The rim in very large wheels is generally fastened to the arms, as shown in fig. 84. The arms are fastened to the

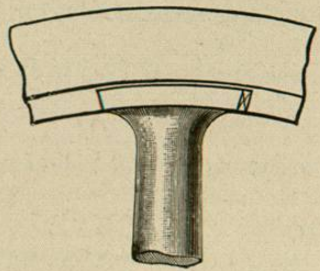

Fig. 84.

boss in a similar manner, and the latter, in the case of large wheels, is often cast in two halves, which are either bolted together or attached by wrought-iron rings shrunk on.

CHAPTER VII.

VALVES AND VALVE GEARS.

Action of the simplest form of D slide valve driven by single eccentric—Definitions of 'lap' and 'lead'—Position of eccentric as affected by the lap and lead of the valve—Effect on the steam distribution of the lap and lead of the valve—Effect of ratio of length of connecting rod to length of crank in modifying steam distribution—Means of varying the rate of expansion and of reversing—Stephenson's link motion—Effect of diminishing the throw of the eccentric—Reversing lever—Ramsbottom's reversing screw—Variations in the details of Stephenson's link motion—Other systems of link motion—Other means of varying the rate of expansion — Meyer's separate expansion valve —Corliss's valve gear — Varieties of valves—Valve gears in which eccentrics are dispensed with—Joy's gear—Geometrical representations of the action of slide valves—Zeuner's valve diagrams—Case of valve without lap or lead—Case of valve with lap and lead—Problems on simple valve setting—Zeuner's diagrams applied to valves driven by link motions—Analytical method of fixing centres of valve circles—Graphical method—Problems in link motion—The method of suspending link motions—Zeuner's diagrams applied to Meyer's valve gear—Reversing by Meyer's gear—Problems on valve setting with Meyer's gear.

THE successful and economical working of a steam engine depends in a very large degree upon the design and adjustment of the valve or valves which regulate the distribution of the steam in the cylinders. The subject is, perhaps, more complicated in its nature than any other question affecting the design of the engine. In order to treat it simply and, at the same time, systematically, it is intended in this chapter, first to explain the simplest examples, and then to proceed to the description of the cases which more frequently occur in practice.

Action of the simplest form of slide valve driven by a single eccentric.—As the motion of a slide valve is modified by the length of the connecting and eccentric rods relatively to the length of the crank arm and to the throw of the eccentric respectively, we will suppose, in the first case, that these rods are infinite in length. Fig. 85 represents a portion of a cylinder with steam chest, slide valve, and passages, in which the above condition as to length of rods is supposed to obtain. The slide valve D is exactly the length contained between the outer edges of the steam ports. This point is important to notice, as will appear presently. Also the faces *d d'* of the valve are just sufficient to cover the width of the steam ports and no more.

The general arrangement of the slide valve, steam chests, steam and exhaust passages, in relation to the piston and

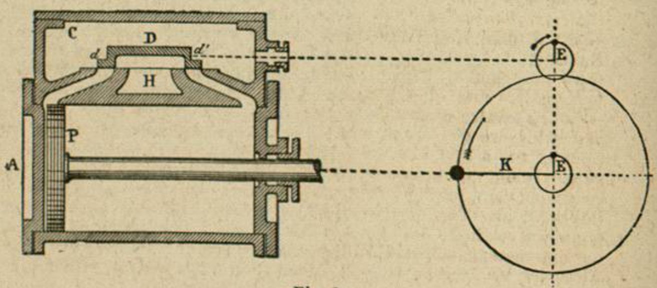

Fig. 85.

cylinder having been already explained (see page 202), the reader will have no difficulty in understanding what follows. In practice the eccentric is always mounted on the crank shaft, and revolves in a plane parallel with that containing the crank arm, while the slide valve works on the side of the cylinder. In figs. 85 to 93 the valve is shown on the top of the cylinder, and the eccentric E revolves in the same plane as the crank K, and above the latter, as in this way alone can the relative motions of valve, piston, crank, and eccentric be shown simultaneously. The arrangement of the eccentric and crank circles is not one that could be carried out in an actual steam engine.

The piston P is represented at one end of the cylinder,

and the valve is shown in its middle position exactly covering the two steam passages, so that no steam can pass from the steam chest C to either side of the piston ; while, on the other hand, none can escape from the cylinder through either of the passages into the exhaust. As the piston is at the end of its stroke the crank is on the dead centre, and as the valve is at mid stroke the arm of the eccentric must also be in the position midway between the two dead centres ; that is to say, it is at right angles to the crank. Let the piston, however, be moved in the slightest degree to the right-hand side, turning the crank K and the eccentric radius E in the direction of the arrows, and two things will in-

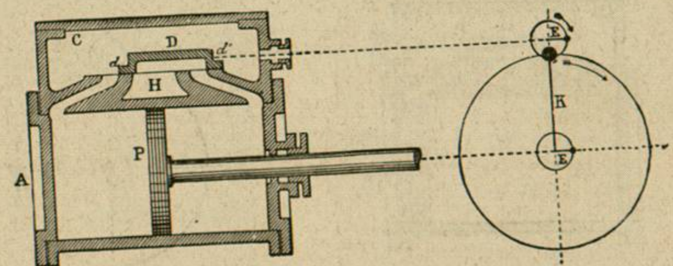

Fig. 86.

stantly happen. The eccentric, whose action has been already explained (see page 229), will pull the valve D slightly to the right, so that the outside edge of the face *d* will open the left-hand steam port, and thus admit steam to the left side of the piston, while the inner edge of the face *d'* will uncover the right-hand steam port, and thus permit whatever steam may be in the cylinder on the right side of the piston to escape along the passage to the under or hollow side of the valve, whence it finds its way to the exhaust passage H. The result will be that the entering steam will propel the piston forward, and the crank and eccentric will continue to rotate in the direction of the arrows.

When the crank reaches the position shown in fig. 86, which is at right angles to its first position, the piston will be at half-stroke, and the eccentric radius will also be at right angles to its first position. From an inspection of the diagram it is evident that the eccentric has now pulled the slide valve as far to the right as it will go, and that, as the crank continues to revolve, the eccentric will commence to travel back from right to left. Also it is evident that the total space through which the eccentric has moved the valve from its original or central position is exactly equal to the half-diameter of the circle described by the eccentric radius. As will be seen from the figure, the left-hand steam port is now fully open to the entering steam, while the other is fully open to the exhaust.

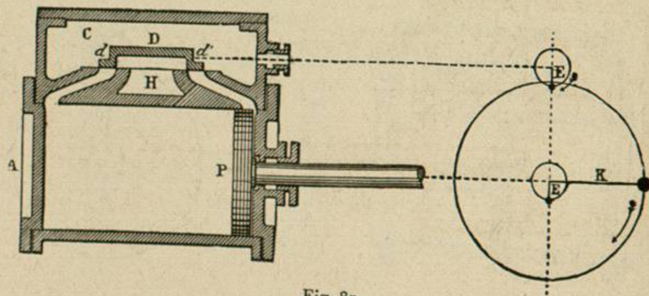

Fig. 87.

At the end of another quarter-revolution the piston will have reached the end of its stroke. The crank and eccentric will occupy the positions shown in fig. 87, while the valve has now regained its central position, closing both ports. The slightest motion to the left will now admit the steam to the right side of the piston, and cause it to commence to move backwards from right to left, and will at the same time open the left-hand port to the exhaust. At the end of the next quarter-revolution the crank and eccentric will occupy the positions shown in fig. 88; the right-hand port is now fully open to the entering steam, while the other is fully open to the exhaust, and the valve has reached the farthest limit of its travel to the left. From the above we see that

the total distance moved by the valve, called *the travel of the valve, is exactly equal to the diameter of the circle described by the radius of the eccentric.*

The next quarter-revolution will bring everything to the positions occupied at starting, and the whole series of operations may be repeated over and over again so long as the steam supply lasts. We thus see that by means of a slide valve and a single eccentric, the operations of opening and closing the steam and exhaust inlets can be satisfactorily accomplished.

It will be noted, however, that the valve just described, which only just covers the steam ports when in its central

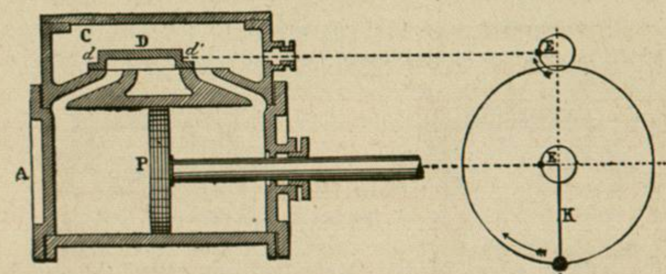

Fig. 88.

position, when driven by an eccentric set at right angles to the crank, keeps the admission steam port open during the whole length of the stroke, and thus does not permit of the expansive working of the steam. Similarly it keeps the exhaust open during the whole length of the stroke, thus rendering compression or cushioning of the exhaust steam impossible. Moreover, it only opens the admission and exhaust ports just *after* the stroke has commenced. In practice these features are inadmissible. In order to effect economy in working the supply of steam must be cut off comparatively early, and expanded during the remainder of the stroke. Similarly the exhaust should be closed before the end of the stroke, so that the steam left in may be compressed before the advancing piston, and aid in bringing the reciprocating parts to rest. Moreover, the steam must be admitted just before, instead of just after, the commencement of the stroke.

These objects may all be accomplished, within certain limits, by adding to the length of the slide valve so that it overlaps the outer edges of the steam ports, by diminishing the width of the hollow portion D so that the faces of the valve overlap the inner edges of the ports, and lastly by altering the position of the eccentric on the shaft relatively to the crank.

Before investigating this question the following definitions must be stated.

Outside lap.—Any portion added to the length of a valve more than is absolutely necessary in order to cover

Fig. 89.

the outside edges of the steam ports, is called the outside lap of the valve. In fig. 89 the portions *c c* are the outside lap.

Inside lap.—Any portion added to the hollow portion D of the valve more than is necessary in order to cover the inner edges of the steam ports, is called the inside lap of the valve. In fig. 89 the portions *i i* are the inside lap.

Lead.—The amount by which the admission steam port is open when the piston is at the commencement of the stroke is called the lead of the valve. Thus in fig. 89 the space *b* is the lead.

Action of a slide valve provided with lap and set with lead.—Referring back to fig. 85, it is obvious that if the valve were provided with outside lap, and had a certain lead, it would have to be moved out of its central position by an amount

equal to the lap and the lead together when the piston was at the commencement of its stroke Consequently the position of the radius of the eccentric can no longer be central, that is to say, at right angles to that of the crank, but must be inclined forward at such an angle, DCE, fig. 90, that the space CL intercepted between the perpendicular EL and the centre C shall be equal to the lap and lead added together. It is also obvious that the travel of the valve will have to be increased, for it has to move sufficiently to uncover fully the steam port, and in order to do so it must travel over a space equal to the width of the port *plus* the lap. The result of altering the position of the eccentric is that all the operations effected by the valve will be completed earlier than in the previous examples. Consequently, not only will the admission steam port be partly open at the commencement of the stroke, but it will also be entirely closed to the steam before the end of the stroke, and the steam will consequently expand during the interval. Similarly the exhaust will be closed before the end of the stroke, and the exhaust steam remaining in the cylinder will undergo compression. This is shown in the following four diagrams, which show the points of the stroke at which the steam and exhaust ports are opened and closed.

The relative positions of valve and piston during the stroke will of course be very materially modified if we take into account the ratios of the lengths of the connecting and eccentric rods to the length of the crank and the throw of the eccentric respectively. As a rule the length of the connecting rod is from three to six times the length of the crank, according to the class of engine employed. The travel of the valve, and consequently the throw of the eccentric, is, however, always kept as small as possible, so as to diminish to the utmost the waste work expended in overcoming the friction of the valve on its seating; hence the ratio of the length of the rod to the throw of the eccentric is usually from $\frac{15}{1}$ to $\frac{30}{1}$; and it will be easily seen

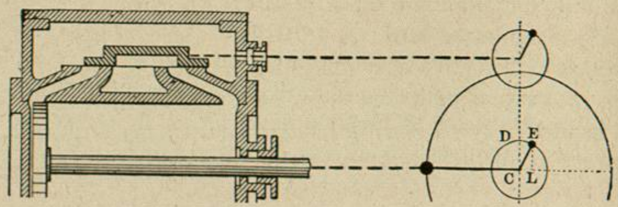

Fig. 90.—Left-hand port just opened to steam by the amount of lead.

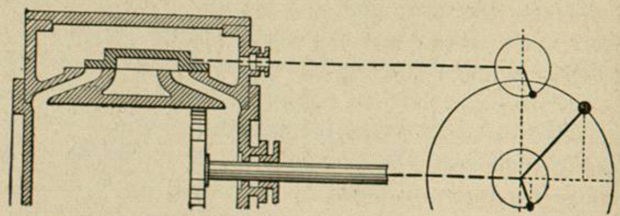

Fig. 91.—Left-hand port just closed to steam; expansion commencing.

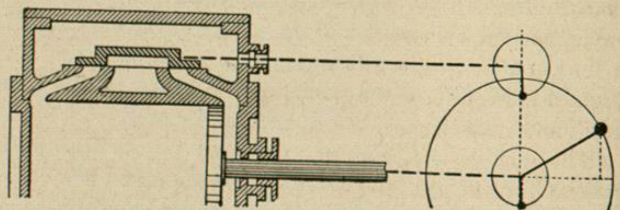

Fig. 92.—Right-hand port just closed to exhaust; compression commencing.

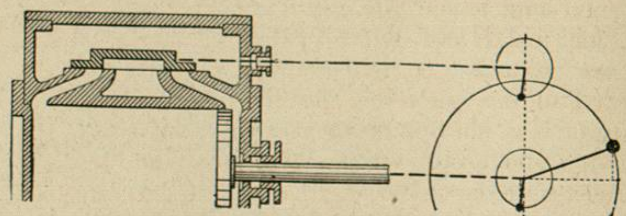

Fig. 93.—Left-hand port just about to open to exhaust: piston not yet at end of stroke.

that the position of the valve is much less affected by the obliquity of the eccentric rod than is the piston by that of the connecting rod; also the effect on the position of the valve is most apparent at those points in its travel which cause the least possible disturbance to the steam distribution. The effect of the obliquity of the connecting rod upon the position of the piston has already been explained (see page 183). The general effect of a connecting rod of finite length is that it causes the piston in its advance towards the crank to be always in advance of the position which it would occupy were the rod of infinite length; and *vice versâ*, in the return stroke the piston lags behind. Hence, as the movements of the valve are practically the same, but those of the piston quite different relatively to the positions of the crank, so also will the steam distribution be different in the two strokes.

Means of reversing the engine and of varying the rate of expansion.—The arrangement above described of a single eccentric driving a properly proportioned slide valve will answer very well for engines which have always to work in one direction at a uniform rate of expansion. In many engines, however, the rate of expansion has to be constantly varied, and in some types, such as locomotives, marine, winding, and rolling-mill engines, the direction of working has to be constantly changed. In order to provide for these requirements other arrangements have to be adopted. Referring to fig. 86 it will be readily understood, that if there were a second eccentric keyed on the shaft exactly opposite to the original one, and if the valve were by any means connected with this second, and disengaged from the first eccentric, the valve would be moved to the opposite end of its travel, and the steam port, which in the figure is shown as open to the exhaust, would be opened to the fresh steam, and *vice versâ*; the result of which would be that the engine would commence running in the reverse direction.

A convenient arrangement for effecting this reversal and for regulating the distribution of the steam is the link motion invented by Stephenson, which is illustrated in fig. 94.

The centre of the crank shaft is at C, and the centres of the two eccentrics at *o o'*. It will be noticed that the two latter are not exactly opposite to each other, as they would be if the valve had no lead, but are brought nearer to each other by twice the amount of the angular advance. The ends of the two eccentrics are connected to a slotted link, L, at the two points P P'. The link is curved, the radius of curvature being the length of the eccentric rod, and is suspended from the point P by means of a system of levers

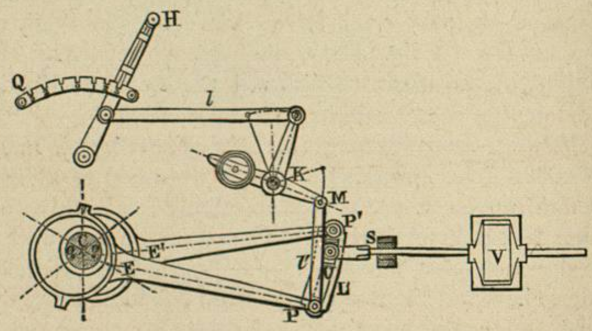

Fig. 94.

and link work clearly shown in fig. 94. In the slotted portion of the link is a block, U, which fits the slot exactly; and when the link is raised or lowered in position by means of the hand lever H, acting through the bell-crank lever K, and the two rods *l l'*, the block U slides in the slot, and is capable of taking up an intermediate position between P' and P, as is shown in the two diagrams, fig. 95, which represent the link raised to such positions that the block occupies first the centre of the link, and then a point opposite the end of the lower eccentric.

The block U, fig. 94, is connected directly to the spindle S, which drives the valve V. Now when the block occupies

the position nearest to P' it is almost wholly under the influence of the eccentric E', and the engine will run in one direction. Let, however, the link be raised so that U comes into the position nearest P, the block is then under the influence of the eccentric E, and the position of the valve will be so shifted that the engine will run in the reverse direction.

When U occupies a position intermediate between P' and P it is under the control of both eccentrics, but most under

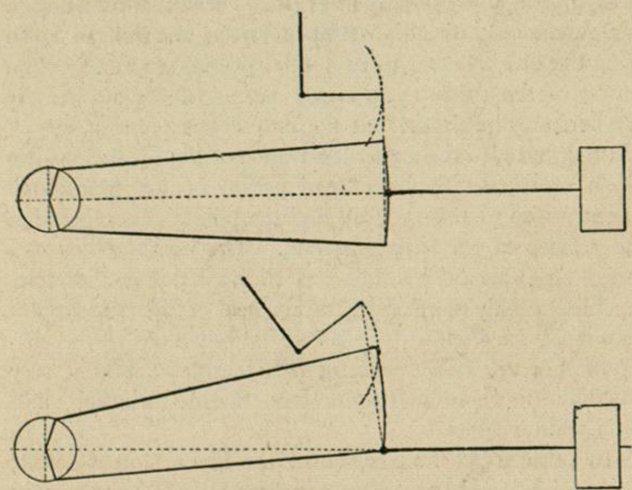

Fig. 95.

the control of the one to which it is nearest. When it occupies the exact centre of the link it is equally under the influence of both, and the consequence will be that the engine will not run in either direction. When, however, it occupies intermediate positions the effect is very curious and most important. The block, being actuated by two eccentrics working to a great extent against each other, will not travel the full horizontal distance due to the throw of either eccentric, but a distance which gets gradually less as the block approaches the central point of the link. The effect on the valve is the same as if it were driven by a new eccentric of lesser throw than the original one. Now if we refer back to figs. 90 to 93, and keep everything, with the exception of the throw of the eccentric, the same as in these figures, it can easily be proved, by drawing the positions of the valve corresponding to the positions of the crank, that the distribution of the steam is entirely altered, the cut-off being effected at a much earlier period of the stroke, and the rate of expansion consequently increased. It will thus be seen in a general way, that the result of raising the link so as to bring the block nearer to its central position is to effect the cut-off of the steam at an earlier period of the stroke. It will hereafter be shown that not only is the point of cut-off affected, but also the angle of advance of the ideal eccentric which represents the combined action of the two actual eccentrics, as well as the lead and the points of compression and release of the exhaust steam. The combination of a pair of eccentrics with a link and sliding block is, therefore, capable not only of effecting the reversal of the direction of running of an engine, but also of entirely altering the distribution of the steam, and for this reason we find it very generally employed in locomotives, marine, winding, and rolling-mill engines.

In order to fix the position of the block U in the slide, the hand lever H, fig. 94, is provided with a catch and a notched quadrant Q. Each notch corresponds with a separate rate of expansion in forward or back running. The central notch is the position of no motion of the engine. By dropping the catch on the hand lever into any given notch the link is kept in its new position relatively to the block. Thus a quadrant with three notches on either side of the centre is capable of running an engine at as many different rates of expansion. In order to provide for any possible rate of expansion the arrangement shown in fig. 96 was invented by Mr. Ramsbottom. In this plan a

screwed spindle works the lever, which also makes it easier to reverse the engine when running.

The above is a general description of the action of a particular sort of link motion. The actual motion of the link

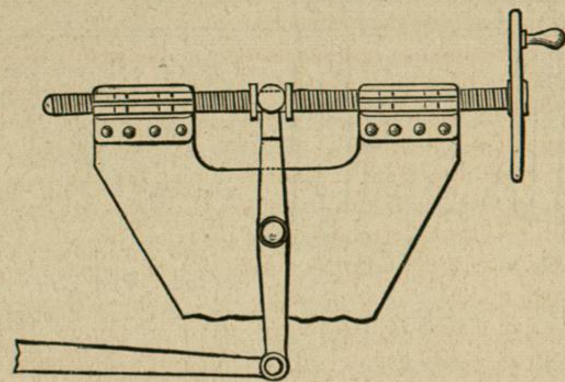

Fig. 96.

under the influence of two eccentrics is extremely difficult to follow accurately, and is further complicated by the method of suspension. So complicated, indeed, is the motion, that the travel of the slide valve can only be approximately expressed by mathematical calculation or by geometrical construction. The approximate geometrical method of determining the motion of a slide valve driven by link motion will be given hereafter.

There are many different types of link motion in use, and even considerable variations in the details of Stephenson's motion. For instance, in some cases the shape of the link is that shown by figs. 94 and 97A, in which the points of *p' p* are respectively above and below the extreme positions of the block U, the result of which arrangement is that the valve is never exclusively under the control of either eccentric, and never receives its full motion. Consequently with this arrangement the throw of the eccentric requires to be greater than the full travel of the valve. Fig. 97 represents a link