SYNTHESIS OF ROLLING PAIRS BY ACR-LIKE DISPLACEMENTS OF THE CENTER OF ROTATION OF MOVABLE SHAFT

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***Abstract*:** A solution of the problem of geometric synthesis of certain schemes of rolling pairs with arc-like displacement of the center of rotation of movable shaft is considered in the paper. A set-up and a principle of operation of above-mentioned rolling pairs are given and their numerous schemes are briefly analyzed. Two most frequently used schemes are chosen and methods of their geometric synthesis in determination of optimal geometric parameters are shown in dependence of technological requirements demanded of these rolling pairs, that is, in determination of the length of radius of the arc, along which the center of rotation of movable working shaft is displaced with account of the thickness of processed material and given displacement of the axes of rotation of free working shafts from vertical line crossing the axes of rotation of rotating working shaft.

Key words: Synthesis, rolling pair, transmission mechanism, working shaft, roller machine, arc-like displacement.

1. INTRODUCTION

A number of scientists are working on development of rolling technological machines, such as: Kuznetsov G.K., Smirnov B.I., Fomin Yu.G., Pod'yachev A.V., Lodoin U. and others (Kuznetsov, 1970; Smirnov, 1980; Fomin, 2001; Pod'yachev, 2003; Lodoin 2006). A review and analysis of scientific-research studies in the field of the theory of roller machines, used in different spheres of economy, show that in the bases of the most of roller machines lay rolling pairs with one of working shaft (hereinafter rotating working shaft) with axial rotation, forming rotating pair with the base box, and the second working shaft, which besides axial rotation, performs reciprocal motion along the arc with certain radius of curvature relative to rotating working shaft (hereinafter movable working shaft) (Burmistrov, 2006; Bakhadirov, 2010; Abdukarimov, 2012). A generalized rolling pair is shown in Fig. 1.

This rolling pair consists of a base box *0*; working shafts *1* and *2*; a lever *3*. In such rolling pairs during technological process, when processed material *4* passes working shafts, the center of rotation O_2 of movable working shaft *2* is displaced in both vertical and horizontal lines on a certain value Δ relative to the center of rotation O_1 of rotating working shaft *1*. Depending on the purpose and structural features of machines the path of this displacement may be different. According to location of this path relative to vertical line, crossing the axis of rotation O_1 of rotating roll *1* and relative to horizontal line crossing the center of rotation O_3 of a lever *3*, rolling pairs may be divided into numerous types. As the location and the size of this path influences on many technical and operational characteristics of machines, it is reasonable to thoroughly analyze the types of location of these paths relative to vertical line crossing the axis O_1 of rotating shaft and relative to horizontal line crossing the axis of a lever, which fixes movable working shaft to base box O_3. The place of location of this path during technological process depends on initial location of working shafts before the beginning of technological process, when working shafts are in reciprocal contact.

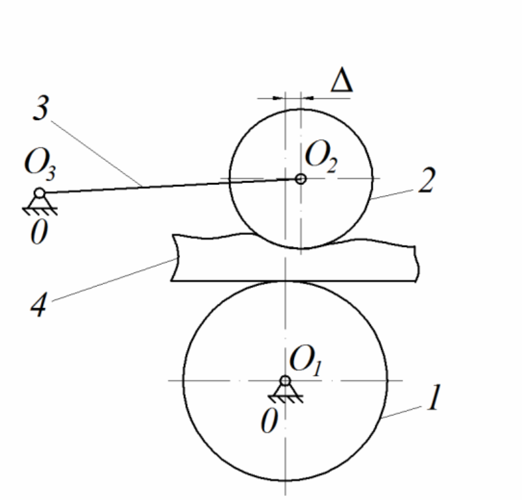

Fig. 1. Scheme of rolling pair with the center of movable working shaft displaced along the arc of circle: *1* – rotating working shaft; *2* – movable working shaft; *3* – lever; *4* – processed material; O_1, O_2, O_3 – axes of rotation

There are nine characteristic types where working shafts are in reciprocally contacting location (Fig. 2).

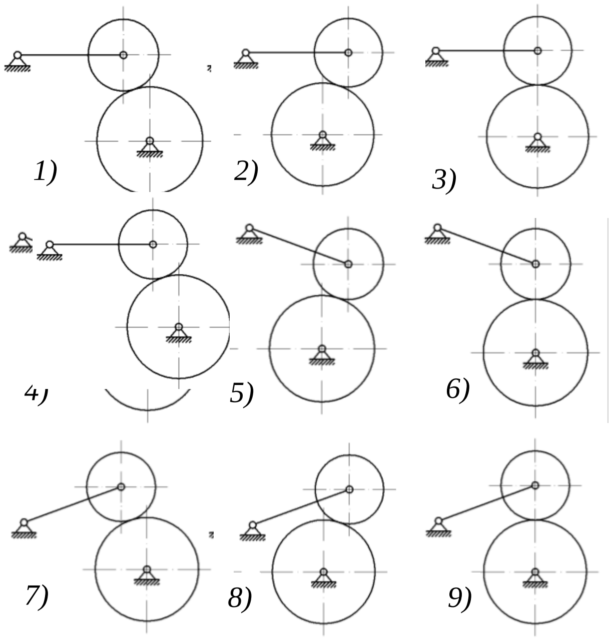

Fig. 2. Schemes of reciprocal location of working shafts before the beginning of technological process, when working shafts are in reciprocal contact

These locations relative to vertical line crossing the axis of rotation of rotating working shaft present three characteristic types:
1. Axis of rotation of movable working shaft is located prior to vertical line of feeding of processed material (Fig. 2., 1), 4), 7));
2. Axis of rotation of movable working shaft is located behind vertical line of feeding of processed material (Fig. 2., 2), 5), 8));
3. Axis of rotation of movable working shaft is located along vertical line (Fig. 2., 3), 6), 9)).

Each of these three characteristic types depending on location of the center of rotation of movable working shaft relative to horizontal line crossing the axis which fixes the lever to base box, has three characteristic types:
1. Axis of rotation of movable working shaft is located along horizontal line (Fig. 2., 1), 2), 3));
2. Axis of rotation of movable working shaft is located lower than horizontal line (Fig. 2., 4), 5), 6));
3. Axis of rotation of movable working shaft is located higher than horizontal line (Fig. 2., 7), 8), 9)).

All these nine types occur in feeding of processed material both from the side of lever position and from opposite side of lever position. So, there may be eighteen types of possible characteristic types of location of movable working shaft relative to rotating shaft.

During technological process depending on chosen schemes of reciprocal location of working shafts prior to technological process, the place of location of the path of the center of rotation of movable working shaft may have twenty five options, and relative to vertical line crossing the axis of rotation of rotating working shaft, has five characteristic types:
1. The path is located prior to vertical line of feeding of processed material;
2. The path is located prior to vertical line of feeding of processed material, but it has a point of contact with vertical one;
3. The path is located behind vertical line of feeding of processed material;
4. The path is located behind vertical line of feeding of processed material, but it has a point of contact with vertical line;
5. The path is located on both sides of vertical line.

Each of these five characteristic types of the places of location of the path of the center of rotation of movable working shaft depending on location of the center of rotation of movable working shaft relative to horizontal line crossing the axis which fixes the lever to base box, also has five characteristic types:
1. The path is located on both sides of horizontal line;
2. The path is located in upper part of horizontal line, but it has a point of contact with this horizontal line;
3. The path is located in lower part of horizontal line, but it has a point of contact with this horizontal line;
4. The path is located in upper part of horizontal line;
5. The path is located in lower part of horizontal line.

Taking into account the feeding of processed material from the side of lever location or from the opposite side of lever location, characteristic points of location of the path of the center of rotation of movable working shaft relative to vertical line crossing the axis of rotation of rotating working shaft and relative to horizontal line crossing the axis which fixes the lever to base box, may have fifty options.

In scientific literature the theories of roller machines with constant inter-axial distance of working shafts and theories of roller machines with rectilinear motion of the center of rotation of movable working shaft are mainly considered (Burmistrov, 2006; Bakhadirov, 2010; Abdukarimov, 2012), as for roller machines with arc-like displacement of the center of rotation of movable working shaft – they are not deeply studied. Thus carried out analysis encourages a detailed development of the theory of roller machines and gives a possibility to outline the directions of scientific investigation in this sphere aimed to create a new highly effective technological roller machine. The development of the method of design of roller machines with arc-like displacement of free working shaft on the whole, and its synthesis in particular, presents an actual problem in creation of modern highly effective roller machines. Development of a new roller machine with arc-like displacement of free working shaft, elaboration of new transmission mechanisms, design of the methods of analysis and synthesis of these machines and mechanisms – are the aims of our investigation in the future.

2. GEOMETRIC SYNTHESIS OF ROLLING PAIRS WITH ARC-LIKE DISPLACEMENT OF THE CENTER OF ROTATION OF MOVABLE WORKING SHAFT

In the most of roller machines a rolling pair shown in Figure 1 is used: one of working shafts *1* rotates on axis O_1, which forms rotating pair with base box *0*, and the second working shaft *2* rotates on axis O_2, which is connected on hinges to base box with lever *3* on axis O_3 (Burmistrov, 2006; Bakhadirov, 2010; Abdukarimov, 2012). In this rolling pair at the moment of change of inter-axial distance of working shaft O_1O_2 the center of rotation of movable working shaft O_2 is displaced from vertical line crossing the axis of working shaft *1*, axes of rotation of the latter O_1 form rotating pair with base box *0* on a certain distance Δ. This displacement may be: 1) in the direction of feeding of processed material *4* only; 2) in opposite direction of feeding of processed material *4* only; 3) combined one in both directions.

Besides in these rolling pairs before the beginning of technological process, that is, in the absence of processed material *4* between working shafts, the center of rotation of movable working shaft initially may be displaced on a certain value Δ_1 in direction of feeding of processed material (Fig. 3, *a*) or on a certain value Δ_2 in direction opposite to feeding of processed material (Fig. 3, *b*). This displacement also may be equal to zero (Fig. 3, *c*).

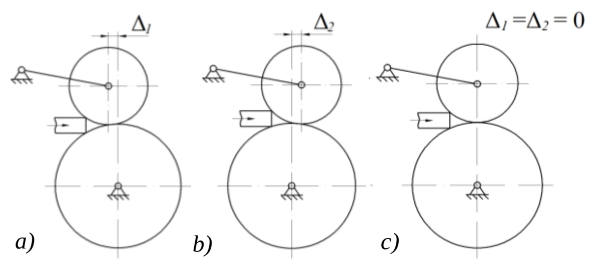

Fig. 3. Types of initial displacements in rolling pairs: *a)* displacements in direction of feeding of processed material; *b)* displacements in opposite direction of feeding of processed material; *c)* the case without displacement

The value of each of these three types of displacements occur in three characteristic locations of a lever: the lever is located in horizontal line crossing the axis which fixes this lever to base box; higher than horizontal line and lower than it.

The presence, character and values of changes of these displacements have an effect on the procedure of technological process, namely: the quality of grip of material by rolling pair; the quality of processed material after processing; the durability of technological machine and its elements. That is why the synthesis of geometrical parameters of rolling pair, which provides the running of technological process with allowable values and types of displacements, presents an actual problem.

Consider rolling pair corresponding to above-mentioned scheme, with the following geometrical parameters: radii of working shafts R_1 and R_2 respectively; possible maximal thickness of processed material, located in the zone of processing δ_1, which leads to the change in inter-axial distance O_1O_2 of working shafts. Let rolling pair satisfy the following conditions:

1. Before the beginning of technological process the displacement should be equal to zero, that is, $\Delta_2=0$.
2. At the moment of operation of technological process movable working shaft may be displaced in direction opposite to feeding of processed material on a value no greater than a certain maximal value of Δ.

This problem assumes two approaches to solutions satisfying the second aspect of given conditions:

1. In operation of technological process when the change of inter-axial distance reaches its maximal value, the displacement Δ is changed from zero to its maximal value.
2. In operation of technological process when the change of inter-axial distance reaches its maximal value, the displacement Δ is changed from zero to its maximal value and then back to zero.

2.1 The first approach to solution of the problem of synthesis

Consider the first approach. Figure 4 shows design scheme for estimation of geometric parameters of rolling pair, corresponding to mentioned above first conditions. As seen from the scheme, to satisfy given conditions the center of rotation of the lever *3* (O_3) should be placed on the side of feeding of processed material *4* on the distance δ_1 from horizontal line crossing the axis O_2, that is:

$$mO_3 = \delta_1 \tag{1}$$

Solving the triangle kO_2O_3, we determine minimal length of a lever *3* satisfying above conditions:

$$(L-\Delta)^2 + \delta_1^2 = L^2 \tag{2}$$

where *L* – is a length of a lever.

$$L^2 - 2\Delta L + \Delta^2 + \delta_1^2 - L^2 = 0 \tag{3}$$

$$2\Delta L = \Delta^2 + \delta_1^2 \tag{4}$$

$$L = \frac{\Delta^2 + \delta_1^2}{2\Delta} \tag{5}$$

$$\beta = \arcsin\left(\frac{\delta_1}{L}\right) \tag{6}$$

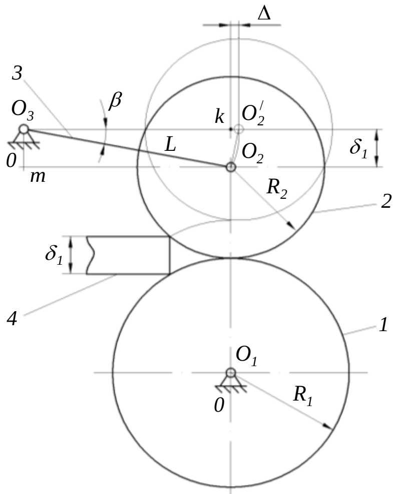

Fig. 4. Design scheme of rolling pair to determine the location and the length of a lever for the first approach to solution of the problem

To provide the value of displacement Δ no greater than the one given by conditions of the problem, planned length (L_n) of a lever *3* should be no less than the one obtained by formula (5)

$$L_n \geq L \tag{7}$$

2.2 The second approach to solution of the problem of synthesis

Consider the second approach. Fig. 5 shows design scheme for estimation of geometric parameters of rolling pair, corresponding to mentioned-above second conditions.

As seen from the scheme, to satisfy given conditions the center of rotation of a lever *3* (O_3) should be placed similar to the first case on the side of feeding of processed material *4* on the distance $\delta_1/2$ from horizontal line, crossing the axis O_2, that is

$$mO_3 = \frac{\delta_1}{2} \tag{8}$$

Solving the triangle nO_2O_3, we determine minimal length of a lever *3*, satisfying above mentioned conditions:

$$(L-\Delta)^2 + \left(\frac{\delta_1}{2}\right)^2 = L^2 \tag{9}$$

$$L^2 - 2\Delta L + \Delta^2 + \frac{\delta_1^2}{4} - L^2 = 0 \tag{10}$$

$$2\Delta L = \Delta^2 + \frac{\delta_1^2}{4} \tag{11}$$

$$L = \frac{4\Delta^2 + \delta_1^2}{8\Delta} \tag{12}$$

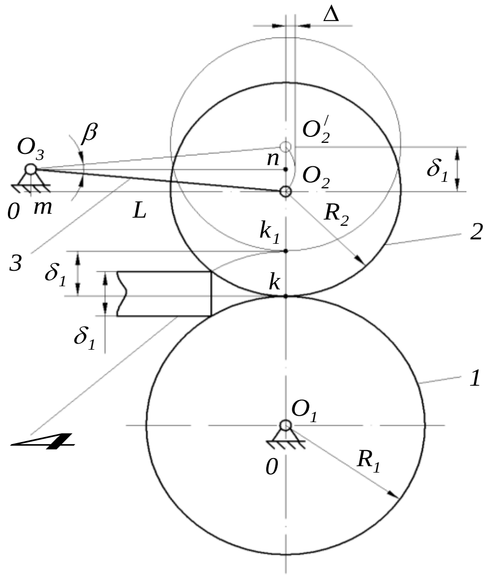

Fig. 5. Design scheme of rolling pair to determine the location and the length of a lever for the second approach to solution of the problem

$$\beta = 2\arcsin\frac{\delta_1}{2L} \tag{13}$$

In this case to provide the value of displacement Δ no greater than the one given by conditions of the problem, planned length of a lever *3* should be no less than the one obtained by formula (12)

$$L_n \geq L \tag{14}$$

Solving equations (5) and (12) relative to the thickness of processed material δ_1 we will get

$$\delta_{1(3)} = \sqrt{2\Delta L - \Delta^2} \tag{15}$$

$$\delta_{1(4)} = \frac{\sqrt{2\Delta L - \Delta^2}}{2} \tag{16}$$

here $\delta_{1(3)}$ – is a possible thickness of processed material according to the scheme, given in Figure 4;

$\delta_{1(4)}$ – possible thickness of processed material according to the scheme, given in Figure 5.

Analysis of formulae (15) and (16) demonstrates that with similar lengths of levers and similar acceptable displacements in rolling pair, designed by the scheme in Fig. 4, it is possible to process material with two times greater thickness than in rolling pair designed by the scheme, given in figure 4.

Figures 6 and 7 show the graphs of dependences of the thickness of processed material δ_1 on the length of a lever L under different values of Δ for schemes of rolling pairs, shown in figures 4 and 5.

Solving equations (5) and (12) relative to appearing displacement Δ, we will get:

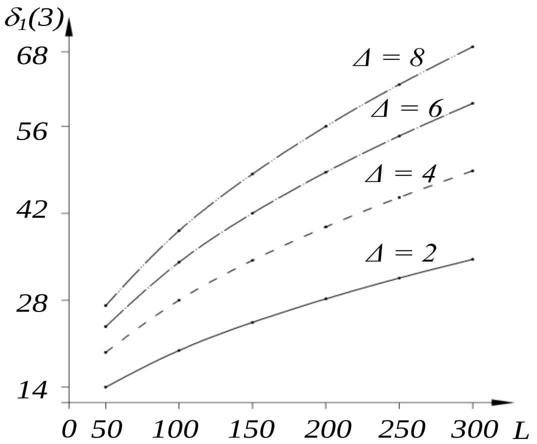

Fig. 6. Graph of dependence of $\delta_1(3)$ on L under different values of Δ for a scheme, given in Fig. 4

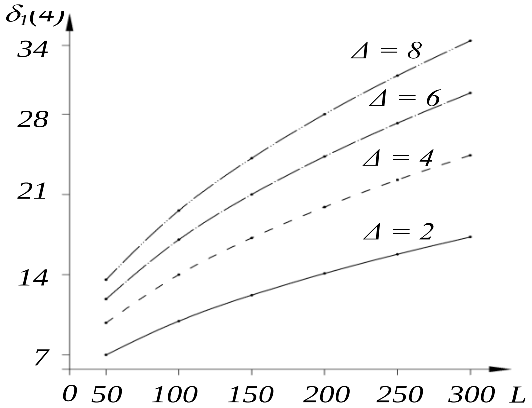

Fig. 7. Graph of dependences of $\delta_1(4)$ on L under different values of Δ for a scheme, given in Fig. 5

$$\Delta_{(3)}^2 - 2L\Delta_{(3)} + \delta_1^2 = 0 \qquad (17)$$

$$\Delta_{(4)}^2 - 2L\Delta_{(4)} + \left(\frac{\delta_1}{2}\right)^2 = 0 \qquad (18)$$

where Δ(3) – is a displacement by the scheme, given in Fig. 4; Δ(4) – is a displacement by the scheme, given in Fig. 5.

Solution and analysis of quadratic equations (17) and (18) show that with similar parameters of rolling pair and similar parameters of the change in thickness of processed material in rolling pair, designed by the scheme, given in Fig. 5, the displacement will be approximately four times less than in rolling pair designed by the scheme, given in Fig. 4.

Real roots of equations (17) and (18) are:

$$\Delta_2(3) = L - \sqrt{L^2 - \delta_1^2} \qquad (19)$$

Figures 8 and 9 show the graphs of dependences of displacement of the center of rotation of movable working shaft (Δ2) relative to vertical line crossing the axes of rotation of rotating working shaft in dependence on the length of a lever (L) and the thickness of processed material (δ1) under different values of δ1 for the schemes of rolling pairs, given in Fig. 4, 5.

$$\Delta_2(4) = L - \sqrt{L^2 - \left(\frac{\delta_1}{2}\right)^2} \qquad (20)$$

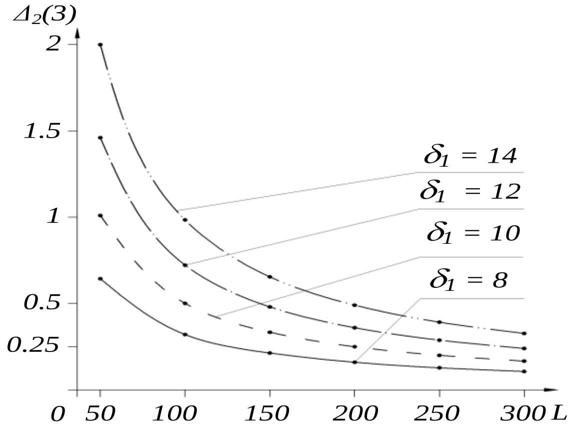

Fig. 8. Graphs of dependence of $\Delta_2(3)$ on L and δ_1 under different values of δ_1 for the scheme, given in Fig. 4

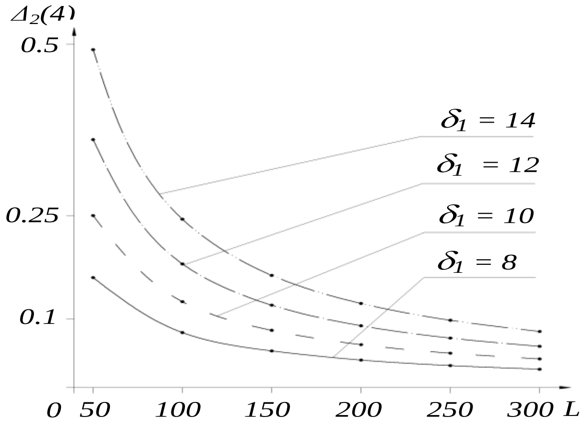

Fig. 9. Graphs of dependences of $\Delta_2(4)$ on L and δ_1 under different values of δ_1 for the scheme, given in Fig. 5

2.3 Synthesis of rolling pair in three parameters (L, Δ and δ_1)

In rolling pair corresponding to a scheme given in Fig. 4, with given maximal thickness of processed material δ_1, the length of a lever L and maximal value of displacement Δ (technological process is performed under given length of a lever L, maximal thickness of processed material δ_1, not exceeding the value of displacement Δ) it is necessary to fix the lever on base box in such a way that rolling pair could satisfy above mentioned conditions. Determine the coordinates of the point for fixation of a lever on base box in relation to the center of rotation of free working shaft in initial position (in the absence of processed material between working rollers), which further satisfy mentioned conditions.

Figure 10 gives design scheme to determine the coordinates of the point of fixation of a lever on base box. It was stated that in initial position of rolling pair, that is, at $\Delta=0$ and $\delta_1=0$, the axis of rotation of movable roller O_2 is located on vertical line crossing the axis O_1.

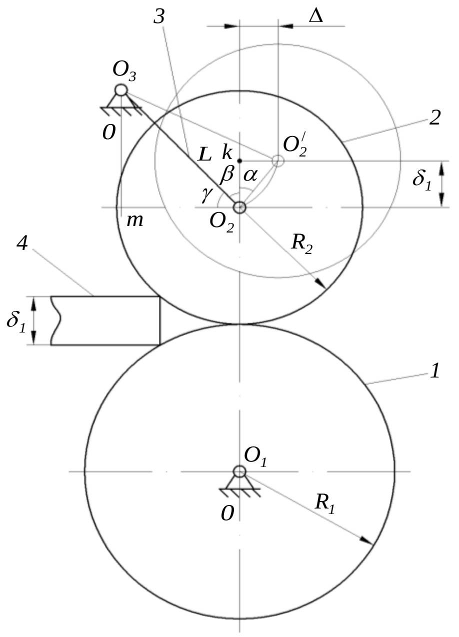

Fig. 10. Design scheme to determine the coordinates of the point of fixation of a lever on base box

When the thickness of processed material reaches its maximal value δ_1 the axis of movable shaft occupies the position O_2'.

It is necessary to find the point of fixation of a lever on base box (O_3) relative to axes O_1 or O_2.

Solving triangles kO_2O_2', $O_2O_3O_2'$ and mO_2O_3, we find the distances mO_2 and mO_3.

From $\Delta kO_2O_2'$ we determine:

$$\alpha = \arcsin\frac{\Delta}{\sqrt{\delta_1^2+\Delta^2}} \quad (21)$$

And from $\Delta O_2O_2'O_3$ we determine

$$\beta = \arcsin\frac{\sqrt{4L^2-(\delta_1^2+\Delta^2)}}{2L} \quad (22)$$

$$\beta-\alpha = \arcsin\left(\frac{1}{2L}\left(\delta_1\sqrt{\frac{4L^2}{\delta_1^2+\Delta^2}-1}-\Delta\right)\right) \quad (23)$$

$$\gamma = 90-(\beta-\alpha) = \arccos\left(\frac{1}{2L}\left(\delta_1\sqrt{\frac{4L^2}{\delta_1^2+\Delta^2}-1}-\Delta\right)\right) \quad (24)$$

$$mO_2 = L\cos\gamma = \frac{1}{2}\left(\delta_1\sqrt{\frac{4L^2}{\delta_1^2+\Delta^2}-1}-\Delta\right) \quad (25)$$

$$mO_3 = L\sin\gamma = L\sqrt{1-\left(\frac{1}{2L}\left(\delta_1\sqrt{\frac{4L^2}{\delta_1^2+\Delta^2}-1}-\Delta\right)\right)^2} \quad (26)$$

Formulae (24), (25) and (26) allow us to determine the coordinates of the point of fixation of the axis which connects on hinges the lever of movable working shaft with base box on conditions satisfying the requirements of design.

3. CONCLUSIONS

Rolling pairs with arc-like displacement of the center of rotation of working shaft were analyzed and their options were shown. Methods of geometric synthesis were worked out on the example of certain types of characteristic schemes of rolling pairs with arc-like displacement of the center of rotation of movable shaft.

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