The above suggests a very simple method of ascertaining the position of the valve for every angle occupied by the crank, and this method is the basis of all Zeuner's valve diagrams. We have only to draw the line OE, connecting the centre of the eccentric with the centre of the crank-shaft, when the crank is at either of the dead centres, and upon this line as a diameter to describe a circle; then the chords of this circle, O*e*, O*e*′, O*e*″, &c., will represent the spaces traversed by the valve from its central position when the crank occupies successively the positions opposite to O*e*B′, O*e*′C′, O*e*″D′, &c. During the return stroke the motion of the valve will be indicated by the corresponding chords of the circle described on the line OK.

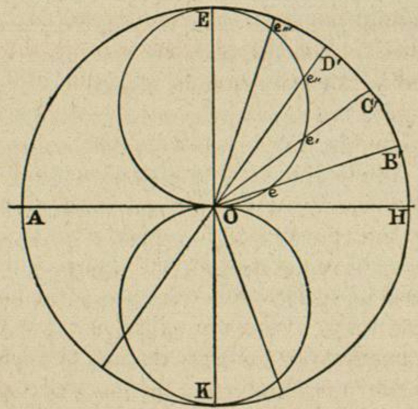

Fig. 108.

The application of this diagram to the valve shown in fig. 85 is very easy, it being remembered that the valve has no lap, and that it occupies its central position when the piston is at the commencement of the stroke. Commencing with the edge of the valve *d* which works the left-hand steam port, we see that when the crank occupies the position opposite OH, fig. 108, in consequence of the position of the circle on OE, there is no chord intercepted by any part of the line OH, and consequently when the crank is on the dead centre the port is not open at all; but directly the crank moves through any arc, no matter how small, there will be a chord intercepted by the periphery of the circle, and the valve

will be opened by an amount equal to the length of the chord. The port will continue to open till the crank-pin reaches the position E, at which point the valve will have travelled to one end of its beat, for no arc of a circle can be drawn longer than the diameter. From this point the valve commences to close the port, but does not completely close it till the end of the stroke. Similarly the motion of the valve during the return stroke can be ascertained by means of the circle on OK.

The diagram is equally useful in tracing the exhaust side of the valve. While the crank is travelling in the direction of the arrow, fig. 85 (represented of course in the diagram by the opposite direction), the outer edge *d* of the valve is keeping the steam port open, but as soon as the piston reaches the end of its forward stroke the valve has returned to its central position, and during the first half of the return stroke continues its motion towards the left. Directly the crank is over the dead centre the inner edge of the valve opens the left-hand port to the exhaust, and the arcs intercepted between O and the periphery of the circle OK, fig. 108, measure the extent to which the port is opened. Following the motion as before, we see that the exhaust is fully opened when the crank is at OK, and that it remains open till the end of the stroke (compare fig. 88).

How to indicate lap and lead on the valve diagram.—When a valve is provided with outside lap, and when the port has to be opened by the amount of the lead at the commencement of the stroke, the valve can no longer be in its central position when the crank is on the dead centre. This has been shown in fig. 90, which also illustrates the manner of setting the eccentric. Describe a circle, fig. 109, with radius OA equal to the half-throw of the eccentric. From O measure off OB equal to the outside lap, and BC equal to the lead. When the crank-pin occupies the dead centre A, the valve has already moved to the right of its central position by the space OB + BC. From C erect the perpendicular CE, and join OE. Then will OE be the position occupied by the line joining the centre of the eccentric with the centre of the crank-shaft at the commencement of the stroke. On the line OE as diameter describe the circle OCE; then, as before, the chords O*e*, OE, O*e*′, will represent the spaces travelled by the valve from its central position when the crank-pin occupies respectively the positions opposite

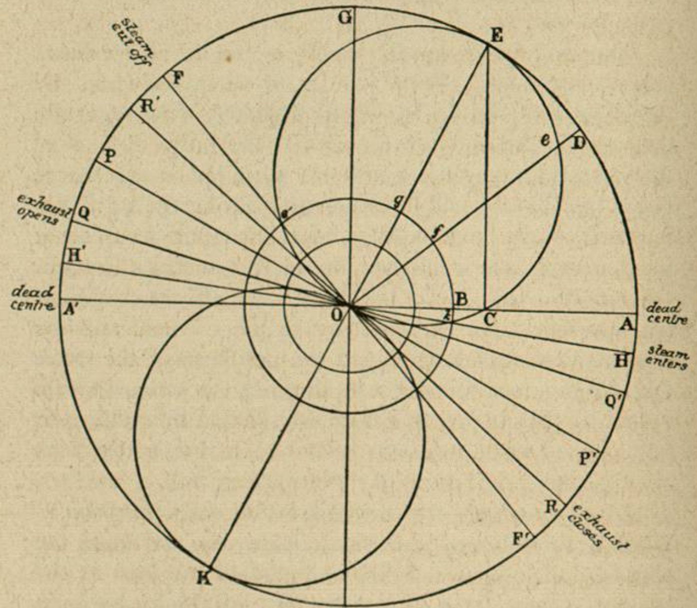

Fig. 109.

to D, E, and F. But these chords will no longer represent the extent to which the outer edge of the valve has opened the steam port, because before the port is opened at all the valve must have moved from its central position by an amount equal to the lap OB. Hence to obtain the space by which the port is opened we must subtract from each of the arcs O*e*, OE, &c., a length equal to OB. This is re-

presented graphically by describing from centre O a circle with radius equal to the lap OB; then the spaces *fe*, *g*E, &c., intercepted between the circumferences of the lap circle B*fe*′ and the valve circle OCE, will give the extent to which the steam port is opened. Tracing the motion of the valve as before, and remembering that, when we speak of the crank occupying the position, say, OD, it really occupies the position symmetrically opposite on the other side of the diameter OG, we shall see at once how different is the distribution of the steam to that illustrated in the last case.

To begin with, take the point *k*, at which the chord O*k* is common to both valve and lap circles. At this point it is evident that the valve has moved to the right by the amount of the lap, and is consequently just on the point of opening the steam port. Hence the steam is admitted before the commencement of the stroke, when the crank occupies the position OH, and while the portion H A of the revolution still remains to be accomplished. When the crank-pin reaches the position A, that is to say at the commencement of the stroke, the port is already opened by the space OC − OB = BC, called the lead. From this point forward till the crank occupies the position OE the port continues to open, but when the crank is at OE the valve has reached the furthest limit of its travel to the right, and then commences to return, till when in the position OF the edge of the valve just covers the steam port, as is shown by the chord O*e*′, being again common to both lap and valve circles. Hence when the crank occupies the position OF the cut-off takes place and the steam commences to expand, and continues to do so till the exhaust opens. For the return stroke the steam port opens again at H′ and closes at F′.

So far we have traced the action of the valve in admitting and cutting off the steam. There remains only the exhaust to be considered. When the line joining the centres of the eccentric and crank-shaft occupies the position opposite to OG at right angles to the line of dead centres, the crank is in the line OP, at right angles to OE; and as OP does not intersect either valve circle the valve occupies its central position, and consequently closes the port S, fig. 89, by the amount of the inside lap *i*. The crank must, therefore, move through such an angular distance that its line of direction OQ must intercept a chord on the valve circle OK, equal in length to the inside lap, before the port can be opened to the exhaust. This point is ascertained precisely in the same manner as for the outside lap, namely, by drawing a circle from centre O, with a radius equal to the inside lap; this is the small inner circle in fig. 109. Where this circle intersects the two valve circles we get four points which show the positions of the crank when the exhaust opens and closes during each revolution. Thus at Q the valve opens the exhaust on the side of the piston which we have been considering, while at R the exhaust closes and compression commences, and continues till the fresh steam is readmitted at H.

Thus we see the diagram enables us to ascertain the exact position of the crank when each critical operation of the valve takes place. Making a *résumé* of these operations for one side of the piston, we have—

Steam admitted before the commencement of the stroke at H.

At the dead centre A the valve is already opened by the amount BC.

At E the port is fully opened, and valve has reached one end of its travel.

At F steam cut off, consequently admission lasted from H to F.

At P valve occupies central position, and ports are closed both to steam and exhaust.

At Q exhaust opened, consequently expansion lasted from F to Q.

At K exhaust opened to maximum extent, and valve reached the end of its travel to the left.

At R exhaust closed and compression begins, and continues till the fresh steam is admitted at H.

Solution of problems relating to simple valve gearing by Zeuner's diagrams.—All problems bearing on valve gearing involve relations between the following variables:—

The inside and outside laps of the valve.

The angle of advance and the throw of the eccentric.

The angles of the crank or points of the stroke at which take place the admission and cut-off of the steam, and the opening and closing of the exhaust.

Occasionally, and more especially when the valves of an old engine have to be altered, we have also to take account of the width of the steam ports, and the extent to which they have to be opened.

Problem I.—The simplest problem which occurs is the following. Given the length of throw, the angle of advance of the eccentric, and the laps of the valve, find the angles of the crank at which the steam is admitted and cut off and the exhaust opened and closed.

This problem is solved in the manner shown in fig. 110. Draw the line OE, representing the half-throw of the eccentric at the given angle of advance with the perpendicular OG. Produce OE to K. On OE and OK as diameters describe the two valve circles. With centre and radii equal to the given laps, describe the outside and inside lap circles. Then the intersection of these circles with the two valve circles give points through which the lines OH, OF, OQ, and OR can be drawn. These lines give the required positions of the crank.

Problem II.—Given the points at which the steam is to be admitted and cut off, and the exhaust to be opened, also the throw of the eccentric, find the proper angle of advance and the laps of the valve, also the point at which the exhaust closes.

Describe a circle AGA′, fig. 110, with radius equal to the half-throw of the eccentric, AA′ being the dead centres. Let

OF be the crank angle when steam is cut off, OQ when the exhaust opens, OH when the steam is admitted. Now the valve is in exactly the same position when the steam is admitted and cut off; consequently it reaches the end of its travel midway between these positions. Bisect the angle HOF by the line OE, then OE is the direction of the crank when the valve is at the end of its stroke; that is to say, the chord of the valve circle made by the line of direction of the crank will be a maximum at E, or in other words, OE is the diameter of the valve circle. Produce EO to K; on OE and OK describe the valve circles. Now the circle on OE intersects the line OF at the point *e*. Therefore O*e*=the outside lap. Similarly OQ intersects the circle on OK at the point *i*, therefore O*i* is the inside lap. Describe the two lap circles with radii O*e* and O*i*. The intersection of the smaller lap circle with the valve circle OK gives the direction of the crank OR when the exhaust closes. The line *cd* gives the lead, that is, the extent to which the steam port is admitted when the stroke commences.

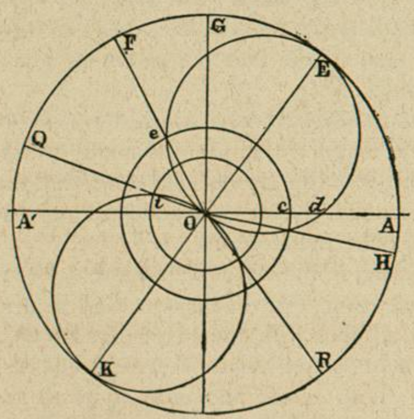

Fig. 110.

If the amount of the lead *cd* had been given instead of the angle of lead we should have had to proceed in a different manner.

First assume that there is no lead, but that the port opens when the crank is on the dead centre. Bisect the arc AOF at the point E′, fig 111. From E′ let fall the perpendicular

E′*c*′ on OA. From *c*′ mark off *c*′*d* equal to half the required lead. From *d* erect a perpendicular cutting the circumference in E. Mark off the arc EH equal to EF. Then OH is the required angle of lead. The remainder of the construction will be as before.

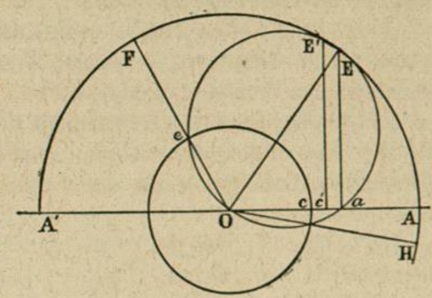

Fig. 111.

Another, and a very simple method of finding the position of the crank when steam is admitted, the amount of the lead being given, is to describe a small circle with centre A and radius equal to the amount of the lead. Call this the lead circle. From F draw a straight line tangential to the lead circle, and prolong it to meet the circumference of the circle AFA′ in the point H. Join OH, then OH is the required position of the crank.

Problem III.—Given the throw of the eccentric, the external lap, and the lead, find the point where the steam is cut off, and the angle of advance. Let OA=the half-throw. With this radius describe a circle. Let O*c* = the external lap. With this radius describe another circle. Let *cd* = the lead. From *d* erect the perpendicular *d*E, cutting the circumference of the outer circle in E. Join OE, and on OE as diameter

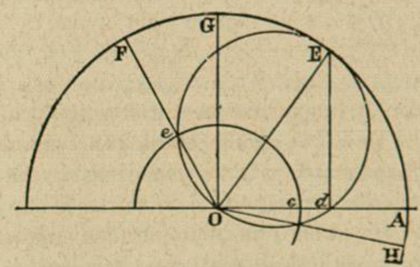

Fig. 112.

describe the primary valve circle. The angle GOE is the angle of advance, and the steam is cut off at the point F, obtained by joining O with the point of intersection of the primary valve and the lap circles.

PROBLEM IV.—Given the outside lap, the lead, and the point where the steam is cut off, find the throw of the eccentric and the angle of advance.

Let O*c*, fig. 112 = the external lap, *cd* = the lead, and OF the position of the crank when the steam is cut off. The problem then resolves itself into describing a circle *e*EO which shall pass through the three points *e*, O, *d*. The diameter of this circle OE gives the length and position of the half-throw of the eccentric, and the line OH gives the position of the crank when the steam is admitted so as to secure a lead = *cd*.

PROBLEM V.[1]—Given the position of the crank when the steam is cut off, the lead, and the amount the valve is to be open for any particular position of the crank, find the throw of the eccentric, the angle of advance, and the lap.

Let *c*E, fig. 113, represent the required lead, and *ca* the extent to which the port is to be opened when the crank occupies a position parallel to EG′. Also let EF′ be parallel to the position of the crank when steam is cut off.

Draw *cc*′ and *aa*′ at right angles to *ca* ; E*g* at right angles to EF′ ; E*b* at right angles to EG′, intersecting *aa*′ in the point *k*. Bisect the angles *gic*′, E*ka*′. The point O where the bisecting lines meet will be the centre of the lap circle.

Draw OA parallel to *ca*. OA will represent the direction of the cranks when on their dead centres. With centre O describe a circle to touch the two lines *ic*′, *ig*. The radius of this circle represents the lap. Join OE, and on OE as diameter describe the valve circle E*n*O. Then OE represents the half-throw and position of the eccentric. From O draw through the point of contact *e* of the lap circle with the line

[1] The very beautiful geometrical solutions of this and the two following problems are due to Mr. Cowling Welch.

E*g* the line O*e*F. Then O*e*F is evidently parallel to the line EF′, because it cuts *g*E at right angles. Also the point *e* is on the circumference of the primary valve circle because the angle O*e*E is a right angle, and as *e* is also on the circumference of the lap circle, therefore the steam is cut off when the crank is at OF parallel to the given direction EF.′

Also the lead is evidently equal to the given lead *c*E ; for, joining E*d*, we have the angle O*d*E in a semicircle equal to a right angle, therefore E*d* is parallel to *cc*′, and therefore *c*E equals the lead as shown by the part of OA intercepted

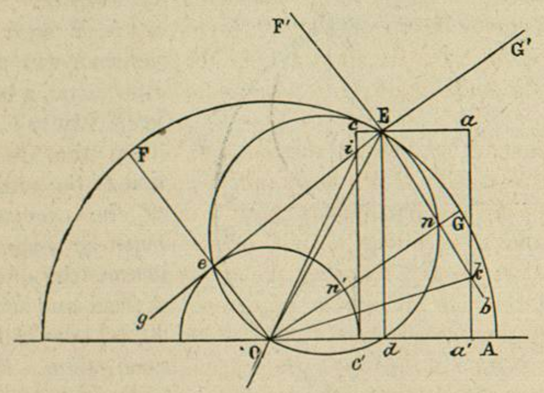

Fig 113.

between the circumferences of the lap and the primary valve circles.

Also through O draw OG parallel to EG′. Then *n*′*n* equals *c*′*a*′, because the two triangles *k*O*n*, *k*O*a*′ are equal, and as *c*′*a*′ equals *ca* by construction : therefore *n*′*n* equals *ca* as required, and all the conditions are fulfilled.

PROBLEM VI.—Given the lead, the angle at which the steam is cut off, and also the angles at which the release takes place and compression begins, find the angle of advance and thow of the eccentric, and the outside and inside laps of the valve.

This problem is useful in solving questions connected with Meyer's valve gear, in which the angles of release and compression, as well as the lead, are regulated by the main or distribution valve.

Take any point E in a horizontal line. Mark off E*c* equal to the lead, and draw EF′, EQ′, and ER′, parallel respectively to the positions of the crank when the steam is cut off, the release takes place, and the compression commences.

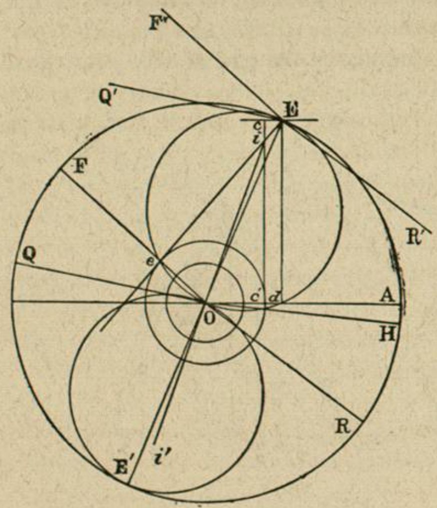

Fig. 114.

At *c* erect a perpendicular *cc*′. At E erect a perpendicular to EF′. Then the direction of the radius of the eccentric must lie halfway between the points of lead and cut-off, or, what is the same thing, between the points of release and of compression. Bisect the angle Q′ER′ by the line EE′. Bisect also the angle *c*′*ie* by the line *ii*′. Through the point O where these two lines intersect, draw the horizontal line OA. From O draw the lines OF, OQ, and OR parallel to EF′, EQ′, and ER′ respectively. Upon OE as diameter describe the primary valve circle. This will of necessity pass through *d*, because the angle O*d*E is a right angle. With centre O and radius O*c*′ describe the outer lap circle. This will of necessity pass through the point of intersection *e* of the valve circle with the line OF. Hence with the dimensions arrived at the lead will be *c*′*d* = *c*E, and the steam will be cut off at F. In order to provide for the release taking place at Q and for the compression commencing at R we have only to draw the other valve circle on OE′, and with centre O to draw the inner lap circle through the intersections of OQ and OR with the circumference of the circle OE′,

The following problem is of great practical utility in the design of steam engines.

Problem VII.—Given the position of the crank when the steam is cut off, the lead, and the maximum opening of the steam port, find the throw of the eccentric, the angle of advance, and the outside lap.

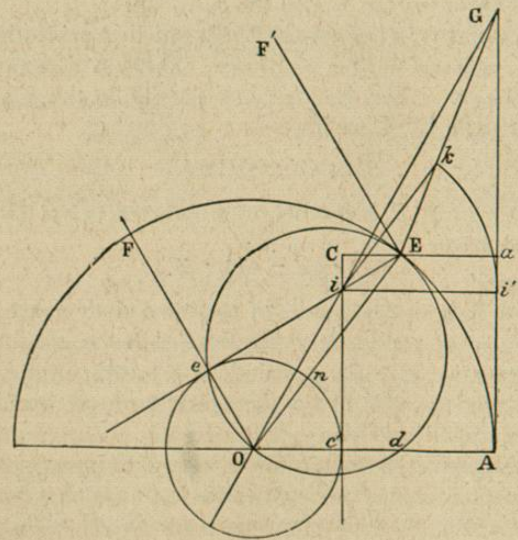

Fig. 115.

Let CE represent the given lead, and C*a* the maximum opening of the port. Let EF′ be drawn parallel to the direction of the crank when steam is cut off. Through C and a draw Cc' and GA at right angles to Ca, and from E draw Eie at right angles to EF′. Bisect the angle eic' by the line Oi, which produce till it intersects AaG in G. Join GE. With centre i and radius $= Ca$ describe an arc intersecting GE in k. Join ki, and from E draw EO parallel to ki, and intersecting iO in the point O. Then O is the centre of the lap circle. Through O draw OA parallel to Ca. With centre O and radius OA describe a circle. Join OE, and on OE as diameter describe the primary valve circle, and with O as centre describe the lap circle touching the line ie in e, and Cc' in c'. Join Oe and produce it to F. Then it can be proved, as in the last problem, that the steam is cut off when the crank occupies the position OF, which is parallel to EF′. Also that $c'd = CE$, the given lap.

It remains only to prove that nE, which is evidently the greatest opening of the port $= ca$. Through i drawn ii' parallel to ca. Then, because ik is parallel to the side OE of the triangle GOE, we have—

$$GO : Gi :: OE : ik.$$

Also, because ii' is parallel to the side OA of the triangle GOA, we have—

$$GO : Gi :: OA : ii'.$$

But $ii' = ik$, both being radii of the same circle; therefore also $OA = OE$; and subtracting from each the equal radii Oc' and On, we have the remainder $c'A = nE$. But $c'A$ is by construction equal to Ca, the maximum port opening; therefore also $nE = Ca$.

Before passing on to the consideration of the more complicated diagrams used to explain the action of expansion gears it may be useful to show how, from any diagram such as fig. 110, to set out the dimensions of the valve and ports. The valve travels to and fro on a plane surface, which is in general made of such a length that when the valve reaches the end of its beat, its edges do not overhang the end of the plane. Take any straight line AB, and suppose the valve to occupy

its central position. It will travel from this position in either direction by an amount equal to the radius of the eccentric. From A mark off AC equal to the radius OE, fig. 110. From C set off CD, equal to Oc, the radius of the lap circle. Now the greatest amount of opening which can be given to the steam port equals the diameter OE, *minus* the radius of the lap circle. From D, therefore, set off DE equal to this difference; this will be the width of the steam port. Next, to determine the width EF of the bridge between the steam and exhaust ports. It is evident that this width must be great enough to render it impossible for the outer edge of the valve, when at the right-hand end of its travel, to open the exhaust port to the fresh steam. Therefore the length CF

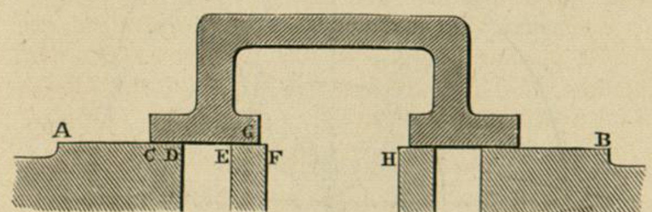

Fig. 116.

must in any case be greater than AC. The only other condition to observe in proportioning EF is that the bridge must be strong enough to withstand the pressure of steam upon it. If the width of the steam port has been properly set off as described, the above-mentioned contingency can never arrive, for the lap of the valve *plus* the width of the port, should together equal the travel. In the present instance the width is three quarters of that of the steam port. From E set off EG equal to the radius Oi of the inner lap circle, fig. 110. In proportioning the width of the exhaust port the principal point to remember is that it must never be throttled, when the valve is at the end of its travel, to such an extent as to affect the back pressure. It is consequently usual to make it of such a width, that when the