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Calculation Model of the Radial Bearing, Caused by the Melt, Taking into Account the Dependence of Viscosity on Pressure

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Abstract

A method for the formation of an exact self-similar solution for the hydrodynamic calculation of a wedge-shaped support (slider, guide) operating in the presence of a lubricant having the properties of a micropolar lubricant and a melt of a low-melting coating of the bearing bush, taking into account the dependence of the viscosity of the lubricant on pressure, is given in this paper.

On the basis of the equation of motion of a viscous incompressible fluid for a "thin layer" and an expression for the energy dissipation rate, an analytical dependence is obtained for the profile of the molten surface of a low-melting coating of the bearing bush, taking into account the dependence of the viscosity of the lubricant on pressure. In addition, the main operating characteristics of the friction pair under consideration are determined.

The influence of the parameter due to the melt of the surface of the low-melting coating of the bearing sleeve and the parameter characterizing the dependence of the viscosity of the lubricant on pressure on the load-bearing capacity and the friction force.

Keywords: hydrodynamics, plain bearing, micro-polar liquid lubricant, molten surface of the surface of the low-melting coating of the bearing bush, viscosity dependence of the lubricant on pressure.

INTRODUCTION

As it is well known in modern engineering, tribonodes for new machines are usually designed taking into account the increase in static and shock loads acting on slip bearings, which is determined by the problems of modern engineering practice. It should be noted that one of the most important equal design elements of fluid friction bearings is the lubricating medium.

One of the methods of solving constructive-operational problems can be the use of smearing with a melt of a low-melting coating of the bearing bush.

Lubrication with liquid metals is used at temperatures at which conventional lubricating media undergo irreversible physical and chemical changes. The advantage of lubrication with the melt is that the lubricant is formed in the contact area where it is necessary. Melting delivers a sufficient amount of lubricant to the friction zone, there are no mechanical and structural difficulties associated with its feeding. Lubrication with a melt was studied in many applied problems, in particular, in the processes of forming and cutting metals [1-7]. A large number of works have been devoted to the hydrodynamic calculation of a system consisting of a slider with its position at an angle to the surface of the guide, in the absence of a lubricant, and without taking into account the dependence of the viscosity of the lubricant material on pressure [8-9]. A significant drawback of the friction pair operating on melt lubrication is a low load-bearing capacity. In addition, the lubrication process of a grease lubricant is not self-sustaining.

Thus, the development of a design model of plain bearings operating on lubricants in the form of metallic melts, taking into account the above aspects of functioning, is one of the promising areas of theoretical studies of modern tribology. The latter determines the novelty and urgency of the solution obtained.

The scientific novelty of the proposed solution and the refinement of the calculation model consist in estimating the effect of the parameter due to the melt of the fusible surface coating of the bearing bush and the parameter characterizing the dependence of the viscosity of the lubricant on pressure, providing slip bearings with an abnormally low coefficient of friction**.**

The purpose of the work: formation of a refined calculation model of a sliding support operating in the hydrodynamic lubrication mode in the presence of a lubricant and a melt of the guide, taking into account the dependence of the viscosity of the lubricant material on the pressure.

TASK SETTING

A model of the steady motion of a viscous incompressible lubricant in the gap of an infinite radial plain bearing coated with a melt of a low-melting coating is under consideration.

The shaft is rotating at the angular speed Ω, and the bearing bushing is stationary. It is assumed that the space between the eccentrically located shaft and the bearing is completely filled with lubricant, and the bearing bushing is made of a material with a low melting point.

The conditions when all the heat released in the lubricating film goes to the melting of the surface of the material of the bearing bushing are considered.

The dependence of the viscosity characteristics of a micropolar liquid lubricant on pressure is given by the following relationship:

$$\mu' = \mu_0 e^{\tilde{\alpha} p'}, \qquad \kappa' = \kappa_0 e^{\tilde{\alpha} p'}, \qquad \gamma' = \gamma_0 e^{\tilde{\alpha} p'}. \tag{1}$$

where μ' is coefficient of dynamic viscosity of the lubricant; κ', γ' are the viscosity coefficients of the micropolar lubricant; μ_0 is the characteristic viscosity of a Newtonian lubricant; p' is the hydrodynamic pressure in the lubricating layer; $\tilde{\alpha}$ is the experimental constant.

THE INITIAL EQUATIONS

A system of dimensionless equations of motion of a lubricant having micro-polar properties is taken as initial equations, for the case of a "thin layer", and also the continuity equation:

$$\frac{\partial^2 u'}{\partial r'^2} + N^2 \frac{\partial \upsilon'}{\partial r'} = \frac{1}{\mu'} \frac{dp'}{d\theta},$$

$$\frac{\partial^2 \upsilon'}{\partial r'^2} = \frac{\upsilon'}{N_1} + \frac{1}{N_1} \frac{\partial u'}{\partial r'}, \qquad \frac{\partial u'}{\partial \theta} + \frac{\partial v'}{\partial r'} = 0. \tag{2}$$

Here u', v' are components of the velocity vector of the lubricating medium; p' is the hydrodynamic pressure in the lubricating layer; μ' is coefficient of dynamic viscosity.

In the polar coordinate system (Figure 1) with a pole in the center of the bearing bush, the equation of the contour of the shaft of the molten surface of the bearing bushing and the surface of the bearing bush covered with a metallic melt is written in the form:

$$r' = r_0(1+H), \qquad r' = r_1, \qquad r' = r_1 + \lambda' f(\theta), \tag{3}$$

where $H = \varepsilon \cos\theta - \frac{1}{2}\varepsilon^2 \sin^2\theta + ..., \quad \varepsilon = \frac{e}{r_0};$ r_0 is the shaft radius; r_1 is radius of the bearing bush covered with a metal melt; e is the eccentricity; ε is the relative eccentricity; $\lambda' f(\theta)$ is the limited function at $\theta \in [0 \div 2\pi]$ subject to determination.

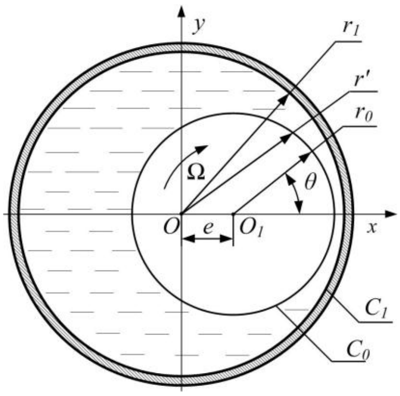

Figure 1: Design Scheme

The boundary conditions in the case under consideration within the accuracy of members $O(\varepsilon^2)$ will be written as:

$$v' = 0, \quad u' = 0, \quad \upsilon' = 0 \text{ at } r' = r_1 + \lambda' f(\theta);$$

$$v' = r_0 \Omega, \quad u' = -\Omega e \sin\theta, \quad \upsilon' = 0 \text{ at}$$
$$r' = r_0 + e\cos\theta;$$

$$p'(0) = p'(2\pi) = \frac{P_a}{P^*}, \quad \lambda' f(\theta) = \Phi(\theta). \tag{4}$$

In order to define the function $\Phi(\theta) = \lambda' f(\theta)$, caused by the molten surface of the bearing, we use the formula for the rate of energy dissipation.

$$-\frac{d\lambda' f(\theta) r_0}{d\theta} \cdot \Omega L' = 2\mu \int_{r_1+\lambda' f(\theta)}^{r_0 + e\cos\theta} \left(\frac{\partial u'}{\partial r'}\right)^2 dr', \tag{5}$$

where L' is specific heat of fusion per unit volume.

The transition to dimensionless variables is realized on the basis of the following formulas:

$$r' = r_1 - \delta r, \ \delta = r_1 - r_0; \quad v' = \Omega r_0 v; \quad u' = \Omega \delta u; \quad p' = p^* p;$$
$$p^* = \frac{(2\mu_0 + \kappa_0)\Omega r_0^2}{2\delta^2}; \quad \upsilon' = \upsilon; \quad \mu' = \mu_0 \mu; \quad \kappa' = \kappa_0 \kappa; \quad \gamma' = \gamma_0 \gamma;$$

$$N^2 = \frac{\kappa_0}{2\mu_0 + \kappa_0}, \quad N_1 = \frac{2\mu_0 l^2}{\delta^2 \kappa_0}, \quad l^2 = \frac{\gamma_0}{4\mu_0}. \tag{6}$$

Performing the substitution of (5) into the system of differential equations (1) and (4), as well as the boundary conditions (3), we arrive at the following system of differential equations:

$$\frac{\partial^2 u}{\partial r^2}+N^2\frac{\partial \upsilon}{\partial r}=e^{-\alpha p}\frac{dp}{d\theta},$$

$$\frac{\partial^2 \upsilon}{\partial r^2}=\frac{\upsilon}{N_1}+\frac{1}{N_1}\frac{\partial u}{\partial r},\qquad \frac{\partial u}{\partial \theta}+\frac{\partial v}{\partial r}=0. \tag{7}$$

$$\frac{d\Phi(\theta)}{d\theta}=-K\int_{-\Phi(\theta)}^{h(\theta)}\left(\frac{\partial u}{\partial r}\right)^2 dr,\qquad K=\frac{2\mu\Omega r_0}{L'\delta}. \tag{8}$$

And boundary conditions

$v=1,\quad u=-\eta\sin\theta,\quad \upsilon=0$ at

$$r=1-\eta\cos\theta=h(\theta);$$

$v=0,\quad u=0,\quad \upsilon=0$ at

$$r=0-\Phi(\theta);\quad p(0)=p(2\pi)=\frac{P_a}{P^*}; \tag{9}$$

where $\eta=\frac{e}{\delta};\quad \eta_1=\frac{\lambda'}{\delta};\quad \Phi(\theta)=\eta_1 f(\theta).$

Taking into account the smallness of the gap, as well as the equality on the moving and fixed surfaces, we average the second equation of the system (7) along the thickness of the lubricating layer, we obtain:

$$\frac{1}{h+\Phi}\int_{-\Phi}^{h}\frac{\partial^2\upsilon}{\partial r^2}dr=\frac{1}{N_1(h+\Phi)}\int_{-\Phi}^{h}\upsilon dr+\frac{1}{N_1(h+\Phi)}\int_{-\Phi}^{h}\frac{\partial u}{\partial r}dr. \tag{10}$$

We seek the solution of (10) in the form:

$$\upsilon=A_1(\theta)r^2+A_2(\theta)r+A_3(\theta). \tag{11}$$

Taking into account the boundary conditions (9) for υ we get:

$$\upsilon=A_1(\theta)\cdot\left(r^2-(h-\Phi)r-\Phi h\right). \tag{12}$$

Substituting (12) in (10), within the accuracy of the members $O\left(\frac{\Phi}{N_1}\right),\quad O\left(\frac{1}{N_1^2}\right),$ we get:

$$\upsilon=\frac{1}{2N_1 h}\left(r^2-rh\right),\qquad \frac{\partial\upsilon}{\partial r}=-\frac{1}{2N_1 h}(2r-h),\quad A_1=\frac{1}{2N_1 h}. \tag{13}$$

With allowance for (13), the system of equations (7) - (9) in the approximation we have adopted has the form:

$$\frac{\partial^2 u}{\partial r^2}+\frac{N^2}{2N_1 h}(2r-h)=e^{-\alpha p}\frac{dp}{d\theta},\quad \upsilon=\frac{1}{2N_1 h}\left(r^2-rh\right),$$
$$\frac{\partial u}{\partial r}+\frac{\partial \nu}{\partial \theta}=0,\quad \frac{d\Phi(\theta)}{d\theta}=-K\int_{-\Phi(\theta)}^{h(\theta)}\left(\frac{\partial u}{\partial r}\right)^2 dr. \tag{14}$$

Let's introduce the sign $Z=e^{-\alpha p}$. Differentiating both sides of the equality, we obtain:

$\frac{dZ}{d\theta}=-\alpha e^{-\alpha p}\frac{dp}{d\theta}$ at $e^{-\alpha p}\frac{dp}{d\theta}=-\frac{1}{\alpha}\frac{dZ}{d\theta}.$

Then the equations (14) take the following form:

$$\frac{\partial^2 u}{\partial r^2}+\frac{N^2}{2N_1 h}\left(2r-h\right)=-\frac{1}{\alpha}\frac{dZ}{d\theta};\quad \frac{\partial u}{\partial r}+\frac{\partial v}{\partial \theta}=0;\quad \upsilon=\frac{1}{2N_1 h}\left(r^2-rh\right); \tag{15}$$

$$Z\frac{d\Phi(\theta)}{d\theta}=-K\int_0^{1-\eta\cos\theta}\left(\frac{\partial u_0}{\partial r}\right)^2 dr \tag{16}$$

With the correspondent boundary conditions

$v=1,\quad u=-\eta\sin\theta$ at $r=1-\eta\cos\theta;$

$$v=0,\quad u=0 \text{ при } r=0-\Phi(\theta);\quad Z(0)=Z(2\pi)=e^{-\alpha\frac{p_a}{p^*}}. \tag{17}$$

Taking K as a small parameter due to the melt and the rate of energy dissipation, we seek the function $\Phi(\theta)$ as:

$$\Phi(\theta)=-K\Phi_1(\theta)-K^2\Phi_2(\theta)-K^3\Phi_3(\theta)-\ldots=H, \tag{18}$$

where $H=-K\Phi_1(\theta)-K^2\Phi_2(\theta)-K^3\Phi_3(\theta)-\ldots.$

Boundary conditions for dimensionless velocity components *u* and *v* on contour $r=-\Phi(\theta)$ can be written as:

$$v\left(0-H(\theta)\right)=v(0)-\left(\frac{\partial v}{\partial r}\right)_{r=0}\cdot H(\theta)-\left(\frac{\partial^2 v}{\partial r^2}\right)_{r=0}\cdot H^2(\theta)-\ldots=0;$$

$$u\left(0-H(\theta)\right)=u(0)-\left(\frac{\partial u}{\partial r}\right)_{r=0}\cdot H(\theta)-\left(\frac{\partial^2 u}{\partial r^2}\right)_{r=0}\cdot H^2(\theta)-\ldots=0. \tag{19}$$

The asymptotic solution of the system of differential equations (16) with allowance for the boundary conditions (17) and (19) can be found in the form:

$$v=v_0(r,\theta)+Kv_1(r,\theta)+K^2v_2(r,\theta)+...;$$

$$u=u_0(r,\theta)+Ku_1(r,\theta)+K^2u_2(r,\theta)+...;$$

$$\Phi(\theta)=-K\Phi_1(\theta)-K^2\Phi_2(\theta)-K^3\Phi_3(\theta)-\ldots;$$

$$p=p_0+Kp_1(\theta)+K^2p_2(\theta)+K^3p_3(\theta)... \tag{20}$$

Performing the substitution of (20) into the system of differential equations (16), taking into account the boundary conditions (17) and (19), we obtain the following equations:

- for the zeroth approximation:

$$\frac{\partial^2 u_0}{\partial r^2}+\frac{N^2}{2N_1 h}\left(2r-h\right)=-\frac{1}{\alpha}\frac{dZ_0}{d\theta},\quad \frac{\partial v_0}{\partial r}+\frac{\partial u_0}{\partial \theta}=0 \tag{21}$$

With boundary conditions:

$v_0=1,\quad u_0=-\eta\sin\theta,\quad \upsilon_0=0$ at $r=1-\eta\cos\theta;$

$$v_0 = 0, \quad u_0 = 0, \quad \upsilon_0 = 0 \text{ at } r = 0;$$

$$Z_0(0) = Z_0(2\pi) = e^{-\alpha \frac{P_a}{P^*}}; \tag{22}$$

– for the first approximation:

$$\frac{\partial^2 u_1}{\partial r^2} = -\frac{1}{\alpha}\frac{dZ_1}{d\theta}; \quad \frac{\partial v_1}{\partial r} + \frac{\partial u_1}{\partial \theta} = 0;$$

$$Z_0 \frac{d\Phi_1(\theta)}{d\theta} = -K \int_0^{1-\eta\cos\theta} \left(\frac{\partial u_0}{\partial r}\right)^2 dr \tag{23}$$

With boundary conditions:

$$v_1 = \left(\frac{\partial v_0}{\partial r}\right)_{r=0} \cdot \Phi_1(\theta); \qquad u_1 = \left(\frac{\partial u_0}{\partial r}\right)_{r=0} \cdot \Phi_1(\theta);$$

$$v_1 = 0; \qquad u_1 = 0, \quad \upsilon_1 = 0 \text{ at } r = 1 - \eta\cos\theta;$$

$$p_1(0) = p_1(2\pi) = 0; \quad K\Phi_1(\theta) = K\tilde{\alpha}, \quad \Phi(0) = \Phi(2\pi) = \tilde{\alpha}. \tag{24}$$

EXACT SELF-SIMILAR SOLUTION

The exact self-similar solution of the problem for the zeroth approximation will be sought in the form:

$$v_0 = \frac{\partial \psi_0}{\partial r} + V_0(r,\theta); \quad u_0 = -\frac{\partial \psi_0}{\partial \theta} + U_0(r,\theta);$$
$$\psi_0(r,\theta) = \tilde{\psi}_0(\xi); \quad \xi = \frac{r}{h(\theta)}; \tag{25}$$
$$V_0(r,\theta) = \tilde{v}(\xi); \quad U_0(r,\theta) = -\tilde{u}_0(\xi)\cdot h'(\theta);$$
$$\frac{dZ_0}{d\theta} = -\alpha\left[\frac{\tilde{C}_1}{h^2(\theta)} + \frac{\tilde{C}_2}{h^3(\theta)}\right]; \quad h(\theta) = 1 - \eta\cos\theta.$$

Substituting (25) into the system of differential equations (21), taking into account the boundary conditions (22), we obtain the following system of differential equations:

$$\tilde{\psi}_0''' = \tilde{C}_2; \quad \tilde{u}_0'' = \tilde{C}_1 - \frac{N^2}{2N_1}(2\xi - 1); \;\; \tilde{u}_0'(\xi) + \xi\tilde{v}_0'(\xi) = 0 \tag{26}$$

And boundary conditions:

$$\upsilon(0) = 0, \quad \tilde{\psi}_0'(0) = 0, \quad \tilde{\psi}_0'(1) = 0, \quad \tilde{u}_0(1) = -\eta\sin\theta, \quad \tilde{v}_0(1) = 0;$$

$$\upsilon(1) = 0, \quad \tilde{u}_0(0) = 0, \quad \tilde{v}_0(0) = 1, \quad \int_0^1 \tilde{u}_0(\xi)\,d\xi = 0, \quad Z_0(0) = Z_0(2\pi) = e^{-\alpha\frac{P_a}{P^*}}. \tag{27}$$

By the direct integration we get:

$$\tilde{\psi}_0'(\xi)=\frac{\tilde{C}_2}{2}\left(\xi^2-\xi\right);\quad \tilde{u}_0(\xi)=\tilde{C}_1\frac{\xi^2}{2}-\frac{N^2}{2N_1}\left(\frac{\xi^3}{3}-\frac{\xi^2}{2}\right)-\left(\frac{N^2}{12N_1}+\frac{\tilde{C}_1}{2}+1\right)\xi+1;\quad \tilde{C}_1=6. \tag{28}$$

From the condition $Z_0(0)=Z_0(2\pi)=e^{-\alpha\frac{P_a}{P^*}}$ we get the following expression:

$$\tilde{C}_2=-C_1\frac{\int_0^{2\pi}\frac{d\theta}{h^2(\theta)}}{\int_0^{2\pi}\frac{d\theta}{h^3(\theta)}}=-\frac{12\left(1-\eta^2\right)}{2+\eta^2}. \tag{29}$$

DETERMINATION OF HYDRODYNAMIC PRESSURE

Taking (29) into account for the dimensionless hydrodynamic pressure, we obtain:

$$Z_0=-\alpha\left(\tilde{C}_1J_2(\theta)+\tilde{C}_2J_3(\theta)\right)+e^{-\alpha\frac{P_a}{P^*}}=\frac{6\alpha\sin\theta}{\left(2+\eta^2\right)\left(1-\eta\cos\theta\right)}\left[\eta+\frac{1}{\left(1-\eta\cos\theta\right)}\right]+e^{-\alpha\frac{P_a}{P^*}}. \tag{30}$$

It is well known that in the case of solving the problem of a flat hydrodynamic theory of lubrication, the pressure is determined to within an arbitrary constant. The value of this constant $\tilde{C}_2$ is established from the condition that there is no negative pressure in the lubricating layer.

To find the values of the expression Z for the first approximation, we must first determine the function $\Phi_1(\theta)$.

To define $\Phi_1(\theta)$ taking into account the equation (23), we arrive at the following equation:

$$\frac{d\Phi_1(\theta)}{d\theta}=\frac{h(\theta)}{Z_0}\int_0^1\left(\frac{\tilde{\psi}_0''(\xi)}{h^2(\theta)}+\frac{\tilde{u}_0'(\xi)}{h(\theta)}\right)^2d\xi. \tag{31}$$

Integrating the equation (31), we get:

$$\Phi_1(\theta)=\frac{1}{Z_0}\left(\int_0^\theta\frac{\Delta_1d\theta}{h^3(\theta)}+\int_0^\theta\frac{\Delta_2d\theta}{h^2(\theta)}+\int_0^\theta\frac{\Delta_3d\theta}{h(\theta)}\right), \tag{32}$$

where

$$\Delta_1=\int_0^1\left(\tilde{\psi}''(\xi)\right)^2d\xi=\frac{\tilde{C}_2^2}{12};\ \Delta_2=\int_0^1 2\tilde{\psi}''(\xi)\cdot\tilde{u}'(\xi)d\xi=\frac{1}{6}\tilde{C}_1\tilde{C}_2;$$

$$\Delta_3=\int_0^1\left(\tilde{u}'(\xi)\right)^2d\xi=4+\frac{N^4}{720N_1^2},$$

$$\sup_{[0\div2\pi]}Z_0=\sup_{[0\div2\pi]}\left|\frac{6\alpha\sin\theta}{\left(2+\eta^2\right)\left(1-\eta\cos\theta\right)}\left(\eta+\frac{1}{\left(1-\eta\cos\theta\right)}\right)+e^{-\alpha\frac{p_a}{P^*}}\right|=\frac{1}{64}. \tag{33}$$

Solving the equations (32)–(33) taking into account $K\Phi_1(0) = K\tilde{\alpha},$ we get:

$$\Phi_1(\theta) = \frac{1}{64}\left\{\frac{1}{\sqrt{1-\eta^2}}\operatorname{arctg}\left(\sqrt{\frac{1+\eta}{1-\eta}}\operatorname{tg}\frac{\theta}{2}\right)\left[\frac{-12}{2+\eta^2}+8+\frac{N^4}{360N_1^2}\right]+\right.$$
$$\left.+\frac{6\eta\sin\theta}{(2+\eta^2)(1-\eta\cos\theta)}+\frac{6(1-\eta^2)\sin\theta}{(2+\eta^2)^2(1-\eta\cos\theta)^2}+\tilde{\alpha}\right\}. \tag{34}$$

Then for the first approximation we get:

$$u_1 = \frac{\partial\psi_1}{\partial r} + U_1(r,\theta); \quad v_1 = -\frac{\partial\psi_1}{\partial\theta} + V_1(r,\theta);$$
$$\psi_1(r,\theta) = \tilde{\psi}_1(\xi); \quad \xi = \frac{r}{h(\theta)};$$
$$V_1(r,\theta) = \tilde{v}(\xi); \quad U_1(r,\theta) = -\tilde{u}_1(\xi)\cdot h'(\theta); \tag{35}$$
$$\frac{dZ_1}{d\theta} = -\alpha\left(\frac{\tilde{\tilde{C}}_1}{h^2(\theta)}+\frac{\tilde{\tilde{C}}_2}{h^3(\theta)}\right); \quad h(\theta) = 1-\eta\cos\theta.$$

Substituting (35) into the system of differential equations (23), taking into account the boundary conditions (24), we obtain the following system of differential equations:

$$\tilde{\psi}_1''' = \tilde{\tilde{C}}_2; \quad \tilde{u}_1'' = \tilde{\tilde{C}}_1; \; \tilde{u}_1'(\xi) + \xi\tilde{v}_1'(\xi) = 0; \quad \frac{dZ_1}{d\theta} = -\alpha\left(\frac{\tilde{\tilde{C}}_1}{h^2(\theta)}+\frac{\tilde{\tilde{C}}_2}{h^3(\theta)}\right) \tag{36}$$

And boundary conditions:

$$\tilde{\psi}_1'(0) = 0, \quad \tilde{\psi}_1'(1) = 0, \quad \tilde{u}_1(1) = 0, \quad \tilde{v}_1(1) = 0; \quad \upsilon_1(0) = 0$$
$$\upsilon_1(1) = 0, \quad \tilde{u}_1(0) = M, \quad \tilde{v}_1(0) = 0, \quad \int_0^1 \tilde{u}_1(\xi)\,d\xi = 0, \quad Z_1(0) = Z_1(2\pi) = 0. \tag{37}$$

By the direct integration we get:

$$\tilde{\psi}_1'(\xi) = \frac{\tilde{\tilde{C}}_2}{2}(\xi^2-\xi), \quad \tilde{u}_1(\xi) = \tilde{\tilde{C}}_1\frac{\xi^2}{2} - \left(\frac{\tilde{\tilde{C}}_1}{2}+M\right)\xi + M, \quad \tilde{\tilde{C}}_1 = 6M. \tag{38}$$

From the condition $Z_1(0) = Z_1(2\pi) = 0$ we get:

$$\tilde{\tilde{C}}_2 = -\frac{12M(1-\eta^2)}{2+\eta^2}, \tag{39}$$

where

$$M=\sup_{\theta\in[0:2\pi]}\frac{\partial u_0}{\partial r}\bigg|_{r=0}\cdot\Phi_1(\theta)=\sup_{\theta\in[0:2\pi]}\left(\frac{-\eta\sin\theta}{1-\eta\cos\theta}-\frac{N^2(1-\eta\cos\theta)}{12N_1}+\frac{3}{(2+\eta^2)}\left[\frac{\eta(\cos\theta-\eta)}{1-\eta\cos\theta}+\frac{\cos\theta-\eta\cos^2\theta-2\eta\sin^2\theta}{(1-\eta\cos\theta)^2}\right]\right)\times$$

$$\times\frac{1}{64}\left(\frac{1}{\sqrt{1-\eta^2}}\operatorname{arctg}\left(\sqrt{\frac{1+\eta}{1-\eta}}\operatorname{tg}\frac{\theta}{2}\right)\left[\frac{-12}{2+\eta^2}+8+\frac{N^4}{360N_1^2}\right]+\frac{6\eta\sin\theta}{(2+\eta^2)(1-\eta\cos\theta)}+\frac{6(1-\eta^2)\sin\theta}{(2+\eta^2)^2(1-\eta\cos\theta)^2}+\tilde{\alpha}.\right).$$

Taking into account (36) for Z_1 we obtain:

$$Z_1=-\alpha\left(\tilde{\tilde{C}}_1J_2(\theta)+\tilde{\tilde{C}}_2J_3(\theta)\right)=\frac{6\alpha M\sin\theta}{(2+\eta^2)(1-\eta\cos\theta)}\left[\eta+\frac{1}{(1-\eta\cos\theta)}\right]. \tag{40}$$

Then for $Z = Z_0 + KZ_1$ we get the following expression:

$$Z=\frac{6\alpha\sin\theta}{(2+\eta^2)(1-\eta\cos\theta)}\left(\eta+\frac{1}{(1-\eta\cos\theta)}\right)(1+KM)+e^{-\alpha\frac{p_a}{p^*}} \tag{41}$$

or $e^{-\alpha p}=\Delta\alpha(1+KM)+e^{-\alpha\frac{p_a}{p^*}}$,

where $\Delta=\dfrac{6\sin\theta}{(2+\eta^2)(1-\eta\cos\theta)}\left(\eta+\dfrac{1}{(1-\eta\cos\theta)}\right)$.

Applying the Taylor expansion for functions $e^{-\alpha p}$, $e^{-\alpha\frac{p_a}{p^*}}$, we get:

$$1-\alpha p+\frac{\alpha^2p^2}{2}-1+\alpha\frac{p_a}{p^*}-\frac{\alpha^2}{2}\left(\frac{p_a}{p^*}\right)^2=\alpha\Delta(1+KM). \tag{42}$$

Solving the equation (42) within the accuracy of the members $O(\alpha)^3$, $O(\xi)^2$, $O\left(\frac{p_a}{p^*}\right)^3$ for the hydrodynamic pressure we get

$$p=\frac{P_a}{P^*}-\Delta(1+KM)\left(1+\alpha\frac{p_a}{p^*}-\frac{\alpha^2}{2}\left(\frac{p_a}{p^*}\right)^2\right). \tag{43}$$

RESULTS OF STUDY AND THEIR DISCUSSION

Let us now turn to the determination of the basic operating characteristics of the bearing.

Taking into account (21), (23), (43) for the component of the supporting force vector and the frictional force, we obtain:

$$R_y=\frac{(2\mu_0+\kappa_0)\Omega r_0^3}{\delta^2}\int_0^{2\pi}\left(p_0-\frac{P_a}{P^*}\right)\sin\theta d\theta=$$
$$=\frac{6\mu\Omega r_0^3\pi\eta\left(\left(1-\eta^2\right)+1\right)}{\delta^2\left(2+\eta^2\right)\sqrt{\left(1-\eta^2\right)^3}}(1+KM)\left(1+\alpha\frac{P_a}{P^*}-\frac{\alpha^2}{2}\left(\frac{P_a}{P^*}\right)^2\right);$$

$$R_x=\frac{(2\mu_0+\kappa_0)\Omega r_0^3}{\delta^2}\int_0^{2\pi}\left(p-\frac{P_a}{P^*}\right)\cos\theta d\theta=0.$$

$$L_{\text{тр}}=\frac{(2\mu_0+\kappa_0)\Omega r_0^2}{\delta}e^{-\alpha p}\int_0^{2\pi}\left[\left.\frac{\partial u_0}{\partial r}\right|_{r=0}+K\left.\frac{\partial u_1}{\partial r}\right|_{r=0}\right]d\theta=$$
$$=\frac{(2\mu_0+\kappa_0)\Omega r_0^2}{\delta}\left[-\frac{N^2\pi}{6N_1}-\frac{2MK}{1+\eta}arctg\frac{2\pi\sqrt{1+\eta}}{\sqrt{1-\eta}}+\frac{3(1+MK)}{\left(2+\eta^2\right)}\left(\frac{2}{1+\eta}arctg\frac{2\pi\sqrt{1+\eta}}{\sqrt{1-\eta}}(1-\eta)+\right.\right.$$
$$\left.\left.+\frac{8\eta}{\sqrt{1-\eta^2}}arctg\frac{2\pi\sqrt{1+\eta}}{\sqrt{1-\eta}}\right)\left(1-\alpha p+\frac{\alpha^2}{2}p^2\right)\right. . \quad (44)$$

The following values are used for the verification calculations, based on the theoretical models obtained:

μ = 0,0608 Нс/м^2; η = 0,3…1 м; r_0 = 0,019985…0,04993 м;

P_a = 0,08 $\div$0,101325 МПа

δ = 0,05 · 10^{-3}…0,07 · 10^{-3}; K = 0,0000022…0,00052;

L' = 3,9 ·10^5 Н/м^2; M = 0,16 … 25,6; Ω = 100…1800 с$^{-1}$.

Based on the results of numerical calculations, the graphs shown in Fig. 2-4 were built.

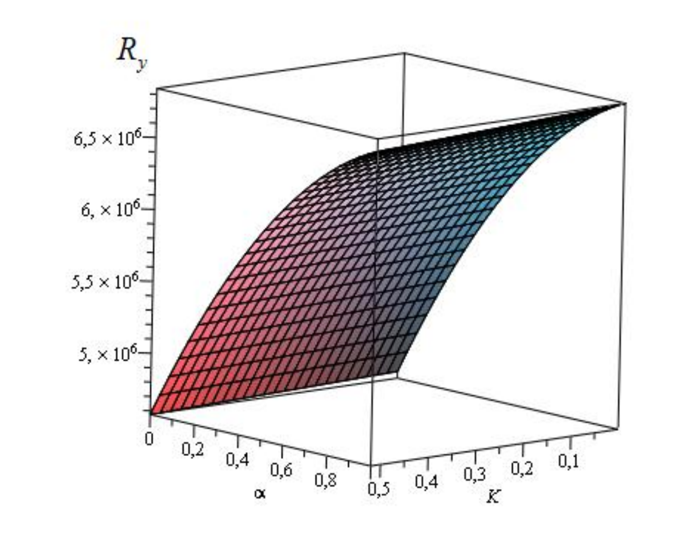

Figure 2: Dependence of the components of the supporting force (R_y) on parameters: α, characterizing the dependence of viscosity on pressure, and K, due to the melt and the rate of energy dissipation

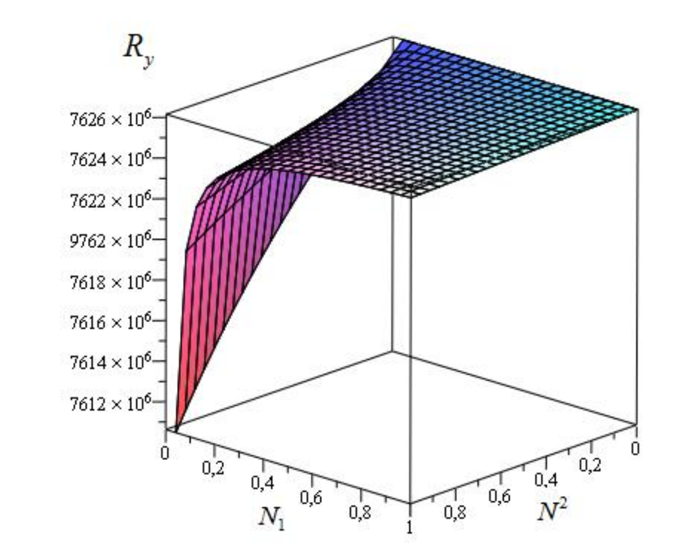

Figure 3: Dependence of the components of the supporting force (R_y) on the structure-viscosity parameters (N and N_1) of micro-polar lubricant

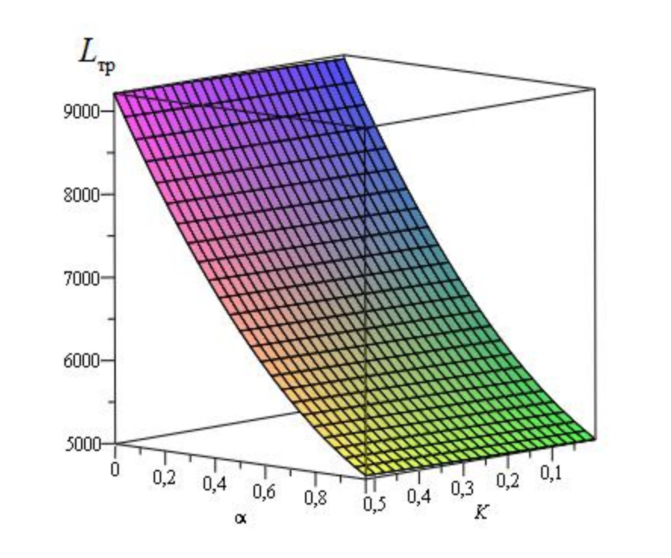

Fig. 4. Dependence of the friction force on parameters: α, characterizing the dependence of viscosity on pressure, and K, due to the melt and the rate of energy dissipation

CONCLUSIONS

The bearing capacity of a radial bearing increases insignificantly with an increase in the parameter α, which characterizes the dependence of viscosity on pressure, and decreases insignificantly with an increase in the parameter K, which characterizes the rate of dissipation of mechanical energy. As the values of the structural-viscosity parameters increase (N и N_1) of the micro-polar lubricant material increases sharply.

- As a result of the theoretical studies, the main regularities of the influence of the structural-viscous parameters of a micro-polar lubricant (N и N_1) on bearing capacity and friction force.

Conclusion. The obtained results in the form of computational models can be used in the development and carrying out of verification calculations of the structure of slip bearings working on micropolar lubricants taking into account the structural and viscosity characteristics that provide a significant reduction in the effect of workloads on the friction units, which are one of the promising directions modern tribology.

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