this proceed as in paragraphs (6) and (7) until the successive values nearly coincide.

(9) Should the final value of e differ greatly from that assumed from paragraph (3), a redetermination of the ratio of the constant charges to the total cost of steam and transmission of power (see paragraph 5) may be necessary, and another series of approximations to the value of e will also become necessary.

In closing, the writer wishes to say that he does not feel that this topic is by any means exhausted, and that he trusts that some one will endeavor to give the correct solution of the problem a simpler form.

Philadelphia, Feb. 3, 1882.

CONTRIBUTION TO THE HISTORY OF THE LINK MOTION.

By JOHN L. WHETSTONE, Esq., Cincinnati, Ohio.

To the Committee of Publication of the Franklin Institute.

GENTLEMEN:—In view of the recent proposed changes in the system of link motion for steam engines it seems very desirable that the work already done in the same direction should be recorded. I therefore wrote to my friend Mr. Whetstone for his recollection of a system originated by him, whereby he obtained with one eccentric a reversing link, and employed the motion of the cross-head to give the lap and lead. Also for his method of plotting the ordinary link motion. The paper now submitted has been sent to me for such use as I may desire to make of it. During the time that he was engaged on the work he describes I had full knowledge of his methods, as I was with him in the same establishment, being foreman of the locomotive shop in which he had charge of the drawing room. Mr. Whetstone was one of the most brilliant of the mechanical engineers who at that time turned their attention to the locomotive, but the necessity arising for him to take charge of important interests not involving so directly an attention to this branch of mechanical engineering, his attention has in some measure been directed from it. Submitting his paper with this note as explanatory, I am,

Yours truly, COLEMAN SELLERS.

In the years 1851-2 the writer assisted in the designing and constructing some locomotive engines for a special purpose, and the arrangement of the valve gear was especially assigned to him. From the peculiarity of the general arrangement of the machinery it was found impracticable to use more than one eccentric for operating the valves of each engine, and it was necessary to use a valve with considerable lap. There being barely room for one eccentric for each engine on the driving axle, the device of shifting a lead eccentric across the axle for the purpose of obtaining lead for the forward and backward movements could not be applied. The valve gear which was finally adopted was substantially the same as represented in Fig. 7, with slight modifications. The eccentric was set so as to be at half throw when the crank pin was at the ends of the stroke or at the dead point, and connected by a rod to an arm on the rocker shaft having at its other end a double arm, carrying a link bar for the purpose of giving reversing movements to the valve. The position of the rocker arm and link bar was therefore the same when the crank was at either end of the stroke, viz., that shown in the Fig. 7, at *A B C*. For the purpose of giving the advanced movement requisite for the lap and lead of the valve, the shifting or reversing rod (one end of which is properly swiveled to the link bar) is connected to the fulcrum *F* of a lever, the longer arm of which is suitably attached to the cross-head of the engine, the shorter arm being geared to the valve rod at *G*, or to any suitable device necessary to transmit the movement to the valve. The length of the arms of this lead-lever are such that when the fulcrum *F* is at the half throw of the eccentric the upper wrist of the lever *G* is removed from the centre line *H K* to the extent of the lap and lead of the valve, the longer end connected with the crosshead then at one end of the stroke, and if the cross-head be at the other end of the stroke, the upper wrist will be as far removed to the opposite side of the centre line.

It will also be observed that the position of the wrist operating the valve rod will remain the same, in whatever part of the link bar the reversing bar or rod *D F* may be situated, whether in full gear forward or backward, or at any intermediate point, and the lead of the valve will be the same at both ends of the stroke. The throw of the eccentric for this valve gear will be shorter than the travel of the valve, inasmuch as part of the valve movement is obtained from the crosshead. In practice it is found that about two-thirds of the lead of the valve is obtained from the crosshead, and the eccentricity of the eccentric is lessened to that extent. At first sight it would seem as though the whole was due to the cross-head, but it must be borne in mind that during the last half of each stroke of the piston the eccentric motiou is in a direction opposite to that of the crosshead, thus combining the two movements to extend the travel of the valve. The effect of this combination is to accelerate the movement of the valve at the opening of the ports, and to retard it at and towards the end of the throw of the valve, thus giving a longer admission of steam with a given lap of valve then by the eccentric motion alone. It would be quite practicable to operate the rocker arm link of one engine from the crosshead of the opposite engine, the lead being obtained from its own crosshead, and probably the greatest objection to such an arrangement would arise from the fact that the disability of one engine through an accident would render the valve movement of the other engine inoperative.

In 1853-4 the link motion, as it is termed (combining the movement of the forward and backward eccentrics), began to be generally adopted on locomotives, in place of the hooked or forked eccentric rods previously employed for reversing movements of the engine, in connection with separate eccentrics and valves arranged for the purpose of cutting off the steam at different parts of the stroke. The almost universal employment of the link motion at the present time in engines of every description, which are required to run at high rates of speed, affords evidence of its acknowledged superiority over other forms of valve gear.

At the time of their first introduction, the great difficulty of adjustment of the working parts so as to produce equality of cut-off or suppression of the steam on both strokes of the piston at all desired positions of the link gear operated as a serious objection to their use. The writer being then engaged in designing and constructing locomotives in a large establishment determined, if possible, to devise a system of arrangement of the various parts of a link gear which should secure the above results. The difficulty of this problem is enhanced by reason of the variety of elements modifying the movements of the valve, and which must be taken into the account in its solution—as for instance the proportionate lengths of the main connecting rod and crank, the lap and lead as compared with the travel of the valve, length of rocker arm, radius of link, all of which to some extent require modifications of the link gear. Adopting as a motto the aphorism of Lord Bacon that Nature can only be conquered or rendered subservient to our purposes by implicit obedience or compliance with her laws, the writer determined to find the several positions of the link requisite to produce suppression or cut-off at the principal points in the stroke of the piston, in forward and back gear, and then endeavor to arrange the reversing gear, so as to maintain the link in the position so ascertained. For this purpose the positions of all the main lines and centres of the several parts of the engine involved were accurately laid down of full size on a drafting table, viz., the centre line from cylinder to driving axle, showing centre of crosshead wrist at each end of the stroke, and at half stroke, and three-quarters and seven-eighths stroke each way; they are described by the centre of wrist on rocker arm to be operated by the link on which are marked the lap and lead for the valve, as previously determined upon; the centre line from driving axle bisecting the arc described by the rocker arm in its travel. In the accompanying illustrations, this last named line is coincident with the centre line from cylinder to driving axle. The circles

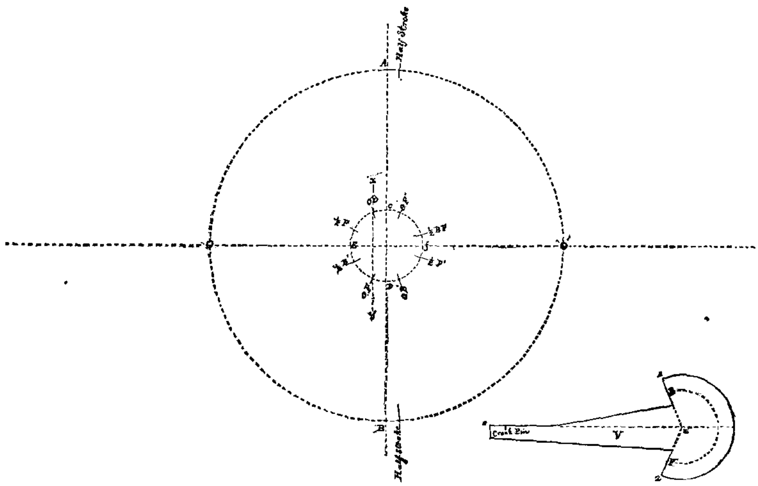

Fig. 1.

O A O′ B, Figs. 1, 2, represents the circuits described by the crank wrist, and *D E c f* the circuit described by the centre of the two eccentrics. The positions of the crank pin at the different parts of the stroke are obtained by using a tram or beam compass set to the length of the distance between the centres of the driving axle and that of the crosshead wrist at half stroke shown at ½ on line *G H*, Fig. 3 (thus representing the length of the main connecting rod), one leg of tram being placed at the desired point in the stroke, with the other leg arcs are described intersecting the crank circle *O A O′ B* at points marked half stroke, Fig. 1, and $\frac{7}{8}F$, $\frac{7}{8}B$, $\frac{7}{8}F'$, $\frac{7}{8}B'$, Fig. 2, the position of the forward and back eccentric are determined by drawing a line, *A B;* Fig. 1, through the centre of the driving axle at right angles to the centre line extending to the rocker arm to be operated by the link, and another line, *X Y,* parallel to *A B,* and distant from it equal to the amount of lap and lead to be given to the valve, the points of intersection with the circle *D E c f* will represent the centres of the two eccentrics when the crank pin is at *O* at the end or commencement of the stroke.

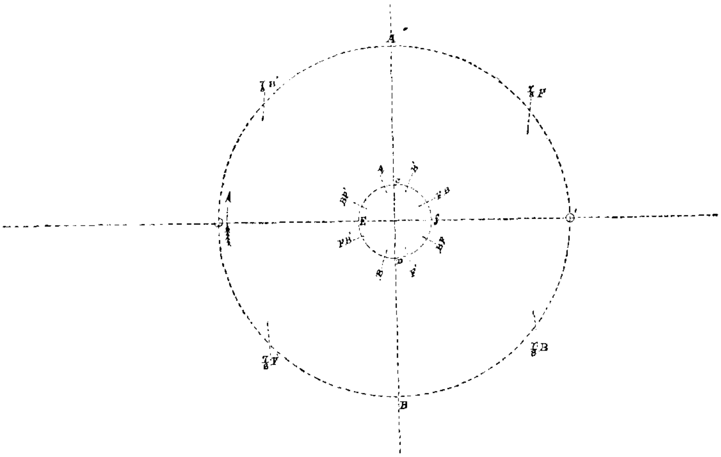

Fig. 2.

A template *V*, Fig. 1, is made of sheet metal or stiff card board, having a small hole at *z*, and with edges coincident with the crank pin, and with radial lines *z* 1, *z* 2, passing through the centre of the eccentrics *F B*, and by inserting a needle through the small hole *z* into the centre of the driving axle, and placing the edge *z c* at the intersections representing the crank pin at various portions of the stroke, the positions of the eccentrics at each position of the crank can be marked with a pencil or pen intersecting the circle *D E c f.* Thus the forward and back eccentrics respectively will be at *O F,* and *O B,* Fig. 1, when the crank is at *O;* at $\frac{1}{2}$ *F*, $\frac{1}{2}$ *B F* when crank is at half stroke; at *O F′* and *O B′* with crank at *O′* and at $\frac{1}{2}$ *F′* and $\frac{1}{2}$ *B F′*, with crank at the other half stroke. By a similar procedure the relative positions of the eccentrics at any other desired point of the stroke, say seven-eighth stroke, is obtained as shown in Fig. 2, where *F* and *B F* are the centres of the forward and back eccentrics with crank at $\frac{7}{8}$ *F*, moving in the direction of the arrow, and *F′* and *BF′*, with crank at $\frac{7}{8}$ *F′*, and *B* and *F B*, with crank at $\frac{7}{8}$ *B*, and *B′* and *F B′*, with crank at $\frac{7}{8}$ *B′*, moving in the opposite direction.

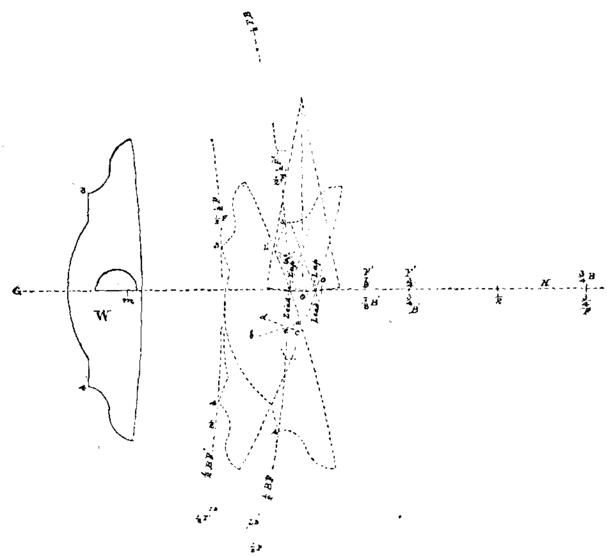

Fig. 3.

Another template *W*, Fig. 3, is made with a curved edge having a radius equal to the distance from the points *C* or *D*, Fig. 1, 2, to the rocker arm wrist when at mid throw, the corners 3 4 representing the centres of the knuckles connecting with the eccentric rods, a hole being cut through the template, one side of which coincides with a straight line dividing the link into two equal portions. The length of the eccentric rods is obtained by placing the curved edge of the link template opposite to the corner 3 in contact with the rocker arm wrist centre when at mid throw, at *O′*, Fig. 3, and moving the body of the template to a position where the same tram will touch the points *D*, Figs. 1 and 3, on the template, and *C*, Fig. 1 and 4 on the template. With the length thus obtained as a radius, and the centres at the intersection $\frac{1}{2}$ *F* and $\frac{1}{2}$ *F′*, Fig. 1, describe the arcs $\frac{1}{2}$ *F*, $\frac{1}{2}$ *F′* above the centre line *G H*, Fig. 3, and from the centres $\frac{1}{2}$ *B F* and $\frac{1}{2}$ *B F′*, Fig. 1, describe below the centre line the arcs $\frac{1}{2}$ *B F* and $\frac{1}{2}$ *B F′*, Fig. 3. The lap of the valve having been marked as shown in Fig. 3, the template *W* is now placed with its corner 3 in contact with the

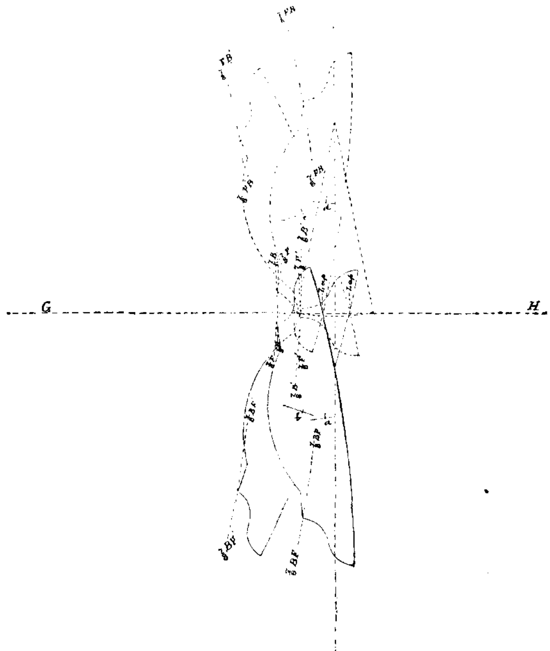

Fig. 4.

arc $\frac{1}{2}$ *F*, and corner 4 in contact with arc $\frac{1}{2}$ *B F*, and moved along until it reaches the place indicated in Fig. 3, where the curved edge cuts the point marked *Lap*, being the point of suppression or cut-off, and with a pen or pencil the line *a b* is drawn along the straight side of the hole in the template. By a similar process, using the arcs $\frac{1}{2}$ *F′* and $\frac{1}{2}$ *B F′* the line *c d* is obtained, and their intersection at *e* determines the vibrating centre of the link and its position to cut-off at half stroke on the forward movement of the engine in the direction of the arrow, Fig. 1. By a similar process the intersections at *g* are obtained, being the position of the link-vibrating centre for the backward movement of the engine. The vibrating centre of the link should be marked on the template at *m*.

The next step to be taken is to obtain the position of the vibrating centre of the link in order to cut off the steam at seven-eighths stroke of the piston in forward and back gear. For this purpose, with the centre *F*, Fig. 2, and the length of eccentric rod for radius as before, the arcs $\frac{7}{8}$ *F*, Fig. 4, is described downwards from the centre line and a little above it, each end of the arc being suitably marked to identify it, and from the centre *B F*, Fig. 2, the arc $\frac{7}{8}$ *B F*, Fig. 4, is described at some distance below the centre line, and suitably marked. By traversing the corners 3 4 of the link template *W* along these arcs until the curved edge intersects the lap point, the position of the vibrating centre in order to effect cut-off at seven-eighths stroke is found to be at *a*, Fig. 4. By describing the arcs $\frac{7}{8}$ *F'* and $\frac{7}{8}$ *B F'*, Fig. 4, from the centre *F'* and *B F'*, Fig. 2, and traversing the template *W* as before, the position for the vibrating centre of the link for cut-off at seven-eighths stroke in forward gear is found to be at *b*. By similar procedure the corresponding positions for back gear are found at *c d*, Fig. 4.

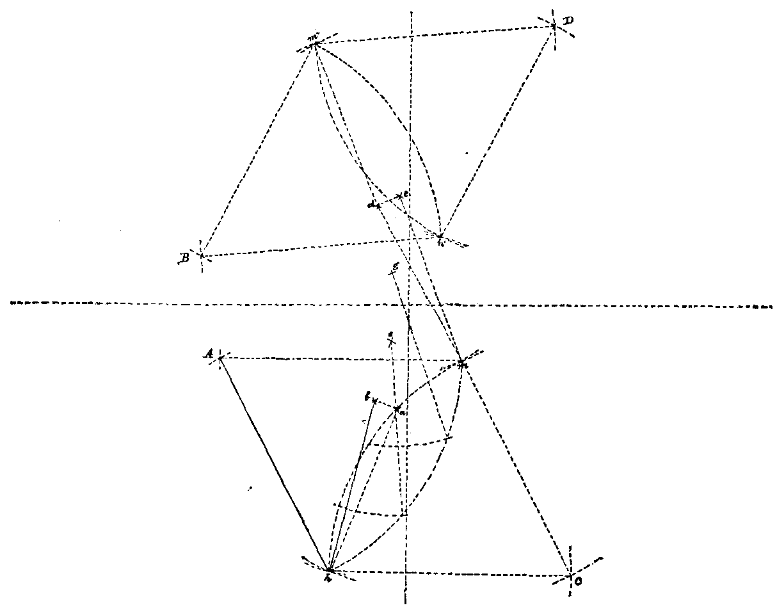

Fig. 5.

Having now ascertained the precise vibrating centre of the link, and its required positions to effect equal suppression of steam at the most important parts of the stroke both in forward and back gear, it now remains to adjust the reversing gear to meet those requirements. Fig. 5 represents at *a b c d e g* the several points determined in the other drawings. The length of the suspending or sustaining bar on which the link vibrates being determined upon, with this length for radius the intersecting arcs *h* and *h′* are described from *a* and *b* as centres, and *m* and *m′* from the centres *c* and *d*. Then with the centres *h m* with the length of the lifting arm for radius the intersecting arcs *A C* are described, and from *h′* and *m′* the intersecting arcs *B* and *D*, all which points indicate a possible position for the reversing shaft. The reversing shaft may be located at any of the points *A B C* or *D*, though in practice the writer always adopted that shown at *A* in all the locomotives constructed under his direction. In practice all the operations were performed on one drawing by describing the arcs of the eccentric rods in different colored inks, and

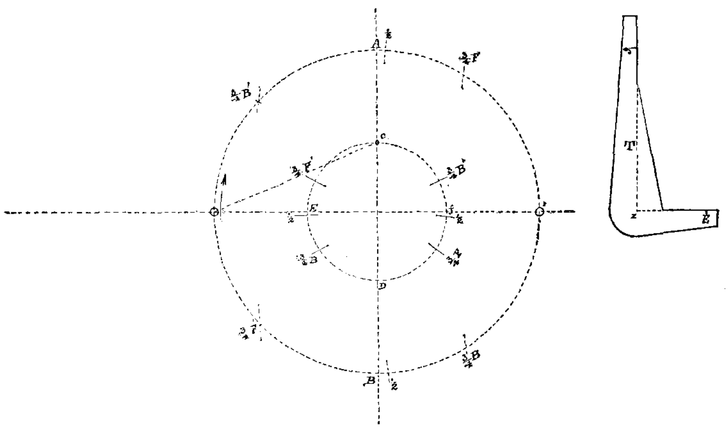

Fig. 6.

with dotted or full lines to avoid confusion of lines, and the indications of the diagrams were fully realized in practical operations of machinery constructed in accordance therewith. To ensure against possible errors in the drawings, every different class of valve gear was tested on a full-sized adjustable working model before commencing on a working machine. With a well-constructed working model capable of adjustment to all the varied positions and proportions for cranks, eccentrics, rocker arms, connecting rods, etc., with links of proper radii, the position for the vibrating centre of the link at the various points of suppression or cut-off can be readily obtained after careful adjustment of the eccentrics and rods so as to obtain the correct lead to the valve, when the piston is at either end of the stroke, by moving the vibrating centre of the link on the central line as *G m*, Fig. 3, until the position *m* is obtained such that with the piston at either half stroke, when the link is moved to the point of suppression for either stroke, the vibrating centre shall be at the same point, which can be ascertained after a few trials. The exact position on the link for its vibrating centre being determined, if the crosshead is set at three-fourths or seven-eighths stroke for each stroke, the position of the vibrating centre of the link can be noted for the point of suppression at each stroke, both in forward and back gear, and the position for the reversing shaft can be determined as explained for Fig. 5.

Fig. 7 represents the general arrangement of rocker arms, link and crosshead attachment for a valve movement with a single eccentric, or its equivalent, which in this case, Fig. 6, is a wrist on the end of one arm extending from the crank pin toward the axle centre, and adjusted so as to occupy the position marked *C* at right angles to the line from the axle centre to the rocker arm at mid-throw when the crank pin is at *O*. The template *T* is used for marking the positions of the wrist *C*, Fig. 6, at various parts of the stroke, as in the case before described, and the template *a b c d e f g h*, with a hole corresponding to the rocker shaft is used to mark the positions of the link at corresponding parts of the stroke, the dotted lines *k m*, *n m*, represent the positions of the lead lever to cut off at both half strokes. Now with the centre *p*, and the shifting bar for radius, the arc *s t* is described, whose intersections 2 3 show the proper position for the shifting bar to cut off at half stroke in forward and back gear, and with centre *r* and same radius, the arc *u v* is described for the purpose of determining the cut-off points, 4 5, for the other half stroke. By marking off on a straight edge the length of the shifting bar and the point of suppression *D*, and laying this straight edge at *p* 2, *p* 4, the points of suspension c' d' are obtained. By similar process the points a' b' e' f' g' h' are ascertained, being the points of suspension for cut-off at half stroke and three-quarter stroke for both strokes in forward and back gear. From these points as centres the intersecting arcs i' k' m' n' are described, with the suspending bar for radius, and by bisecting the chords i' m' and k' n', the centre for the reversing shaft *x* is found, and the length of reversing arm determined. The reversing shaft may be placed above the centre of the rocker shaft, and its position ascertained by

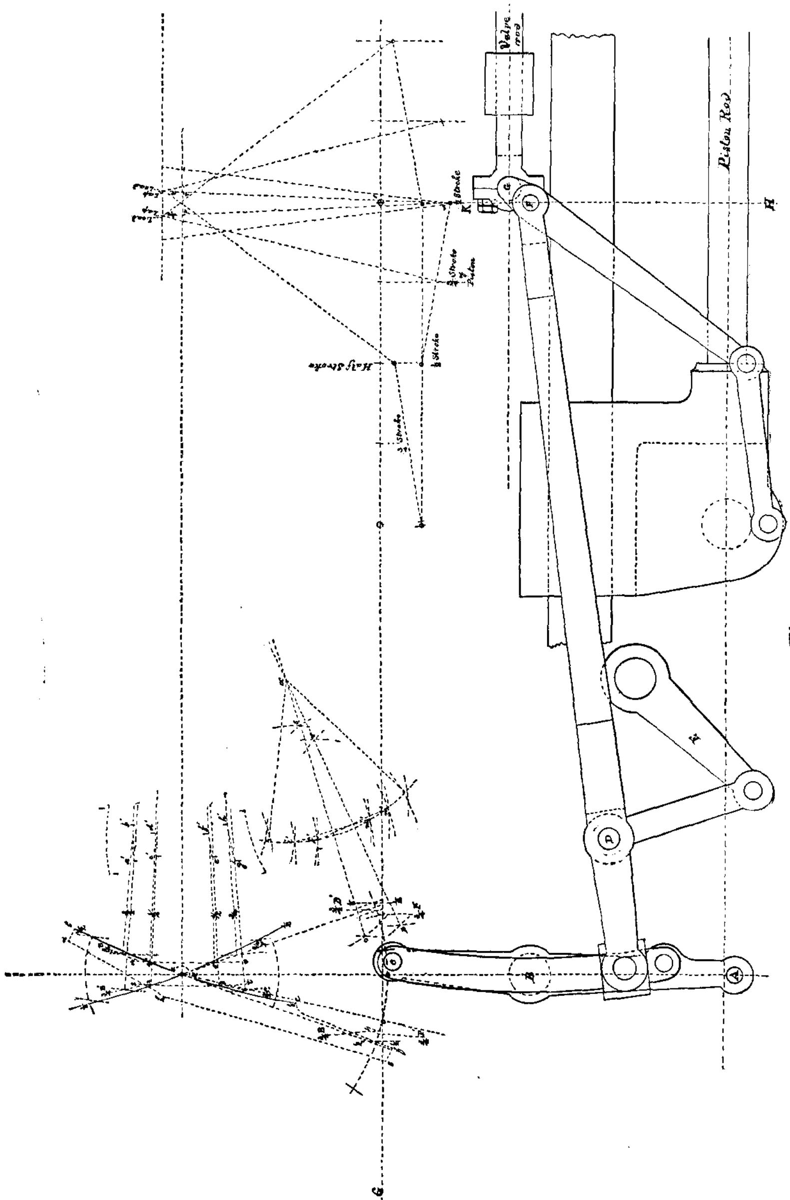

Fig. 7.

similar process; but when practicable the position below the rocker shaft is preferable. This style of valve gear is more especially applicable and adapted to freight engines having small drivers, inasmuch as all the valve gear is readily within sight and reach, and with a given lap and travel of valve a longer admission of steam in full gear is attained, with the same range of cut-off as in the shifting link. The uniformity of lead at all positions in gear is not favorable to the attainment of the highest speeds required in passenger traffic.

A NEW THEORY OF THE SUSPENSION SYSTEM WITH STIFFENING TRUSS.

By A. Jay DuBois, Ph.D.

Professor of Dynamic Engineering in the Sheffield Scientific School of Yale College.

The points in which the present discussion differs from the theory generally received, are as follows:

The ordinary suspension system is assumed to consist of cable, truss and stays. The cable is supposed to carry the entire dead and full live load. The stays are inserted for additional stiffness at the flanks, while the truss is constructed to merely rest upon the abutments, and it is assumed that it so distributes any partial loading that the curve of the cable remains practically unchanged. That is, the curve of the cable is assumed to be parabolic and it is assumed that the truss distributes any partial load *so as to make it take effect upon the cable as a uniform load*, thus preserving the parabolic shape.

In opposition to this generally received theory, we maintain in our present discussion that the curve of the cable does *not* remain parabolic, but takes the curve of equilibrium due to the loading. We thus claim to obtain a more accurate, rational and scientific theory of the stiffening truss. We also discard stays entirely, upon the ground that they are unnecessary. Finally, we suppose the truss firmly bolted down at the ends, so that the tangent to the curve of deflection at the ends is always horizontal, and that it supports its proper portion of the live load.

All of these points are too obvious to need defence. The common assumption that the curve of the cable remains always a parabola, and that the truss distributes the load *uniformly*, every engineer knows to