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INSTRUMENT FOR INNER CYLINDER SURFACES VIBRATING ROLLING AND ITS STRUCTURAL PARAMETERS DETERMINATION TECHNIQUE

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Summary. *Design of instrument for regular topography making by vibrating rolling on inner cylinder surfaces has been developed. It provides vibrorolling effort regulation for the materials with various physical and chemical properties. The technique of the instrument structural parameters determination was suggested. Analytical dependencies for interrelated structural parameters of the instrument on the pre-determined data have been obtained.*

Key words: *vibrorolling, instrument, structural parameters, hole, deforming element, cylinder surface, ball*

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Problem statement. One of quality improvement of inner cylinder surface (hydrocylinders of crane truck, hydrocylinders of control mechanisms of flywheel clutch, steeling cylinder etc.) is surface strengthening by forming regular micro-reliefs on this surface.

Inner cylinder surface strengthening support is realized by surface plastic deformation using specific instruments [1 – 4]. Structural parameters of such instruments [5, 6] are defined by some peculiarities, particularly by parameters of roughness and indices of regular micro-reliefs [1, 10].

At the same time, in cited literature [1, 5, 6, 8, 10] methods for determination of tool's size parameters are not explained enough, which are used for forming regular micro-reliefs on inner cylinder surface and mutual influence of size parameters was not taken into account.

Hence, new type of instrument development for inner cylinder surface vibrating rolling and methods for its structural parameters determination is crucial task.

Review of recent investigations and papers. In [1], by instrument for vibrorolling, a holder for deforming elements fixation: balls; diamond and high-alloy tips and in some cases, cutting tools and deforming elements is meant. To support effective work of these instruments, it is necessary to create condition under which dominate rolling friction between deforming element (ball) and surface takes place.

This condition occurs when friction between ball and working surface is higher than friction between ball and lean surface, that is

$$F \cdot r_k > F_1 \cdot r_k + F_2 \cdot r_k \text{ або } F \cdot r_k > F_1 \cdot r_k + F_2' \cdot r_k$$

where F – frictional force between ball and working surface;
F_1 – frictional force between ball and area of bearing;
F_1 і F'_2 – frictional force between ball and side of separator;
r_b – radius of ball.

This condition is realized constructively by setting deforming element in ball bearing, the use of bronze separators and fluoroplastics as area of bearing.

The known device burnisher [11], in which separator balls are set which lean on conic surface of bearing disks and these balls give possibility to change their angle location in

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perpendicular surface to the axis of burnisher owing to that each ball is located in separator's hole and interacts with the wedge set in this hole. Such construction allows getting different types of regular micro-relief because of different deep created grooves. The disadvantage of the known technical decision is complexity of construction and setting up & impossibility to support the given type of regular micro-relief because of different deep created grooves. In [1] the given construction of three-ball vibrating head consisting of body in which deforming elements are balls, the location of which are fixed from one side by a separator and from another side by conic surface and this cone spring-loaded bottom-up. One more disadvantage of this construction is the complexity and, sometimes impossibility of its use for forming regular micro-reliefs in small diameter holes, in different alloys, absence of dependences for structural parameters determination what complicates the process of design and manufacturing.

In [7], the given algorithm allowing choosing the scheme of instrument depending on quality indices of working surface was suggested. For basic data the following parameters should be taken into consideration: initial density and roughness; technological inheritance (preprocessing history); physical and mechanical characteristics of process material and its ability to strengthening.

Analyzed literature [1 – 4] showed, that at present time, there are no dependences according to which structural parameters of the suggested instrument would be determined taking into account the possibility of its construction, location of balls of the definite diameter enclosed around a circle and determination of size of body according to diameter of deforming element – ball and diameter of working surface.

Research objective. Design of instrument for inner cylinder surfaces vibrating rolling and methods for determination of its structural parameters.

Problem statement. To develop three-ball instrument for vibrorolling of inner cylinder surface supporting balanced vibrorolling and receive analytical dependences for determination of structural parameters of the instrument on the base of analysis of known technical decisions taking into account existing drawbacks of analogs.

Research results. Instrument for forming regular microrelief by vibration running consists of the body 1 (Figure 1) made as hollow stepped cylinder with transparent cylinder holes 14, 22, 23 around the circle in the bottom, where deforming holes 13, 24, 25 are fixed on one side with the separator 12 and on another side they are fixed with conic surface of pointed cone 15 made on the lower part with movable axle of cylinder rod 8 are located. The separator is fixed in the lower part of outer cylinder surface of the body 1 with nut 11, which is fixed with contra-nut 10.

Pointed cone cylinder rod with movable axle 15 is located on inner cylinder surface 7 of bigger diameter of the body 1 spring-loaded to the bottom by compression spring 6 the length of which is limited by plank 5 passing through the windows 4 and 18, which were made in the wall of the upper part of the body 1. In the center of plank 5, transparent hole 19 was made. Through this hole 19 and compression spring 6, screw 20 is free passing, which lower part is fixed in cutting hole 16 of cylinder rod with movable axle 8.

Plank 5 is fixed with upper special nut 3 fastened with cutting surface 21 which is located in the upper part of outer cylinder surface of the body 1 and this nut 3 is fixed with contra-nut 2. In the middle part of cutting surface 21 of the body 1, the lower regulating nut 17 and contra-nut 9 are located.

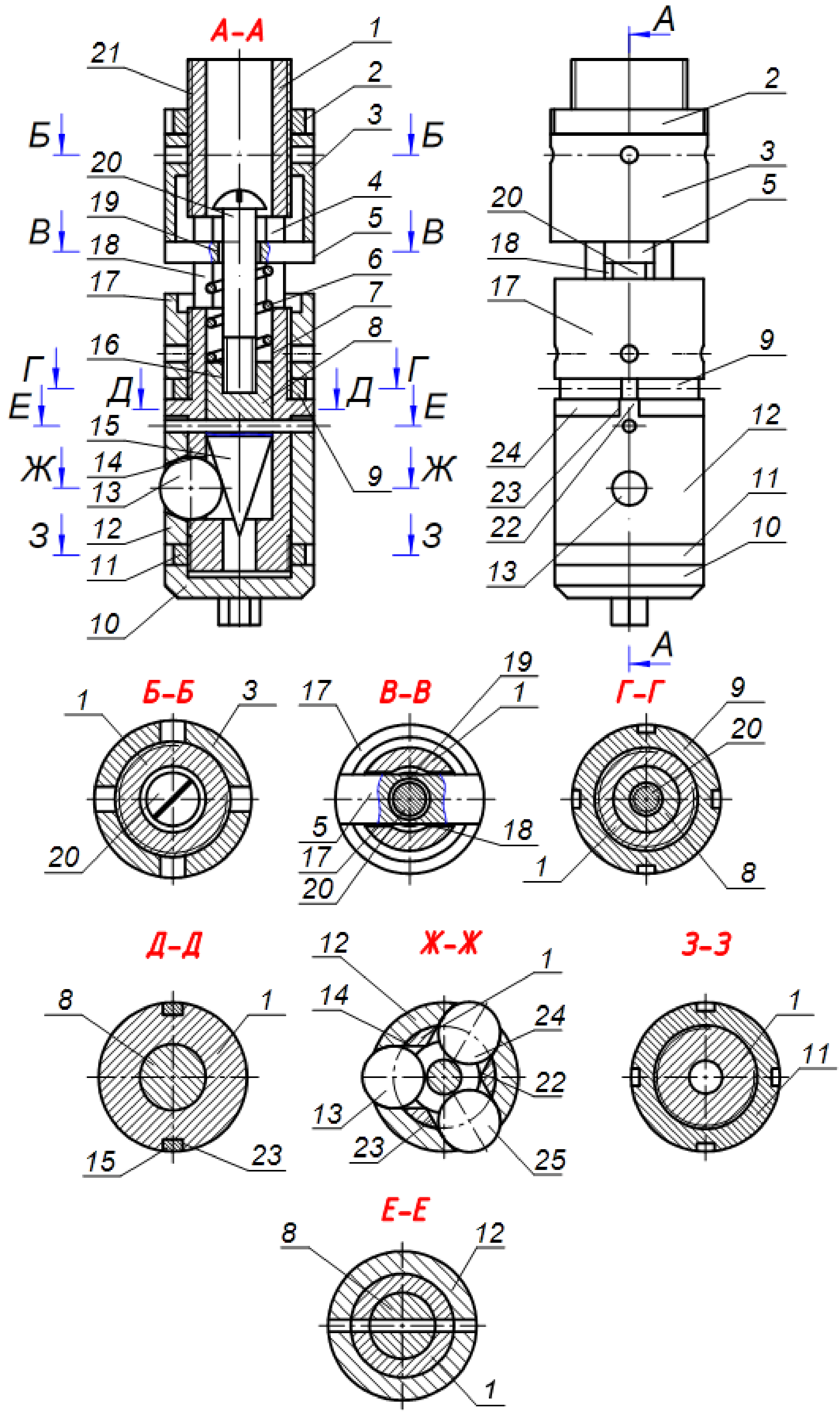

Figure 1. Tool for forming regular microrelief by vibration running

The tool works in the following way. Firstly, the tool setting is done. Special device for tensometric beam calibration is used for this purpose (Figure 2).

The movable rod 6 with spherical tags, the radius of which is not less than the radius of deforming element – ball is put into side hole 9 of the body 8, which is fixed on the plate 1. Transparent groove 5, where tensometric beam 3 is fixed with the screw 4 in wall 14 strongly fixed on the plate 1 is made in the central hole 7 of the body 8. The compression dynamometer 11 is located on the stand 10, e.g. DOCM 3-01, which is leaned on spherical surface of movable rod 6 and on spherical end of the screw 12 screwed up in cutting hole 13 made in wall 14 strongly fixed on the plate 1. Left spherical end of the movable rod 6 models deforming element – ball of tool and it is leaned to the middle point of tensometric beam 3. The strain meter 2 is fixed to the opposite side of tensometric beam 3 and to strain-gauge station (it is not show in Figure).

Calibration strain meter 2 is made in the following way. The screw 12 is screwed up, clearance is chosen and supported by contact of the following pair: the left spherical end of the movable rod 6 – tensometric beam 3; the right end of the movable rod 6 – the left end 16 of the compression dynamometer 11; the right end of the compression dynamometer 11 – spherical end of the screw 12.

The preliminary tension is provided with creating screwed up screw 12, e.g. 0.5 H. The movable scale 15 of the indicator of clock type 11 and indicator of recording device, e.g. milliamperemeter to «zero» is set (it is not shown in Figure).

Stage-by-stage, e.g. in 5 H screwing up the screw 12 the efforts are created on the compression dynamometer 11 and registered corresponding indications of milliamperemeter. Having made maximum loading, e.g. 250 H, the screw 12 is screwed off gradually, compression dynamometer 13 is unloaded to 0.5 H and the indications of milliamperemeter are registered.

Hence, the diagram of loading and unloading is got with some hysteresis. For each loading and unloading meanings of dynamometer, the average meaning and its corresponding indication of electric current in milliamperes is found.

According to the received data, the calibration graph in coordinates is built: power influencing tensometric beam – electric current.

Further, the screw 12 is screwed off, compression dynamometer 11 and stand 10 are taken away, and the movable rod 6 is taken out from the body 8. The tool for forming regular vibrorolling microrelief on inner cylinder surface (Figure 1) is put into the central hole 7 of the body 8 of calibration device in such a way that top of deforming element – ball is located in the middle of tensometric beam 3.

Screwing up the upper regulating nut 3 of the tool (Figure 1), the plank 5 is transferred and while compression string 6 is deformed, and cylinder rod 8 with movable axle with pointed cone 15 is transferred down and balls 13, 24, 25 are transferred radially from the centre. Deforming element – ball 13 (Figure 1) influences tensometric beam 2 (Figure 2) of the calibration device deforming it in this case and electric current is defined on the scale of milliamperemeter. Having used calibration graph, the necessary effort of vibrorolling is created by the deformation compression string 6, which will influence the working inner cylinder surface of tool from the side of spherical surface of balls 13, 22, 24 showing the vertical position of the plank 5. Then, the upper regulating nut 3 of tool is screwed off making free balls 13, 24, 25 and tool, is taken from calibration tool.

Hereafter, the upper regulating nut 3 is screwed up to earlier fixed location and transferring the plank 5 down, the nut 3 is fixed with contra-nut 2 finishing tool setting to given effort for forming regular vibrorolling microrelief on inner cylinder surface.

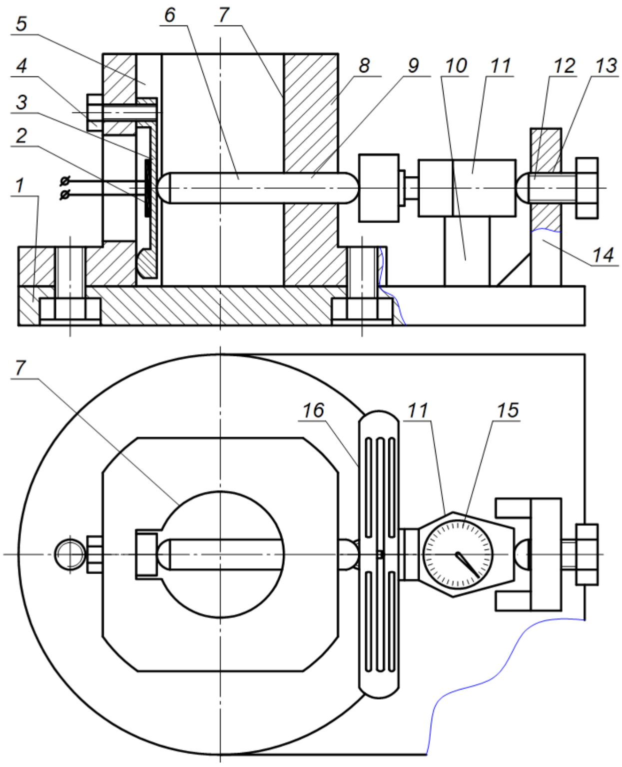

Figure 2. Special device for calibration of tensometric beam

Set instrument works in the following way. Instrument for inner cylinder surfaces vibrating rolling is fixed to upper end of cutting surface 21 (Figure 1), e.g. to spindle with translational and oscillating movement. Some part, e.g. cylindrical bush is put into holder of this machine. Putting part in rotating motion (circular supply) and instrument for inner cylinder surfaces vibrating rolling in longitudinal supply and oscillating movement, the instrument is put into its cylindrical hole of working part and make inner cylinder surfaces vibrating rolling.

After passing deforming parts – balls through inner cylindrical surface of working part all movements are cut off and instrument is disconnected from spindle.

Working part is taken from holder, the next part blank is fixed and the process takes place again.

Methods for determination of tool's size parameters. Structural parameters of the instrument for inner cylinder surfaces vibrating rolling is defined stage-by-stage in Figure 3 in the next sequence of operations.

1. Depending on the value of diameter D_∂ inner cylindrical surface of hole of the part (Figure 3), the meaning of the diameter of deforming elements – balls are determined.

Taking into account Figure 3 b, it is possible to write

$$D_\partial = 2\left(K_0O_2 + O_1O_2 + O_1O\right)$$

Taking into consideration

$K_0O_2 = \dfrac{d_\kappa}{2}$ and ΔON_1O (Figure 3) we will receive $\angle N_1O_1O = \pi/6$; $N_1O_1 = d_\kappa/2$,

Then

$$OO_1 = ON_1/\cos(\pi/6) = d_\kappa / 2 \cdot \cos(\pi/6).$$

The value $O_1O_2 = NL_1 = M_1K_1$ like opposite sides of the corresponding parallelograms $NO_1O_2L_1$ and $NL_1M_1K_1$.

The value M_1K_1 is determined by ΔMM_1K_1.

$$\angle MM_1K_1 = \alpha/2.$$

$$\frac{O_1O_2}{MM_1} = tg\left(\alpha/2\right); \; O_1O_2 = MM_1 \cdot tg\left(\alpha/2\right).$$

$$O_1O_2 = 0,5 \cdot d_\kappa \left[\frac{ctg\left(\alpha/2\right)}{\cos\left(\pi/6\right)} - 1 - ctg\left(\alpha/2\right) \cdot \left(\frac{1}{\cos\left(\pi/6\right)} - \frac{1}{\cos\left(\alpha/2\right)}\right)\right] \cdot tg\left(\alpha/2\right) \qquad (1)$$

$$MM_1 = FC - KO - OC.$$

The value *FC* is determined by Δ*MCF*

$$FC = MF \cdot ctg\left(\alpha/2\right).$$

Taking into account $MF \cdot = \frac{d_\kappa}{2 \cdot \cos\left(\pi/6\right)}$, we will receive

$$FC = \frac{d_\kappa \cdot ctg\left(\alpha/2\right)}{2 \cdot \cos\left(\pi/6\right)}. \qquad (2)$$

The value OC is determined by Δ *LOC* (Figure 3).

$$OC = LO \cdot ctg\left(\alpha/2\right).$$

In its turn

$$LO = OO_1 - O_1L = \frac{d_\kappa}{2\cos\left(\pi/6\right)} - \frac{d_\kappa}{2\cos\left(\alpha/2\right)} = \frac{d_\kappa}{2}\left(\frac{1}{\cos\left(\pi/6\right)} - \frac{1}{\cos\left(\alpha/2\right)}\right) \text{ or}$$

$$LO = \frac{d_\kappa}{2}\left(\frac{1}{\cos\left(\pi/6\right)} - \frac{1}{\cos\left(\alpha/2\right)}\right).$$

Then value *OC* is determined by formula

$$OC = 0,5 \cdot d_\kappa \cdot ctg\left(\alpha/2\right) \cdot \left(\frac{1}{\cos\left(\pi/6\right)} - \frac{1}{\cos\left(\alpha/2\right)}\right).$$

Hence $KO = d_\kappa/2$, we will have

$$MM_1 = \frac{d_\kappa \cdot ctg\left(\alpha/2\right)}{2 \cdot \cos\left(\pi/6\right)} - \frac{d_\kappa}{2} - \frac{d_\kappa}{2} \cdot ctg\left(\alpha/2\right) \cdot \left(\frac{1}{\cos\left(\pi/6\right)} - \frac{1}{\cos\left(\alpha/2\right)}\right).$$

Simplifying we will receive the expression

$$MM_1 = 0,5 \cdot d_\kappa \left[\frac{ctg\left(\alpha/2\right)}{\cos\left(\pi/6\right)} - 1 - ctg\left(\alpha/2\right) \cdot \left(\frac{1}{\cos\left(\pi/6\right)} - \frac{1}{\cos\left(\alpha/2\right)}\right)\right]. \qquad (3)$$

Substituting the corresponding meaning of value from right side of equation (3) we will receive

$$D_{\partial} = 2\left\{\frac{d_{\kappa}}{2} + \frac{d_{\kappa}}{2}\cdot\left[\frac{ctg(\alpha/2)}{\cos(\pi/6)} - 1 - ctg(\alpha/2)\cdot\left(\frac{1}{\cos(\pi/6)} - \frac{1}{\cos(\alpha/2)}\right)\right]tg(\alpha/2) + \frac{d_{\kappa}}{2\cos(\pi/6)}\right\},$$

Moreover, after simplifying we will have

$$d_{\kappa} = \frac{D_{\partial}\cdot\cos(\alpha/2)}{2,155\cdot\cos(\alpha/2) + 1 - \sin(\alpha/2)}; \quad (4)$$

Provided that α=30°, dependence (4) will be in the following way $d_{\kappa} = 0,342\cdot D_{\partial}$.

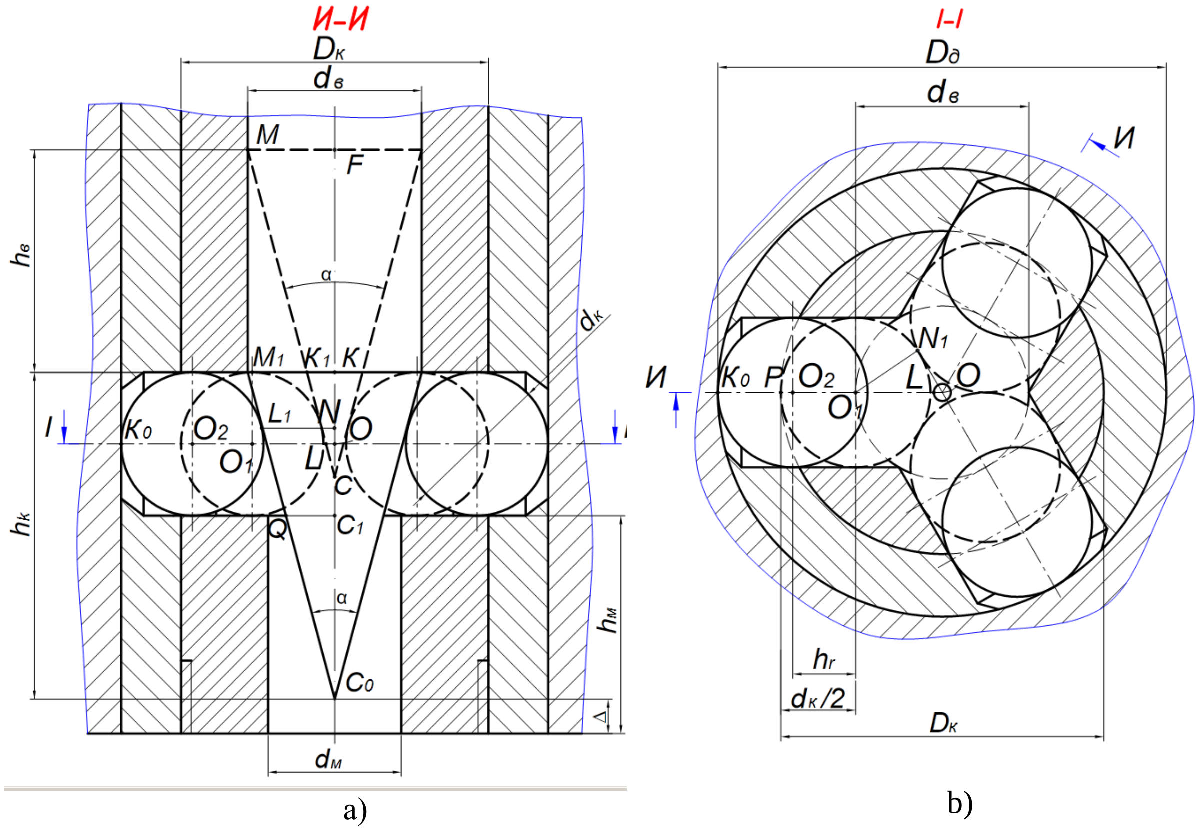

Figure 3. Analytical model for determination of tool's size parameters

From equation (4) we will write

$$\alpha = 2\arccos\left(\frac{2\left(\frac{D_{\partial}}{d_{\kappa}} - 2,155\right)}{\left(\frac{D_{\partial}}{d_{\kappa}} - 2,155\right)^2 + 1}\right) \quad (5)$$

Determining minimal value of flat angle at top of pointed cone in secant plane passing through longitudinal axis of rod, it is taken into account that to support working capacity of the instrument it is necessary to keep condition of self-releasing pair of cone-ball.

This condition is realized in the following way, that angle between trace of conic surface of pointed cone 9 and trace of cylindrical surface with movable axle of cylindrical rod 8 (Figure

1) in secant plane passing through longitudinal axle of the body should be bigger than angle of friction of gliding, that is $\alpha / 2 > arctg\varphi_{mp}$, where φ_{mp} – coefficient of friction of gliding between conic surface of cone and spherical surface of a ball. According to data we take that angle $\varphi_{mp} = 0,2$. Than $arctg 0,2 = 11^{\circ}19'$.

According to data [9] we choose the nearest meaning of angle – $\alpha / 2 = 15^{\circ}$.

Having determined the meaning of angle α within $30 \le \alpha \le 85$ we can define the correlation between diameter of working hole and diameter of deforming part (ball).

Substituting the limit value of angle α in expression (5) and showing $d_к$ through $D_д$ we will find the interval of meaning of diameter of deforming balls $d_к$ expressed through the diameter of inner cylindrical surface of working hole of part $D_д$

$$0,32 D_д \ge d_к \ge 0,22 D_д .$$

At that the diameter of a ball – $d_к$ is chosen on the base of recommendations [1].

2. Determination of the value of diameter $D_к$ of outer cylindrical surface of the body, which depends on the diameter $d_к$ of deforming part – ball.

The value of outer diameter $D_к$ of the body is determined under the condition of support of possibility to set separator on the body when all three balls are touching and located in the nearest from longitudinal axle of the body (Figure 2).

This condition is available in the following way. From ΔONO_1 we will have.

$$\angle N_1 O_1 O = \pi/6 ; \; N_1 O_1 = d_к/2 , \text{тоді } D_к = 2OP = 2\left(OO_1 + O_1 P\right) .$$
$$OO_1 = ON_1 / \cos\left(\pi/6\right) = d_к / 2 \cdot \cos\left(\pi/6\right).$$

Then

$$D_к = d_к \cdot \left(1 + \frac{1}{\cos\left(\pi/6\right)}\right). \qquad (6)$$

Taking into consideration $\cos\left(\pi/6\right) = 0,866$ after simplifying we will receive

$D_к = 2,155 \cdot d_к$.

3. We take such meaning, which is equal to diameter of circle passed in secant plane, which is perpendicular to longitudinal axle of the body through the centers of three balls, as bigger diameter $d_в$ of inner cylindrical surface of the body.

Taking into account Figure 3 we will receive

$$d_в = 2 \cdot O_1 O = \frac{d_к}{\cos\left(\pi/6\right)} = 1,155 \cdot d_к \qquad (7)$$

4. We will determine vertical movement of cone $h_в$, at which balls are located in radial direction from the nearest location placed in longitudinal axle of the body to contact of balls with working inner cylindrical surface of the part using Figure 3.

Firstly, we determine the height of cone – $h_к$.

Using Δ *MFC* (Figure 3) we can write

$h_к = FC$.

From equation (2), the height of cone $h_к$ is defined by formula:

$$h_к = \frac{d_к \cdot ctg(\alpha/2)}{2 \cdot \cos(\pi/6)}.$$

For case when $\alpha = 30^\circ$, substituting meaning in formula $ctg(\alpha/2)$ and $\cos(\pi/6)$ we will receive

$h_к = 2{,}155 \cdot d_к$.

Then the value of vertical movement of cone $h_в$ (Figure 3 a) is determined by the dependence.

$h_в = MM_1$

Taking into account the dependence (3) we will receive

$$h_в = 0{,}5 \cdot d_к \left[\frac{ctg(\alpha/2)}{\cos(\pi/6)} - 1 - ctg(\alpha/2) \cdot \left(\frac{1}{\cos(\pi/6)} - \frac{1}{\cos(\alpha/2)} \right) \right] \quad (8)$$

For case when $\alpha = 30^\circ$ the received formula is the following

$h_в = 1{,}43 \cdot d_к$.

5. The value of radial centrifugal movement h_r of balls from their initial location to the contact with working cylindrical surface of the part (Figure 3) will be equal to the value O_1O_2. Taking into account dependence (1) we will receive

$$h_r = 0{,}5 \cdot d_к \left[\frac{ctg(\alpha/2)}{\cos(\pi/6)} - 1 - ctg(\alpha/2) \cdot \left(\frac{1}{\cos(\pi/6)} - \frac{1}{\cos(\alpha/2)} \right) \right] \cdot tg(\alpha/2) \quad (9)$$

For case, when $\alpha = 30^\circ$ the value h_r will be equal to

$h_r = 1{,}43 \cdot d_к \cdot 0{,}2679 = 0{,}383 \cdot d_к$.

7. The depth $h_м$ of the central hole of smaller diameter $d_м$ in body (Figure 3 b) will be equal.

$h_м = C_1O_0 = KC_0 - KC_1 + \Delta$;

$KC_0 = FC = h_к = \dfrac{d_к \cdot ctg(\alpha/2)}{2 \cdot \cos(\pi/6)}$; $KC_1 = d_к$; $\Delta = k_0 \cdot d_к$; $k_0 = 0{,}1 ... 0{,}4$.

$$h_м = d_к \left(\frac{ctg(\alpha/2)}{2 \cdot \cos(\pi/6)} - 1 + k_0 \right). \quad (10)$$

8. The value of smaller diameter $d_м$ of central hole in body will be equal to

$$d_м = 2 \cdot QC_1 + \Delta .$$

From Δ *C0QC1 – QC1 = C1C0 = C1C0 * tg (a/2);*

$$C_1C_0 = KC_0 - KC_1 = h_к - d_к = d_к \left(\frac{ctg(\alpha/2)}{2 \cdot \cos(\pi/6)} - 1 \right);$$

$$QC_1 = d_к \cdot tg(\alpha/2) \cdot \left(\frac{ctg(\alpha/2)}{2 \cdot \cos(\pi/6)} - 1 \right).$$

Taking into account the last we will receive

$$d_м = 2 \cdot d_к \left(\frac{1}{2 \cdot \cos(\pi/6)} - tg(\alpha/2) + k_0 \right). \quad (11)$$

In case, when $\alpha = 30^\circ$ and $k_0 = 0{,}1$ the value $d_м$ will be equal to $d_м = 0{,}818 \cdot d_к$.

Received dependences (4) – (11) give the possibility to develop efficient instrument for inner cylinder surfaces vibrating rolling.

According to received dependences at initial date $d_к = 0,27 D_д$ mm; k_0=0.1 mm, diagrams of dependences of corresponding structural parameters on diameter of working surface of the instrument are built.

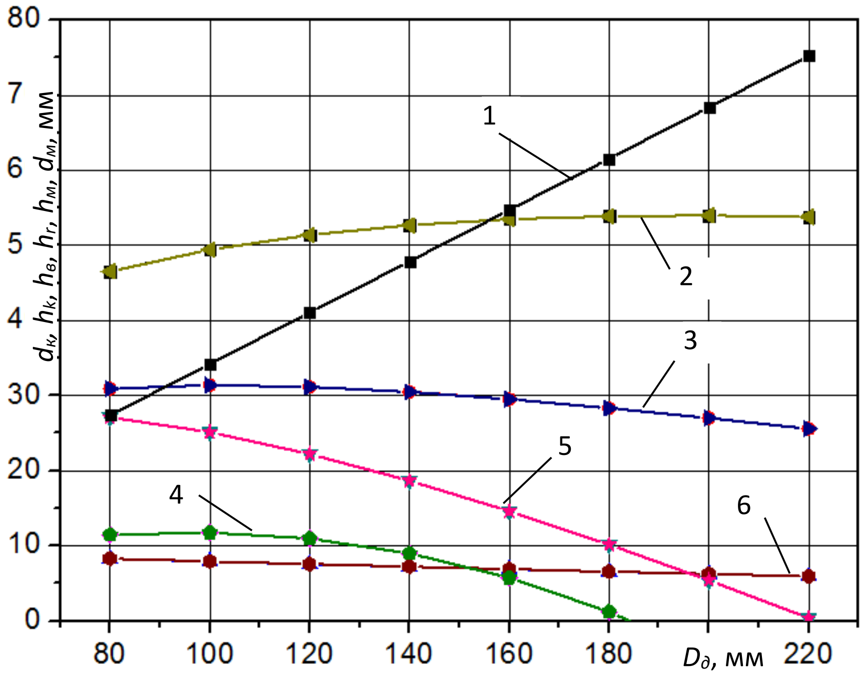

Figure 4. Value of tool's size parameters for forming regular microrelief by vibration running at different value of diameter $D_д$ inner cylindrical surfaces

1 – $d_к$; 2 – $h_к$; 3 – $h_в$; 4 – $h_г$; 5 – $h_м$; 6 – $d_м$

Conclusions

1. The suggested new construction of the instrument for inner cylinder surfaces vibrating rolling has substantial differences of novelty and is free from the main disadvantages of famous analogs.

2. Received dependences allow determining structural parameters of the instrument for forming regular microrelief by vibration running on inner cylindrical surface of working parts. The corresponding software for automated calculation of these parameters can be developed on the base of these dependences in future.

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ІНСТРУМЕНТ ДЛЯ ВІБРАЦІЙНОГО ОБКОЧУВАННЯ ВНУТРІШНІХ ЦИЛІНДРИЧНИХ ПОВЕРХОНЬ І МЕТОДИКА ВИЗНАЧЕННЯ ЙОГО КОНСТРУКТИВНИХ ПАРАМЕТРІВ

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Резюме. *Розроблено конструкцію інструмента для формування вібраційним обкочуванням на внутрішніх циліндричних поверхнях регулярних мікрорельєфів із забезпеченням регулювання зусилля віброобкочування для матеріалів з різними фізико-механічними властивостями. Запропоновано методику визначення конструктивних параметрів інструмента. Отримано аналітичні залежності для визначення взаємопов'язаних конструктивних параметрів інструмента залежно від заданих вихідних даних.*

Ключові слова: *віброобкочування, інструмент, конструктивні параметри, отвір, деформуючий елемент, циліндрична поверхня, кулька.*

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