the same reason the angle C*e*E is a right angle, therefore the remaining angle BE*e* is a right angle, and the quadrilateral is a parallelogram, and consequently BE equals *e'e*; and therefore Cϵ = *e'e*; that is to say, the chord intercepted between C and the circumference of the circle CG in the direction CD is equal to the differences of the chords intercepted in the same direction between the point C and the circumferences of the circles CE and CK.

This proof is perfectly general for all cases where the

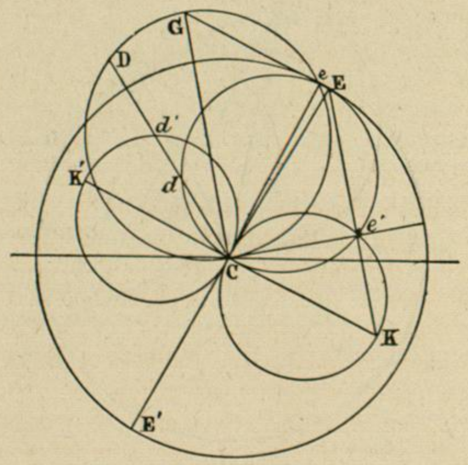

Fig. 126.

direction of the crank intercepts the circumferences of all three circles. Take, however, the case when it passes through the point of intersection *e*, fig. 126, of two of the circles. In this case the difference between the chords of the two circles on CE and CK equals C*e*, which is a chord to both circles CE and CG; therefore the line C*e* should not form any chord with the circumference of the circle on CK. Join *e*G and *e*E. Then the angle C*e*G, being in a semicircle, is a right angle; and for the same reason C*e*E is a right angle;

therefore GE is a straight line, and as CG is drawn equal and parallel to EK, therefore GE is also parallel to CK, and therefore the alternate angle G*e*C is equal to the alternate angle *e*CK; therefore *e*CK is a right angle, and consequently the line *e*C is a tangent to the circle CK at the point C, and therefore the direction of the crank C*e* does not intercept any chord from the circle CK. A similar proof would hold good for the point *e'*.

It must be borne in mind that the chords of the circles CK and CE represent the movements of their respective valves to the right of their central positions, while the corresponding circles on CE produced to E' and CK produced to K' indicate movements to the left. If, therefore, any line of direction of the crank CD should intersect simultaneously say the expansion valve circle CK' and the distribution valve circle CE, then the distances apart of the centres of these two valves will not be represented by the difference of the chords C*d* and C*d'*, but by their sum; and it may readily be proved that the chord CD of the circle CG equals this sum. Hence we see that for every possible position of the crank the chords of the resultant circles CG and CG' represent the distances apart of the central lines of the valves.

We must next show the connection between the distances apart of the centres of the valves, and the opening which the expansion valve EE', fig. 127, permits in the port of the distribution valve DD'.

First let the centres of the two valves coincide as in the upper diagram, fig. 127, and next let both valves be moved to the right, but of course to different extents, so that their centres no longer coincide as shown in the lower diagram. Let *k* be the distance from the centre of the distribution valve to the outer edge of the port. Let *l* be the length of the half of the expansion valve. Let *u* be the distance which the inner edge of the expansion valve is moved by the screw spindle (see fig. 98) from the centre line. The distance *u* is variable, so as to allow of the rate of expansion being altered. Let r be the distance from the edge E of the expansion valve to the outer edge of the port in the distribution valve. The value of r is of course variable, and depends upon u, so that

$$r = k - l - u.$$

Now let both valves be moved to the right by their respective eccentrics; let the distance moved by the distribution valve be x, and that by the expansion valve x'; also let the opening in the port in the distribution valve be e; then it is evident from the figure that—

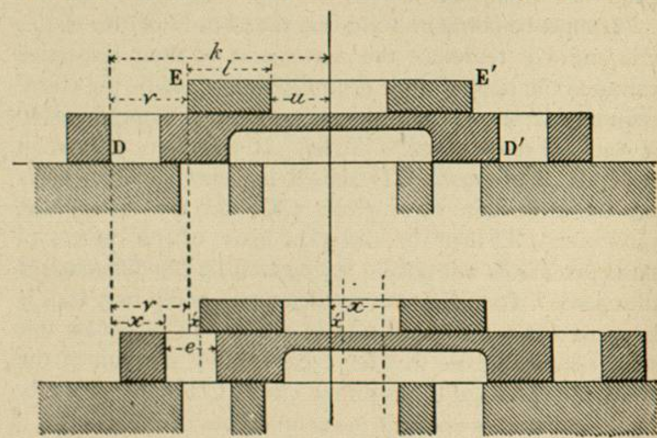

Fig. 127.

$$r + x_1 = x + e.$$

$$\therefore e = r - (x - x_1) = k - l - u - (x - x_1),$$

which expression gives the opening of the port in the valve in terms of the two fixed dimensions k and l, the distance u which is under control, and the distances x and x', traversed by the valves.

It is very easy to show this opening of the port in the valve graphically. As has already been proved, the chords

of the two resultant circles CG, CG′, fig. 128, give the values of $x - x_1$ for any position of the crank. If with centre C and radius CH $= k - l - u$ we describe a circle, then the difference between any radius of this circle, such as Ce, and the corresponding chord of the resultant valve circle, viz. Ce', gives the opening of the port in the distribution valve.

We have now the means of tracing the distribution of the steam throughout the stroke, and also of ascertaining the effect on the expansion due to the alteration of u, the half-distance apart of the two portions of the expansion valve.

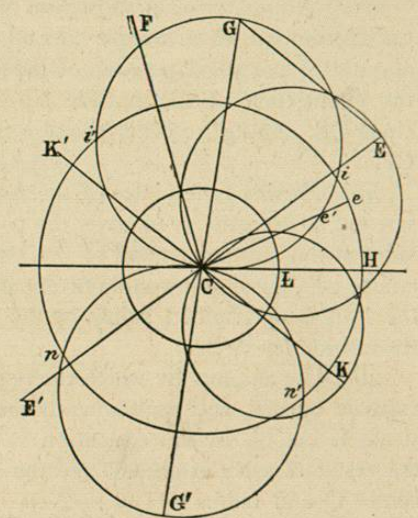

Fig. 128.

We see that when the crank lies in the direction Ci the port in the distribution valve is just closed, for at the point i where the resultant valve circle intersects the circle described with $k - l - u$ as radius we have $k - l - u = x - x_1$, and consequently the value of e in the above equation is zero. Between the points i and i the port in the distribution valve remains closed, but at i' it is reopened, and the steam would be readmitted to the cylinder were it not for the fact that by this time the cylinder port is closed by the distribution valve, as is proved by drawing the line CF through the intersection of the primary valve circle CE and the lap circle CL.

The tracing out of the steam distribution by means of this diagram will be greatly facilitated if we bear in mind the following points.

1st. The opening and closing of the exhaust are determined solely by the distribution valve, are not affected in the slightest degree by the existence of the expansion valve, and may consequently be traced by noting the intersections of the valve circle CE with the outside and inside lap circles in the manner already explained.

2nd. No matter what the action of the expansion valve, the distribution valve *always* cuts off the steam on its own account at the fixed position of the crank determined by the intersection of the outside lap circle with the valve circle CE. In fig. 128 this position is denoted by the line CF.

3rd. Provided the plates of the expansion valve are not screwed so far apart as to cover the ports in the distribution valve at the commencement of the stroke (which would of course be absurd, as it would prevent all admission of steam), the lead is determined solely by the valve circle CE and the outside lap circle.

4th. The amount by which the port in the distribution valve is opened, and consequently the point at which the steam is cut off by the expansion valve, is determined by the resultant valve circle CG and the circle described from centre C and radius CH $= k-l-u$. That is to say, it is so determined for all positions of the crank between the dead point and the position CF; for once the position CF is passed the steam is cut off by the action of the distribution valve, and the expansion valve can have no further effect. The amount by which the ports in the distribution valve are opened are measured for the port farthest from the crank shaft by the differences between the radii of the circle described with radius CH and the corresponding chords of the resultant valve circle CG, but for the other port the chords must be taken of the circle CG′. Thus we see that the far port in the distribution valve is, in the case of fig. 128,

opened during the whole of the stroke except while the arc ii' is being described, and similarly the near port is closed only during the arc nn'.

5th. The details of the valves and eccentrics having been fixed, the rate of expansion is altered solely by varying the distance apart of the two halves of the expansion valve, that is to say, by varying the radius CH.

We must now examine more closely the results obtained by varying this radius. Fig. 129 is similar to a portion of fig. 128 to a larger scale, but with the eccentrics set at different angles, and with all unnecessary complications left out.

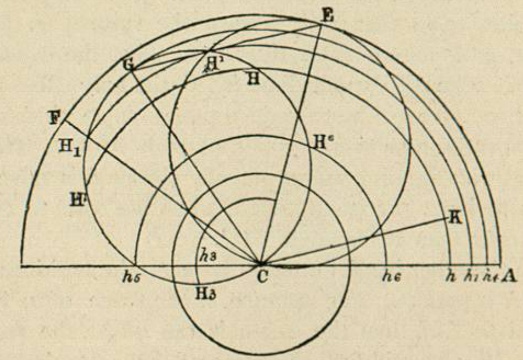

Fig. 129.

The length CA corresponds with the value $k-l$. The length Ch corresponds to the value $k-l-u$ shown in fig. 127. In this case we see that the steam is cut off at the position CH of the crank, the port in the distribution valve is closed while the arc HH_1 is described, and at the point H_1 the port in the valve is reopened, and steam would be readmitted into the cylinder were it not for the fact that the port in the cylinder itself is closed by the distribution valve when the crank is at CF. If now we diminish the value of u, so that $k-l-u = Ch_1$, the expansion valve is so set that it cuts off the steam at the position CH^1 of the crank and reopens the valve port at the position CH_1 ; that is to say, at the same moment that the distribution valve covers the cylinder port. The position CH^1 is therefore the *latest* cut-off which it is possible to effect by means of the valve gear represented by the above diagram; for it is obvious that if u is still further diminished, then the valve port will be re-opened before the cylinder port is closed by the distribution valve, and consequently steam will be readmitted to the cylinder during a portion of the stroke. If the value of u be still further diminished, say to Ah^4, the circle described with Ch^4 as radius will not intersect the circle CG at all, but will merely touch it at the point G, showing that the expansion valve then only closes the valve port for an instant, and consequently does not affect the expansion. While if u be still further diminished, the only effect of the expansion valve will be to reduce the available width of the valve port during a short portion of each stroke. Thus we see that with the dimensions actually chosen this valve gear ceases to have any useful effect when we wish to cut off steam *later* than at the angle CH^1.

On the other hand, its action between the positions CH^1 and CA is perfect. For instance, if the value of u be increased to Ah^6, then the steam is cut off at the position CH^6. If u be still further increased, so as to be greater than $k-l$, say to Ah^3, then the cut-off will be effected at a position found by prolonging the line H^3C backwards; while if u be still further increased to Ah^5 the steam can be cut off at the commencement of the stroke, while in each of the latter cases the reopening of the valve port does not take place till after the position CF has been passed.

Hence we see that the valve gear represented above is perfectly efficient for any cut-off between the dead point and the position CH^1. If we wish to be able to cut off at later positions than CH^1, we must alter the positions and throws of the eccentrics. An inspection of fig. 129 will prove that the nearer the diameter CG of the resultant circle approaches

the position CF, where the distribution valve cuts off the steam, the later will be the position when the expansion valve can cut off the steam. Fig. 130 will show that it is

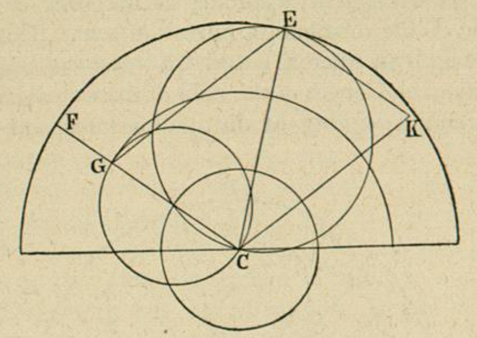

Fig. 130.

perfectly possible so to arrange the eccentrics that the steam may be cut off at any point that may be desired between the dead point and the position CF where the distribution valve closes the cylinder port. In the case of fig. 130 this result is attained by keeping the throw and angle of advance of the eccentric represented by CE as before, and by altering the angle and throw of the other eccentric to such an extent that the diameter CG of the resultant circle coincides with the direction of the line CF. It may here be noticed that in designing a Meyer valve gear it is unnecessary to give the length $AC = k-l$, fig. 129, a greater value than CG, the diameter of the resultant valve circle, for by so doing we merely admit of the possibility of the expansion valve being absolutely useless under certain conditions. This would be the case in fig. 129, for instance, whenever u had a less value than Ah^4.

Reversing by Meyer's valve gear.—If the engine to which Meyer's valve gear is applied is expected to be able to run backwards as well as forwards, the choice of the angle of advance of the expansion valve eccentric will require a good deal of consideration, for it is evident that unless this latter eccentric is situated exactly midway between the two distribution valve eccentrics, the diameter of the resultant circle will be quite different according as the back or forward eccentric of the distribution valve is in gear. This is illustrated in fig. 131, where CE and CE′ represent respectively the positions and length of the radii of the forward and back gear eccentrics working the distribution valve, and CK that

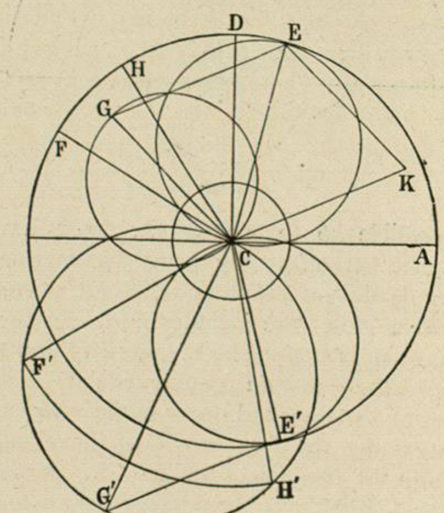

Fig. 131.

of the expansion valve. We see that owing to the angle of advance of the expansion valve eccentric DCK not being 90°, the length and position of the diameter of the resultant circle CG is quite different from that of the resultant circle CG′, and consequently the limits within which we can vary the expansion are quite different according as the engine is running backwards or forwards. For instance, when the eccentric CE is in gear, the expansion can be controlled by

the expansion valve as far as the position CH of the crank; but when the eccentric CE′ is in gear, then the cut-off can only be effected by the expansion valve between the limits CA and CH′, which is a much smaller per-centage of the stroke.

It is easy to see that the more perfect the action of this gear when the eccentric CE is in gear, the less perfect will it be for the eccentric CE′. Hence, when an engine has to do the greater part of its work running in one direction, it is desirable so to arrange the eccentrics that the action of the valve gear will be most perfect for this direction.

As in the case of simple valve gears and link motions, Zeuner's diagrams may be applied not only to analyse the steam distribution when the dimensions, &c., of valves and eccentrics are given, but also to solve problems—that is to say, to find out some of the dimensions when other dimensions or conditions are given.

Problem.—Given the lead, the angles of the crank when steam is cut off, the release takes place, and the compression commences, find the position and throw of the eccentric of the expansion valve which will permit of all degrees of expansion between the dead point and the point where the distribution valve closes the cylinder port. Also find the length of the plates of the expansion valve, and the distances apart of these plates for any given degree of expansion.

The data all refer to the distribution valve. From them we proceed to deduce the position and throw of the eccentric belonging to this valve in the manner explained in Problem VI., page 285. Having thus found the angle of advance and the length of the throw CE, fig. 132, the external and internal lap circles are found in the usual manner.

We have next to find the angle of advance and throw of the expansion valve eccentric. If the main valve is to close the cylinder port at the same instant that the expansion valve covers the port in the distribution valve, the diameter

CG of the resultant circle should coincide in direction with the line CF, which indicates the direction of the crank when steam is cut off by the distribution valve. The length of the diameter CG may be anything we like so as to suit the remainder of the design. The longer we make CG, the greater will be the angle ECK between the eccentrics of the two valves; and for engines which have to reverse, it is desirable that the angle of advance of CK should be as nearly as possible a right angle. Having fixed the length

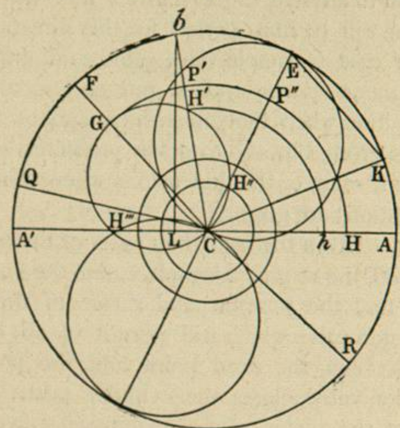

Fig. 132.

CG, join GE, and draw CK parallel to GE, and EK parallel to CG; then CK is the position and half length of throw of the expansion valve eccentric.

The minimum length of $k-l$ equals CG (see page 311). With centre C and radius CG describe an arc of a circle intersecting CA in H; then CH corresponds with the line CA, fig. 129, and equals $k-l$. We have now to fix the distance apart of the plates of the expansion valve for any degree of expansion. Let AL to AA′ be the required ratio of expansion; that is to say, supposing AA′ to represent the stroke, the steam is supposed to be cut off at L. Erect a perpen-

dicular from L intersecting the circumference of the circle described on AA′ in b. Join bC; then, neglecting the influence of the length of the connecting rod, Cb is the angle of the crank when steam is cut off. Cb intersects the arc GH in P′ and the resultant valve circle in H′. With centre C and radius CH′ describe an arc of a circle intersecting the line CA in h. Then it will be evident, from the description accompanying fig. 129, that Hh is the half-distance apart of the plates of the expansion valve for the given ratio of expansion. But hH = P′H′, hence we can measure the distance required directly, as the part of the line Cb intercepted between the arc GH and the circumference of the resultant valve circle. Similarly, if steam were cut off when the crank stood at the angle CE, the half-distance apart of the plates would be represented by P″H″. If steam were cut off at the commencement of the stroke the half-distance would be HH‴.

To find the length of the plate l of the expansion valve we must first fix the highest grade of expansion. Having done so, we can find the half-distance apart of the two valves in the manner above described. This gives the value u in the formula $r = k - l - u$. And as we know that $k - l = \text{CH}$, we can deduce r, that is the distance between the outer edge E of the expansion valve, fig. 127, and the outer edge D of the port in the distribution valve when both valves simultaneously occupy their central position. If the grade of expansion is very high, say one-eighth of the stroke, we shall find that u is greater than $k-l$, which means that E would stand to the left of D when the valves were simultaneously central. Having thus fixed the position of E when the two valves are supposed to be in their central position, we must find its position when the valves are at their greatest distance apart. Now the greatest distance apart is when the crank lies in the direction of the diameter CG of the resultant valve circle, and the distance apart equals CG. Hence it will readily be understood by reference to fig. 127 that when the crank occupies the position CG, fig. 128, the edge E of the expansion valve must lie still further to the left of the point D by the distance CG, consequently the edge E will be distant from D by the total length $r+CG$. But when the crank is in this position the plate of the expansion valve must *fully* cover the port in the distribution valve, otherwise steam would be momentarily readmitted into the cylinder. Hence the length of the plate must be equal to $r+CG+$the width of the port in the distribution valve$+$a small overlap. Now the width of the port is supposed to be known, and the small overlap may be arbitrarily chosen, hence we know the length of the plate l; and as $r+l+u=k$ (see page 306), we can deduce k, the half-length of the distribution valve.

It would be possible to multiply examples of the application of Zeuner's valve gear to the solution of problems connected with Meyer's valve gear, but the explanations given are quite sufficient to enable the student to solve by himself the great majority of the questions which may arise.

CHAPTER VIII.

INDICATORS AND INDICATOR DIAGRAMS.

Uses of indicator diagrams—Richards' indicator—General character of indicator diagrams—The lines of admission, expansion, release, exhaust, and compression—How to measure the power exerted during a stroke of the piston—How to ascertain from diagram the horse-power exerted by the engine—How peculiarities and defects are revealed by the diagram—Loss of pressure during admission—Slow cut-off of steam—Effects of clearance on expansion curve—Effects of condensation and re-evaporation in cylinder on expansion curve—Usual form of the expansion curve—Late and early release—Effect of wet steam on the exhaust line—Causes affecting the back pressure—Cushioning or compression of exhaust steam—Principal causes affecting forms of diagrams—Examples of diagrams from defective engines—How to draw the hyperbolic curve of expansion—Initial condensation and re-evaporation shown by diagram—Leaky pistons and slide valves—Gross and net indicated power—Cause which limits the economical rate of expansion—How to deduce from indicator diagrams the effective pressure on piston—How to ascertain the expenditure of steam accounted for by the diagram.

It has been already explained (p. 79) how the work done during the expansion of a gas can be represented graphically by an area, while the exact way in which the work is done is shown by the nature of the lines bounding the area. It is of the greatest importance to be able to take diagrams of the work done in the cylinder of a steam-engine, for by computing the area of the diagram we can ascertain exactly the power exerted by the engine, and by examining closely the bounding lines we are enabled to see how the work is being done at each successive instant, and can tell, for instance, when the steam is cut off, whether expansion proceeds in the proper manner, when the cylinder is open to the exhaust, what is the amount of the back pressure, when the valves are closed to the exhaust, when the readmission of steam