[No 73.]

G.W.R. Mechanics' Institution.

SWINDON ENGINEERING SOCIETY.

TRANSACTIONS, 1906-7

INTERMEDIATE MEETING.– Tuesday, December 18th, 1906.

Chairman – Mr. G. H. Burrows, Assoc.M.I.Mech.E.

" STEPHENSON *versus* WALSCHAERT VALVE GEAR, "

BY

W. H. PEARCE (Member).

With Discussion

The locomotives of the present day, instead of having the valve driven directly from the eccentric, have interposed between the eccentrics or points from which the motion is derived for the valve, certain descriptions of gear, by the employment of which the motion, imparted to the valve can be modified in various ways.

The valve gears for consideration in this paper are the Stephenson, or shifting link motion, and the Walschaert or radial gear motion.

These gears have to act in the two-fold capacity of reversing and expansion gears. The reversing is easily attained ; whereas to give correct expansions fore and back demands considerable care and attention in the proportioning and arrangement of their parts.

STEPHENSON GEAR.

In general use, two eccentrics are employed, the position of these on the driving axle being such that one eccentric can give to the valve (Fig. 1) the motion required when the engine is moving forward, whilst the other furnishes the means of moving in the opposite direction. The quadrant link connecting the ends of the eccentric rods is moved vertically, being supported by lifting links from the end of the reversing arm, whilst the sliding quadrant link block, by which the motion is transferred from the link to the valve spindle, is subjected to horizontal movement only. The motion is said to be in fore- or back-gear, according to whether the joint of the fore- or back-gear eccentric rod is nearest the centre of the block.

There are various forms of expansion link by which the ends of the eccentric rod are connected. The principal varieties in ordinary use are represented in Figs 2, 3, 4, 5 and 6. These differ, as will be seen, not only in their mechanical construction, but also in the relative positions occupied by the points at which the eccentric and lifting links are attached. Each of the varieties of link has its own peculiar effect

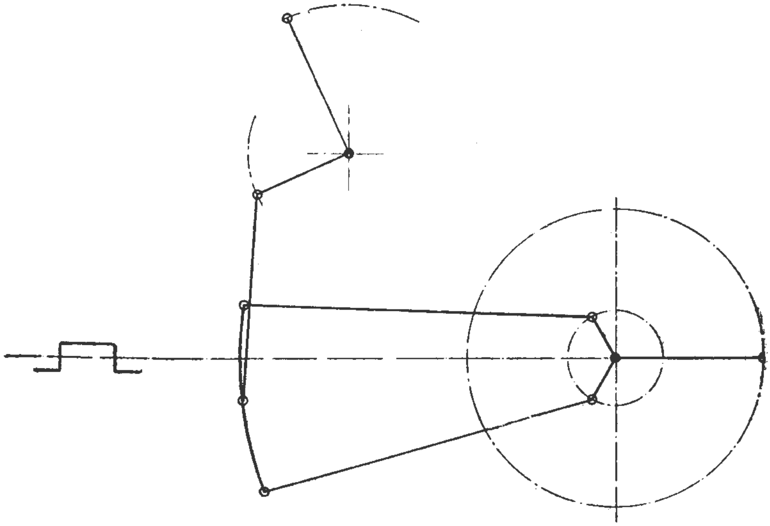
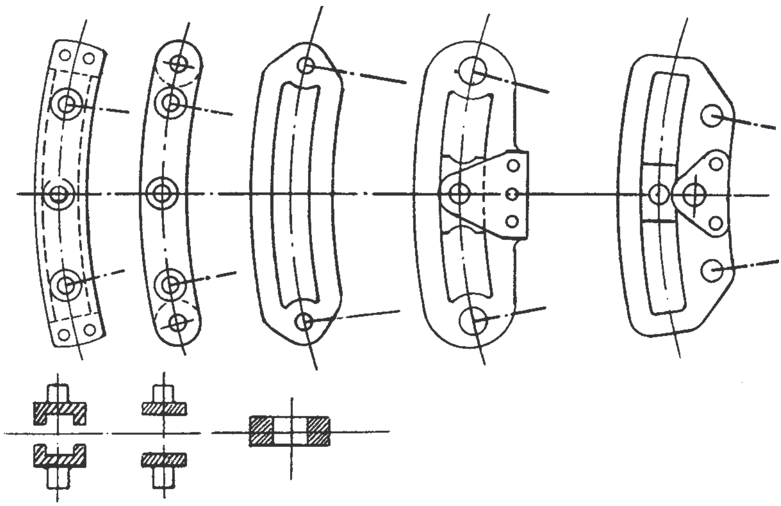


Fig. 1.— Stephenson Valve Gear : Variable Lead.

upon the motion of the valve. When the motion is in full gear, the centre line of one of the eccentric rod pins coincides with that of the link block, so that the position which the eccentric in gear should occupy with respect to the crank, should be the same as if that eccentric alone was employed to work the valve, the linear advance being equal to the lap plus the lead. This reasoning applies to both eccentrics. When, however, the link is placed in mid-gear, the valve will possess a greater or less amount of lead, according to the manner in which the eccentric rods are attached to the link, also the length of eccentric rods and the amount of eccentric throw.

Generally, the eccentric rods are arranged so that the lead of the valve is increased as the link approaches mid-gear position, which defines open rods. Under these circumstances it is impossible to avoid an increase of the lead in moving from full to mid-gear.

For a distance of 12″ between eccentric rod ends, if the rods are lengthened three times their original length the variation of the lead is decreased by one half, and by doubling the distance on the link centres the variation in lead is doubled. For a difference of 60 per cent, in cut off, the present increase is $\frac{1}{4}$″ in a good designed gear. Another element which affects the amount by which the lead is increased in



FIGS. 2, 3, 4, 5 and 6.

mid-gear is the throw of the eccentrics, which causes an increase in variation for an increased throw.

With the Stephenson it is a difficult matter to obtain sufficient lead with large cylinders in the longer cut-offs, and at the same time keep down the lead and consequent pre-admission and excess of compression at short cut-offs, where most of the high-speed work is performed.

These notes suggest designing the Stephenson gear with the minimum throw of eccentrics. The minimum distance between the eccentric rod centres on the link and the maximum length of eccentric rod, so that the amount of such increase in lead toward mid-gear may be diminished.

These suggestions apply to rectifying the effect of the link proportions with regard to lead when the crank is obviously at the end of its stroke, but the angularity of the connecting rods more seriously affect the cut-off and expansion proportions, and these are found to be rectified by varying the position of the lifting link on the quadrant (Fig. 6), and also the point of suspension from the reversing shaft (Fig. 1), though at the expense of increased slip of the link on its block, from which lost motion would ensue and the delicate action of the offset would be destroyed. This motion lends itself very freely for adjustment to these several parts to influence the motion of the valve, consequently it is very sensitive, and can be arranged to give a balanced distribution, front and back, when first set. But, should any spring exist in the gear, or wear in the various adjustable points, a like defect is conveyed to the valve, quickly disturbing the original distribution.

The introduction of a rocking shaft reverses, or does not reverse, the phase of the motion of the valve with regard to the piston according as the arms of the rocker are on the opposite or on the same side of the axis of the shaft. Again, the phase may be reversed by taking steam on the inside of the valve.

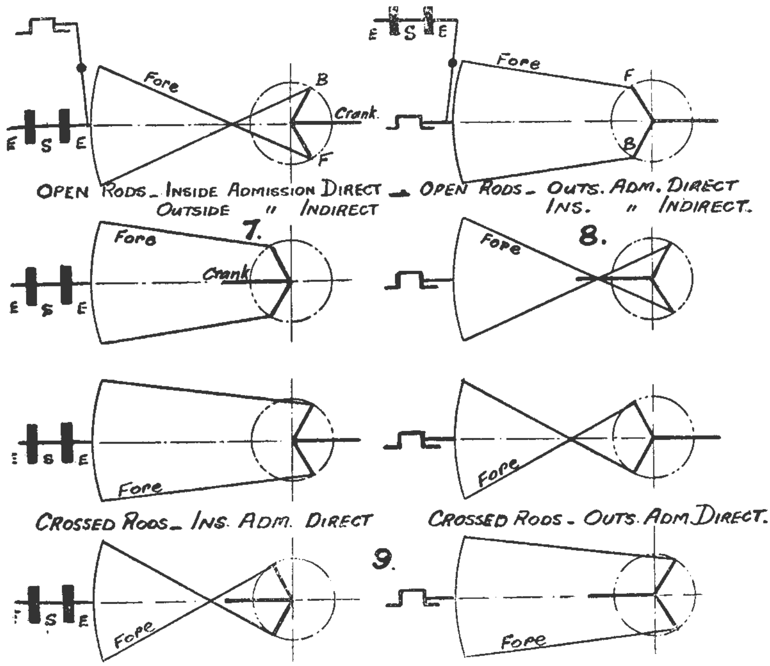
The diagrams, 7, 8, 9, show the general arrangement of the gear in various cases, each arrangement being fitted with open or crossed rods, under all conditions, with the crank on a deadpoint ; that is, the piston at the end of its stroke with the valve open to lead.

Figs. 7 and 8 show open rods arranged for inside admission piston valve with direct motion, which remain the same for a slide valve with indirect motion, that is, worked from a rocker whose arms are on opposite sides of the axis.

Fig. 9 shows crossed rods which give a decreasing lead toward mid-gear ; thus they are very rarely used.

A point peculiar to link motions is that the vertical distance between the centre of the reversing shaft and the centre of the crank axle is always changing, because the greater part of the valve gear is carried by the spring-supported frames, whilst the centre of the crank axle is an invariable distance from the rail. If the valves are originally set to give an exact equality of lead this equality would be slightly destroyed when the engine was in service. The changes are greater if the axis of the valve gear is inclined to the line of stroke. If the cylinders and gear be inclined very much the engine would not work, as will be seen if it is attempted to erect vertical cylinders and gear, for the rise and fall of the axle in the horns (generally about 1″) would have to be allowed as clearance in the cylinder, and unknown proportions for the valve.

With regard to the expansion of the valve spindles tending to vary the leads, it applies in a like proportion for all gears, causing an increase of lead both ends for inside admission piston valves, though more in



FIGS. 7, 8 and 9.

the end farthest from the spindle connection ; and an increase in the end nearest the spindle connection, with a decrease on the far end for slide valves.

Locomotive designers have continued to apply the Stephenson Practically to the exclusion of all other valve motions. It has proved successful on locomotives of moderate size, and has given good satisfaction, but due to enlarged locomotives and their various parts, it appears impracticable to increase the valve gear proportions in proper ratio. If the size of the eccentrics be increased proportionately, they would give trouble because of high surface velocity.

Although the link motion has been long in use, it seems the general idea that no reversing gear has been introduced superior to it in every point, while in respect to at least one vital condition, that of durability, it probably surpasses them all. The simplicity of its parts has enabled it to contend successfully with all rivals, and at the present day it remains in substantially its primitive form. Thus the link motion was a good solution of the problem of arranging a convenient reversing gear, and a fortunate solution of the greater problem of designing a simple gear by means of which expansive working was possible. Once its properties were known, it was carefully examined as an expansive gear, and numerous other forms proposed, varying to a greater or less degree from the original type. The reason of its general adoption, no doubt, is attributed to the fact that the majority of locomotives have been arranged for inside cylinders, with the valves between on the horizontal cylinder centre, consequently it gives the best condition for the direct Stephenson. Should the valve be placed above or below, it necessitates an inclination for the gear, introducing irregularities, leaving scope for improvement. When outside cylinders are used, and the valves also outside the frames, it is difficult to adopt the Stephenson without the introduction of a rock shaft, which is objectionable, as it means an extra reciprocating part, beside a considerable offset from the centre line of eccentrics. The motion communicated to the valve by the Stephenson gear is one which, beginning from rest, increases to maximum, and then gradually diminishes, until at the end of its travel it comes to rest again. It is therefore clear that a valve so actuated, unless designed to give port openings which will be excessive for slow speeds, must give rise to wire drawing at higher speed. It is commonly assumed that wire drawing in locomotives is objectionable, but it is useful in assisting the maintenance of uniform conditions upon the boiler while the engine is running under various conditions of speed, by preventing the cylinder from taking from the boiler more steam than it can supply. But there are objections which arise from the fact that as wire drawing proceeds, the cylinder action becomes less efficient, and at high speeds it is responsible for some increase in steam consumption.

WALSCHAERT GEAR.

The Walschaert gear was invented by Egide Walschaert, master mechanic of the Belgian State Railway, about the year 1844, and for many years it has been commonly employed upon locomotives throughout the continent of Europe. English and American practice has, until recently, adhered with few exceptions to the Stephenson. Walschaert gear has been growing in favour abroad, and has lately attracted wide attention from all engineers. The popular favour with which it is being received wherever it has been recently introduced, gives indication that it is in every way better suited for the heavy modern locomotive than the shifting link so long in use.

The increasing use on home railways is a matter for comment. Until 1904, practically no British railway employed it, but at the present time it is being introduced on several railways either for locomotives or motor cars. It seems certain that in cases where valve gear has to be located outside the frames, it posesses undoubted advantages, whilst its character for good steam distribution is well known. Of course there are causes which produce variation in all mechanical movements that have their origin in circles or parts of circles, and are transferred to a reciprocating or lineal motion.

The motion of the valve is derived both from the cross-head and the eccentric crank, from a driving axle. The cross-head connection imparts the lap and lead at the extremities of the stroke, when the eccentric crank is in its middle position. The eccentric crank in this position imparts its fastest movement to the valve to give a very quick opening. In construction, the desired lap and lead are selected, and the stroke of the piston being given, the combining lever is proportioned so that a motion equal to twice the lap and lead is given to the valve when the cross-head is moved from one end of the stroke to the other. For outside admission valves, the radius rod is attached to the combining lever between the valve spindle and cross-head connection, and for inside admission (piston valves) it is attached above the valve spindle (Fig. 10). The suspension of the lifting link should have a locus, which causes the link block to travel as nearly as practicable on a chord of the arc described by any point of the lifting link wherever the block happens to be when the link is swung into its extreme positions. As this point cannot be made to follow the theoretical locus, it is determined by favouring the position of the most commonly used cut-offs. Even a good arrangement of this method gives more slip of the block in back gear than fore, and the slip is reduced in proportion as the suspension link is correctly carried. The best condition is most closely approached by a lifting arm with guide block, which does not swing, through which the radius rod slides, and this gives the same result in fore and back gear. The quadrant link is exactly in its central position when the piston is at either end of its stroke ; this allows the block to traverse the link without producing any horizontal movement to the radius rod or tendency to move the valve, thus producing a constant lead.

For large locomotives, where the driving axles are of such diameter as to greatly increase the size of the eccentrics, this gear is useful. Only a

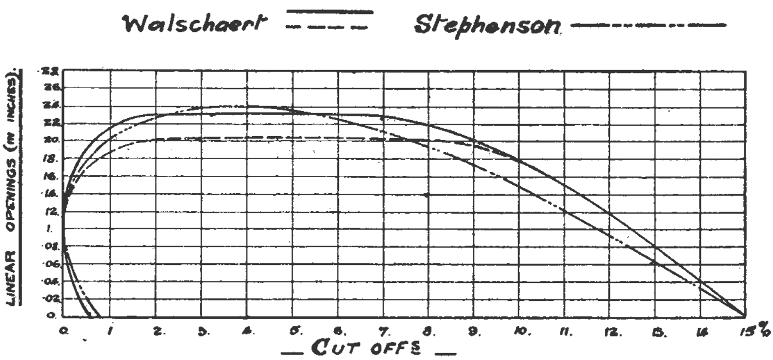


Fig. 10.

single eccentric is necessary for each valve. As usually constructed, it is found more convenient to substitute a return crank, thus reducing the pin bearings to the smallest possible diameter, so that they may be readily lubricated, and owing to the small amount of work they have to do, give absolute freedom from heating. One of its features is the opportunity that the parts afford for good bearings, which give it a most desirable degree of stability (Fig 11).

Valves placed immediately over the cylinders are the most convenient arrangement for the attachment of the Walschaert. It is very convenient for inspection, rendering it unnecessary for men to go under the engine in order to make a careful examination of the vital parts.

The gear is direct or indirect, according as to whether the engine is in the fore-gear or back-gear. The difference in this gear for outside and inside admission valves must be considered in setting the eccentric crank, and as the forward motion of the engine should preferably be taken from the lower end of the link, the eccentric crank will *follow* the main crank for inside admission valves and lead the main crank for outside admission valves. Consequently, in fore-gear the valve is moved by direct motion, and in back-gear the motion becomes indirect (Fig. 11). So far as the distribution of steam in the cylinder is concerned, the constant lead, which is a feature of this motion, is not considered objectionable and it has some distinct advantages. Under such conditions it is possible to determine upon the amount of lead the engines should have at the most economical point of the cut-off. This point determined, and so designed, it cannot be maliciously altered by anyone in the shop or running sheds. It prevents valve setters from

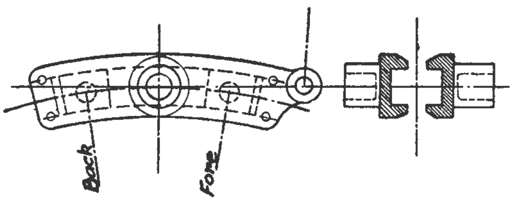


FIG. 11.

attempting to produce results by moving the eccentrics into improper relations one to another.

The constant lead gives a definite pre-admission and prevents the sealing of the cylinders by the piston valve when the piston is at the end of its stroke or approaching it. Whereas with the link motion, either by derangement or by excessive wear, the valve laps the port at the end of the stroke, thus causing excessive compression and many other troubles.

Under ordinary conditions very little lead is needed to cushion the reciprocating parts, as the rods and reciprocating parts rarely run so smoothly as when running with the regulator closed. This can be verified by observation when drifting at high or low speeds. But with a constant lead of, say $\frac{1}{4}''$ and full gear cut-off, steam will be admitted when the Piston is $2''$ from the end of the stroke. Under these conditions the valve is travelling rapidly and piston slowly, so that steam is admitted instantly, causing a momentary check to the power of the engine on the other side. A small lead of, say $\frac{1}{8}''$, would probably suffice in long cut-offs to cushion the reciprocating and at the same time reduce the pre-admission and compression at short cut-offs.

This gear should be correctly laid out and constructed from a diagram, as the proportions cannot be tampered with by experimental changes without seriously affecting the correct working of the device. The only part capable of variation is the eccentric rod, which is adjusted to correct errors in the distribution.

It is interesting to know how the steam distribution is influenced by the riding of the engine on the springs. It cannot be large, because the motions taken from the engine for the movement of the valve are all at right angles to the motion due to play on the springs. The variations for $1\frac{1}{2}''$ rise have been determined to be about 1·5% at medium cut-offs, and the lead shows a slight change.

Engines of the same class fitted with the two gears prove to give a reduction in weight of 30% in favour of the gears of the Walschaert. Another feature is the ease of handling the reversing handle at all speeds.

The Walschaert link, not being influenced by an eccentric provided for back-gear only, does not pendulate through as large an angle as the ordinary Stephenson. This means that the link has a more favourable action on the linkblock, and does not spring the motion as much as the Stephenson when at or near the extremity of its stroke.

The motion, as usually constructed, does not lend itself as freely to adjustment as does the Stephenson with independent eccentrics, and for this reason it is not as liable to get out of adjustment.

To entirely overcome the irregularities inherent in all motions transferred from circular into lineal cannot, for practical reasons, be expected, but the errors may be reduced to such an extent that they do not affect either the power or economy of the locomotive.

The rules which should be observed in designing a new valve motion are few in number, and may be summarised as follows:—

The movement of the crosshead should be transmitted as exactly as possible to the valve ; the crosshead link should be made long, and where there is space it should swing about a central horizontal position.

The influence of the angularity of the eccentric rod should be overcome by moving the linkjoint toward the crank. The best position can be found by trial, as two or three points usually give the required solution. By this means short eccentric rods can be used if necessary ; the throw of the link being slightly increased. In locating the top of the suspension link, a point should be found which makes nearly a right angle between the link and radius rod when in fore- or back-gears.

There is no fundamental reason that the Walschaert gear should produce large economy in steam consumption over the Stephenson motion when both are in the best conditions, but an average in this respect comes to the former by the fact that it remains in its good condition if once made so, from one general repair to another, and is, therefore, on an average more economical both in steam consumption and maintenance of the gear than the latter.

The curves in Fig. 10 will, nevertheless, assist to draw conclusions, as these are plotted from actual results from both gears, though it seems difficult to arrange suitable ratios from which to deduce statements. It is generally accepted that if the Corliss movement of valves could be satisfactorily produced on locomotives, they would produce economical results ; so with this idea, it has been attempted to ascertain the approach to this of the two gears under consideration.

The cylinder dimensions and ratios are similarly designed, which leaves them as a constant, so the difference must be in the valve gear alone. On a percentage of stroke as base, and cut off 15 per cent. in each case, with linear port openings as ordinates, the actual curves have been plotted and superposed to the same scale for comparison. With a similar lap and lead for the two gears, the Walschaert proves to give a greater port area. The relative mean height by the length of port gives the available port area in square inches for a given volume. Corliss 100%, Walschaert, 74%, Stephenson, 68%. On similar engines, by adopting Walschaert in place of Stephenson, 7% more efficient port area would be procured.

It will be noticed when the piston is at 1% and 8% of its stroke, the Walschaert gives the port an increased opening over the Stephenson ; also, there is a decided dwell on the valve, produced by quicker opening and sharper cut off, both being very desirable at high speeds, as the entire interval during which the port is open is less than one-twentieth of a second.

The point to be considered is the small amount of port openings at high speed cut off. With a given cut off the fraction of the whole time which the port is open is independent of speed. In an hour's run there will be a certain definite number of minutes that each port will be open whatever may be the speed, hence the increase of average port opening for that time is advantageous.

Reference has been made to the irregularity due to separate connections from the eccentric or return crank on the crank axle to the valve, and also inclined cylinders, so the problem was suggested to do away with this inaccuracy and be independent of the spring action, &c. This resulted in a modification of its nearest approach, the Walschaert gear, to a valve gear (as it will be seen from the Author's model), without eccentric or return cranks, whereby the entire motion for the valve is taken from the crossheads alone, as it is obvious any disturbed motion of the crosshead or piston should be conveyed to the valve to balance it, as the vital parts to run in harmony are the piston and valve only. In conjunction with this is introduced the sliding block lifting gear, which gives the same result fore and back-gear. This general arrangement, therefore, theoretically, has surmounted most difficulties ; and also has proved to give these results practically.

DISCUSSION.

The Chairman, in opening the discussion, said the Americans claimed that the main advantage of the Walschaert over the Stephenson gear was accessibility. That was only true with outside cylinders, as they used these only over there because it was more important in their case than in the case of most of the railway companies in England who used the inside cylinder arrangement. Of course, the accessibility for the inside cylinders was the same for both gears, but when outside-cylinder engines were considered the Walschaert scored. With our later two-cylinder engines it was necessary with the Stephenson gear to have a rock shaft to transfer the motion of the valve which was outside the frames, and that shaft was a source of continual trouble, as it had a bearing about 11″ long, which wore considerably, and after engines had been out a certain time the valve gear had to be run over again, and frequently the rockshaft bearing had to be put right.

With the Stephenson gear driven with eccentrics it was surprising how much bearing surface was necessary. The larger the eccentric the greater the throw, which meant that more bearing surface was necessary, and that of course, all took up power from the engine. The Stephenson gear had considerably more pins than the other, and every additional pin introduced between the eccentric and the valve itself meant so much lost motion when wear occurred.

In the Walschaert gear there was constant lead instead of a varying lead, but, if Fig. 10 were considered, it would be seen that the constant lead was no detriment to an engine with the Walschaert gear. If the two gears were considered, it would be found with the Walschaert that there was an actual " dwell " on the valve just as the piston was moving from the end of the stroke.

With an engine travelling at high speed more steam got into the cylinder with the Walschaert gear than the Stephenson. It was at the high cut-offs, and just at the beginning of the stroke where the lead was full that more steam was required in the cylinder.

Mr. W. A. STANIER said he wished to thank Mr. Pearce for the clear way in which he he had explained the principles of the two gears. It had certainly been a revelation to him on many points. The Author had mentioned that the cushioning was not so important, because he had noticed that when an engine was drifting the valve gear ran more sweetly than when steam was on. There was very little steam on either side of the piston in that case, and he thought that if there was steam behind the piston, the steam which had been expanded required a little cushioning to reverse the reciprocating gear. There was one point about the Walschaert gear he had noticed even before he knew that there was a bigger area of pressure or, rather, a dwell on the valve, that was, that the Walschaert gear, although it had a number of pins, by its very construction it reduced the wear by the time it got to the valve. If an engine was out two years with the Walschaert gear there was less trouble with the valve owing to wear than with the Stephenson gear. With the latter, when it was in the notch to about 15% cut-off, with our outside cylinder engines there was, about $\frac{1}{4}''$ port opening, which was not very much with piston valves. He had known $\frac{1}{8}''$ of that taken up in six months, so that, when working with that amount of cut-off, there was, no, lead and a very small opening. The rockshafts were objectionable in the Stephenson gear on modern engines. It was so difficult to keep a rockshaft, that was only rocking in a short angle, round one bearing. When it was worn, unless it was skimmed, it could not be repaired properly. The mere letting of the brasses together did no good at all.

Mr. R. H. Smith said that his experience would not allow him to favour the Stephenson gear in face of the satisfactory results obtained from the Walschaert. From experience, he found that the gear (similar to the Author' s model) on G.W.R. Loco. No. 40 had given every satisfaction. In practice, more regular working could be obtained with the Walschaert gear. The results with the French engines had been very satisfactory, and he thought that they left little scope for improvement, as quick cut-offs and good exhaust openings were obtained. No. 40 engine did well with the gear fitted to it, and he thought it had a constant lead (which the Author had not mentioned). Mr. Smith remarked also that with inside cylinders the engineman could not oil the various pins easily, and thought that the time would come when a pump lubricator would be provided on the footplate.

Mr. Nash remarked that the Author had put the matter thoroughly before them. In his opinion (Mr. Nash) the Walschaeart gear, from the mechanical point of view, was better, but in steam distribution it was not equal to the Stephenson gear. In Fig. 10 he noticed that the pre-admission was shewn for the Stephenson gear, which was ·8 per cent. of the stroke, and for the Walschaert gear the pre-admission was something like 6 per cent. He also noticed that the valve travelled $\frac{5}{32}''$ while the piston was going ·5 per cent., which was a crank angle of about 8°. He could not see how this produced $\frac{5}{32}''$ valve travel. It was claimed for the Walschaert gear that it gave a rapid cut-off. He did not know whether this was an advantage, as it checked wire drawing. Wire drawing produced a certain amount of superheating, which has a good effect on the expansion curve. He thought Stephenson gear was unnecessarily heavy, especially as it was claimed that piston valves were practically balanced. The Americans had reduced the difficulty of the rocker by putting a bearing on each side of the rocker arms.

Mr. Pearce, in replying to the Chairman' s remarks on pins, referred to the model before him, and said the arrangement had two sets of gear driving four valves, and on the French engines there were four sets of gear for four valves, which required 51 pins and two large eccentrics. With the first arrangement only 32 pins were required and no eccentrics. This meant a considerable saving in the wearing surface, and taking an ordinary gear, there were about $7\frac{1}{2}$ as against 10 in the simple Stephenson gear where it was direct acting. With regard to cushioning, he thought his remarks were practically verified by the fact that the engine ran so smoothly when steam was shut off. The action of the air in the cylinder gave practically the same result with small cut-off as if steam were being admitted. Compression was a vital point, and unavoidable, and it seemed sufficient to overcome the action of the reciprocating parts, hence, for this purpose,

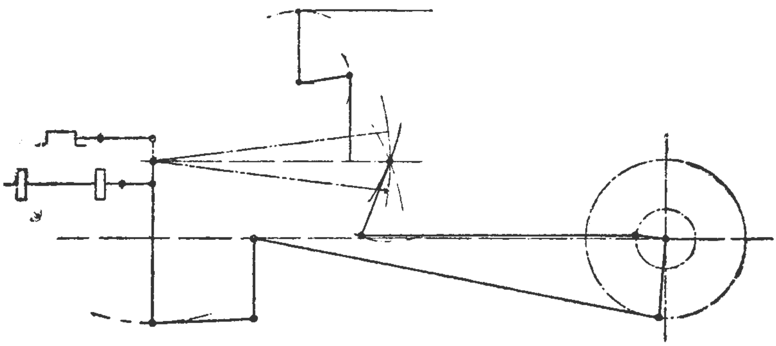


FIG. 12.—Walschaert Valve Gear, showing arrangement for Slide Valve, or Inside Admission.

lead and pre-admission were not necessary. But it was good practice to give just sufficient lead to fill the clearance space, and cylinders with a small per cent. clearance space to cylinder volume, a small lead would be given as the pressure at the end of compression would be increased. Referring to Fig. 10, there was very little difference between the pre-admission points for the Walschaert and Stephenson gears. Pre-admission of course varied with the lead given, and for a similar lead with the two gears there was only a difference of ·2% in the pre-admission, the Walschaert being ·2% less than the Stephenson at 15% cut off. It would be seen from Fig. 12 why the valve travelled at such speed compared with the piston, as the valve was moved by an eccentric, which was at an angle of 90° to the crank, thus, when the crank was passing the dead centre and giving no motion to the piston, the eccentric was on the top centre and moving its fastest, causing the valve to travel at that instant faster than the piston. With regard to the sharper cut off given by the Walschaert, it was generally recognised to be a great improvement, as it certainly reduced the wire drawing and approached the Corliss valve movement in this respect, which was accepted as an ideal method for controlling the steam distribution. To get a wire drawing effect to produce any superheating, a small steam lap was necessary, and this had been proved to be detrimental to efficient openings at high speed cut-offs ; consequently, the probably small amount of superheating was sacrificed for a larger steam lap, which certainly gave an increased port opening for admission at early cut-offs and a more effectual opening to exhaust. With regard to increased opening, Mr. Stanier had remarked that engines lost a certain amount of opening due to wear. They were sent out originally with $\frac{1}{8}''$ lead at 25% cut-off, which gave $\frac{5}{16}''$ port opening. Due to wear and lost motion from the arrangement of the rockshaft the $\frac{1}{8}''$ lead was soon decreased, and it was advantageous to adopt large steam laps, as this increased the port opening for the same per cent. cut off. A better solution would be to do away with the rockshafts or adopt the Walschaert gear. Fig. 10 was a portion of the well known valve ellipse, which was largely used by the French engineers to shew the working of their valves, and in some cases the actual curves were produced by a mechanism attached to the engine. It clearly shewed the movement of the valve relative to the piston, and indicated the advantage of the Walschaert gear from the fact of a quick port opening and sharp cut off being obtainable. With the Stephenson it was a slower opening and closure, and as wire drawing was generally to be avoided, this would tend to increase it. At high speed cut-offs it was essential to reduce wire drawing and secure a quick maximum opening and sharp cut-offs. With reference to " cushioning " with the French engines, the Author said they had less, due to a negative exhaust lap which was frequently adopted on compound engines.