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"VALVE MOTION DEVELOPMENTS"

BY

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With Discussion.

In this paper it is intended to explain the effect of the numerous variations in valves and valve motions as applied more particularly to locomotives.

The manner in which the steam is admitted to or released from the cylinder of a steam engine, and the points of the stroke of the piston at which these events commence and terminate are subject to variation in three distinct ways :—

1. By an alteration in the form or proportions of the valve or valves by which the distribution of the steam is effected.
2. By a variation in the valve gear driving such valve or valves.
3. By an alteration in the relative proportions of the connecting rod and crank.

The action of each of these various causes may be shown either by a model of the particular arrangement under consideration or by the method of geometrical construction, the latter being generally preferable for the purpose of investigation.

The action of an ordinary slide valve and single eccentric will first be considered.

The form of slide valve, as applied to locomotives, combines in one mechanism the means of admitting, suppressing and releasing the steam to and from the cylinder. The designations applied to its proportions are numerous, and each has a special influence over the distribution of the steam action upon the piston.

The slide valve has been called the heart of the steam engine, for it is a distinct and vital part of the engine, controlling and regulating the circulation of its life fluid in a manner suggestive of the name given to it.

It is the function of the slide valve to direct the motion and action of the steam to the best advantage and without waste in order to make the engine an effective and economical motor. As the valve must be designed to effect an economical steam distribution in the cylinder, it has attained a peculiar significance in scientific steam engine construction, but durability and permanency of form are requirements not less imperative, and they involve constructive problems of a different order.

The term "slide valve" is applied to flat-faced valves having a reciprocating sliding motion whereby steam is alternately admitted to and exhausted from a cylinder. The sliding surfaces may be cylindrical, and this does not affect the principles of the valve motion, but in such cases different names are used—as piston valve, corliss valve, semi-rotary or oscillating valve, etc. These valves are only modifications of the original slide valve and of whatever design they can be easily referred to, and compared with the common D valve, their functional properties in all cases being closely related.

When they perform their functions well the locomotive is prompt and precise; if they are faulty it limps in its course or allows its energies to waste. From the early days of locomotive operation valves and their gears have challenged alike the skill of practical mechanics and professional engineers.

In essaying the study of an intricate subject like the relative motions of the piston and the ordinary slide valve of a steam engine, it is of the utmost importance to first divest the parts of all the complicating influences which arise from special constructions and present them in such simple and elementary forms that the discovery of the fundamental laws governing their motions may be facilitated. If these are clearly defined the deductions of others adapted to special cases will subsequently be accomplished with comparative ease.

The entire series of events which take place within the cylinder occur when the piston has reached definite positions in its complete stroke. The stroke of the piston will be regarded as equal to unity, and the positions at certain important periods as decimal portions of the entire stroke.

While the piston performs one stroke the crank pin makes a semi-revolution (180°), each position of the former consequently corresponds with some angular position of the crank arm, and, if these angles are arranged in a table, it can be determined therefrom the number of degrees over which the pin must pass to bring the piston to any required position.

As an illustration, the following has been tabulated for simple harmonic motion and furnishes angular positions of the crank arm, corresponding with the various points in the stroke which may at times be occupied by the piston:—

Piston position. Stroke.	Crank angle. Degrees.	Piston position. Stroke.	Crank angle. Degrees.
·1	$36\frac{7}{8}$	·6	$101\frac{1}{2}$
·2	$53\frac{1}{8}$	·7	$113\frac{5}{8}$
·3	$66\frac{3}{8}$	·8	$126\frac{7}{8}$
·4	$78\frac{1}{2}$	·9	$143\frac{1}{8}$
·5	90	1·0	180

Considering the valve to derive its motion from a small crank or eccentric, its movement may be represented by the same method.

Having considered the general features of the controllers of motion, the crank and the eccentric, and having resolved them into their elementary forms, it will suffice to consider the parts moved and seek the law of their proportions.

The distribution of steam is regulated by varying the three elements, lap, lead and travel, and their influence may be simply exemplified by means of the motion curve or valve ellipse.

If the travel, lap and lead be increased in the same ratio, say trebled, it appears that the distribution is unaltered. It is to be inferred that, if the three elements be increased or diminished in the same proportions, the percentage of admission continues unaltered, and likewise the points of release, compression and preadmission of steam.

The influence of the values of travel, lap and lead taken separately, readily give appreciably distinct results. With a constant lap and lead, the travel varied, the period of admission is reduced as the travel is reduced.

With a constant travel and lead, but by increasing the steam lap, a special effect is produced (like that of decreasing the travel) of shortening the period of admission and lengthening the period of exhaust.

Varying lead is the less influential of the three elements. With a constant lap and travel, if the lead is increased the period of admission is slightly decreased.

The values of the periods of expansion, for varying periods of admission, are measures of the comparative efficiency of the three

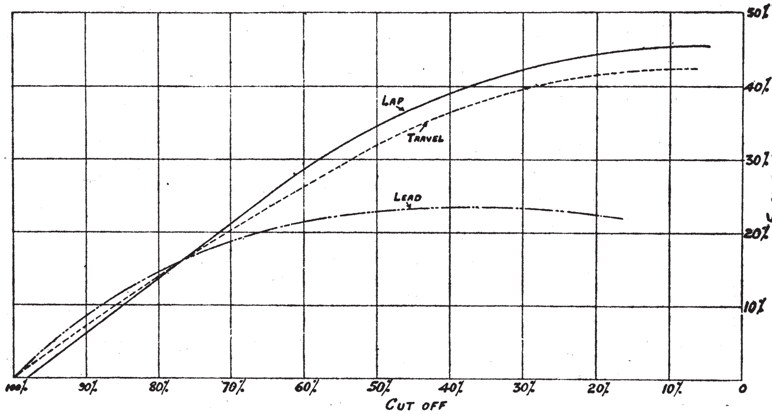

FIG. 1.

modes of proceedure. With varying travel the period of admission and expansion are as follows:—

Admission. Per cent.	Expansion. Per cent.
81·5	12
73·5	17·5
62	23
39	34·5

Similar figures may be tabulated for a variation in lap and lead, then plotted as in Fig. 1.

It appears that varying lap is the most efficient method of working with variable expansion. It is better for expansive working than varying travel; and its periods of pre-admission are shorter. Variations of lead are obviously a poor method of working, the expansive period soon reaching its maximum. Of the two modes of varying expansion by lap and travel, the latter involves mechanism of a simpler character than that which is required by the former. Variation by travel, with constant lap, appears generally to be the most eligible means of producing efficient expansion.

The influence of exhaust lap, if increased, defers the point of release, and consequently prolongs the period of expansion. But it hastens the compression. Increase of exhaust clearance operates reversely: it hastens the release, shortens the expansion and delays the compression. Experience shows that neither exhaust lap nor exhaust lead is required for the ordinary slide valve in simple expansive engines.

When the displacement of the valve is equal to the steam lap, the engine is either at admission or cut off; and at release or compression when the displacement is equal to the exhaust lap.

The valve ellipse (Fig. 8) may be advantageously used to investigate

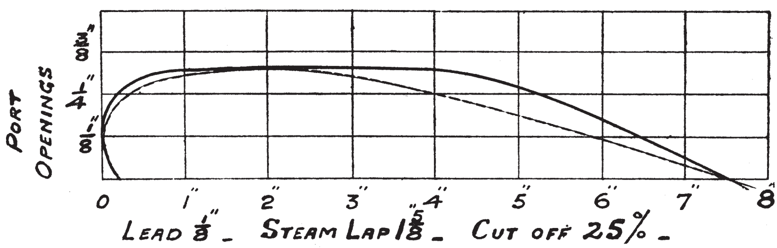

FIG. 8.—Full line: Walschaert Gear. Dotted line; Stephenson Gear.

the action of a valve, having an irregular motion, such as is given by some special valve gears, and it should be drawn during the design of the valves and gear for every important engine. The motion of valves of an existing engine may he investigated by causing the engine to draw its own valve ellipse. By assuming various elements of the valve to be known, a series of problems relating to the plain valve may be stated and solved by some suitable graphical method described in the Author's paper on "Valves and Valve Diagrams" (session 1903-4).

It has been explained that to realize the benefit of expansive working by means of a single valve, lap is essential, and, in simple connection with an eccentric, the valves so made may be proportioned and set so as to yield any definite degree of expansive action.

To vary the degree of expansion is the province of the link and, though simple in construction, it is delicate in its motions. These are affected materially by apparently slight modifications of design and arrangement. So sensitive is the link, that all the difference between a very good and a very bad valve motion may arise from the mode of suspending it, and from the arrangement of the joint or points of attachment. It is therefore necessary that the leading varieties of link mechanism should be considered, as well as the main circumstances by which the motion derived from the link is affected.

The motion of the valve, when driven directly by an eccentric, is simply rectilineal and reciprocating, and is precisely on a smaller scale what the motion of the piston is on a larger. This is manifest in considering that the eccentric is but a crank of a very small radius (as mentioned), which has, like the greater crank, its own circle of revolution, its own throw, and its own dead points, which terminate the reciprocations of the valve in the one case and those of the piston in the other.

The motion of the valve must, of course, be considered in relation to that of the piston. The relation of these motions is founded upon the uniform circular motions of the crank and eccentric. These, being fixed on one axle, have the same angular motion, and accomplish their revolutions in the same time. Their relation, therefore, and those of the piston and valve derived from them, may be established by following them through a complete revolution.

The motion of the piston is ruled by two circumstances, the varying angularity of the crank and of the connecting rod, but mainly the former. With an indefinitely long connecting rod, simple harmonic motion is the result on the piston. The two halves of the stroke are described in equal times, and in these halves the variation of the velocity of the piston are exact counterparts. As the motion part of the valve is the counterpart of the longitudinal movement of the eccentric, the position of the valve is directly determined by the position of the centre of the eccentric—the obliquity of the connecting rod and eccentric rod being neglected. A complete revolution of the crank from a dead centre will carry the piston throughout its forward stroke and return it to the starting point. Whatever events take place in the front stroke should be repeated in the same order on the return stroke, and, while the piston is making one entire stroke, the valve must accomplish a half and a return half of its stroke.

Thus far the attention has been confined to a form of connection giving simple harmonic motion, which makes it possible to deduce laws governing the proportions of the various parts of the valve. But this connection seldom obtains in practice. It becomes necessary to modify the general proportions, to eliminate as far as possible all the irregularities the practical gears tend to create.

With the ordinary crank and piston connection by a connecting rod, the piston is drawn beyond its half stroke when the crank attains an angle of 90°, and it follows that this distance will vary with the different ratios that may exist between the length of the crank arm and the connecting rod. As a general comparison of the disturbing effect, the crank arm is taken as unit measure, and that of the connecting rod as a certain number of times the length of the crank arm. It becomes evident, therefore, that the effect of this form of connection is to carry the piston ahead of its proper positions throughout the forward stroke, and on the return stroke to make it lag behind the positions due to the locations of the crank pin.

As mentioned, the eccentric connection has a similar influence on the events of the valve motion, producing like irregularities. The movement of the valve from its true position is dependent on the ratio between the throw of the eccentric and the length of its rod.

Practically the slight difference in the equality of the various events does not become sufficient to affect the general action, for their ratio is usually too large and gives a variation too small to influence the general admission, &c.

A motion which should work the valves truly during both fore and back gear, appears to have been a frequent study for locomotive engineers.

After Corliss had established the superior economy of early cut off, and by his peculiar and efficient valve gear had produced nearly a sharp cut off at moderate speed, it became almost an axiom that a sharp cut off is essential for best economy. It has apparently been the object of engine builders, ever since, to produce an indicator diagram with a "Square cut off," which means a nearly horizontal steam line terminating abruptly where it joins the expansion line. The valve gear of a modern locomotive contends with conditions which are difficult to meet. It is designed to so move the valve it drives as to open the port by an amount which, at running cut off, usually does not exceed $\frac{3}{8}$ inch, and, at such speed, the entire interval during which any port is open is less than a twentieth of a second. If normal steam distribution is to be maintained the valve must move with great precision, since even a slight change in the extent of its travel or in the time of its action becomes relatively large when measured by the small port opening and the brief interval during which the port is open.

It is necessary that the gear which actuates such a valve must be free from lost motion, and that it be so stiff as to admit of no deformation of its parts. It is evident, in order that the steam distribution in the cylinder may be as efficient as possible for all speeds and all points of cut off, that the utmost care must be exercised in the designing of the valves and machinery by which they are driven, for in determining the efficiency of a locomotive as a whole the valve motion must be considered, and too much stress cannot be put upon the valve of a proper design for this element of the engine.

Up to within a few years the flat slide valve was in universal use. At first it was the common unbalanced D valve, which was followed, as the steam pressure was increased, by the balanced valve, while the current practice, where high pressures are used, lies between the flat balanced valve and the piston type. The piston valve was introduced for the purpose of securing a balanced valve, thus reducing friction. It has been designed in various forms, and much experimental work done with packing rings of different shapes, but it has been gradually developed and successfully applied, so that it has become a well established practice on the Great Western Railway.

The piston valve increases the amount of port opening for a given cut off, and possesses some advantages over the flat valve in that it is fully balanced, though certain modifications of the slide valve are practically satisfactorily designed in this respect. It is a matter of choice and convenience which shall be used, though the tendency of modern practice is toward an increasing use of the piston valve.

The flat slide valve is invariably arranged for an outside admission, but a piston valve allows the arrangement for an inside admission. The advantages are:—

The steam passages can thus be better protected from the cold and radiation, and the steam chest covers and packings relieved from all pressure except that of the exhaust steam.

The question of the lubrication of piston valves while drifting is one which is still in the experimental stage, but it is one to which proper attention must be given in order to make the use of such valves entirely satisfactory.

As for the mechanism by which the valve is moved, there are five different systems in use upon locomotives, which are named after their designers, Stephenson, Gooch, Allen, Walschaert and Joy.

Seeing that the Stephenson motion is the one generally used in this country it will be first considered. This gear, which is so familiar to all, contains at least ten joints between the axle and the valve spindle,

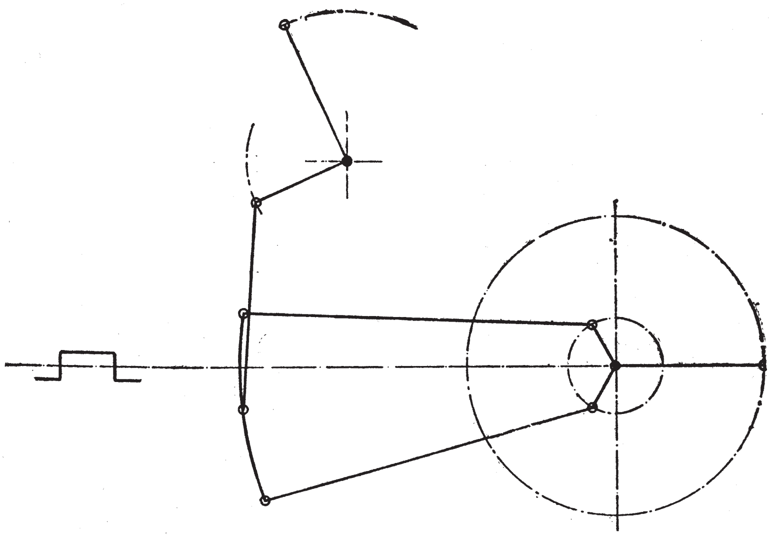

Fig. 2.—Stephenson Valve Gear—Variable Lead.

having motion when the gear is in action. Lost motion in any of these will modify the valve motion.

Modern workmanship has, however, made the joint of the link motion reasonably satisfactory. The principal constructional defect at present is in the link and its support, the link hanger. The fact of this being attached to one side of the link leads to the introduction of twisting strains, which affect the whole system. The remedy is to be found in a more general adoption of the marine type of link, with double hangers giving support to the link on both sides.

In the link motions in general use two eccentrics with open or crossed rods are employed, the position of these on the driving axle being such that one can give to the valve the motion required when the engine is moving forward, whilst the other furnishes the means of moving in the opposite direction.

The Stephenson gear is also recognised as the shifting link motion, as the link, with its attachments only, is moved to produce the required direction of motion.

Owing to the arrangement of outside and inside admission valves and the present day rocker to give a direct or indirect motion, there is need for a general definition for open and crossed eccentric rods. In the diagrams the position of the crank must be carefully noted.

Whenever both the eccentric centres lie between the link and a

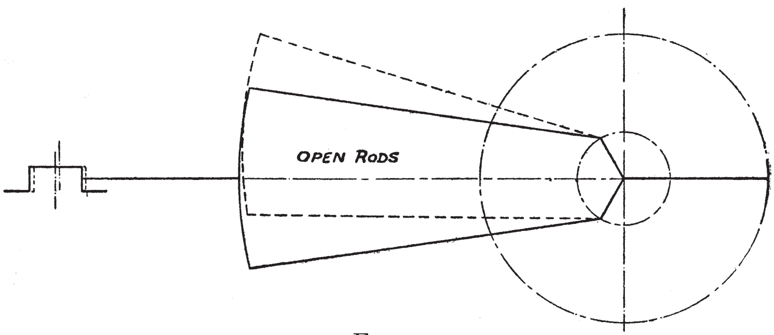

FIG. 3.
Showing decrease of lead from mid-gear to late cut off, with Stephenson Gear.

vertical line through the centre of the driving axle around which they rotate as in Fig. 3, if the rods are open and do not cross, the arrangement is termed "open rods."

Whenever a vertical line drawn through the centre of the axle about which the eccentrics rotate lies between the centre of both eccentrics and the link (as in Fig. 4), the arrangement is termed open rods when the rods cross, and crossed when the rods are open.

It is open rods when the forward eccentric is connected to the top of the link and backward eccentric connected to the bottom of the link.

For crossed rods the forward motion eccentric is connected to the bottom of the link and the back eccentric connected to the top of the link.

From a further investigation of Figs. 4 and 5 it will be seen that, if the rocker be removed from Fig. 5 and added to Fig. 4, the full lines of Fig. 5 is the arrangement for a direct acting engine with internal admission valves, and in Fig. 4 the arrangement for an indirect acting engine with internal admission valves.

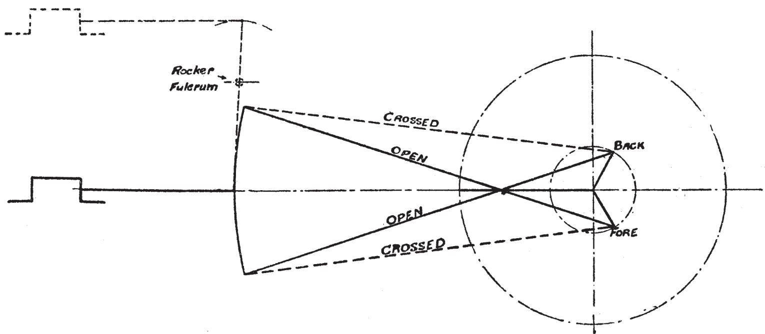

FIG. 4.

Open rods give an increasing lead from full toward mid gear (Fig. 3), while crossed rods give a decreasing lead from full toward mid gear (Fig. 7).

Crossed rods may be used to one advantage, for then the engine can be stopped by setting the link at mid gear, but they are very rarely adopted. In this connection it may be remarked that an engine con-

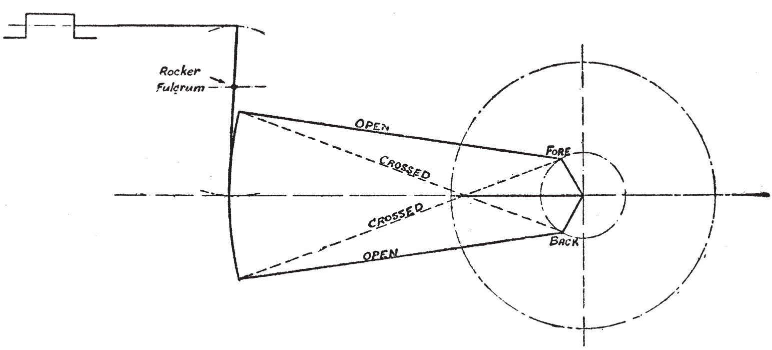

FIG. 5.

trolled with open rods will not necessarily stop when the link is placed in mid gear, provided the engine is running under no load or a very light load, though the engine will not start with the link in that position.

The action of the reciprocating parts of a high speed engine is of great importance. A considerable part of the work of the steam is expended in imparting motion to the reciprocating parts during the second half of the stroke, as the reciprocating parts come to rest. In order that they come to rest quietly at the end of the stroke, the piston should be cushioned by compression. Now a valve that gives a variable

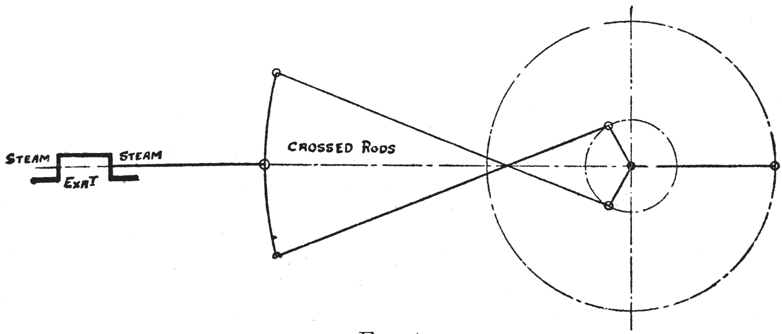

FIG. 6.

cut off and a variable compression is likely to have too little compression at full gear and too much at a short cut off. An engine with a large clearance will suffer less from this difficulty than one with a small clearance, consequently clearance is often made large, but a large clearance is not conducive to economy in the use of steam.

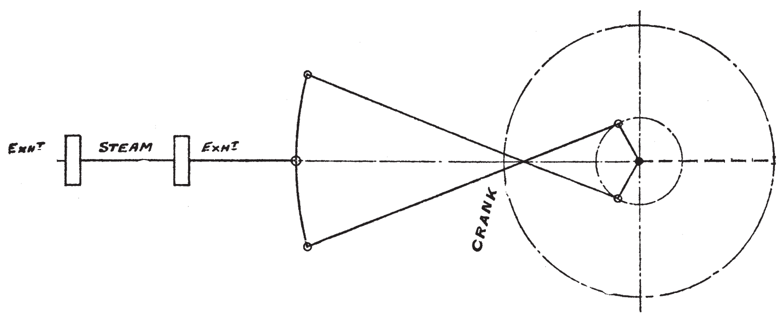

FIG. 7.—Crossed Rods.

Lead acts as does compression, to stop the reciprocating parts and to fill the clearance space with steam, so that in general the more compression an engine has the less lead it will need. The Stephenson gear does not give this effect, as the lead increases toward mid gear. Some forms of gear are so arranged in order that the decreasing lead toward mid gear may partially compensate for the increasing compression.

With equal laps the necessary and sufficient condition for equal leads, at all grades, is that the radius of the link arc shall be equal to the length of the eccentric rod.

The Stephenson arrangement has been practically the standard valve gear since the beginning of railroading, the chief reason being that it combines simplicity and reasonable efficiency. Its simplicity accounts for its general adoption in locomotive design, somewhat regardless of its deficiencies and irregularities of steam distribution for extreme economy.

Small port openings when running at high speeds with short cut offs, excessive wiredrawing of the steam during admission, restricted release and consequent high back pressure, and early exhaust with excessive compression, are inherent faults of this gear and slide valve gears generally.

The motion communicated to the valve by the Stephenson gear is one which, beginning from rest, recedes therefrom with a relatively slow motion to maximum and then gradually diminishes until the end of its travel, it comes to rest again. The gradual change in its rate of motion can well be seen from the valve ellipse, shown dotted in Fig. 8. The form of curve represents the motion of the valve and will serve as a comparison for a modification of existing gears designed to accelerate the valve motion when the piston is at the end of its stroke.

The purpose of other devices is to secure a quick and liberal opening of the port, to hold the valve nearly stationary during admission, and to close the port promptly at cut off. A number of different gears have from time to time been proposed and used. While the means employed vary greatly in different gears the form of valve ellipse will be much the same for all. In contrast with the figure shown, it will be a figure having the same total length and width, but with ends much flatter, indicating the higher velocities of the valve on either side of its points of reversal. This fact, due to rapid acceleration, suggests some of the difficulties to be met in designing and maintaining any of these accelerating devices. (Full line, Fig. 8—*see* p. 157.)

The point to be considered is the small amount of port openings at running cut offs. At the speed of, say, 20 m.p.h., cut off at 20 per cent., the events of the stroke are well marked, but, as the speed increases, the points representing the change of pressure are less clear. This is the effect of wire drawing, and is typical of the Stephenson link motion. With each increment of speed the duration of each stroke is shortened, and hence the amount of steam which can enter a given opening of port becomes less. With a given cut off the fraction of the whole time which the port is opened is independent of speed.

In an hours run there will be a certain definite number of minutes that each port will be open whatever may be the speed; hence the volume of steam passing a port in a given time is constant. With the total volume passing approaching a constant, it is seen that when the number of strokes increase, the amount admitted per stroke must diminish. Therefore, any valve actuated by a Stephenson link motion gives a wire drawing effect at the higher speeds, unless designed to give excessive port openings at slower speeds. This fact suggests the use of large steam laps whereby the essential requirements are more nearly approached, as it is evident, for a given cut off; the port opening is increased for the same time, also a relative increase in velocity at the points of admission, cut off, release and compression.

As a comparison the following figures have been calculated for 60 m.p.h.:

		$1\frac{1}{2}$in. lap.	2in. lap.
Velocity of valve at 25% cut off		3·25 ft. per sec.	4·38 ft. per sec.
Acceleration ,,	,,	49·39 ft. per sec. per sec.	66·316 ft. per sec. per sec.
Port opening valve	,,	·23″	·31″
Instant of opening to closing		·04 secs.	·04 secs.

Recent experiments tend to prove this theory, and it is probable a greater adoption of this principle will be applied in preference to accepting other types of gears.

Various other forms of valve gear have been devised to overcome the deficiencies of the link motion gear and to give a good steam distribution under all conditions. Most of these, while giving better steam distribution, perhaps, have been so complicated and the cost of maintenance has been so high that they have never had any practical application in service. It is not likely, however, that the link motion slide valve gear steam distribution can be excelled by any mechanism equally simple and, if improvement is desired, something more complicated will have to be accepted.

The essential condition that a link motion must fulfil if it is to be used as an expansion gear, is that the changing of the position of the motion block in the link should not seriously interfere with the lead.

It has been shown in the case of the Stephenson that the leads may be equalised for both cycles, yet, when the position of the link block is changed, the lead increases toward mid gear with open rods and decreases with crossed rods for outside admission valves when driven direct.

In the Gooch link motion the lead remains constant for all positions of the motion block in the link, but this is not secured without making the gear more complex, as will be seen from the centre line sketch, Fig. 9. The centre of the link is compelled to move in an arc of a

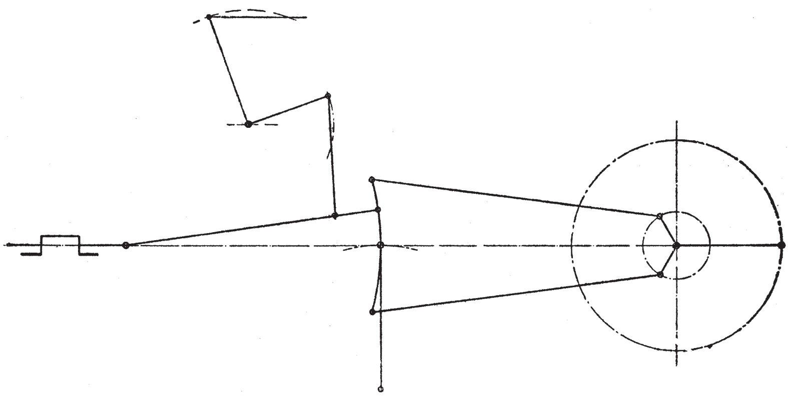

Fig. 9.—Gooch Valve Gear—Constant Lead.

circle by the supporting link, which vibrates about a fixed centre. The valve rod being jointed with the valve spindle is held by the suspending or lifting link, the point of suspension being at the reversing shaft arm.

The position of the block in the link is controlled by the turning of the reversing shaft about its fixed axis. In this gear the displacement of the radius rod joint attached to the valve spindle represents the displacement of the valve. The action of the Gooch link is equivalent to the Stephenson, and the rods may be open or crossed. The common and popular practice is to make the radius of the link arc equal to the length of the radius rod, and, when so made, the lead is constant for all grades of the link.

Although the Gooch gear was extensively used for locomotives in earlier days on account of its then peculiar possession of constant lead for all values of cut of, it has dropped out of use in the present day.

A comparison of the Stephenson and Gooch shows that the Gooch has more parts and more joints at which lost motion will result from wear and that it occupies nearly twice the longitudinal space required for a Stephenson. As an offset may be urged its properties of giving a constant lead.

At the time when link motions were first used, the curved surfaces of either the Stephenson or Gooch link could be properly finished only with considerable difficulty and expense. To obviate this difficulty a straight link was devised by Allen which had the general appearance of the Gooch link, but which had both the link and the radius rod movable in such a way as to give a proper motion to the valve. This gear is

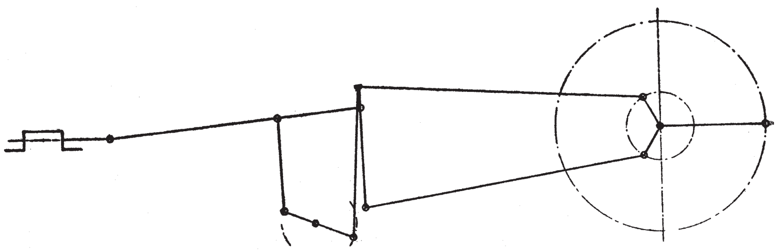

Fig. 10.—Allan Valve Gear—Slight Variable Lead.

intermediate between the Stephenson and Gooch link motions; for example, it had a variable lead, though its variation was less than with a Stephenson link having like proportions.

The gear is similar to the Stephenson in the respect that the link is raised or lowered when the position of the block is altered, and it is similar to the Gooch motion in the respect that the valve rod is raised or lowered for the same purpose. The combination of the mechanical peculiarities of both motions makes it possible to use a straight link. The advantage of this gear over the Stephenson is that much less room is required vertically to accommodate the link in the two extreme positions, since the vertical motion of the link is so much smaller. Also a smaller angular motion of the weigh bar shaft is required to change the link from one extreme position to the other, and no balance weights or springs are required on the reversing shaft.

With modern machine tools and shop methods there is no especial difficulty in finishing the curved surfaces of links; and the Allan link has consequently not been widely adopted. The loss of power incident to the irregularities of the ordinary slide valve would be difficult to calculate, would be more difficult to believe, and, if believed, would be still more difficult to amend.

From the beginning of locomotive valve gears countless devices have been proposed, affecting either the valve or the gear which gives its motion, whereby the indicator card made be made larger than that which results from the normal link driven plain valve. Taking into consideration the margin upon which those who would improve valve gears have to work, it must be admitted that it is not large.

From the results of a simple locomotive it may be compared to the

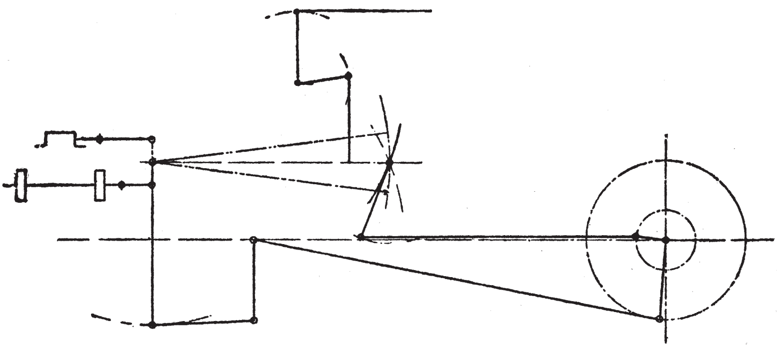

Fig. 11.

Walschaert Valve Gear, showing arrangement for Slide Valve, or Inside Admission Piston Valve.

Corliss engine, the action of which is generally accepted by all improvers of valve gears as a standard of perfection. It is difficult to give a fair comparison, as Corliss engines, having cylinders comparable in size with those of locomotives, and which work under a similar range of pressure, are not numerous. The best performance recorded of a simple Corliss engine exhausting into the atmosphere and applied theoretically to the locomotive conditions results approximately to 8 per cent. less on the consumption and 2 lbs. less of steam per h.p. per hour. While this saving is well worth attention it cannot revolutionise practice.

The introduction of the Walschaert valve gear and the apparent determination to give it a fair trial gives promise that perhaps a change for the better in the matter of valve gearing is approaching. This form of gear differs materially in mechanical construction from either of the ordinary types of link motion. It may be either inside or outside the frames of the engine. Its design makes a strong appeal to the designer who adopts outside cylinders, and is forced to go outside the frame with his valve motion. For this reason its use has been found more practicable in Continental Europe, and its satisfactory efficiency is being recognised by American engineers, where its use is likely to increase in preference to their recent standard Stephenson gears.

The Walschaert valve gearing combines two motions, as the motion of the valve is derived both from the crosshead and the eccentric crank from a driving axle.

The eccentric crank is equivalent to an eccentric, and is in the form of an eccentric when connected to the driving axle for inside cylinders, and its relation to the driving crank is nearly the same as in the ordinary valve gear. The relative adjustment is at 90° to each other, instead of being about 80° before and after the driving crank, as is usual with double eccentrics in ordinary slide valve gears. The eccentric crank in this 90° position imparts its fastest movement to the valve to give a very quick opening. In the construction of the Walschaert gear the desired maximum cut off and lead are selected. The stroke of the piston being given, the combination lever is proportioned so that a motion equal to twice the lap and lead is given to the valve when the crosshead is moved from one end of the stroke to the other. Also the angle of swing should not exceed 55° in order to diminish any bending effects or lifting effects on the valve spindle.

The guiding link from the crosshead to the combining lever should be at least three quarters the length of the stroke, to reduce any angularity effects and reproduce practically the actual motion of the crosshead to the combining lever. This transmits on a smaller scale the piston movement to the valve, which all valve motions try to accomplish with every exactitude; and the more nearly this is approached, the more efficient is the gear with regard to an equalisation to cut off points on front and back strokes. In consequence of this, the acceleration or retardation of the piston movement is immediately accompanied by like effect in that of the valve, thereby diminishing the irregularities incident to the angular advance of eccentric rods in the ordinary valve motion.

The direct and accurate transmission of the crosshead motion to the valve, and its consequent continued exact relation to the piston, is its most important advantage. For outside admission valves, the radius rod is attached to the combining lever between the valve spindle and crosshead connection, and for inside admission (piston valves) it is attached above the valve spindle (Fig. 11).

The radial link is actuated by only one eccentric or its equivalent, and, not being influenced by a double system of eccentrics, does not oscillate through so large a space as the ordinary link, consequently decreasing the spring in the motion when at or near the end of the stroke. Here again the angle of swing should not exceed 55°, as beyond this number would produce increased slip of the block, especially toward full gear. No slip would result if the block were kept at a constant distance from the link centre for each given cut off, consequently this gives certain positions for a given point along the radius rod. The nearer the loci of the lifting link is made to coincide with this point less slip will be the result.

The use of the Walschaert valve motion on heavy goods engines, and also on the most recent type compound locomotives, has brought the merit of the gear to the attention of all English designers. The engines represent extreme conditions as to the speeds for which they are intended. This indicates that the gear is well adapted to any kind of service. The chief difference between the Walschaert and Stephen. son motions is the constant lead with the former when the valve travel is changed. This is due to the fact that, at the end of the stroke, the crosshead alone determines the position of the valve, and, as the crosshead always has the same position at the end of the stroke, the valve will also have a definite location, and the travel may be decreased, but the lead remains constant.

For high speed locomotives of the ordinary simple two-cylinder types the constant lead may not be regarded as desirable, as early cut-offs are then used; and it is necessary to have greater pre-admission when the cut off is so short, in order to permit the steam to enter the cylinder without excessive wiredrawing.

To take advantage of the constant lead under these conditions, the wiredrawing may be reduced to a minimum by varying the, valve proportions or by increasing the steam lap, to give a larger port opening for the same time, and consequently a greater velocity of the valve at the point of cut off. This allows the unavoidable high compression to retard the reciprocating effect without an additional check by pre-admission.

With the four-cylinder balanced compound the cut off is not so short, consequently this is more favourable for the adaption of the Walschaert gear.

As far as the distribution of steam is concerned, it will produce results better than the shifting link.

The weight of the gear is also about 20 per cent. less than with a Stephenson arrangement fitted to the same engine.

Joy's gear.—This is a radial gear which has been extensively applied to locomotives and gives very good results, considering it theoretically.

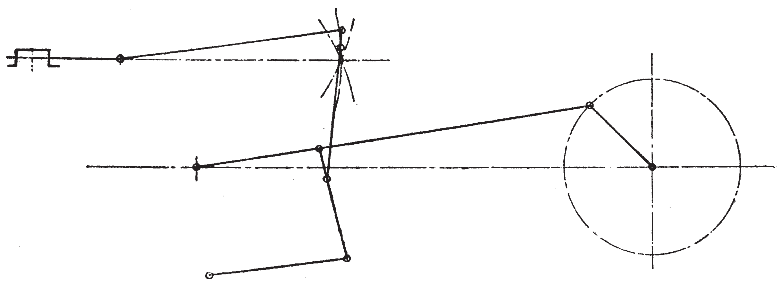

Fig. 12.—Joy Valve Gear—Constant Lead.

Motion is derived indirectly from a point in the connecting rod through the interposition of the stirrup links and radial rod.

In one-half revolution of the crank from a dead centre, the end of the floating lever which is attached to the valve spindle travels through a distance equal to twice the lap and lead, in addition to which, owing to the vertical movement of the connecting rod, it moves up and down a curved slide, whose varying inclination determines the cut off position, besides effecting the reversal of the engine. Moving the curved slide does not affect the component of the motion of the lever proportioned to give twice lap and lead, consequently the lead is constant.

The rise and fall of the axle relatively to the engine frame affects the distribution with this gear, especially one of the tank engine class, because the variation in weight of the engine, due to the gradual consumption of the fuel and water, allows the frame to rise slightly on the springs, carrying with it the axis of the slide without any corresponding movement of the crank axle. Inevitable wear at the joints and especially in the curved guides is more readily perceptible on the port openings than in the case of link motions.

The forms of valve gear that have been considered are not the only ones that have been applied to locomotives; but the use of other forms is so exceptional as to render it unnecessary to discuss them in detail in a paper of this limit. More theoretically perfect gears are no doubt preferable in other kinds of engines, but for locomotives, simplicity, freedom for reversing, and freedom from liability to derangement are the primary requisites, and these conditions the gears mentioned very well fulfil, especially the shifting link motion. Real and lasting improvement is to be looked for along more mechanical lines than in attempts to improve the character of the motion imparted to the valve. The real economy which may result from the adoption of a better gear is to be found in its lower maintenance cost and in the greater certainty of its action, rather than in pounds of coal saved. What is most desired in a valve gear is a mechanism which, under the adverse conditions of actual locomotive service, will give to the valve that precision of movement it is designed to have.

Along these lines there is ample opportunity to improve the present practice. Imperfect steam distribution is not only a large factor in causing wear of the gear itself, but causes wear and tear to many other parts of the locomotive. Therefore efforts of designers of substitutes should be directed toward the attainment of the dual object of improved steam distribution and decreased maintenance. Only under these conditions would a more complicated mechanism find favour.

DISCUSSION.

Mr. Burrows, referring to the author's remarks, said that the great superiority of the piston over the slide valve lay in the fact that a far greater area of steam port opening for the same travel and point of cut off could be obtained. An increased opening for early cut offs is an advantage which adds considerably to the efficiency of the locomotive.

Mr. Nash then asked for a general definition of open or crossed rods, as the piston valve with inside admission would necessitate a different arrangement of eccentric rods than a slide valve with outside admission.

In reply to this question the author re-read his remarks on open and crossed rods, mentioning the definition, that open rods gave an increasing lead from full gear towards mid-gear, or no lead at 75 per cent. cut-off would be $\frac{1}{4}''$ lead at 25 per cent. cut-off. Crossed rods gave a decreasing lead toward mid-gear, or $\frac{1}{4}''$ lead at 75 per cent. cut-off would be nil at 25 per cent. cut-off.

Mr. W. H. Stock said the author had shown that higher efficiency was obtained by increasing the steam lap, but would it be so practicable to increase this with the Walschaert type of gear?

In reply it was mentioned by the author that within certain limits, probably the Stephenson Gear allowed of a longer steam lap, and thus a greater valve travel than the Walschaert, because with the latter a long travel necessitated an increase in the angle of swing of the combining lever and quadrant link, causing excessive angularity. On the other hand, owing to a quicker opening and closing of the port, due to the increased acceleration at the right time, a small steam lap with the Walschaert would give a comparative result with a rather larger lap for the Stephenson.

Mr. Champeney said it appeared that the Walschaert gear was generally applied to 4 or 6-coupled engines. Was it not suitable for single drivers?

In reply, the Author mentioned that this gear as ordinarily applied required for the radius and eccentric rods a reasonable horizontal length, and should this be short, as might be the case with single drivers, it necessitated another arrangement to oscillate the link, which has been worked from the back instead of from the bottom.

Mr. Watkins asked if the author could give any information with reference to the Marshall gear or Corliss gear, as applied to locomotives.

The author replied that he had been seeking information with regard to the published efficiency when the Marshall gear was introduced, but could not give any detailed account, only mentioning that two eccentrics were necessary for its working, and that a constant lead was one of its claims. The principle of the Corliss gear had been modified and applied to locomotives on the Continent and America, and gives a good distribution at the expense of extra complication, and probable increased repair expenses.