LEVER-GEARS FOR TRACTOR-PLOUGHS, I

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With tractor-ploughs, especially with deep-ploughing ones, plough-levers with toothed-arc are employed also in our days. The lever-gear of the Soviet rigol-plough is of the same construction.

The data employed in the computations to be reviewed here are such measurements as have been established with ploughs of several ploughshares used for normal ploughing. For this reason the maximum ploughing depth is taken 28 cm here. The method of computation itself, however, is a guide to establish appropriate measurements for deeper ploughing. The lifting out of the plough can be achieved by turning the stubble, furrow, and rear-wheels.

The deviation angle of the stubble-wheel crank-axle as compared with the vertical is determined by angle α in the initial, i.e. in the raised position by angle β giving the transport height, and by angle γ for ensuring the deepest ploughing.

The deepest ploughing with these ploughs is usually fixed at 28 cm. While the length of the crank-axle, according to measurements developed in practice, is fixed at 480 mm.

Roughly, the stubble-wheel axle can adopt the following positions (Fig. 1).

As in the earlier examples, it is not the lower positions of the wheel-felloe that are indicated, but the height of the hub for between the two there is a single constant difference, i.e. the diameter of the wheel.

So that the plough should fall back owing to its own weight, angle α has to be taken to be large enough, e.g. 20 degrees.

The transport free-height may be chosen as well. Recently it is taken as much higher with tractor-ploughs, while by earlier ploughs it was $sz =$ $= 80$ mm.

With these facts in hand the following relationships can be put down:

$$k - k \cdot \cos(\alpha + \beta + \gamma) = x + 80 + 280 \qquad (1)$$

but if $\alpha = 20°$

$$x = 480 - 480 \cdot \cos 20° = 480 - 451 \simeq 29 \text{ mm}$$

Because from the transport position to the soil the plough must still sink 80 mm

$$k - k \cdot \cos(20^\circ + \beta) = 29 + 80 = 109 \tag{2}$$

or substituting the value of k:

$$480 - 109 = 480 \cos(20^\circ + \beta)$$

Hence

$$\cos(20^\circ + \beta) = \frac{371}{480} = 0.773$$

and

$$20^\circ + \beta = 39^\circ 20'$$

$$\beta = 19^\circ 20' \approx 20^\circ$$

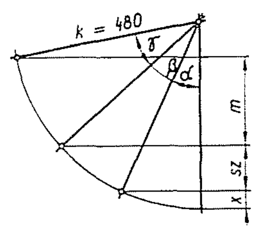

Fig. 1

Angle γ can also be computed in the same way.

$$k - k \cdot \cos(20^\circ + 20^\circ + \gamma) = 29 + 80 + 280 \tag{3}$$

$$480 - 480 \cdot \cos(40^\circ + \gamma) = 389$$

$$91 = 480 \cdot \cos(40^\circ + \gamma)$$

$$\cos(40^\circ + \gamma) = \frac{91}{480} = 0.1875$$

Hence

$$40^\circ + \gamma = 79^\circ 10'$$

$$\gamma = 39^\circ 10' \approx 40^\circ \ .$$

Thus $a + \beta + \gamma = 20 + 20 + 40 = 80^\circ$, i.e. from the transport position to the deepest ploughing the crank-axle has to turn 60°. This means that in case of deepest ploughing the crank-axle descends 10 degrees below the horizontal.

The lifting out of the plough is attained by a cogwheel of r_1 radius revolving jointly with the wheel rolling on the stubble (Fig. 2) and brought into connection with a toothed-arc of r_2 radius which is hinged to the plough-frame. This joing as well as the bearing of the crank-axle are firmly fixed to the frame and in the instant of contact the cogwheel and the toothed-arc form the two stationary joints of a four-jointed mechanism. According to the earlier empirical findings the places of both points are to be chosen in the established way and order, but with any chosen measurement.

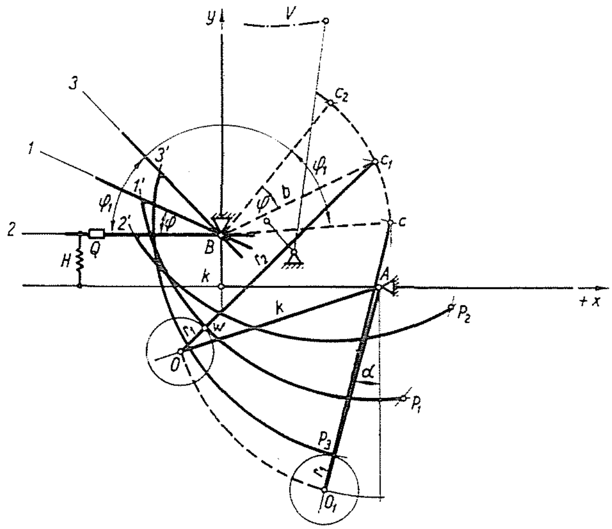

Fig. 2

In our case let the straight line passing through the bearing of the crank-axle be the x-axis, while the vertical passing through the centre of the joint of the toothed-arc be the y-axis of a co-ordinate system. The centrel point of the bearing of the crank-axle is marked A, its position in the co-ordinate system is determined by x_A and O co-ordinates. The centre of rotation of the toothed-arc being B, its co-ordinates are: O, y_B, while the distance of the two points is

$$t = \sqrt{x_A{}^2 + y_B^2}\,.$$

The length of the crank-axle, $OA = k$, had already been chosen earlier. But the rotating radius of the cogwheel revolving jointly with the wheel on O-axle, r_r, as well as that of the curvature of the toothed-arc, r_2, may be chosen freely.

If the lever mechanism is drawn according to these data in any position whatsoever, it can be seen that connecting the end point of r_2 radius, C_r, with B a four-jointed mechanism will be obtained, the stationary side of which is BA. The length of OC arm in any position is $r_1 + r_2$, while points C and O constantly change their positions.

The toothed-arc is always connected at the intersection of the circle with radius r_1 and straight line OC, i.e. the toothed-arc can be drawn in any position by drawing an arc with as radius r_2 around the respective centre C through the point of connection.

In the lowered position, i.e. in working position, the cogwheel and toothed-arc must not be in contact. While for hoisting the contact is attained by turning the lever of the second order holding the toothed-arc around its centre of rotation. In ploughing position the lever of the second order is in horizontal position, i.e. parallel with the plough-frame. Then there is no contact between the cogwheels and the toothed-arc. To attain contact it is necessary that the arm holding the toothed-arc should turn at a certain angle. This turning is achieved by exerting pressure from above with a roller up to the inner arm of the lever of the second order.

The geometrical conditions required can be stated as follows:

The position of the lever of the second order holding the toothed-arc which is brought about by the pressure of the roller in case of deepest ploughing is chosen freely. Let this be Position 1. Now the lever of the second order forms an angle of φ with the horizontal.

When lifting from ploughing position the contact point of the cogwheel and the toothed-arc, W, is freely chosen, then r_1 and r_2 are the values which were earlier chosen, point C_1 is obviously given. Drawing an arc around C_1 with radius r_2 its intersection with Position 1 of the lever of the second order gives Position 1′, the point of contact of the toothed-arc and the lever or the second order.

The virtual axle, BC, of the presumed four-jointed mechanism ($BCOA$) is fixed at a constant angle to the lever of the second order of the toothed-arc. This kind of connection cannot exist in reality; as the cogwheel and the toothed-arc can only contact when both radii (r_1 and r_2) coincide in a single straight line, therefore, $r_1 + r_2 = OC$ always form a single straight line. Thus, the point of contact (W) is also moving, consequently point C also changes its place. But point C can change its place only in case the lever of the second order also turns about the central point B. As the toothed-arc and its centre, C, are in firm connection with each other, point C must also turn at the same angle about B. Thus, the virtual axle turns at the same angle as that of the lever-arm.

Accordingly, if from Position 1. the lever of the second order achieves a state of rest by turning about at an angle of φ, BC_1 also turns about at an angle of φ and along arc $BC_1 = b$ the centre of the arc with radius r_2 goes over to C_2. When an arc is drawn around C_2 with radius r_2 the intersection of the arc with the lever of the second order, when in a vertical position, gives the point of contact 2′.

To determine the entire length of the toothed-arc it is necessary to draw the crank-axle along its whole raised position. For this purpose an arc with radius k shall be drawn around point A with O as its starting point till the vertical passing through A. There angle can be measured according to what was said earlier and the straight line AO_1 represents the crank-axle along its whole raised position.

Since the centre of the toothed-arc r_2 turns about point B with radius $BC_1 = BC_2 = b$, point C corresponding to position AO_1 can be found by drawing an arc with radius $r_1 + r_2$ around point O_1 then the intersection of this arc and of the circle with radius b gives point C.

As with the lever of the second order in its state of rest the centre of the toothed arc is to be found in C_2, to reach the wholly raised position point C_2 turns at an angle of φ_1, i.e. $C_2BC = \varphi_1$, the lever of the second order reaches its raised position as well by turning at an angle of φ_1. This is Position 3. The arc drawn with radius r_2 around point C cuts out point $3'$, thus the whole length of the toothed-arc extends from point $3'$ as far as the intersection of O_1C and the arc drawn around O_1 with radius r_1, accordingly the whole length of the arc is: $3'\ P_3$.

Axle O_1A in its raised position shall be fixed in a way to be shown later; the contact of the cogwheel and the toothed-arc must cease so that the cogwheel jointly rotating with the stubble-wheel should not contact the toothed-arc.

This can be attained by discontinuing the cogging and caulking the space. In this way the cog of the cogwheel shoves the toothed-arc away and the lever of the second order holding the toothed-arc tilts back into its horizontal position with the aid of H spring and Q counterweight. The end of the toothed-arc then comes in position P_2.

With the available geometrical relations the analytical relationships can also be established.

The position of point O in the co-ordinate system is determined by the intersection of the straight line passing throught point A at an angle of 10° to x-axis and the arc drawn around point A with radius k. The equation of the straight line 1., if $m = \text{tg } 10°$:

$$y = \text{tg } 10° \, (x - x_A) \tag{4}$$

While the equation of the circle:

$$k^2 = (x - x_A)^2 + y^2 \tag{5}$$

Hence the co-ordinates of point O, x_0 and y_0 can be obtained. Of the two pairs of values the suitable ones should be accordingly chosen.

According to what was previously said, r_1 and r_2 can freely be chosen, but since the centre of r_2 lies on the arc drawn around point B with radius b, it can be assumed that $b = k$ and an arc is drawn around O with radius $r_1 + r_2$. Where it intersects the arc with radius b point C_1 will be obtained. The intersection of OC_1 and the circle drawn around point O with radius r_1 gives the momentary point of contact, W.

The co-ordinates of point C_1 are derived from the intersection of the two circles; the equations are:

$$b^2 = x^2 + (y - y_B)^2 \ . \tag{6}$$

Since $x_B = O$ and

$$(r_1 + r_2)^2 = (x - x_B)^2 + (y - y_0)^2 \ . \tag{7}$$

Solving the equation two intersections of the two circles are obtained. The pair of values should be chosen where the given straight line AC_1 is the shorter. These co-ordinates will be x_{C_1} and y_{C_1}.

It has been stated, there is neither the arm OC nor the arm BC in reality. Arm OC is replaced by the contact of the cogwheel with radius r_1 and the toothed-arc with radius r_2 that points out direction OC.

With the motion of the point of contact, W, the direction of OC is also changing and centre r_2 is shifting accordingly. Thus, the toothed-arc also turns. The toothed-arc being firmly fixed to the lever of the second order its turn causes the lever of the second order to turn, too.

If the centre of rotation of the lever of the second order, B, were connected with point C in reality, i.e. BC were a real shaft, according to what was said earlier, it would turn at the same angle as the lever of the second order. By assuming the shaft $CB = b = k$ the angle of inclination of the toothed-arc to the lever of the second order is determined.

Point C_1 is, for this reason, the place of the centre of curvature of the toothed-arc in the moment the lifting starts. This moment, however, sets in only when the cogwheel and the toothed-arc come into contact. This contact can be attained by moving the lever of the second order from its Position 2. and turning it at an angle of φ.

The turn of the lever of the second order is done by pressing down its inside shorter arm. This is performed by the tractor-driver himself by pulling a V-rope (Fig. 3). This V rope turns the lever of the second order about point S together with roller G. The roller exerts pressure on the shorter arm of the lever of the second order.

In state of rest roller G does not lie on the shorter arm of the lever of the second order only when the lifter has turned at an angle of ε. After a further turn at an angle of ε_1 the lever of the second order performs a turn at an angle of φ. Between ε_1 and φ the following relation can be found:

Let the given straight line SG be equal to s. Presuming the former co-ordinate system, the equation of the straight line passing through point B parallel with x-axis (i.e. the equation of the straight line denoting the state of rest of the lever of the second order) is:

$$y = y_B \; .$$

That of the straight line after a turn at an angle of φ (at the instant of lifting out):

$$y = \operatorname{tg} \varphi \cdot x + y_B \; . \tag{8}$$

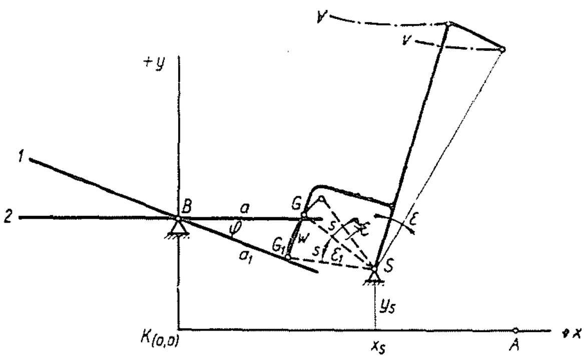

Fig. 3

Of the intersections of both straight lines and the circle around point S drawn with radius s, the smaller pair of values belonging to the ordinate give the co-ordinates of G and G_1. The equation of the circle in question is:

$$s^2 = (x - x_s)^2 + (y - y_s)^2 \; . \tag{9}$$

The coordinates of point S can freely be chosen. The required length a of the shorter arm of the lever holding the toothed-arc can be computed from the following relation:

$$a_1^2 = x_{G_1}{}^2 + (y_B - y_{G_1})^2 \, . \tag{10}$$

As $GG_1 = u$ can also be computed being

$$u^2 = (x_G - x_{G_1})^2 + (y_G - y_{G_1})^2 \, . \tag{11}$$

Angle ε_1, the required turn of arm s, can also be computed:

$$\sin \frac{\varepsilon_1}{2} = \frac{u}{2s} \; . \tag{12}$$

Now the inclination of the lever of the second order is φ and thus the toothed-arc contacts the cogwheel.

Moreover, the angle of inclination of the toothed-arc must be known at the point of contact of the toothed-arc and the lever of the second order, 1'.

This is given by the angle of the tangent drawn to the arc at the intersection. For its determination let us take the equation of the straight line for the lever of the second order at the very instant of contact. Thus is nothing but the straight line passing through point B at an angle of φ. Its equation is:

$$y = \operatorname{tg} \varphi . x + y_B . \tag{13}$$

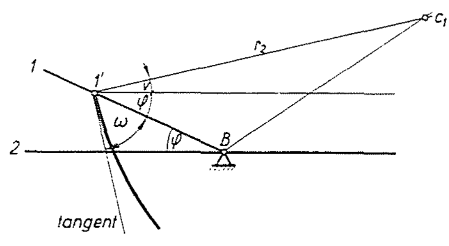

Fig. 4

Point 1' on it at a distance of r_2 from C_1 can be found. Let us take, therefore, the equation of the circle around the centre C_1 with radius r_2.

$$r_2^2 = (x - x_{C_1})^2 + (y - y_{C_1})^2 \tag{14}$$

Of the two possible solutions let us choose the pair of values where the circle cuts the lever of the second order on the left side. It will be x_1 and x_2 co-ordinates of point 1'.

The given straight line C_1 1' is radius r_2 itself, and the equation of its straight line gives the tangent of direction (Fig. 4). The equation of the straight line passing through points C_1 and 1' is

$$y - y_{C_1} = \frac{y_{1'} - y_{C_1}}{x_{1'} - x_{C1}} \cdot (x - x_{C_1}). \tag{15}$$

The straight line perpendicular to it and passing through point 1' is accordingly the tangent to the circle at point 1'.

Its tangent of direction is:

$$\frac{x_{C_1} - x_1'}{y_{C_1} - y_1'}$$

while the equation of the tangent is:

$$y - y_{1'} = \frac{x_{C_1} - x_{1'}}{y_{C_1} - y_{1'}} \cdot (x - x_{1'}) . \tag{16}$$

Thus, the angle of inclination of both straight lines can also be analytically computed. It is, however, more simply executed as follows:

The angle of inclination of straight line $C_1\,1'$ to axis-x is ϑ, where:

$$\operatorname{tg} \vartheta = \frac{y_{C_1} - y_{1'}}{x_{C_1} - x_{1'}} . \tag{17}$$

The angle sought for is the inclination of the tangent to the toothed-arc and the lever of the second order, ω. It can be obtained from the following relationship:

$$\omega = 90^\circ - \vartheta - \varphi .$$

Moreover, the length of the toothed-arc is to be established, i.e. arc $3'\,P_3 = 2'\,P_2$ (Fig. 2). For this purpose the raised position of the plough is to be taken, where the axle of the stubble-wheel is at an angle of $\alpha = 20^\circ$ to the perpendicular line passing through point A. In this case the equation of the straight line of the crank-axle is nothing but the equation of the straight line passing through point A at an angle of $90^\circ - \alpha$ to axis-x:

$$y = \frac{1}{\operatorname{tg} \alpha} \cdot (x - x_A) . \tag{18}$$

The intersection of this equation and the circle with radius r_2 around point A as its centre gives the co-ordinates of O_1. The equation of the circle is:

$$k^2 = (x - x_A)^2 + y^2 . \tag{19}$$

Of the two intersections that with negative co-ordinates on axis-x is chosen, i.e. the lower intersection. These values will be x_{O_1} and y_{O_1}.

Now the centre of the toothed-are becomes C. Its co-ordinates are given by the intersection of the circles drawn from point B with $b = k$ radius and from point O_1 with radius $r_1 + r_2$. As both circles have two intersections, those values are chosen where the co-ordinates on axis-x are higher.

The equations of both circles are:

$$k^2 = x^2 + (y - y_B)^2 \tag{20}$$

$$(r_1 + r_2)^2 = (x - x_{O_1})^2 + (y - y_{O_1})^2 . \tag{21}$$

The co-ordinates of point C will be: x_C and y_C. In Fig. 2 can be seen, when the crank-axle has an inclination to the vertical at an angle of α, i.e. the end-point of the toothed-arc contacts the cogwheel, the lever of the second order has turned from the horizontal position at an angle of φ_1. But b (imaginary) shaft has also come from BC_2 position to position BC by turning at an angle of φ_1.

The co-ordinates of C_2 are not known yet. $\overline{C_1C_2}$ can, however, be computed since angle φ was freely chosen. Therefore, it is a known value. Thus from the equilateral triangle belonging to it:

$$\sin \frac{\varphi_2}{2} = \frac{\frac{\overline{C_2C_1}}{2}}{b} \tag{22}$$

and

$$\overline{C_2C_1} = Z = 2b \cdot \sin \frac{\varphi}{2} .$$

The circle drawn from C_1 with radius Z intersects the circle drawn from B with radius b. The equations of both circles are:

$$Z^2 = (x - x_{C_1})^2 + (y - y_{C_1})^2 \tag{23}$$

$$b^2 = x^2 + (y - y_B)^2 \tag{24}$$

Of the two intersections that with greater co-ordinates on y-axis are chosen, thus the co-ordinates of C_2 are obtained, x_{C_2} and y_{C_2}.

Since arm b comes from BC_2 position in BC position by turning at an angle of φ_1, angle φ_1 can be computed as well.

If $\overline{C_2C} = Z_1$ then

$$\sin \frac{\varphi_1}{2} = \frac{\frac{Z_1}{2}}{b}$$

where

$$Z_1^2 = (x_{C_2} - x_C)^2 + (y_{C_2} - y_C)^2 . \tag{25}$$

Accordingly, the equation of the lever of the second order in Position 3 can also be set down because compared with the horizontal it also turned at an angle of φ_1.

$$y = \operatorname{tg} \varphi_1 \cdot x + y_B . \tag{26}$$

The intersection of this straight line and the circle drawn from point C with radius r_2 gives $3'$ point, where the toothed-arc starts out from the lever of the second order, i.e. the co-ordinates of the starting point of the toothed-arc.

The equation of the circle is:

$$r_2^2 = (x - x_C)^2 + (y - y_C)^2. \tag{27}$$

It is obvious that here too two intersections are obtained. Of these that with greater co-ordinates on y-axis will be chosen; thus x_3, and y_3, co-ordinates are obtained. But the intersections of the very same circle and the straight line passing through points O_1 and C furnishes the co-ordinates of P_3, the equation of the straight line is:

$$y - y_{O_1} = \frac{y_C - y_{O_1}}{x_C - x_{O_1}} \cdot (x - x_{O1}). \tag{28}$$

Since this system of equation has also two solutions, it can be seen (Figure 2) that the pair of values is to be chosen where the co-ordinates on y-axis are smaller, i.e. falling in the lower area. Thus, x_{P_3} and y_{P3} co-ordinates can be obtained.

To find the length of the toothed-arc $3'\,CP_3 \sphericalangle = \xi$ shall be known. Chord $\overline{3'\,P_3} = Z_2$ can be computed from

$$Z_2^2 = (x_{P_3} - x_{3'})^2 + (y_{P_3} - y_{3'})^2 \tag{29}$$

Hence from the equation

$$\sin \frac{\xi}{2} = \frac{\frac{Z_2}{2}}{r_2} \tag{30}$$

ξ can be computed. Accordingly, the length of the toothed-arc:

$$i = 2\,\pi \cdot r_2 \cdot \frac{\xi}{360^\circ} = \frac{\pi \cdot r_2 \cdot \xi}{180^\circ}. \tag{31}$$

As soon as the cogwheel has run the length i of the toothed-arc, the plough will come in to a raised position and the cogwheel — toothed-arc contact well cease because the toothed-arc has no cogs further on being caulked, and thus the cogs of the cogwheel push the toothed-arc away. In consequence the spring and the counterweight will pull the lever of the second order as well as the toothed-arc in to Position 2.

The raised position of the plough, however, must be upheld, therefore the crank-axle must be fixed in this lifted position. The fixing in position is done by clutching arm b wedged into the horizontal part of the crank-axle with handle k (Fig. 5).

The geometrical conditions for the proper working of the mechanism are established as follows:

The angle formed by arm b and axis $AO = x$ can freely be chosen; similarly also the length of arm b.

In ploughing position cam g at the end of arm b is not in contact with anything; on lifting out, however, it lies down upon face a of arm k and turns arm k around pin S whereby spring r tightens. When the plough has just

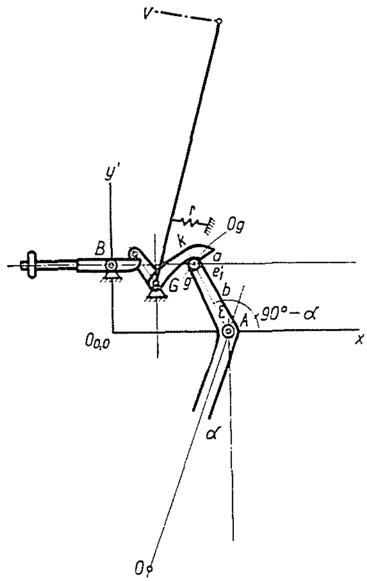

Fig. 5

reached its lifted position, face a of arm k will also come to an end and a gap with a radius equal to that of the curvature of cam g begins. Spring r then pulls arm k back and its gap reclines on the $^1/_4$ surface of cam g. The rest of the gap of arm k is equal to the arc drawn with radius Ae' around point A. Thus, if the toothed-arc turns crank-axle AO somewhat further away, no break occurs. The lowering of the plough is done by pulling rope V, whereby arm k moves against spring r and the weight of the plough turns away axle AO standing at an angle of ε, i.e. the plough falls from its raised position.

On pulling rope V point e_1, of arm k has to turn around pin S at such an angle that arm $\overline{Ae'} = b + r_g$ should pass through under it.

The co-ordinates of points A and S have already been computed; arm b and the radii of the cam, r_g, as well as the angle formed by arm b and axle AO, $180 - \varepsilon$, were freely chosen. The co-ordinates of point e' are obtained if the circle drawn around point A with radius $b + r_g$ is cut by the straight line passing through point A and forming an angle of $90° - a + \varepsilon$ with x-axis.

The equation of the circle is:

$$(b + r_g)^2 = (x - x_A)^2 + y^2. \tag{32}$$

The equation of the straight line:

$$y = \text{tg}\,(90° - \alpha + \varepsilon) \cdot (x - x_A) = \frac{1}{\text{tg}\,(\alpha + \varepsilon)} \cdot (x - x_A). \tag{33}$$

Of the two solutions of the equation system the greater pair of values belonging to y-coordinate is to be chosen, this gives the co-ordinates of e', i.e. x_e, and y_e. The straight line passing through the centre of cam g and perpendicular to straight line Ae' gives the equation of edge-line a. The intersection of this straight line and the circle around point O_g with radius g gives us the co-ordinates of e'. The co-ordinates of point O_g are obtained as shown in Figure 6.

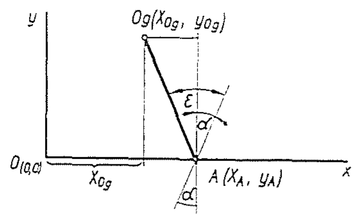

Fig. 6

$$x_{Og} = x_A - b \cdot \sin(\varepsilon - \alpha)$$

$$y_{Og} = b \cdot \cos(\varepsilon - \alpha)$$

The equation of the circle around O_g with radius g:

$$g^2 = (x - x_{Og})^2 + (y - y_{Og})^2. \tag{34}$$

The equation of the straight line perpendicular to arm b and passing through point O_g is:

$$y - y_{Og} = \frac{x_A - x_{Og}}{y_{Og}} \cdot (x - x_{Og}). \tag{35}$$

Since two solutions are obtained here too, the greater pairs of values of x and y are chosen. These will be $x_{e_1'}$ and $y_{e_1'}$. Since e' is the extreme outside point of the cam as well as of arm b, while e_1' is the innermost point of the handle-arm, the contact of both contact-parts ceases as soon as e' coincides with e_1'. It comes to be when the circle drawn with radius S_{e_1}' cuts the circle with radius Ae'. If $S_{e_1}' = k$ the equation of the two circles are:

$$k^2 = (x - x_s)^2 + (y - y_S)^2 \tag{36}$$

$$(b + r_g)^2 = (x - x_A)^2 + y^2 \ . \tag{37}$$

Of the two intersections the greater x and y pairs of values are chosen which give the co-ordinates of the last point of contact of both arms, i.e. x_u and y_u. That arm b, however, should pass under the edge, arm k must turn at a definite angle. The measure of the turn can be computed as follows (Fig. 7).

$$\frac{\frac{Z_u}{2}}{k} = \sin \frac{\xi}{2} \ . \tag{38}$$

Angle ξ thus obtained need not be equal to angle ε, shown in Figure 3, at which roller G and its arm

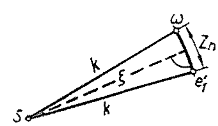

Fig. 7

shall turn in order to lie down upon the arm of the lever of the second order, but it can be less than that, i.e. $\xi < \varepsilon$.

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