. In the central position of this weigh-lever, the vibration of the suspending link *L* will make the centre *F* of the lever *E* describe identically the same arc as if moving in the slot *J* while in its central position ; and by rotating the weigh-lever *N* to either side of the centre line, the arc described by the link will correspond precisely with the curve of the slot in either of its extreme positions, as well as in every intermediate position to which the reversing lever may be set.

The peculiarities of this motion having now been described, it will be evident that it may be applied wherever the link gear is now employed : with this difference of general arrangement, that, where the link gear requires the centre line of the valve to be in the plane which contains the centre lines of the cylinder and crank-shaft, this gear requires the valve centre-line to be set in the plane which contains the cylinder centre-line but is at right angles to the crank-shaft

centre-line; that is, in a horizontal engine the valve must be on the top of the cylinder, and in a vertical engine it must be at the front of the cylinder, instead of at the side.

Several applications are shown in the drawings; that to an overhead marine engine is given by Figs. 2 and 3, Plate 57, and in the model No. 1. The application to horizontal engines, including rolling-mill engines, and all other classes of mill engine, is given in Figs. 4 to 6, Plate 58, and in model No. 2. The application to locomotives is given in Figs. 16 to 22, Plates 61 to 63, showing an inside-cylinder engine: though it will be clear that the gear is equally suitable for outside cylinders. For steam-plough and other engines, the arrangements are the same as shown by model No. 2. The gear has also been arranged with a separate cut-off valve, worked also from the extremity of the lever E, Fig. 4, Plate 58, which is lengthened for that purpose beyond the attachment of the main-valve link G. The lines given by this valve, for various points of cut-off, are shown by the parallel dotted lines in Fig. 10, Plate 60: while the similar lines in Fig. 11 represent the lines of the usual form of expansion valve, applied on the back of the main valve of a link motion.

We now come to the advantages claimed for this system. Taking the link gear for our standard, for the reason already mentioned, these may be stated as follows. First, it is simpler and less costly than the link gear by fully 25 per cent., taking the best forms of application in both. The writer has placed this advantage first, not because he thinks it by any means the most important, nor because any engineer would assign to it that place; but because, as is well known, the first question asked by a proposing purchaser, regarding any new invention which may be offered to him, always is—"Will it cost more than the old system?" To prove this, the various parts of a very well designed link motion have been compared with an equally carefully designed set of the new gear. In each case large and equally balanced wearing surfaces are provided for, no overhung bearings are allowed, and the best facilities for taking up wear and for overhauling are provided; and while the total weights for the

link gear are 5 tons 6 cwts. 0 qr. 25 lbs., those for the new gear are 4 tons 0 cwt. 1 qr. 27 lbs., showing a saving in weight, in favour of the new gear, of 1 ton 5 cwts. 2 qrs. 26 lbs., or about 25 per cent. The saving is not only in weight however, but also in the greater simplicity of parts, allowing increased facility for tooling and fitting.

Secondly, by placing the valve in the positions shown, namely in front in a marine engine, and on the top in a horizontal engine, a more simple and easily constructed form of engine is obtained. The cylinders also lie closer together, so that the engine is shortened in the line of the crank-shaft, see the dotted lines in Fig. 3, Plate 57. Thus in a marine engine space is gained in the engine-room, while in a locomotive larger cylinders may be got into the confined space between the frames; and, the cranks being closer together, room is left for increasing the length of the main bearings of the crank-shaft. All the centre lines of construction are also either parallel or at right angles to one another. Thus all the parts of an engine come direct off the tool, and go square together, without any inclined faces, such as require care in setting and are more costly in erection.

Thirdly, the new gear is more correct. In point of fact it is almost mathematically correct. By setting out the centre lines properly, a valve-path diagram is given similar to that shown in Fig. 9, Plate 60, where the lead and cut-off are exactly equal for both ends of the cylinder, and remain so in all grades of expansion to mid-gear; and where the port opens and closes by the amount given as lead at equal distances on each side of the centre line. The only variation is that the port for the rising stroke, in an overhead marine engine, opens a little wider than the port for the falling stroke. In practice however, for setting the valves of such an engine, it is only necessary to lift the valve on the valve spindle by the adjusting nuts, so as to allow say $\frac{1}{8}$ in. lead for the top and $\frac{3}{8}$ in. for the bottom. Then the points of cut-off will follow relatively in similar proportion, and valve-path diagrams will be produced as shown in Fig. 10, where the leads and points of cut-off for a 48-in. stroke are respectively $\frac{3}{8}$ in. lead and 37 in. cut-off for the rising stroke, as shown by the upper

line, and $\frac{1}{8}$ in. lead and 35 in. cut-off for the descending stroke, as shown by the lower line. These, compared with parallel diagrams, Fig. 11, taken from a link gear, show the errors of the link corrected; the lead and cut-off with the link being $\frac{3}{8}$ in. and 35 in. for the rising stroke, and $\frac{1}{8}$ in. and 37 in. for the descending stroke. From this latter distribution of steam, as given by the link gear, there is a greater pressure of steam to drive the piston down, when it is assisted by the falling weights, and a less pressure for the up stroke in which all the weights are to be lifted. This produces the result shown in the following Table, as compared with the result given by the new gear.

TABLE OF TOTAL PRESSURES.

	DOWN STROKE.	UP STROKE.
Joy's Gear	Mean Pressure = 98 Tons. (cut off at 35 in.) + weights falling = 2 <hr/> Total..... 100	Mean Pressure = 102 Tons. (cut off at 37 in.) - weights lifted = 2 <hr/> Total..... 100
Link Gear	Mean Pressure = 102 Tons. (cut off at 37 in.) + weights falling = 2 <hr/> Total..... 104	Mean Pressure = 98 Tons. (cut off at 35 in.) - weights lifted = 2 <hr/> Total..... 96

It will be seen that with the new gear the total effective pressure is the same in both the up and the down stroke; while with the link there is an inequality (in the case of the particular figures given) of about 8 per cent.: an inequality very noticeable when an engine is running slowly, and, though hardly to be detected, still existing even when the engine is at full speed. The equalising and relieving of the strains by the new gear necessarily results in a more smooth and equal working, and less wear and tear, than can be obtained with the link arrangement.

Further, an examination of the valve-path diagrams given by the new gear, and a comparison of them with others of similar constituents

given by the link, will disclose another fact; namely that the movement of the valve by this gear departs more widely from a continuously even speed than with the link motion; the acceleration is relatively augmented and the retardation prolonged, so that the valve receives a movement more resembling that produced by cams or tappets, but entirely free from the jerks or shocks inseparable from those motions, since the movement is here continuous. The circle, Fig. 15, Plate 59, shows the crank-path of a vertical engine divided into eight intervals. While the crank is passing its top centre, through the interval marked A to B, the motion imparted to the valve is caused by the centre F of the lever E, Fig. 7, swinging down the inclined arc in which it moves, while the lever action of E is almost suspended. During this time the valve is being opened sharply by the inclination of the arc, and the result is a very rounded curve in the valve-path diagram, as shown by the full line on Fig. 12, Plate 60. During the next interval B to C in the down stroke, the centre F of the lever is continuing to swing down the inclined arc; but the lever E itself has now begun to take action as a lever, and this action is counter to, and partially neutralises, the movement of its centre F. The result is a longer dwell of the valve, at the time when it is fully opened, the effect of which is seen in the diagram, Fig. 12, from B to C. During the next interval, while the crank passes from C to D, the movement of the centre F is almost *nil*, while the lever action of E is fully developed, and its motion is at its quickest. During this time the valve is being closed, and hence comes the prompter cut-off, as seen in Fig. 12. In the next interval D to E, when the valve is closed, the lever action of E continues, though its effect gradually decreases, while its centre F is now swinging up the inclined arc; thus both are acting in the same direction, but, as one diminishes while the other increases, the result is to maintain the speed of the valve nearly constant, until approaching the point E, when a considerable acceleration takes place by the centre F swinging more rapidly up the inclined arc. This occurs just at the point required for the release, which is thus effected by a quick opening of the exhaust port as it is uncovered by the inner edge of the valve, giving the round full curve shown in the release diagram, Fig. 14.

Then for the upward stroke the same action is repeated which has just been described for the downward one. On the same diagram, Fig. 12, is shown by a dotted line a similar valve-path produced by the link: in this the comparatively slower opening and closing of the ports is very apparent.

While the above advantages are gained for the full admission of steam, still greater arise as we approach the higher grades of expansion. From the constant and unaltered lead at all points of cut-off, coupled with the peculiar acceleration and retardation given to the valve, as described above, a sufficiently satisfactory valve-path diagram can be obtained with a cut-off at one-third of the stroke, thus obviating the necessity for the employment of the usual additional expansion valve and gear. The full line in Fig. 13, Plate 60, shows this diagram. It will be seen that the correct lead of $\frac{3}{8}$ in. (taking the up stroke) is maintained, the valve commencing to open about $\frac{1}{2}$ in. before the beginning of the stroke of the piston, and giving a considerably increased opening for the port, and a smart cut-off. On the same Fig. 13 is shown dotted a parallel diagram taken from a link. Here the lead, which for the full admission was set at $\frac{3}{8}$ in., is now increased to about $\frac{7}{8}$ in.; and the steam would be admitted to the piston about $1\frac{1}{4}$ in. before the beginning of the stroke. Beyond the amount thus given as lead the port is opened very little, and almost immediately begins to close again.

A number of less important but yet valuable points remain to be named, but these need not be enlarged upon.

The new gear is more accessible than the old, as all the main working parts are brought down, and out to the front, and are placed close together under the direct inspection of the engineer, and within easy reach for examination and oiling. They do not, as with eccentrics, encumber the shaft and main bearings, which are here left quite open, and without moving parts about them other than the crank, thus rendering examination of and attention to these important parts more easy.

Again, the complete gear is always in useful action, and for backward running the very same parts are employed as for forward

running, and no others: the difference of direction being simply due to the altered positions of the parts. Hence no duplicate parts are carried, such as are required in the link gear, in which a complete set of eccentrics, straps, rods, &c., have to be provided for backward running. The whole of these are continually in motion, notwithstanding that in forward running their motion is not only useless, but is even prejudicial to the action of the forward gear. In Atlantic steamers, for instance, this useless working is continued for about ten days together, solely in order that the backward section of the gear may serve for a few back turns on arriving in port.

Overhauling for repairs and for taking up of wear will also be more easily executed with the new gear, as the parts are removable more independently of each other; and one great source of wear, namely the eccentrics, is done away with.

This gear is also more easy to reverse, requiring less power than the link-gear; and the effect on the engine can be carried much further, as it is only necessary slightly to increase the angle of the slot J, Plate 58, or of the arc in which the lever-centre F swings, Plate 59, in order to increase the opening of the port, and prolong the action of the steam on the piston, so far that, in whatever position an engine might be standing, it would start. Hence in a marine engine it would never be necessary to reverse in order to get off the bottom centre; and in a locomotive there would be no need for backing, such as is often resorted to when an engine is unable to start, owing to the considerable lap given to her valves, for the sake of employing high degrees of expansion. In either case it would only be necessary to move the reversing lever forward beyond the usual full-steam notch (for which a provision is made), in order to permit the steam to follow the piston, if required, for even 9-10ths of the stroke; the engine would then have power to start, whatever the position of the cranks, or whatever the weight of the load.

Discussion.

Mr. Joy exhibited working models of the valve-gear for locomotive and marine engines, and explained its action.

Mr. F. C. MARSHALL said, as Mr. Joy had been good enough to mention his name in the paper in connection with the question of new valve-gears, he had ventured to show, Plate 65, his own valve-gear as he was at present fitting it to a large number of marine engines. The principle of this gear was precisely that adopted by Mr. Joy, both of them arising out of the original invention of John Wesley Hackworth. It was the principle of a movable centre connected to the valve, which centre traversed an arc passing through the centre of the reversing shaft, and coincided with that centre when in the dead position; thus securing a uniform lead at all points of cut-off, and obtaining an equal cut-off at both ends of the stroke or otherwise, as might be desired. Six sets of engines were now at work at sea with this valve-gear, indicating from 100 to 1800 H.P. The action in the motion, as in Mr. Joy's, was simply perfect, so far as the distribution of steam was concerned, as also in the relief of strain on all the working parts, and in the means of giving a slightly increased quantity of steam on the underside of the piston; also in maintaining uniformity of lead, so that there was a uniform pressure at the top and bottom of the stroke when the engines were on the centres.

He scarcely liked to compare his own design with Mr. Joy's; but there was one advantage it possessed that he might point out. While they both attained the same objects, his design had only five working parts for each engine, instead of eight in Mr. Joy's. It was seen in Fig. 25, Plate 65, that the eccentric was opposite the crank under all conditions; and when the crank was on either centre, the valve connecting-rod and the main connecting-rod were parallel to each other. The valve-chest was fixed at the corner of the cylinder casting, having an angular position in the plan, which was

allowed for by making the pin-joint in the valve-rod parallel to the crank-shaft. The eccentric-rod, which with its strap was made usually of cast steel, extended to where the reversing shaft L was fixed, on which was keyed the arm K, Figs. 26 and 27; the extremity of the arm formed the fulcrum for the suspending link J, the other end of which was jointed to the extremity of the eccentric-rod. For reversing or working expansively, the reversing arm K was thrown over into its opposite extreme position, indicated by the dotted line in Fig. 25, or into any intermediate position; this could be done by any plan that might be preferred, the screw gearing into a toothed quadrant, as shown in Fig. 25, being merely a typical arrangement. The point of attachment for the valve-rod to the eccentric-rod was determined in due relation to the throw of the eccentric, the stroke of the engine, and the lengths of the connecting-rod and eccentric-rod. In Mr. Joy's design he believed there was the same number of parts as in the ordinary link motion. The only points of objection that he saw were the very long travel of the valve lever, equal to that of the connecting-rod, say ranging from 3 ft. to 6 ft. as in the *City of Rome*; and the sliding motion at the opposite end of the lever, in the reversing weigh-shaft sliders. Perhaps at the end of a thirty days' voyage, or even an Atlantic voyage, some serious difficulty might be experienced in the way of repairs to the engines, from the fact of the pin joints wearing out. Being attached to the connecting-rod, the lever would be subject to heavier wear than if attached to the ordinary eccentric, and so having a much less distance to travel.

The shortening of the engine-room, as claimed by Mr. Joy, was only a very small matter, because the length was generally governed by the size of the condenser. His own motion was worked with only one eccentric instead of two. The smallest vessel worked in that way was a yacht, belonging to Capt. Lee Guinness of Dublin. The highest power was that of the *Lady Tyler*, 1650 H.P. Figs. 28 and 29, Plate 66, were exact copies of original indicator diagrams taken from the *Osmanli*, the highest power indicated being 1409 H.P. By the cut-off, as shown, the power was varied from 1409 down to only 389 H.P., the revolutions of the engine coming down from 57 to 35

per minute, and the engines working in a fashion which, with the ordinary link gear, was very exceptional. The fact of having increased admission of steam on the underside of the piston had a wonderful effect in relieving the bearings. There had never been a hot journal in any of those engines, not even in their trial runs. He believed Mr. Joy's design would have the same effect, because either of these motions gave perfect control over the admission of the steam, and always secured uniformity of lead. The simple difference between Mr. Joy's motion and his own was that Mr. Joy's worked from the connecting-rod, while his own worked from an eccentric.

Mr. F. W. WEBB said that, when Mr. Joy showed him his gear, he was himself busy designing a larger type of goods engine, and was endeavouring as far as possible to increase the bearing surfaces, having adopted 18-in. cylinders and 140 lbs. steam-pressure. It was difficult to get such large bearing surfaces as he wanted, having to provide four eccentrics on the crank-shaft; and when Mr. Joy came to him he was busy at work with another modification of Hackworth's gear. He thought well enough of Mr. Joy's proposal to ask his directors to have an engine built to try the experiment; and this engine itself had been sent down to Barrow for the members to examine, and to look into all the details at their leisure after the meeting. The indicator diagrams, Figs. 23 and 24, Plate 64, showed the working of the valve-motion; and the motion itself and other details of the engine were also shown in Plates 61 to 63. Of the diagrams, one, Fig. 23, was taken at a slow speed to show the perfect action of the steam in the cylinder; and the other, Fig. 24, at higher speed, with an earlier cut-off.

There was another point in this engine, in connection with the valve-motion. It was not of course a new idea, being known as the Trick or Allen valve. By that arrangement, Fig. 18, Plate 62, owing to the passage through the back of the valve, there was a double admission on the lead, and though the valve was not open for the admission of steam until the piston got within about one-hundredth part from the end of the stroke, yet $\frac{1}{4}$ in. opening was got almost

instantaneously; and there was also a more sudden cut-off, as shown in the diagrams.

The success in getting an increased bearing surface was well seen in Figs. 17 and 22, Plates 62 and 63, showing an engine with 18-in. cylinders, placed 1 ft. 10 in. centre to centre. There was a 9-in. axle-box, and 5½-in. width of crank-pin instead of the ordinary 4 in. He had got plenty of surface for the connecting-rod and cross-head, and there was plenty of room to get up and examine or clean the engine-motion. The reversing shaft was a hollow casting of cast iron. The curved segments forming the slides for the valve-motion, Fig. 19, were turned up in the lathe in a circle of the proper radius, and then cut off in sections of the required length; they were made of mild steel and afterwards case-hardened. For oiling the valve slide-blocks the oil-cups were carried on the top of the slides, Fig. 19, so that they could be oiled while the engine was running at full speed. All the working and wearing parts were circular bushes of hard phosphor-bronze; and any of them could be removed by slacking back the oil-cup, which was used for locking in the bush. The oil-cup entering into the bush, as shown in Fig. 19, prevented the bush from revolving; and by simply slacking back the oil-cup, the bushes could be removed. The coupling rods were bushed on the same method of locking in the bronze bushes by the oil-cups; and the oil-cups were themselves locked in in a simple way by a bit of wire.

There was another thing in this locomotive which Mr. Joy's valve-motion had enabled him to do. There were only two cotters, those for coupling the piston-rods to the cross-heads. Having that extra width of crank-pin to work upon, instead of putting in an ordinary cotter in the large end of the connecting-rod, Fig. 20, Plate 62, he had put in a circular taper pin through the block B for holding in the brasses; so that, in disconnecting the engine, all that had to be done was to take off the bottom nuts of this taper pin, tighten up the upper nut half a turn, and the pin was free to take out.

There was also another advantage that was obtained, namely in the tightening up and slacking of the connecting-rod brasses. Instead of having the edge of a cotter bearing against the brass, which was

generally the case, he did away with the cotter, and used a cast-iron block C with a bolt through it, and through the connecting-rod fork; so that by tightening the top nuts the brasses were tightened up; and if the bearing got warm, then by slacking the top and tightening the bottom nuts the brasses might be relieved.

With the President's permission he should like to mention a few other deviations which he had made in this engine from the ordinary practice, though they did not directly refer to the subject of valve-motion. One was, doing away with the solid foundation-rings in the fire-box, and using a water bottom instead, as shown in Fig. 16, Plate 61, thus giving more room for expansion and contraction. The fire-hole door was also arranged without a ring, and a similar opening was placed in the bottom for the purpose of removing the ashes at any time, a sliding door being provided over it, worked from the footplate. A mouthpiece was arranged in front for the admission of air under the fire-bars, as shown, extending the whole breadth of the fire-box; and the tube-plate could be renewed, or the fire-box repaired, without having to take out the entire box, or remove the water bottom. The damper was made to open inwards, so as to deflect the air towards the middle of the fire.

The footplates in all the North Western engines were now made one standard width over all, as shown in the cross section, Fig. 22, Plate 63; making it worth while to cut rolls for a special section, and so economise both labour and materials in their construction. The man-hole lid and the dome cover were also made each out of a flat plate, stamped up under the steam-hammer in three or four successive dies, to bring it to the finished shape.

It was an important point for engineers to consider, whether some uniform dimensions could not be adopted for the parts of engines, in the same way that Sir Joseph Whitworth had adopted a uniform type of screw. If some such uniform plan could be adopted, it would much facilitate the work of English private firms in competition with the rest of the world.

The PRESIDENT enquired whether, with the longer bearing surfaces in the connecting-rods of the goods engine now described, there was

found to be any evil arising from the slightly winding position of the crank-axle, whenever by the action of the springs at the ends of the axle it was allowed to deviate from its true horizontal position. Did this throw anything of a twist upon the connecting-rod or bushes?

Mr. WEBB replied there had not been any difficulty from that cause, owing to the arrangements made for allowing ample play; the connecting-rod bushes had $\frac{1}{16}$ in. side play, and the brasses were just eased out at top and bottom, which was enough to provide for all torsional movements due to the vertical play of the axle ends.

Mr. J. H. KITSON said that, having been concerned in the working of a steam tramcar for some years, it had become necessary to him to get rid of eccentrics in some way; and this could be done in several different ways. His arrangement, shown in Fig. 30, Plate 67, was simply a modification of the Walschaert gear, Fig. 38, Plate 69; but the eccentric used in that gear was here got rid of altogether, by deriving motion from the coupling-rod C through a link B, the upper end of which was attached to an arm A on the ordinary curved and slotted expansion-link E. A rocking motion was thus imparted to the link E about its fixed centre; and the rod from the link slide-block being attached to the valve-lever D a little below the valve-rod pin G, while the lower extremity of the lever D was linked to the piston-rod cross-head J, the resultant motion imparted to the valve was a combination of that communicated from the coupling-rod C through the expansion-link E, with that received from the cross-head. In the earlier half of each stroke these two movements were acting in conjunction, and in the latter half in opposition, besides varying in their relative efficiencies throughout the stroke: the slide-valve thereby received a rapid travel at each end of the piston stroke, with a long dwell during the middle of the stroke. By this arrangement, on the principle of taking from the coupling-rod a motion at right angles to that from the cross-head, the same result exactly was obtained as in Mr. Joy's or Mr. Marshall's gear, namely a perfect distribution of steam with a perfect lead; and the very

rapid wear of the eccentric was got rid of by substituting simple oscillating joints instead of the rubbing surface of the eccentric. He did not know whether it was wanted or not, but preparation had been made for taking up wear in the expansion-link and link-block by drawing together the two bars forming the link. In practice that provision would be got rid of if possible; but in sending out new work of an experimental character, like a tramcar engine, he wished to be prepared for everything.

Mr. JAMES HUMPHRYS said that, from his intimate association with Mr. Joy, he had had his valve-gear before him for some time, and had enquired very carefully into all its working, and as to the probability or otherwise of its complete success. He had no hesitation in stating his opinion that it was as perfect a motion, for obtaining the cut-off in steam engines, as could well be designed. There could be no doubt, he thought, that for many purposes it would be difficult to obtain a more perfect arrangement than that of Mr. Joy. Of course his own particular business was with the marine engine; and the advantage of Mr. Joy's system might not be of such paramount importance in the case of the marine engine as with other types of engine, particularly the locomotive, where steam of a very high pressure was used in a single cylinder, and where therefore a very even cut-off in the forward and backward strokes was of primary importance. Mr. Joy's system might also be very beautifully applied to rolling-mill engines, cotton-mill engines, and other engines of that type, where great uniformity of power in the two strokes was a desideratum.

In the case of the marine engine, it was a question of the comparative cost of the old link-motion and of Mr. Joy's gear. They had had the details very carefully considered in the event of their having to apply the system, as he hoped they would do some of these days. They had arranged with Mr. Joy a series of details for his gear, by which they got adequate bearing surfaces, such as he was sure would carry a vessel in safety across the Atlantic; and he was convinced that, where the wearing surfaces and joints were well considered, there was no more difficulty or danger in attaching the

valve-gear to the connecting-rod than there was in attaching the connecting-rod itself to the crank-pin. After having got all the details as satisfactory as those of the best link-motion, they compared the two, and found that the cost was decidedly less in the case of Mr. Joy's gear, and that there were also a number of advantages which would accrue from its use, such as the better disposition of the valves. There could be no doubt that where the valves could be readily worked from the front of the engine, it was more advantageous in a steamship than if they were placed between the pair of engines, because of course in the latter case they were somewhat less accessible.

Having thus made a careful analysis of the two gears, they were quite disposed to make an experiment on a marine-engine; but of course the builders were not the only people to be consulted in matters of that kind; and shipowners naturally, and he supposed rightly, had great hesitation in adopting any innovations, because in so many instances any deviation from the old plan had been followed by little difficulties, which had not been foreseen. The shipowners naturally had to exercise the greatest possible amount of caution, lest some little hitch should arise in the middle of the ocean, a thousand miles away from everywhere; and they much preferred therefore leaving experiments to some one else than themselves. That was the reason why Mr. Joy's gear had not yet been applied to any of the engines built at the Barrow Shipbuilding Works; but so far as he was personally concerned he should have no hesitation in applying it with the most confident expectation of success. With regard to the question of the wearing, he thought if the bearing surfaces were well considered, there was no reason to apprehend any difficulty on that point. To his mind Mr. Joy's gear would fulfil its functions with a less amount of friction than any other gear he had ever seen.

Mr. WILLIAM BOYD said Mr. Joy had been singularly fortunate in having the powerful advocacy of Mr. Webb, and in having a practical illustration of his gear so prominently brought before the members of the Institution. He was sure that all of them who had

seen the locomotive with this gear on the previous day must have been very much gratified with the way in which the gear was worked, and with the exact movements of the various parts. It was however especially in reference to marine engines that he desired to say a few words. In the first place he had to differ from his friend Mr. Humphrys, since he considered the equal distribution of the steam in the cylinder during the up-stroke and the down-stroke was as important in the marine engine as it was in the locomotive or in any other sort of engine. Now Mr. Joy's gear appeared to him to be theoretically perfect; and it was only in regard to its practical application that any remarks could properly be made.

There were one or two considerations entering into the adoption of gear of that sort in marine engines, which were perhaps different from those that related to its adaptation to a locomotive. Mr. Webb had described the facilities with which he could take up the parts of the gear, so as to adjust the wear and tear. In the case of a marine engine however, it might be at sea twenty, thirty, or forty days, and then any adjustment was a much more difficult task; and any multiplication of the various parts requiring adjustment ought not, he thought, to be lightly entered into. Mr. Joy took his first motion for the gear from the connecting-rod. Now that connecting-rod was suspended between two points, being attached to the lower end of the piston-rod and to the crank-pin; and on both those points during a long voyage there was very serious wear. One of the problems before marine engineers was to provide a metal which should reduce that wear to a minimum. Phosphor-bronze, white metal, and all sorts of things were in use. It appeared to him therefore, with all deference to Mr. Joy, that he had made a mistake in taking the first motion from a part which was liable to so much wear, and required such constant adjustment.

With regard to the two parts of the motion, namely the levers or links B and C, Fig. 4, Plate 58, it was remarkable to notice the unsteady motion on the model now exhibited; and even at the moderate speed of marine engines—60 or 70 revolutions per minute—the unsteady or “wobbling” motion of those levers B and C must be serious. He thought it worthy of consideration whether, considering

the rare occasions when the backward gear was used, it might not be advisable to avoid those two levers, and to couple the lever E directly to the connecting-rod, as suggested by Mr. Joy in his paper.

There was another point to which he ventured to take considerable exception. The sliding motion of the block in the slot J would, he thought, be liable to give trouble on long voyages, and it would be impossible to adjust it. It was of course known that the designer of a link-motion always arranged his rods and gear in such a way that the points of the eccentric-rods came in a direct line if possible with the valve-rod itself, so that the sliding motion of the block within the link when working was reduced to a minimum. It was the motion of the block in the link that was most difficult to manage, so as to take up the wear consequent upon it; and good gear was usually designed so as to reduce that sliding motion to a minimum. In the present case he thought it was carried to a maximum.

In reference to Mr. Marshall's gear, he had had the pleasure of seeing it at work, and knew that it was adopted in several boats which Mr. Marshall had constructed, amongst others some steam turret-vessels running 16 knots an hour. The objection to the wear of the eccentric in the strap he thought was exaggerated. The eccentric had done good service in the past, and he thought they were perhaps a little in a hurry to condemn it as untrustworthy and objectionable. For his own part he preferred the regular, continuous, circular motion of the eccentric in the strap to the fore and aft motion of the point D, Fig. 4, by which in Mr. Joy's gear motion was derived from the connecting-rod of the engine.

Mr. JOHN ROBINSON agreed very much in the observations just made by Mr. Boyd. It seemed to him there was a difficulty in the motion shown in Fig. 4, Plate 58, from the immense amount of wear which was sure to come on the block sliding in the slot J. He knew how difficult it was in the ordinary valve-motion of a locomotive to prevent that wear and tear; and, so far as he understood it, he thought this prevention would be more difficult in the case shown in Fig. 4 than in the best examples of the link-motion. The other parts were very simple, and commended themselves very much to

manufacturers of locomotive engines, because they could be produced, as Mr. Webb had shown, without smiths' hammers or fitters' tools: everything could be done by machine-work. On the other hand, he did not like increasing the number of pins around which there was simply an oscillating motion. Such a motion always gave trouble. It was not a matter of difficulty perhaps for locomotive engineers, because it was easy to take up the wear; but in the case of long transatlantic or trans-tropical voyages, difficulties might arise. Theoretically he thought Mr. Joy had succeeded most admirably; and he had no doubt that, with such an excellent precursor as Mr. Webb, locomotive engineers would find out how to get over any practical difficulties which might arise from the adoption of this motion.

Mr. ARTHUR PAGET observed that Mr. Boyd and Mr. Robinson had taken exception to the large amount of travel of the block in the slot. He should like to ask them whether it had occurred to them to compare the amount of travel of the eccentric in its strap with the travel of the block in the slot.

Mr. BOYD said he had explained that the motion of the eccentric in its strap was a perfectly different motion from the sliding motion of the block in the link. One was a continuous circular motion: the other a reciprocating sliding motion; and his own view was that he should prefer the eccentric.

Mr. WEBB asked leave to point out that Mr. Boyd had mentioned, as the great difficulty in the case of an Atlantic voyage, the taking up of the wear in the connecting-rod end; and that motion was a circular motion round the crank-pin. Now in an ordinary locomotive each of the four eccentrics travelled in its strap about 4 feet per revolution, giving about 16 feet in all for each revolution of the engine. He thought that any one riding on a locomotive with 6 ft. 6 in. wheels, and going 60 miles an hour, would wonder how it was that the link-motion lasted a mile. Nevertheless engineers would all be satisfied with the link-motion, if they could

get with it what they wanted to get in the locomotive, namely larger bearing surfaces, so as to keep the engines out of the repairing shop. In some of the London and North Western engines, he had been able to get these larger bearing surfaces; and one engine last year had run 57,000 miles in 52 weeks—a very different result from what they had been in the habit of getting before. He certainly should not be contented with that engine if it would not keep out of the shop for two years; and such a result in regard to mileage he thought would compare with the longest marine voyage that could be made. The vertical motion in the slides in Mr. Joy's gear was 8 in. each way, or 16 in. for each revolution of the engine, and there was one of these blocks for each side; so that the total reciprocating motion in these two slides was only 2 ft. 8 in. for each revolution of the engine, very considerably less than with the eccentrics.

With regard to the number of pins, anybody could count the number of those that had any work to do, which he thought would compare favourably with any link motion, especially if a weigh-bar had to be introduced in the latter, on account of the large cylinders.

MR. JEREMIAH HEAD said at first sight Mr. Joy's design recalled to his mind the old box-link, which was used about thirty years ago in the Great Western locomotives, and the action of which was described in Clark's "Railway Machinery." In that case (Figs. 36 and 37, Plate 68), the curve of the link A was drawn to the radius of the valve-rod link; and in the same way as in Mr. Joy's gear, the block could be moved up and down in the link, when in mid-gear, without altering the lead of the valve. The distribution in fact was about as perfect as Mr. Joy's. For some reason or other—principally, he believed, because of the somewhat complicated construction of those links—they were abandoned in favour of the ordinary open links, the curve of which was drawn from the centre of the axle, thus presenting their curvature in the opposite direction to the old box-link.

There seemed however to be an essential difference between the gear exhibited and the box-link gear. In the latter case it was the eccentrics pushing the link backwards and forwards that did the real

work of moving the slide; but in the gear now exhibited the work of moving the slide was done from the connecting-rod, which made the block mount up in the slot J (Fig. 4), or the reverse. Of course the great resistance was that due to the slide-valve having the pressure of the steam on its back. There were certain angles at which the slotted disc K might be set, where the block would have to be pushed very much up-hill for about a quarter or a third of a revolution, the lever pulling or pushing very much athwart the slot J, and so having great resistance to overcome; and this resistance would no doubt lead to wear. With the old box-link, although it was inclined at the same unfavourable angles at certain times, still, as the eccentrics were pushing the whole of it bodily backwards and forwards, the oblique thrust of the block in the link would not be felt in the working of the link; but if the driver tried to reverse the engine while the link was in that inclined position, it would be very hard work indeed to do so.

It had been stated in the discussion that the slotted disc and lever might give trouble in a marine engine in the course of a long voyage, partly on account of the wear; but in fairness to Mr. Joy it ought to be noticed that those were parts very easily carried in duplicate. He saw nothing whatever to prevent such a simple thing as one of those slotted discs and the block in it being taken in duplicate on every voyage. If there was any undue wear, the part could then be easily replaced; but of course the engine would have to be stopped for doing so.

A good deal had been said in the discussion about eccentrics. Some engineers thought them disadvantageous appliances, and others considered them quite harmless. He was inclined to think no mechanic would put in an eccentric, in order to get reciprocating from circular motion, if he could do without it. Eccentrics were comparatively harmless where they were small; but where they were large they were certainly disadvantageous. The distance traversed at the rubbing surfaces in each revolution was very great, and the wear was proportionately great and not even. On looking at an eccentric after it had been some years in wear, it would be found that on the back half of the sheave the tool marks were scarcely worn

off, whereas the front half, which was the only part that did the work, was considerably worn; and in some cases the eccentric had to be taken out and re-turned, in order to restore the full throw. Then again, when an eccentric after wear got somewhat slack, it was always open at the back part, though touching at the front. That offered a large space for dust, grit &c. to get in; and this was immediately carried round, and helped to wear the front part still more. Therefore he thought that eccentrics were things to be used only as a last resource. That was perhaps the chief disadvantage of Mr. Marshall's motion compared with Mr. Joy's; the former still retained one eccentric for each engine.

In marine engines it frequently happened that three eccentrics were used to each engine, two being used for one end of the link and one for the other, making six altogether, all encumbering the shaft, and making the bearings almost inaccessible. It had been pointed out by Mr. Boyd that the two ends of the connecting-rod often required adjustment to some extent, between the beginning and the end of a voyage, and might therefore be very variable points. It had not been noticed that the motion-bars on the forward side were apt to wear, which would tend to aggravate any error in the same direction; but he did not quite see why the link E, Fig. 4, Plate 58, should not be made adjustable in length. If it was a round rod bellied out in the middle, with a left-and-right screw, its length might easily be adjusted to compensate for wear in the connecting-rod ends. He enquired whether he was correct in thinking that, when the sliding-block was in mid-gear, supposing the engine was running and had a little way upon her, there was enough admission to keep her running, whichever way she was going: so that the engineer would not be able to stop, by the reversing handle alone, if the load were light, unless he pushed the slot-disc over to put the steam on the other side of the piston.

Engineers had all been accustomed to look upon the link-motion with a sort of veneration, as one of the great improvements in the locomotive, which had rendered the name of Mr. Howe famous, and which was supposed to be a complete solution of the question of valve-gears. They had hardly ever thought of disturbing that idea,

or that it would be disturbed, as it was considered to be one of those points that were settled for ever. Mr. Joy however had shown that it might be improved upon; and with regard to tramway engines, Mr. Kitson had pointed out that, with the dust and dirt they had to encounter, eccentrics and eccentric straps were absolutely inadmissible. Mr. Joy therefore deserved great credit for having brought forward his new valve-gear; and his paper was one most suitable for the Institution.

Dr. C. W. SIEMENS said that, listening to the very excellent paper which had been brought before them, and to the observations of the speakers who had taken part in the discussion, one result seemed to his mind to be quite certain, namely that the link-motion was doomed. He must say he did not feel the same regret on that score which appeared to animate Mr. Head. The link-motion had no doubt been a way out of a difficulty; but it was correct only within very narrow limits; and the moment those limits were exceeded it did not produce the expansive action desired. A motion had now been brought before them which challenged comparison with the best expansive gear that could be mentioned. There was a clean cut-off; the steam was put on at once in ample quantity, and the exhaust also was opened promptly at the right time. There was also the means of adjusting the action so as to make the up-stroke and the down-stroke perfectly alike, which, as they all knew, was not the case with the link-motion. And, as Mr. Webb had beautifully illustrated by his locomotive, the new gear had the advantage of giving a large useful space on the main shaft for increasing the length of the bearings. These were very important advantages, which Mr. Joy might claim for his motion. But they had also been put in possession of two other motions, which seemed to be as perfect as Mr. Joy's. Still they need not regret that result. There were points of difference between the gears, though they all aimed at the same result, a very perfect cut-off and a perfect mode of reversing the engine. The object was achieved by different mechanical details, all of which he considered were superior, both theoretically and practically, to the old link-motion.

With the criticism offered by Mr. Boyd, in regard to a portion of Mr. Joy's motion, he thoroughly agreed. The slotted disc, which was turned into a different angular position, with the slide-block grinding up and down in the slot, was not he thought a desirable detail; and he would recommend Mr. Joy to do away with it. He observed it had actually been done away with in the arrangement shown in Plate 59. All the friction was there reduced to the friction on the pins, which must be preferable to friction of sliding surfaces. With that exception Mr. Joy's motion appeared to him perfect, and one that would no doubt receive the most earnest attention of mechanical engineers.

Mr. E. REYNOLDS had not intended to say anything on the paper, but for one expression used by the author, that the present invention helped to show the advantage of the patent laws. That led him to feel there was some danger of being excluded by patent rights from the use of inventions, on account on what appeared to him to be mere modifications of detail. He wished success to both Mr. Joy and Mr. Marshall; but when such small details as the substitution of Brown's sling for the slide of Hackworth's gear became the subject of a separate patent, this danger seemed to become real. Fig. 35, Plate 68, showed an arrangement which he had some time back proposed to use for a very large steamer, and which he thought might be considered as the normal idea of this class of motions—the inaccuracy due to the arc made by the ends of the levers being eliminated by what would be a parallel motion of the simplest kind, if it were not for the side motion of the connecting-rod; which was therefore correctly reproduced.

Another motion, to which some allusion should be made, was Hawthorn's, Fig. 40, Plate 69. Since this was first introduced, it had been a subject of interest with all engaged in locomotives; but it was imperfect, being rather adapted for each motion to work the other engine than to work its own. When Hackworth's gear was brought out, all difficulty vanished, because by adding the slide-block the motion at right angles to the connecting-rod became properly provided for, and the whole thing was very easy. Then the question

whether Mr. Charles Brown's sling or the ordinary slide was used was not of much importance in regard to the principle.

Mr. F. C. MARSHALL asked to be allowed to say one word in reference to the sliding motion. There was only one thing that interfered with the success of the Hackworth motion, Fig. 31, Plate 68, of which his own motion and Mr. Joy's were modifications: what had hindered its general success had been the sliding motion, which Mr. Joy had now introduced into his gear. With regard to the eccentric in his own design, he certainly could not feel any great horror at it, and he believed that, as long as engineers used crank-shafts, they would not be able altogether to dispense with eccentrics. As to the adjustment of the connecting-rod ends, those who had been at sea ten or twenty days would know that connecting-rods, even when made of the best metal, got very serious knocks, and that these were communicated to everything connected with them, and necessarily to the valve-rods which Mr. Joy had introduced. As to the wear on the connecting-rod pin, the pin as introduced into Mr. Joy's gear was somewhat similar to that used in Mr. Charles Brown's tramway engine, upon which a paper had been read before the Institution in January 1880. That engine was now running in Newcastle, and the only difficulty they had with it was with the pin on the connecting-rod.

The PRESIDENT said the subject of slide-motions had been a favourite one with him since he was an apprentice. In olden times he had seen engines with tappet motions, but they were not satisfactory. With the eccentric however everything was thought to be quite right. Capt. Ericsson had tried several forms of motions, when connected with the late Mr. John Braithwaite in business: one favourite form was a slot fixed on the end of a rocking weigh-shaft, so as to form a T with it; the shaft was worked by an eccentric, and the end of a connecting-rod from the slide-rod was movable in this slot, so that the motion of the slide was reversed by moving the connecting-rod end from one side of the axis to the other. This plan of course could not be arranged to give lead both ways, though

the engine could well be reversed whilst in motion, without any danger of the end of an eccentric-rod missing its pin or getting adrift. He (the President) then schemed the plan of using a *short* eccentric-rod, and moving it from a pin fixed to a lever on one side of the weigh-shaft to a pin fixed to a lever on the other side of the weigh-shaft, thus reversing, and obtaining a certain fixed lead each way, owing to the different angle at which the motion was taken off the eccentric.

The problem seemed to be that of taking advantage in some way of the up and down motion of the piston-rod for lead, and also of the side motion of the connecting-rod, or of the eccentric, so as to give the proper action for the travel of the slide. He had tried that himself many years ago, but had failed. He would not have a *sliding block* in a slot; and he fancied that had been the reason why he had failed to combine the two motions. It had since been done much better by Mr. Joy, Mr. C. Brown, Mr. Marshall, Mr. Kitson, and Mr. Walschaert. Hackworth's gear, Figs. 31 to 34, Plate 68, was no doubt the origin of all these. With Hawthorn's gear, Fig. 40, Plate 69, the vibration of the locomotive springs caused great shocks, and the gear had knocked itself to pieces. This was in consequence of the connection between the valve-lever and the pin in the main connecting-rod being made by a large and heavy frame, with a long slot in it the full length of the stroke, instead of by a light connecting-rod. In the way in which Mr. Joy had arranged it, it would be observed there were two plans. One was that of a slide which was constantly in motion within a slot, in contradistinction to the small motion of the slide-block in the link-motion. These were very different things: one was a constant wear, and the other a small local wear at either end of the link. This was avoided in some marine engines, where the link was thrown right over and rested against the block, so that the block did not move in it except when reversing. In the locomotive there was a little motion of the slide-block in the link, which caused the end of the link to wear very much, and it was not long before the size of the whole link had to be increased. The other plan of Mr. Joy's seemed entirely to cure that evil; it was shown in the model exhibited. The

vibrating link or radius-rod, which here gave the inclined motion, entirely avoided the sliding-block; there was no slot, and the centre merely moved backwards and forwards with the link. Then there was another slight inconvenience in any attachment to the connecting-rod in a marine engine, as a considerable space was thereby always occupied, and the engineer could not therefore so safely get at his engine, particularly at the main connecting-rod end, which was always one of his chief anxieties. He thought that was objectionable, and in Mr. Marshall's gear it seemed really to be avoided. The same result was also seen in Mr. Charles Brown's tramway engine, Fig. 39, Plate 69. So that they seemed to have five different motions, all founded on the original Hackworth motion, and all of which had some advantages in one direction or another.

One of the greatest advantages from a practical point of view, which Mr. Webb expected to attain, was that he could get ample room for bearings on his crank-shaft; and that was a good thing. If any one of the valve-motions would give that one advantage, it was worth having, even if the motion was only as good as the common link-motion: but he thought it was better. The motion of the valve was better in the cut-off and in the exhaust, although some portion of the advantage in having a small amount of compression was not due to that motion, but was due to the early exhaust; and the Trick valve also gave a large amount of admission of steam, when the valve first began to open. Mr. Webb's indicator diagram clearly showed this. By that means the cylinder was got clear of steam, and there was a very good back or exhaust line, and a small amount of compression. That was done by cutting out the inside of the slide. It was not universally known that by cutting out the inside of the slide the compression was materially reduced, the bottom line of the indicator diagram was improved, and only a trifle was lost at the end of the stroke from the earlier exhaust. So again in Mr. Marshall's diagrams, which were excellent, a little of the pressure at the end of the stroke was lost by the earlier exhaust; but what was there lost was far more than made up in the improvement of the bottom line in the indicator diagram, and there was a very small compression.

Mr. Jox, in reply, said he feared the paper had already occupied more than its fair share of the time of the meeting, and he would therefore endeavour to be as concise in his answers as possible; but if any question were thus left unanswered, it was not because he had no answer for it, as he was fully prepared for every criticism which had been brought forward. He was partially prepared, but only partially, for the observations made by Mr. Marshall, who had kindly given him a copy of his indicator diagrams, but not in time for a study of them; they were certainly very perfect. Mr. Marshall's gear however went only half way towards improving the link gear, and getting the engine into as short and smart a form as it ought to possess. In that gear the valves were put in at an angle; and that was an element which he himself maintained was wrong, and would make the engine costly. He had seen the engines of this type, built by Richardson at Hartlepool, and understood that they were troublesome to build from that cause. Only one of the eccentrics was removed, and the other was left, still cumbering the crank-shaft. The arrangement also was not well suited for any other class of engine than that for which it was shown; and for locomotives and that class of engines it was entirely unsuitable, as was Hackworth's: while his own gear described in the paper was designed to suit every type or condition into which a steam engine could be put, allowing in every case a better and more compact arrangement than could be obtained with the link motion.

Again, the engine-room was not shortened; and he maintained that there was an advantage in shortening the engine and the engine-room. The navy was now pressing them to put their engines into the smallest possible space. As for the condenser being the limit of the length of the engine, that was not so: if the condenser was too long, it was easy to shorten it and widen it; there was plenty of room for that on board ship in the direction of the width of the ship, where there was always plenty of vacant space. With regard to the number of parts, he might remind them that in Mr. Marshall's gear there was an eccentric running upon a shaft, as against four little pins in his own gear; and it should be remembered that the links B C, Fig. 4, Plate 58, were only doing about one-sixth of the work of the eccentrics, as Mr. Webb had shown. With regard

to the port, he confessed he could not see how Mr. Marshall got his perfect diagram, except by a special device, to which he would refer presently. The long valve-rod link, which had been spoken of as an advantage, he maintained must be a disadvantage, because the arc in which it vibrated was not equal to that in which the eccentric-rod end vibrated; and these arcs crossing each other must produce error. In his own gear these two arcs were made equal, and so corrected each other. There was also an uncorrected arc formed by the obliquity or vibration of the eccentric rod acting as a lever; and this would produce unequal vibration of its suspended end, and therefore inequality in the opening of the ports: the former error, he believed, having the same tendency. From the drawing however he gathered that these errors were corrected by the valve having a long lip at the top end and a port formed in it, Fig. 25, Plate 65, so making a double port for admission at the top end of the valve, with a single port at the bottom; and this appeared really to be Mr. Marshall's point of improvement, and not the gear at all. With regard to the further remark that all these valve-motions were modifications of Hackworth's old gear, he could not agree that his own was so, as it had arisen out of an endeavour to design a valve-motion taken from the air-pump lever and combined with a transverse action from the vibration of the connecting-rod; and in this form he had drawn it out at first. In its present form the link or lever B, Figs. 7 and 8, Plate 59, now took the place of the air-pump lever.

He was much obliged to Mr. Webb for the very prompt and, he thought, far-seeing way in which he had taken up the idea, for the exhaustive analysis to which he had subjected it, and finally for the very perfect and practical way in which he had carried it out. He thought that this was perfectly in accordance with the spirit of the Address of the President, where he said that if they were to keep foreigners out of the market, Englishmen ought to take hold of new things, sift them to the bottom, and, if they were good, carry them out. This was precisely what Mr. Webb had done; and it behoved all English engineers to follow the same bold and prescient policy, if they were to hold their own as the leading engineers of the world.

Mr. Humphrys had gone into the matter most thoroughly, and could therefore speak with authority; he had also told off the best

talent of the Barrow Shipbuilding company's staff to analyse and then work out the question. After he (Mr. Joy) had given all the ideas he could to the draughtsman, the designs were put in hand and carried out without any interference on his own part; therefore the result as stated by Mr. Humphrys might be relied on and accepted as satisfactory. He regretted however that he must differ from Mr. Humphrys when he said that he did not attach so much importance to the exact and equal distribution of steam for compound marine engines, but that it was very good for locomotives; and so it was. But whatever was good for a locomotive, with high-pressure steam, was good also for a marine engine, which was now approaching the higher pressure of the locomotive. If perfection of distribution were good for the one, then it should also be good for the other, especially when obtainable at even a lower cost than the present tolerated imperfection. Marine engines were already working up to pressures of 90 lbs., and he had been asked in London about some ships in which 100 lbs. pressure would be required. He was quite certain they would reach 150 lbs. before long. He fully agreed with Mr. Humphrys however that the greatest difficulty in the way of the introduction of improvements lay in the conservatism of the shipowners and their advisers, who were usually cautious to a fault. No doubt this caution often saved them from making mistakes; but it often delayed the advance of improvement.

A great deal of what Mr. Boyd had said had been answered by Mr. Webb and by Mr. Humphrys; but there was one point which Mr. Boyd had made a great deal of, namely the plunging and knocking of the connecting-rod at sea. He had been at sea himself, and knew all about that. It was true that he took his point of force from the connecting-rod, but in the first place he took it half way along the connecting-rod, and in the second place he took it through the link B, Figs. 7 and 8, Plate 59, and at each step by reduced leverages, thus reducing the knock or looseness that might have been imparted by the connecting-rod. By attaching the lever E to the link B at the point D, the distance travelled by the valve-rod pin was only one-tenth of the distance travelled by the pin D. If there was a quarter of an inch knock in the connecting-rod (an amount impossible to be allowed), and so a quarter of an inch

looseness at the pin D, there would be only one-tenth as much at the other end of the lever E, or $\frac{1}{40}$ in. at the valve, an utterly inappreciable amount. The practice of locomotive engineers was to put interchangeable bushes and pins in all the wearing parts. These were out of the control of the workmen; and when any of the interchangeable bushes or pins failed or gave way, they had not now to set a man fitting two brasses and getting them exactly alike, but they took out one pin or bush and put in another. It had been stated by Mr. Webb that a locomotive engine would run eighteen months or two years without being touched; and yet it was said that in the course of the ten days required to cross the Atlantic a connecting-rod must be so much knocked about as to interfere with the correctness of this valve-motion. With regard to the action of the compensating links B and C, and the "wobbling" of that part of the gear, spoken of by Mr. Boyd, that action was much worse in the ordinary air-pump lever gear, where the coupling links had two vibrations for every revolution; while in this motion the vibrating and radius links B and C had only one movement for every revolution, and indeed during half the revolution the radius-rod C was absolutely at rest, moving only when it had to correct the curve of the arc in the return stroke of the connecting-rod.

Mr. Robinson was one of their highest authorities; but he could not help differing from him in his idea that there would be a great deal of wear and tear from the sliding of the block in the curved slot J, Fig. 4, Plate 58. That there would not be that wear and tear had been pretty clearly proved by Mr. Webb, who had had his engine tested for a breakdown to see what part would fail first; but he could not hear that anything had failed as yet, and the workmen had said that they had never had a bearing hot, or a pin to take out. However he only proposed to introduce this slot where it would suit the arrangement best—say for locomotives, traction-engines, steam-ploughs, and so on, and where simplicity and cheapness were of the first importance. The moment he came to a large engine, he put in the gear shown in Figs. 7 and 8, and had a double radius-link L, one on each side. Then all the motion was in the same plane; there were equal bearings and equal strains on both sides of the connecting-rod, and all the parts were got in a straight line. That could not be

done with an eccentric and link gear, because it would be necessary to put two eccentrics in the same place, which was impossible.

With regard to the wear upon the sliding block however, he would draw attention to this fact : that even if it were considerable, it was not at all equal, as Mr. Webb had shown, to the enormous wear upon the eccentrics, which had four times the area exposed to wear. He could give as much bearing surface in the slot, without making it unsightly, as there was upon the slide-bars of the piston-rod cross-head. And there was never any trouble with slide-bars properly constructed and properly attended to, and no one ever dreamed of carrying a cross-head on radius-links ; yet the slide-bars had enormously more work to do than the inclined slot in this motion, and as they stood wear so should this. Further, for this part of the motion there was an exact precedent, which had stood the test of years of working, in the transmission of the power for working the valves of oscillating marine engines, which were often of very large size ; there the action of the eccentrics was transmitted through a sliding frame having curved slots, in which slid the blocks hung on the ends of the levers working the valves : the only difference between the two cases was that for the above gear all the sliding blocks were carried on overhung pins, while in his own gear the sliding block was double-borne by a pin at each side.

With regard to the facility with which the engine could be reversed, he had found some years ago, when he was a locomotive superintendent, that he could not himself reverse an 18-in. cylinder engine ; but reversing the new 18-in. engine was as easy as possible. The reversing of a link-gear engine was done by drawing the link-block down against the friction in the link ; and when the angle was unfavourable, this was considerable ; but in the present case the only force required was that necessary to pull over the lever and draw the valve along in a straight line.

Mr. Reynolds, after he had been shown the present plan, had sent him copies of his own, and said that a firm of engineers had suggested it should be used ; but it had not been used by Mr. Reynolds himself or by others ; and in that case, as the design had not been introduced and brought out, it was open to any one else to introduce it afterwards. In the paper it was stated that the first drawing of his

own gear was made in 1868, before the designs of Mr. Charles Brown of Winterthur, M. Walschaert, or any of the other inventors ; and that it was laid by, and was afterwards taken up again. It would be observed that Mr. Brown's idea, Fig. 39, Plate 69, was obviously a different one from his own : it aimed at the movement of a tappet-valve, with a very small lift, and a very slight action. His own gear was intended for marine engines, and he knew that it must have large wearing surfaces and great length of stroke. He believed the reason why Hackworth's gear, Figs. 31 to 34, Plate 68, had not succeeded had been that it had only 5-in. or 6-in. stroke in the slide, and had therefore a very excessive angle to work against, and not a slight angle as in his own gear : so that it was constantly working excessively up-hill. The difficulty was that all the motion due to opening the port was given by that incline, which was of very small length, and therefore it had to be set at a very steep angle. The corresponding angle in his own gear for a full port was only 8° or 9° , but he believed Mr. Hackworth's had been about 30° . With regard to the wear in the slot, it would be no more than there was in the present link-block. But in his own gear it was all an even wear from end to end ; so that when it got to knock a little, it would be even all over, and a new block would remedy the evil. In a link-gear the wear was uneven, all at one place and none at another ; so that there was often a little hollow in the link, say 3 inches long, and this necessitated reducing the whole surface of the link. Mr. Head had pointed out quite correctly that at certain angles the sliding block would be pulled or pushed somewhat athwart the slot, which would no doubt lead to wear. That wear would be at once equalised by putting in new blocks.

Before he concluded he wished to thank all the gentlemen who had kindly assisted him both by their criticism and by their direct assistance ; and he desired also to thank the members for the kind way in which they had received his paper, and the fair manner in which they had discussed it.

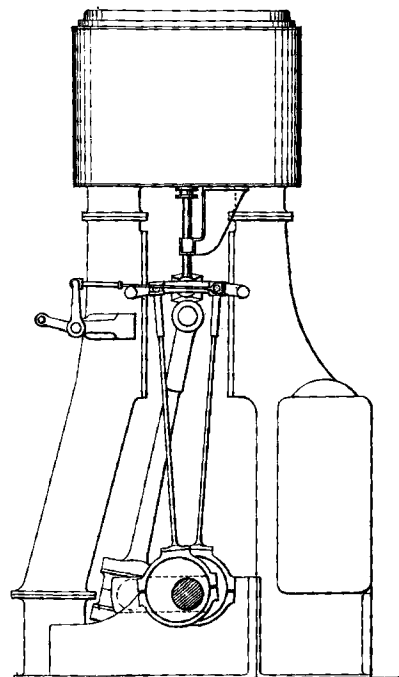
The PRESIDENT moved a vote of thanks to Mr. Joy for his valuable paper, which was carried by acclamation.

The following paper was then read : --

VALVE GEAR.

Plate 57.

Fig 1. *Marine Engine with Link Gear.*



(Proceedings Inst. M. E. 1880.)

Fig 2. *End Elevation.*

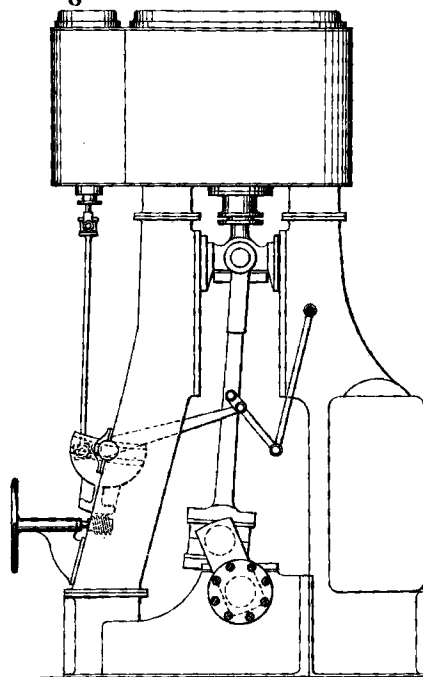
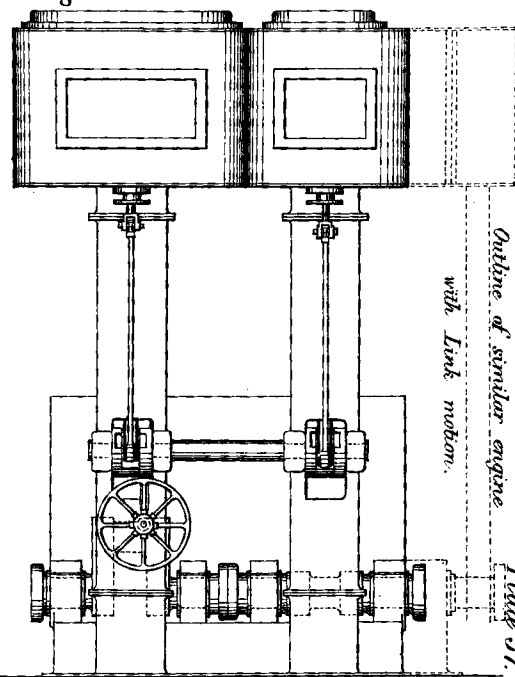


Fig 3. *Front Elevation.*



Outline of similar engine with Link motion.

Plate 57.

0 2 4 6 8 10 12 14 16 18 20 Feet.

Scale $\frac{1}{80}$ in

VALVE GEAR.

Plate 58.

Horizontal Engine with Joy's Gear.

Fig. 4. *Elevation.*

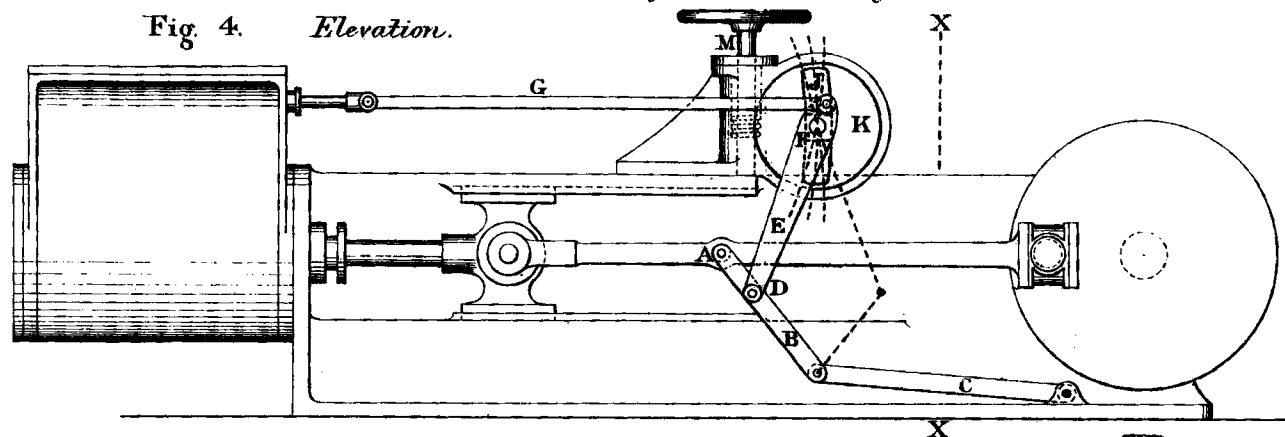


Fig. 6.
Section at XX.

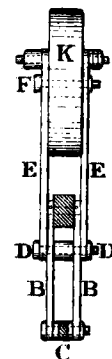
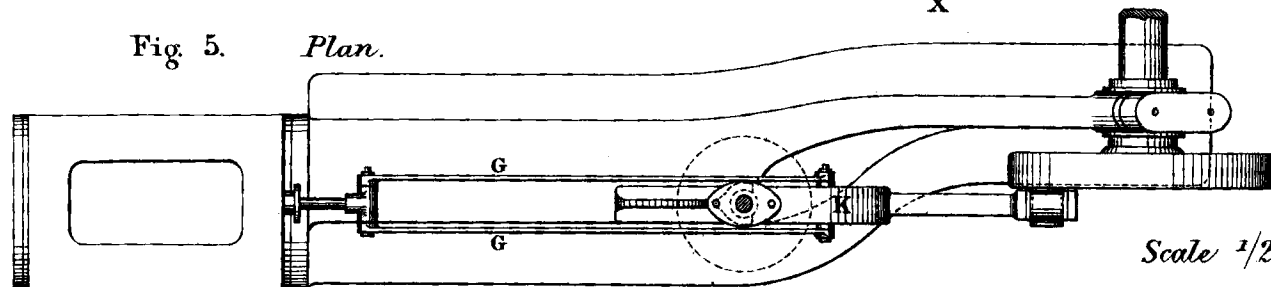


Fig. 5. *Plan.*



Scale $\frac{1}{24}$ in.

(Proceedings Inst. M.E. 1889.) Ins. 12 6 0 1 2 3 4 5 6 7 8 Feet.

Plate 58.

VALVE GEAR.

Marine Engine with Swing Link.

Plate 59

Fig. 7.

Forward Gear.

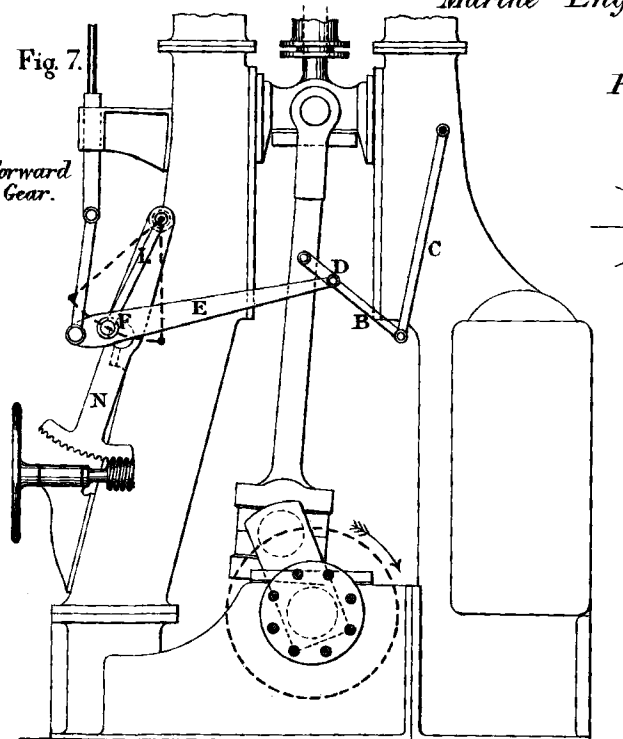


Fig. 15.

Path of Crank.

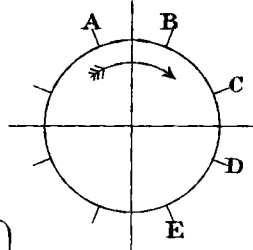
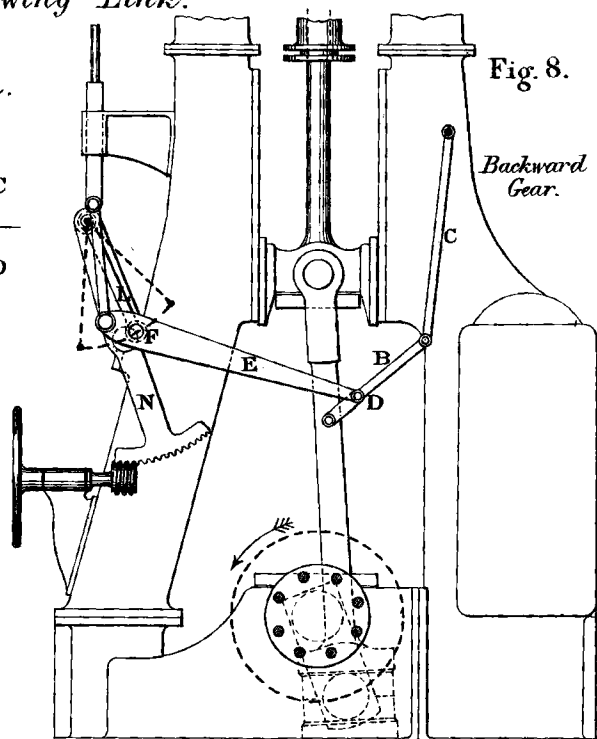


Fig. 8.

Backward Gear.



(Proceedings Inst. M. E. 1880.)

Ins. 12 6 0

2

4

6

8

10

12

Feet.

Scale 1/50th

VALVE GEAR.

Plate 60.

Diagrams showing Opening of Steam Ports.

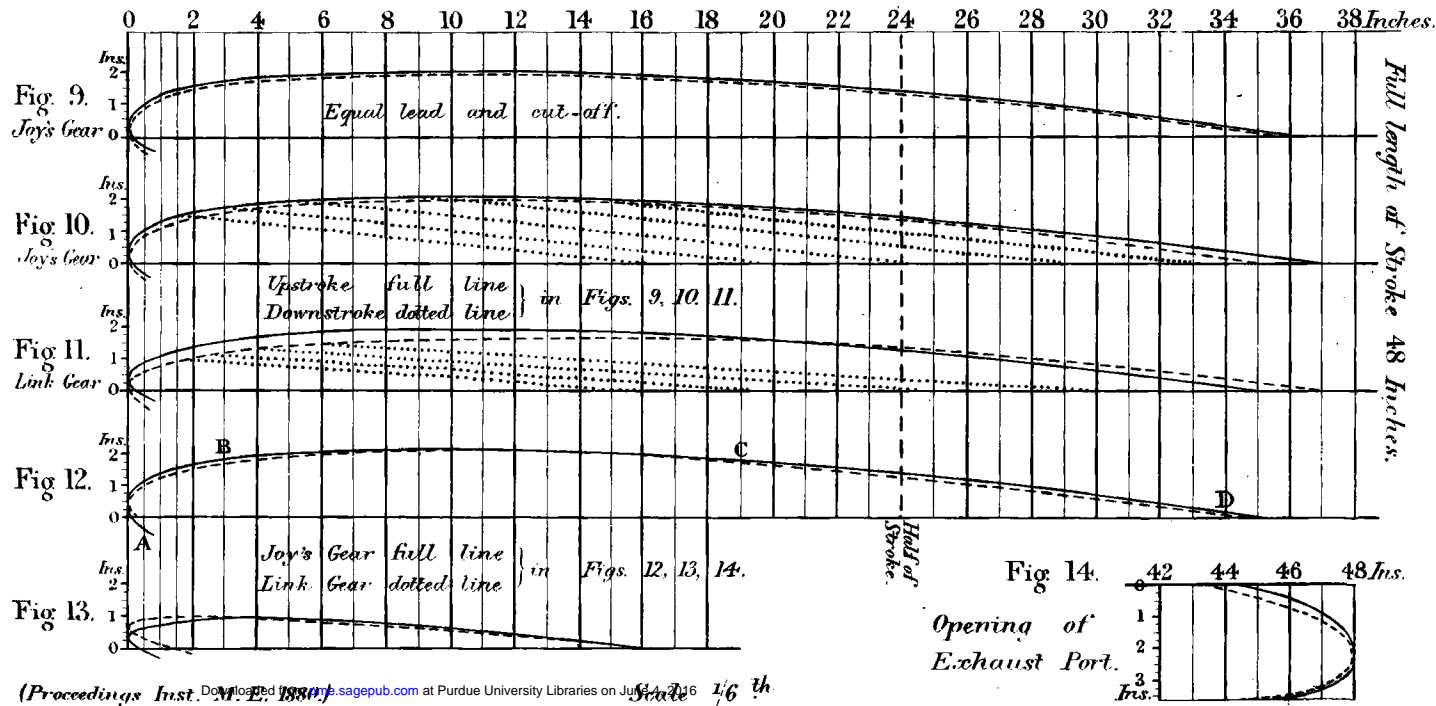


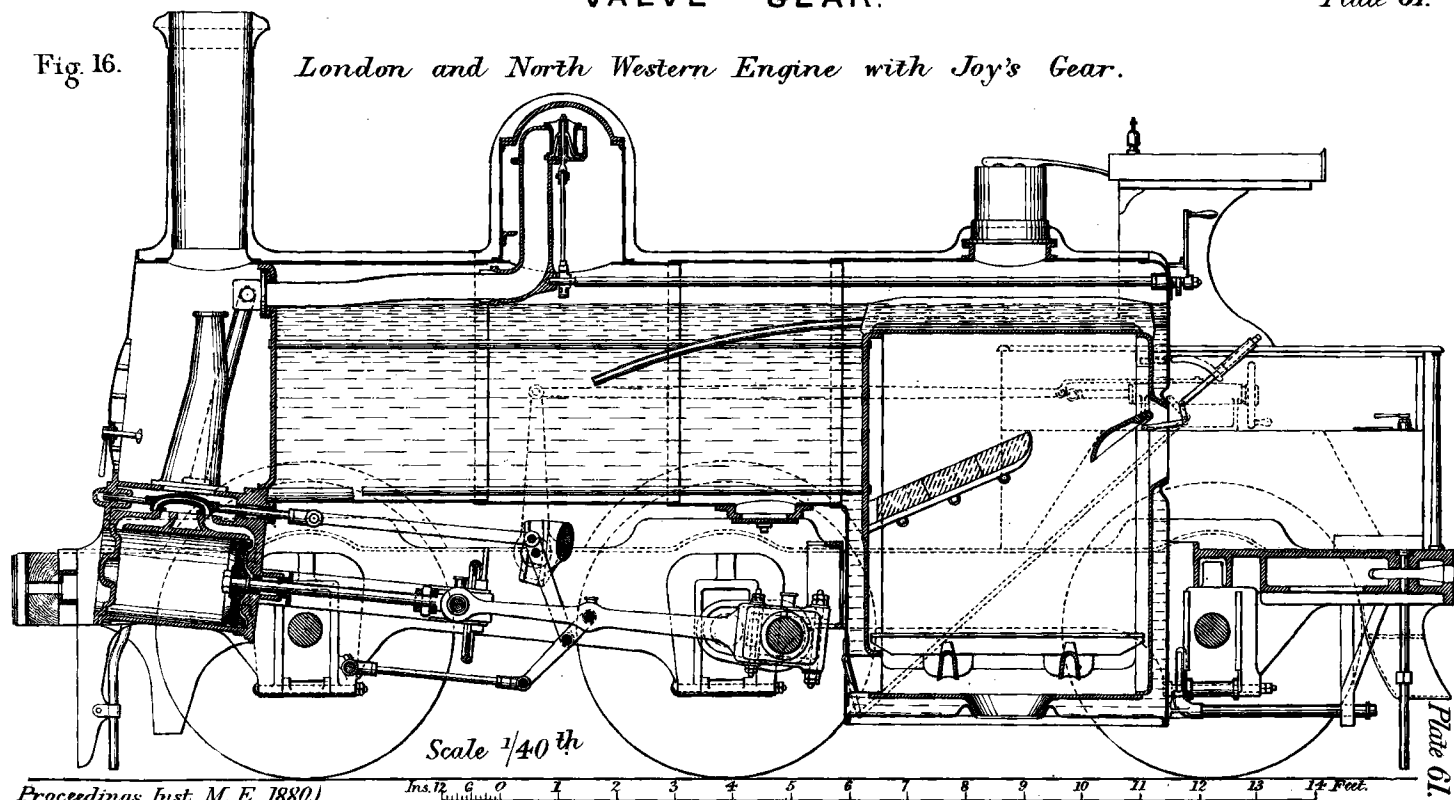
Plate 60.

VALVE GEAR.

Plate 61.

Fig. 16.

London and North Western Engine with Joy's Gear.



VALVE GEAR.

Plate 62.

Fig. 17. *London & North Western Goods Engine with Joy's Gear, Plan.*

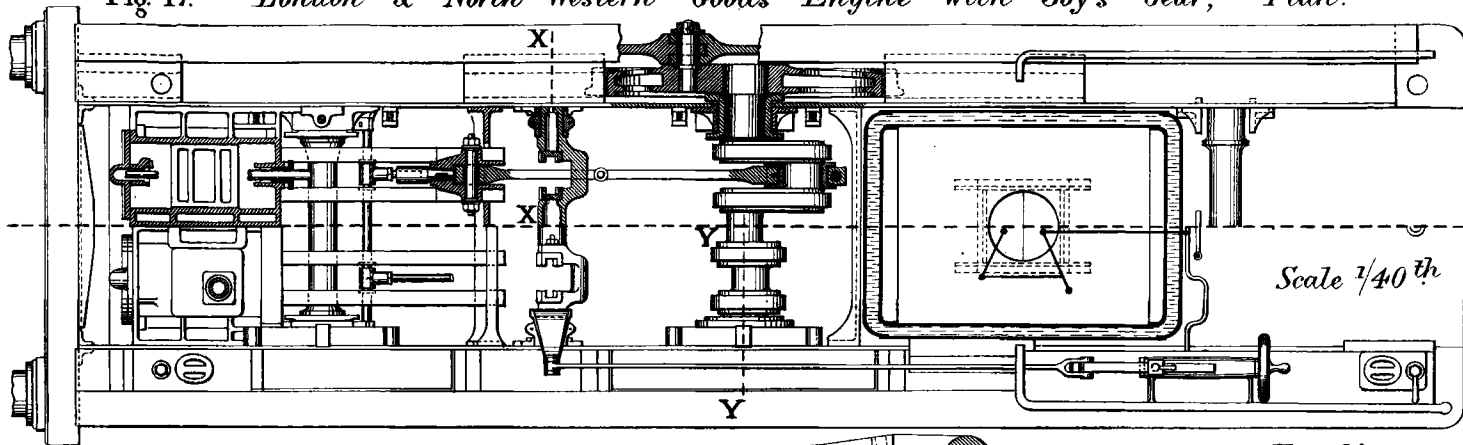
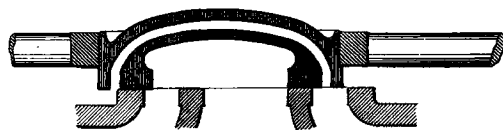


Fig. 18.

Section of Trick Valve.



Scale 1/10th

Fig. 19.

Slide for Valve Motion.

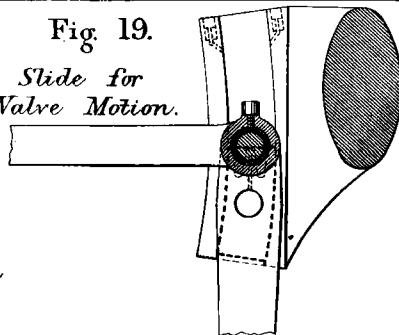
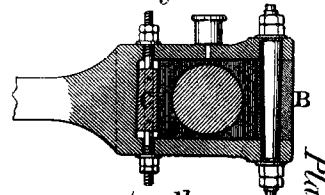


Fig. 20.

Connecting-Rod End.



Scale 1/20th

Plate 62

London and North Western Goods Engine, with Joy's Gear.

Fig. 21.

Valve Gear.

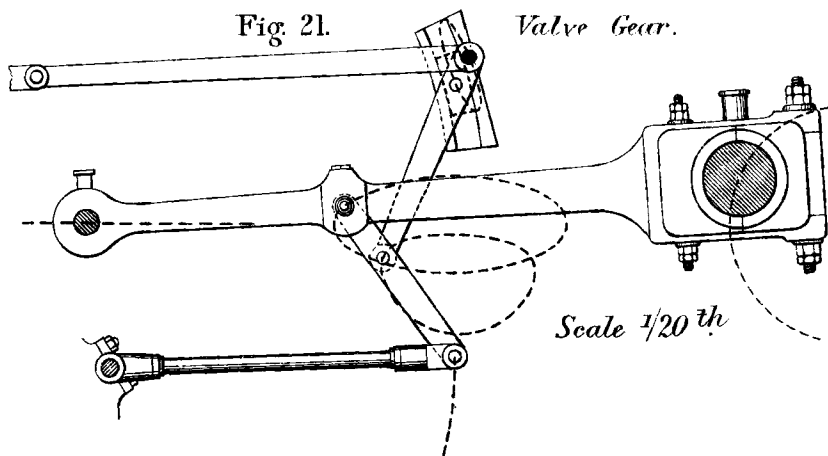
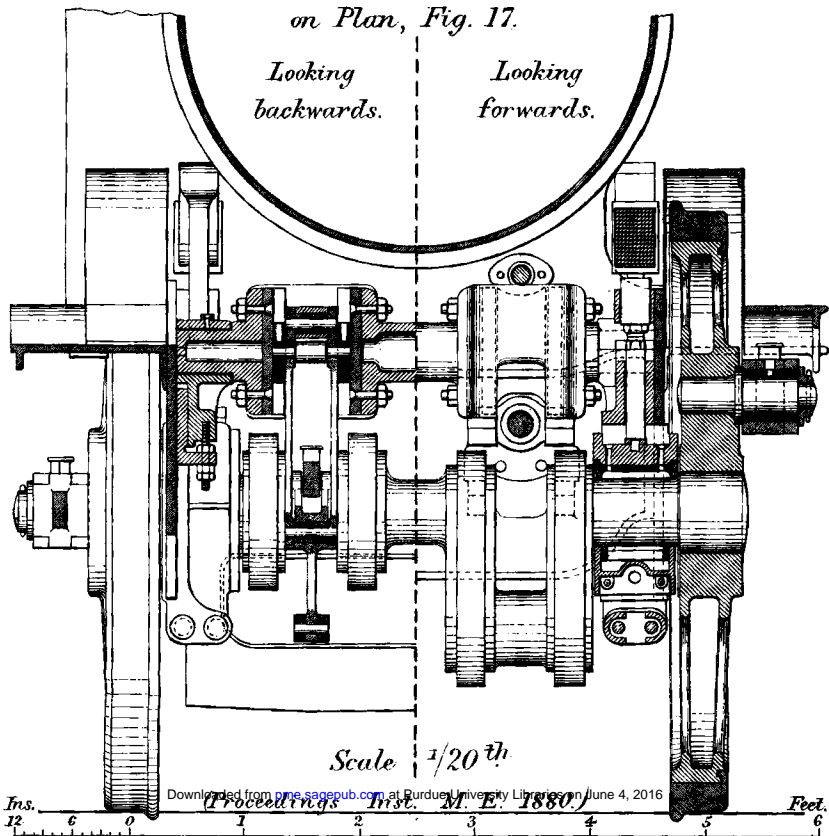


Fig. 22. *Half Cross Sections along XX and YY on Plan, Fig. 17.*



London and North Western Goods Engine, with Joy's Gear:

Fig. 23.

Low Speeds.

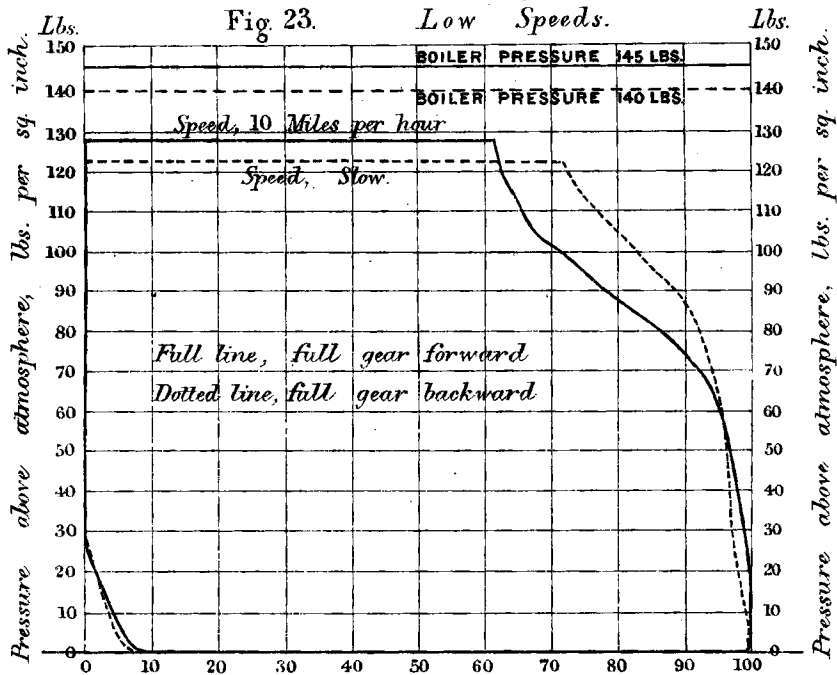
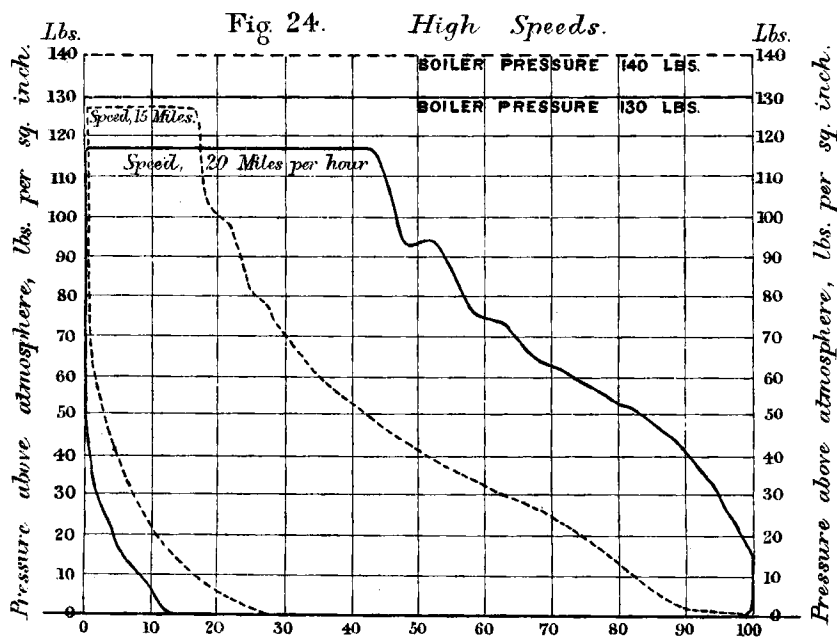


Fig. 24.

High Speeds.



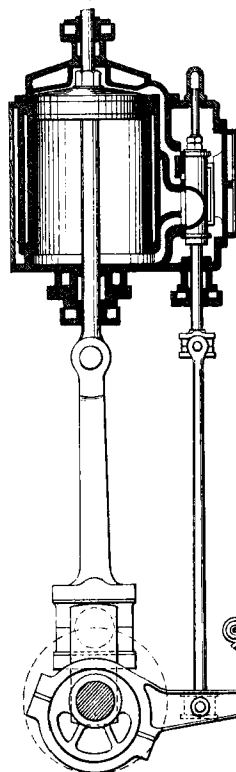


Fig. 25.

*Marshall's Gear
for Marine Engines.*

Scale $\frac{1}{64}^{th}$

Motion Enlarged.

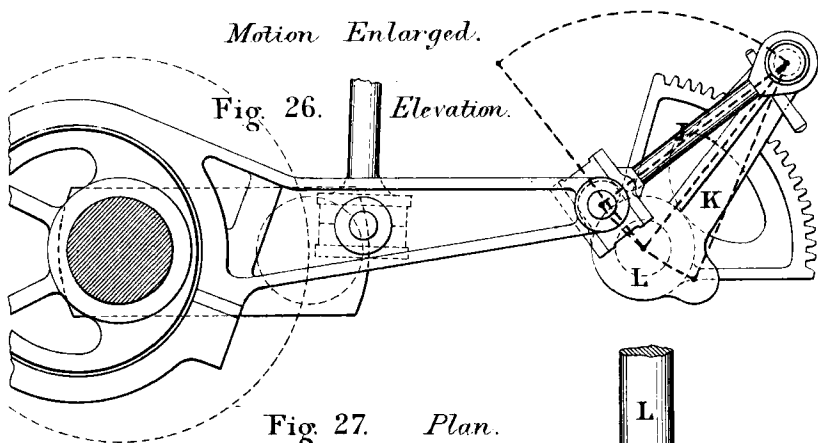
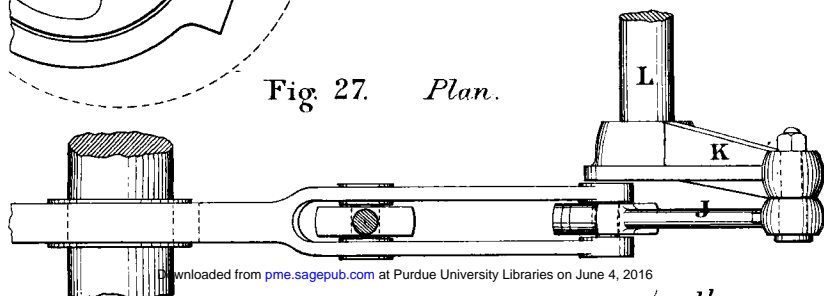


Fig. 26. *Elevation.*

Fig. 27. *Plan.*



Scale $\frac{1}{24}^{th}$

Diagrams from S.S. "Osmanli," with Marshall's Gear.

N ^o of Grade	1	2	3	4	5	6
Revolutions per min.	57	53	50	46	40	35
Ind. H.P. of H.P. Cyl.	715	599	513	395	277	190
L.P. Cyl.	694	542	486	375	270	199
Total	1409	1141	999	770	547	389

Fig. 28. High-Pressure Cylinder.

Diam. 35 ins. Stroke 48 ins.

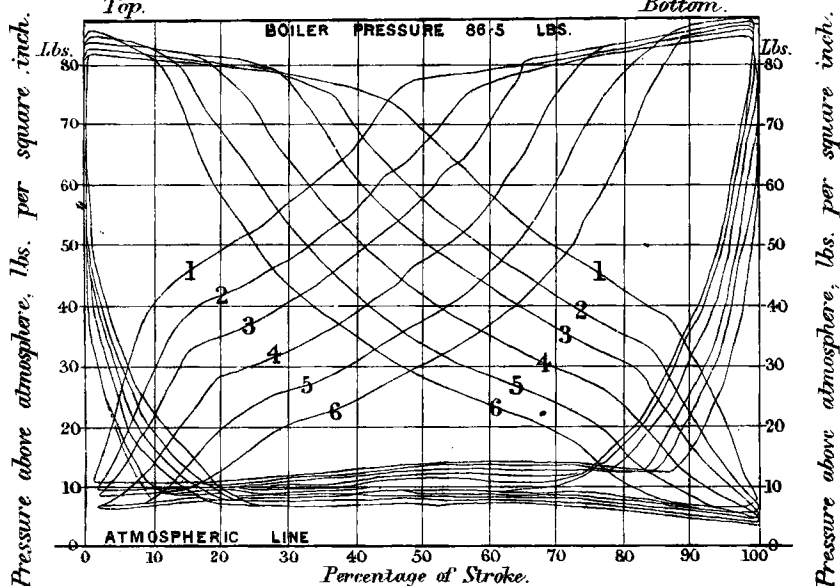
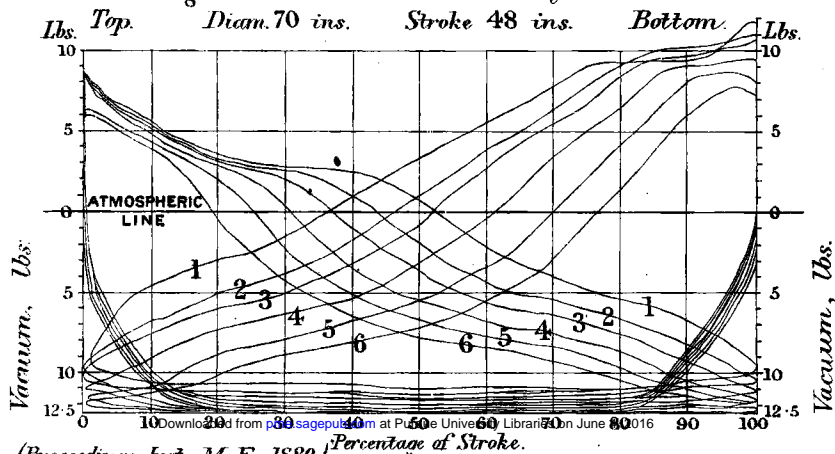


Fig. 29. Low-Pressure Cylinder.

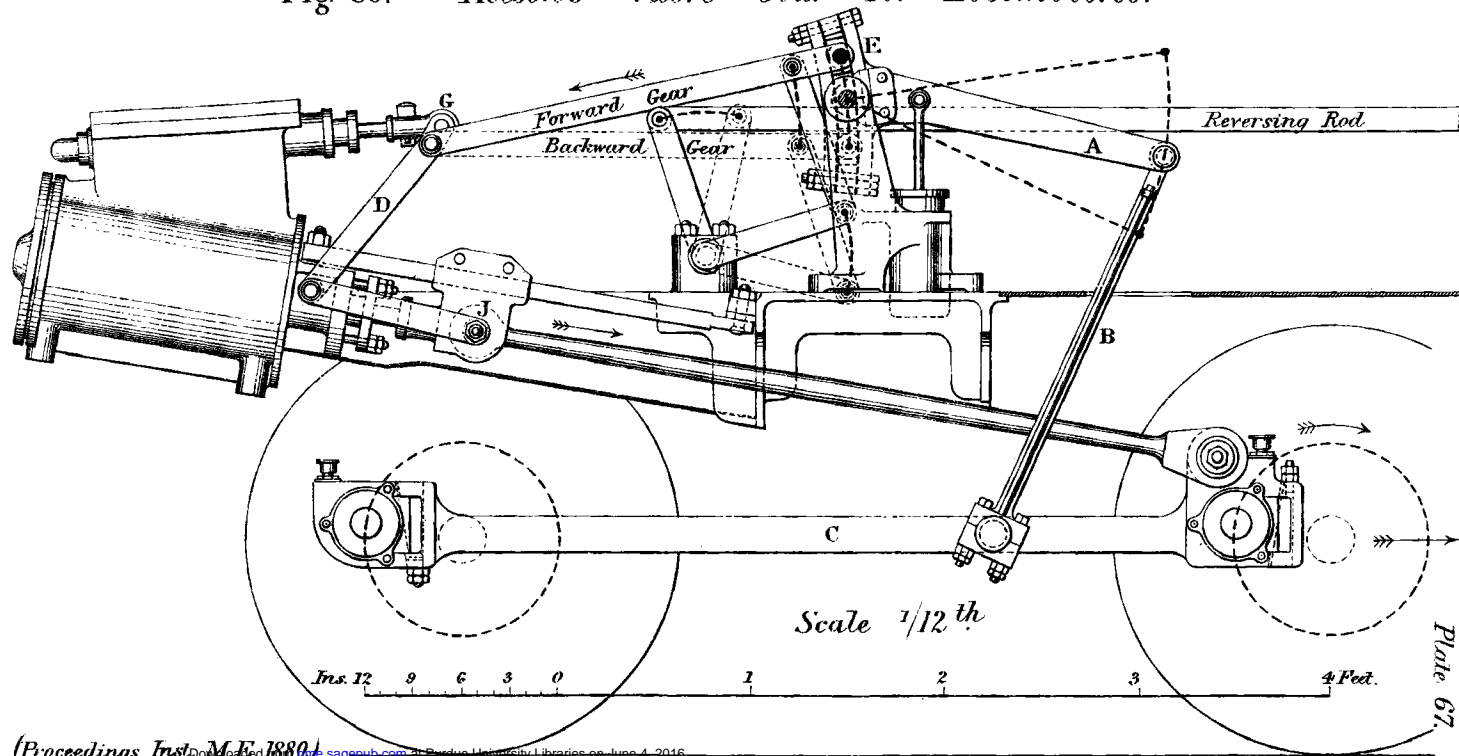
Diam. 70 ins. Stroke 48 ins.



VALVE GEAR.

Plate 67.

Fig. 30. *Kitson's Valve Gear for Locomotives.*



Hackworth's Gear.

Fig. 33.

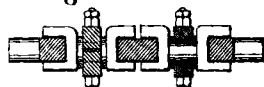


Fig. 34.

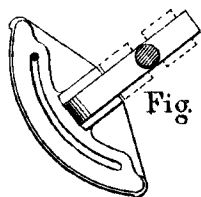


Fig. 31.

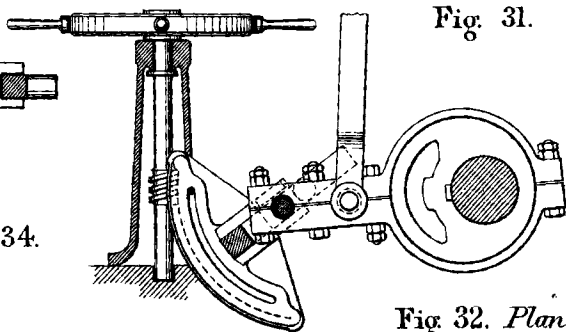
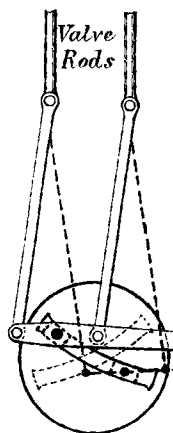
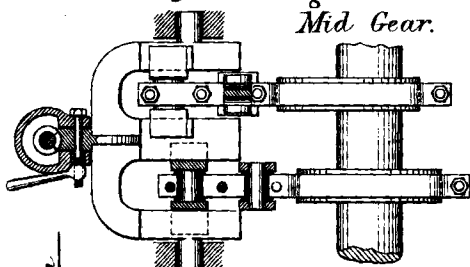


Fig. 32. Plan.
Mid Gear.



Piston Rod.

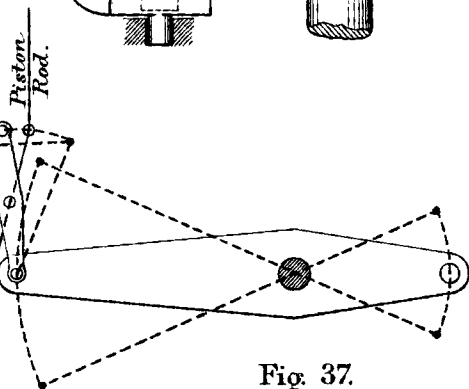


Fig. 35.
Reynolds' Gear.

Connecting Rod

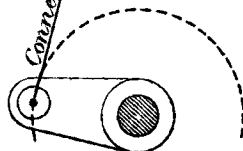


Fig. 37.
Section of Box Link.

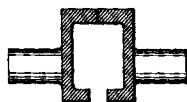


Fig. 36. Box-Link Gear.

(Proceedings Inst. M. E. 1880.)

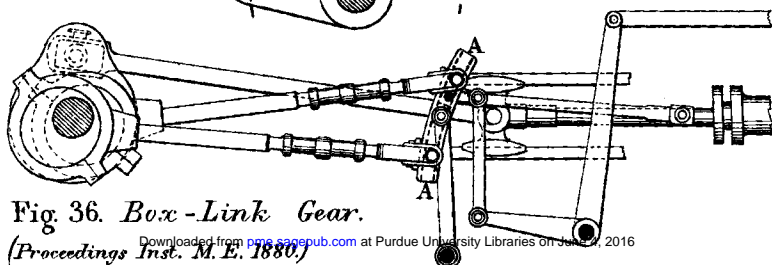


Fig. 38. *Walschaert's Gear.*

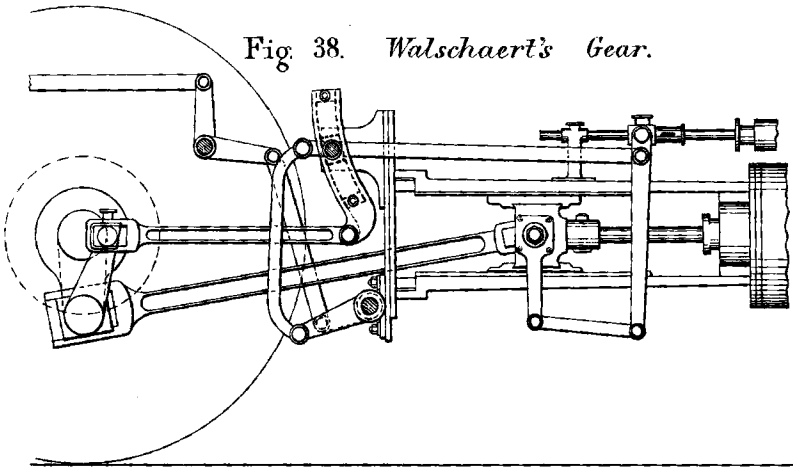


Fig. 39. *Brown's Gear.*

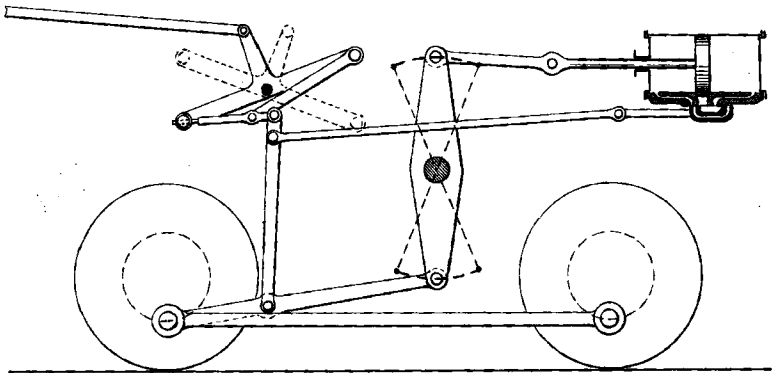


Fig. 40. *Hawthorn's Gear.*

