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Increased Wear Resistance of Surfaces of Rotation Bearings Methods
Strengthening-Smoothing Processing

A.A. Tkachuk \textsuperscript{1,a}, V.U. Zablotskyi \textsuperscript{1,b}, T.V. Terletsyi \textsuperscript{1,c}, O.L. Kaidyk \textsuperscript{1,d}, S.A. Moroz \textsuperscript{1,e}

\textsuperscript{1} – Lutsk National Technical University, Lutsk, Ukraine

a – a.tkachuk@lntu.edu.ua
b – v.zablotsky@lntu.edu.ua
c – t.terletsyi@lntu.edu.ua
d – o.kaidyk@lntu.edu.ua
e – s.moroz@lntu.edu.ua

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\textbf{ABSTRACT.} Trends of modern engineering put forward higher requirements for quality bearings. This is especially true on production of bearings for special purposes with high speeds of rotation and resource. Much more opportunities in the technology management quality surface layers appear in the application of smoothing-strengthening methods, based on superficial plastic deformation. Working models of cutting lathes, grinders and tool smoothing sequence revealed the formation of operational parameters in the technological cycle of roller rings. The model of the dynamics of elastic deformation of the work piece tool helps identify actions radial force in the contact “surface - indenter.” Using mathematical modeling resolved a number of issues relevant process.

\textbf{Introduction.} Trends of modern engineering put forward higher requirements for quality bearings. This is due to the fact that the reliability and durability of the machine mechanical largely depends on the operability established in her bearings. Most of the mechanisms operating in roller bearings are subjected to loads that differ from the calculation. Due to the large number of operational factors and mechanisms of their random nature complicated forecasting bearing behavior in real conditions. This leads to a premature loss of the performance of the bearing. This is especially true on production of bearings for special purposes with high speeds of rotation and resource.

During work bearing an intense local working surfaces wear rings. Tangent surfaces tend to acquire a geometric shape and roughness that best match specific operating conditions. During this emerging higher contact stresses, which can lead to leakage of thermal processes in the surface layer of the metal and reduce its physical and mechanical properties. In areas of maximum deformation of the surface layer of the metal contact stresses the rise to critical values.

However, if during the forming roll surface to ensure optimum operational microgeometry profile and physical and mechanical properties of the surface layer, the reduced period of time grinding in and accelerate the acquisition of stable operating condition. Traditional technologies forming working surfaces bearing rings, does not fully ensure the rational combination microgeometrical characteristics and physical and mechanical properties of the surface layer of abrasive treatment after surgery. Analysis of manufacturing defects functional surfaces showed that ends traditional technologies do not provide a sufficient level of quality required for their manufacture through that, reduced roller wear resistance in general. Much more opportunities in the technology management quality surface layers appear in the application of reinforcing – processing methods, based on superficial plastic deformation, through the emergence of an enabling technological factors. Providing high performance characteristics of the working surfaces of rings by using roller-fixing
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operations is an actual scientific and practical problem \[1\].

**Research results.** Qualitative and quantitative assessment methods for forming mutual rotation surface details and operational requirements for surface rotation rings, served as the basis for modeling relationships structural and technological factors, processes of strengthening processing performance indicators. To evaluate the durability work surfaces rings used composite index \( J \) - intensity of wear that takes into account the impact of technological factors, material properties and performance rings. Dependend deduced grinding in mode:

\[
J_n = \frac{1.2}{n} \frac{Ra^{2/3}}{\lambda Sm t_p^{3/2}} \left( \frac{p}{H_{\mu_0}} \right)^{7/6} \sqrt{15\pi (2\pi Wz H_{\max})^{1/3} \left[ 1 + \frac{2\pi H_{\mu_0} (1 - \mu^2)}{E} \right]},
\]

and the set mode:

\[
J_p = \frac{1.2\pi p^{7/6}}{n\lambda t_p^{3/2} H_{\mu_0}^{2/3}} \sqrt{30 (1 - \mu^2) (2\pi Ra Wz H_{\max})^{1/3}} \frac{E Sm}{},
\]

where \( Ra \) – arithmetic mean deviation of surface roughness profile;

\( n \) – the number of cycles, leading to displays of material destruction;

\( \lambda \) – coefficient taking into account the impact of surface residual stress on the process of wear;

\( Sm \) – average step of roughness profile roughness;

\( t_p \) – the relative length of the reference line roughness profile;

\( p \) – working pressure tangential surface;

\( H_{\mu_0} \) – surface micro hardness;

\( Wz \) – the average height of the waves;

\( H_{\max} \) – maximum height macro deviations;

\( \mu \) and \( E \) – Poisson's ratio and modulus of elasticity of the material details.

Analysis of theoretical and empirical relationships operational properties of details roller shown that they depend on the system parameters of quality of functional surfaces:

- macro deviations – \( H_{\max}, H_p \);
- waviness – \( Wz, Wp, Smw \);
- roughness – \( Ra, Rz, R_{\max}, Rp, Sm, t_p \);
- subjectivity – \( Ra', Sm' \);
- physical and mechanical properties – \( \sigma_0 \) (surface residual stresses);
- \( h\sigma_0 \) (depth of surface residual stress);
- \( H_{\mu_0}, h_n \) (hardened layer depth);
- \( I_8 \) (grain size);
- \( \rho_D \) (dislocation density).

Working models processing blade, abrasive and ironed tool sequence revealed the formation operational parameters in the technological cycle of roller rings \[2\].
It was established that during the formation of edge cutting processing roughness depends on the initial roughness and fluctuations $R_z$ original micro hardness of the surface layer $H_{μ_{max}}$, $H_{μ_{min}}$. The average roughness pitch $S_m$ depends on its initial value, from $R_z$ and changes in the surface micro hardness $H_μ$. Initial ironed have partial heredity and the next processing depending on the initial physical and mechanical parameters of the surface layer, namely micro hardness and depth of the residual stress ($H_{μ_{0}}$, $h_{μ_{0}}$, $σ_{0}$, $h_σ_{0}$). Formation of physical and mechanical properties of the surface layer during machining largely depends on their initial state. Based on the analysis of the impact of quality parameters of the surface layer of processing conditions established hereditary nature and effect relationship of quality parameters of the performance (fig. 1).

To analyze the performance of selected material length of profile at the level $c$ surface roughness. Analysis of different profiles showed that the bearing capacity of the surface layer at a constant height $R_{max}$ ($R_z$) and $Ra$ value is greater, the less smooth height $Rp$ (distance from the line appearances to the midline). Over the same values $Rp$ and $R_{max}$ ($R_z$) bearing capacity of the surface of the greater, the larger parameter ($Ra$). With decreasing height $R_{max}$ microscopic parameters $Ra$ and $Rp$ decreases and increases carrying capacity. Established that the bearing capacity of the surface asperities depends on the parameter $R_{max}$ ($R_z$), height $Rp$ and smoothing of the arithmetic mean deviation of profile $Ra$. According constructed diagrams of distribution of equivalent stress (fig. 2) indenter different geometry configurations and on the basis of the calculations set optimal shape deforming element (fig. 2a).
Stress state in the contact details of the indenter is not determined by starting and plastically deformed as a result of pressing shape its surface. With this in mind when calculating the stresses arising details should be considered not only primary, but also formed curvature plastically deformed surface. In addition, the plastic deformation of the material parts diagrams equivalent stress within the curved deformable layer, reflecting the history of the load. As the flow deformation maximum yield strength increases and deeper until, until it reaches a position which meet peak loads. In the process of strengthening the cross section of the metal surface layer is usually fixed by this result, and micro hardness point alignment determines the limit plastical ly deformed layer depth is strengthening $h_{\sigma}$.

For the general case of contact bodies of arbitrary curvature main stress $\sigma_x$, $\sigma_y$, $\sigma_z$ planes perpendicular to the axes of which $z$ normal to the contact surface, and $x$ coincides with the main axis of the elliptical contact areas are defined as:

$$
\sigma_x = -P_y \frac{b}{a} \left\{ \frac{b^2 + z^2}{a^2} \left( \frac{2a^2}{b^2} - 1 \right) - 2z \left( L - K \right) - 2\mu \left[ 1 - \frac{a^2}{b^2} \left( \frac{b^2 + z^2}{a^2} + \frac{z}{a} \left( \frac{a^2}{b^2} L - K \right) \right) \right] \right\};
$$

$$
\sigma_y = -P_y \frac{b}{a} \left\{ 1 + \frac{z^2}{a^2} \frac{2a^2}{b^2} \left( \frac{2a^2}{b^2} - 1 \right) - 2z \left( \frac{a^2}{b^2} L - K \right) - 1 + 2\mu \left[ 1 - \frac{b^2}{a^2} \frac{z^2}{a^2} + \frac{z}{a} \left( L - K \right) \right] \right\};
$$

$$
\sigma_z = -P_y \left( \frac{1}{1 + \frac{z^2}{a^2}} + \frac{1}{1 + \frac{z^2}{b^2}} \right);
$$

where $P_y$ – radial load;

$a, b$ – axis elliptical contact in the axial and transverse sections respectively.
The main stress is expressed as a function of the ratio of semiaxes $b$ and $a$ fingerprint, the ratio $z \text{ coordinates occurrence study point to the semi axes of the ellipse}$ and the maximum pressure $P_y$ in the contact center. In the formula (3) for $\sigma_x$, $\sigma_y$ appear Poisson coefficient $\mu$ and elliptic integrals of the first $K(e, \theta) = \int_0^\theta \frac{d\theta}{\sqrt{1 - e^2 \sin^2 \theta}}$ and second race $L(e, \theta) = \int_0^\theta \sqrt{1 - e^2 \sin^2 \theta} d\theta$, which depend on the parameter $\theta = \arctg \frac{z}{a}$ and eccentricity of the ellipse $e = \sqrt{1 - (b/a)^2}$. For steel 100Cr6 the coefficient $\mu=0.3$, here you can define the number of values $b/a$ and $z/b$, main (3) and equivalent stress (4):

$$\sigma_{eq} = \sqrt{\frac{1}{2} \left[ (\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 \right]}.$$  \hfill (4)

After equating, according to Huber-Misses condition, medium shear stresses $\sigma_{eq}$ to the yield strength of the material parts in the initial state, found coordinate $z=h_0$ limits plastically deformed layer:

$$\sigma_r = \frac{3}{2} \frac{P_y}{\pi ab} \sqrt{\frac{1}{2P_y} \left[ (\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 \right]}.$$  \hfill (5)

The model of the dynamics of deformation of the workpiece elastic action tool helps identify radial force $P_y$ in the contact "surface – indenter". Design model (fig. 3) corresponds to the scheme axial cam mechanism, where 1 – body, 2 – moving the slider with the indenter 3, are pressed against the workpiece 5 with 4 spring stiffness $c$ with power $P_{yo}=Q_0=cY_0$ through the nut section 6. Rated piece is shaped like a circle 7 of radius $\rho_0$. Actual section piece is presented as a wavy curve, which has a maximum height $W_{max}$, corner step $\varphi_s$ wave, a nominal profile section 7 is the average $m_w$ line waviness 8, which determines the actual radius blank $\rho(\varphi)$.

In the calculation scheme envisaged action following forces:

- $P_{yo} = Q_0 = cY_0$ – nominal power smoothing;
- $P_y = Q$ – the impact of the resultant force of the indenter to the surface in the contact area;
- $\bar{m}\ddot{y}$ – inertia of moving parts of the tool;
- $\bar{P}_y$ – reaction force on the workpiece indenter;
- $\bar{P}_z$ – burnishing resistance force;
- $\bar{P}$ – smoothing the resultant force;
- $\bar{mg}$ – the weight of the moving parts of the tool;
- $\bar{N}_1, \bar{N}_2$ – reaction forces on the bearings slider;
- $\bar{F}_1, \bar{F}_2$ – slip-friction force occurring during driving slider;
- $\eta \bar{V}$ – moment of resistance proportional to the velocity of the slider caused by the presence of cutting fluid.
Using mathematical modeling resolved a number of issues:

– Set the necessary conditions for sustainable harvesting and indenter contact no possibility of separation indenter and indenter occurrence of impact on the surface of the workpiece:

\[ f(\alpha t) = f(\varphi) = \rho , \tag{6} \]

– Speed range defined smoothing \((v_{\text{min}}, v_{\text{max}})\), within which the power will be stored in the smoothing \(Q\) acceptable range \((Q_{\text{min}}, Q_{\text{max}})\), which must endure in order to create quality parameters of the surface layer of the regulated reliability.

\[ Q_{0} - \Delta Q \leq Q_{0} + cf(\alpha t) + M\omega^2 f^\ast(\alpha t) \leq Q_{0} + \Delta Q . \tag{7} \]

– Identified a number of additional conditions tool to select the optimal technological modes of processing, such as:

a) Acceleration slider:

\[ \ddot{y}(t) = \omega^2 f''(\varphi) = \omega^2 f^\ast(\alpha t) ; \tag{8} \]

b) Jamming condition slider:

\[ \tan \gamma_{kr} = \frac{1}{f\left(1 + \frac{2h}{L}\right)} ; \tag{9} \]
c) Equation of forced oscillations:

\[
\ddot{Y} + 2n\dot{Y} + \omega_0^2 Y = \frac{cf(t)}{m};
\]

(10)

d) Factor of dynamism:

\[
\mu = \frac{a}{Y_{cr}} = \frac{1}{\sqrt{\left(1 - \frac{\omega^2}{\omega_0^2}\right)^2 + \frac{4\omega^2 n^2}{\omega_0^4}}} ;
\]

(11)

e) Vibration amplitude:

\[
a = \frac{Y_{cr}}{\sqrt{\left(1 - \frac{\omega^2}{\omega_0^2}\right)^2 + \left(\frac{ka}{c}\right)^2}}.
\]

(12)

Experimental study of the effect of quality parameters of the surface layer on the wear resistance of working surfaces on strengthening rings roller-smoothed operations [3]. The influence of burnishing force \(P_y\) in depth, width, height, and area roughness flows in cross section determined by means of test passes. Fragments studied surfaces and their indicators are shown (fig. 5).

\[\text{Grinding processing} \quad \text{HRC 55} \quad Ra (\text{min...max}) 0,4...0,6\]

\[\text{Superfinish processing} \quad \text{HRC 60} \quad Ra (\text{min...max}) 0,1...0,25\]

\[\text{Strengthening smoothing treatment} \quad \text{HRC 68} \quad Ra (\text{min...max}) 0,06...0,2\]

Fig. 5. Analysis micro geometrical parameters of functional surfaces.
Study parameters as rolling surfaces for surface plastic deformation operations performed by multivariate regression model that reflects the quantitative relationship between radial force burnishing ($P_y$), supply ($S$), spindle speed ($n$), output parameters as the surface layer $Ra_{sou}$ (mean deviation profile, original) $Sm_{sou}$ (average step of roughness profile, basic) and surface layer quality parameters ($Ra$, $Sm$, $Hμ$), developed at the pilot plant.

Influence of technological factors on the geometric parameters of micro-relief and durability investigated on samples of steel 100Cr6 accordance with our methodology. These samples were rough grinding operation, hardness 55...60 HRC, the initial surface roughness is $Ra_{sou}=0.5...0.7$ micrometers.

The effect of technological factors (effort burnishing $P_y$, radius deforming element $R_p$, filing tool $S$, speed spindle $n$) on the geometric parameters of the micro profile (depth $h_n$, width $b_n$ height sag $h_{pn}$ relative bearing area $t_p$, the average step of roughness profile $Sm$, average arithmetic mean deviation of profile $Ra$), physical and mechanical properties of the surface layer (surface microhardness $Hμ$).

The results of experimental studies and mathematical modeling of the empirical dependence (13) (14) (15) parameters of the surface layer after burnishing combined modes of $P_y$, $S$, $n$ microgeometrical for strengthening operations using instrument one inventory elastic action.

$$Ra = 2.761 \cdot 0.0225 \cdot P_y + 7.01 \cdot S - 0.0184 \cdot n - 1.255 \cdot Ra_{sou} - 0.0415 \cdot Sm - 0.000009 \cdot P_y \cdot n + 0.00676 \cdot P_y \cdot Ra_{sou} + 0.00018 \cdot P_y \cdot Sm + 0.0277 \cdot S \cdot n - 0.178 \cdot S \cdot Sm + (13)$$
$$+ 0.00744 \cdot Ra_{sou} \cdot n + 0.000143 \cdot n \cdot Sm + 0.01492 \cdot Ra_{sou} \cdot Sm + 0.59 \cdot P_y \cdot S.$$  
$$Sm = -116.7 + 0.032 \cdot P_y - 106.1 \cdot S \cdot n + (-0.275 \cdot n) + 35.5 \cdot Ra_{sou} + 5.787 \cdot Sm_{sou} - 0.00069 \cdot P_y \cdot n + 429 \cdot S \cdot Ra_{sou} - 23.3 \cdot S \cdot Sm_{sou} + (14)$$
$$+ 0.0896 \cdot Ra_{sou} \cdot n - 2.118 \cdot Ra_{sou} \cdot Sm_{sou} + 3.17 \cdot n \cdot S - 0.00245 \cdot n \cdot Sm_{sou}.$$  
$$Hμ = 3601 + 77.4 \cdot P_y - 3910 \cdot S - 2.04 \cdot n - 11.93 \cdot Ra_{sou} - 41 \cdot Sm - 0.019 \cdot P_y \cdot n - 1.75 \cdot P_y \cdot Ra_{sou} + 10.185 \cdot S \cdot Ra_{sou} + 100 \cdot S \cdot Sm + 0.032 \cdot n \cdot Sm + (15)$$
$$+ 16.4 \cdot Ra_{sou} \cdot Sm - 626 \cdot P_y \cdot S.$$  

Based on experimental and theoretical research built graphic options, depending on surfaces treated microgeometry mode burnishing $P_y$, $S$, $n$ enabling to optimize technological factors reinforcing-ironed operations for surfaces with predicted values of the parameters microgeometry surface layer and improved performance properties.

**Summary.** In order to improve the performance of roller rings and reduce the cost of production offered in the technological cycle of the rings redistribute allowances for grinding operations processing and operation superfinish processing combined burnishing.

Working empirical (13) (14) (15) and graphic dependences revealed that the reduction $Ra$ 6 times reduces the intensity of wear surfaces also 6 times, reducing $Sm$ 2.5 times the intensity reduces wear surface 4.4 times, an increase of 5 $Hμ$ increases the wear resistance of the surface 7.5 times (all other equal conditions). Thus, the most significant impact wear resistance surface microhardness $Hμ$, arithmetic mean deviation of profile $Ra$ and the average roughness pitch $Sm$.

Research roller burnishing strengthening treated for wear resistance were conducted in the following modes: $F_a=21$ kg/cm², $F_r=12$ kg/cm² (axial and radial load, respectively); $n=6000$ rev/min; $T_{10}=229$ hours. Found that through the use of reinforcing-ironed technologies durability surfaces bearing rings roller increases by 15-20%. Physical picture experimental fact increase the durability of functional surfaces after smoothing operations strengthens confirmed the reliability of theoretical positions.
1. Contact the strength of bearing surfaces is provided not only by methods of thermal and chemical-thermal effects, but methods of rational combination of grinding and strengthening ironed-treatment as directed smoothing effect on surface asperities peaks, providing effect of the surface layer, and as a result reduce the period of grinding in contacting surfaces by 30% and increase the service life of 10%.

2. According to the research highly developed technology combined grinding and strengthening ironed-processing surfaces bearing rings, providing an enhanced level of wear resistance roller by 15-20% and reduces the cost of finishing operations by 12%.

3. The mathematical model of burnishing tool one indentation elastic action on the basis of which is determined radial force in the contact “surface – indenter” $P_y=200$ H. The conditions to ensure continuous contact of the indenter piece to piece band rotation – 400...600 rev/min that is the foundation of stability during the process of burnishing process design;

4. Based on modeling the dynamics of the process of smoothing based strain gradient workpiece material reasonably geometric configuration deforming element (indenter) ellipsoid-type core radius $R_{pr}=20$ mm and the ratio of the length of the vertical axis ($l_a$) to the horizontal ($l_b$) – $1 \div 0.63$ respectively and developed a design tool unit with the mechanism of $P_y$.

References


