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METHODS OF FORECASTING OF STABLE HEAT REGIME OF METAL POLYMERIC BUSHES OF BEARING OF SLIDING OPERATING ON NEWTON LUBRICANT

Summary. The purpose of this work was to develop the methods of forecasting of stable heat regime of metal polymeric bushes of bearing of sliding operating on Newton lubricant. It is shown that the most stable temperature regime of bearing work is achieved through non-dimensional temperature Θ^*=0,5 in the case of low plastic lubricant (A<<1) and 0,8 $\leq \Theta^* \leq$ 0,95 in the case of high plastic lubricant(A>1).

МЕТОДЫ ПРОГНОЗА УСТОЙЧИВОГО ТЕПЛОВОГО РЕЖИМА РАБОТЫ МЕТАЛЛОПОЛИМЕРНЫХ ВТУЛОК ПОДШИПНИКА СКОЛЬЖЕНИЯ, РАБОТАЮЩЕГО НА НЬЮТОНОВСКОЙ СМАЗКЕ

Аннотация. Цель данной работы – развитие методов прогнозирования стабильного теплового режима метало – полимерных втулок подшипников скольжения работающих на Ньютоновской смазке. Как следует из работы, наиболее оптимальные температурные режимы достигаются: в случае низко пластичной смазки Θ^*=0,5 (A<<1) и 0,8 $\leq \Theta^* \leq$ 0,95 в случае высоко пластичной смазки (A>1).

According to statistic data more than 80 percent of machine's premature renounces in railway transport is connected with a wear of conjugated details as a result of friction. The most essential this problem is for junctions of road and building machines. Since 1998 in Rostov University of Communications (Rostov Institute of Engineers of Railway Transport) the investigations of possible constructive and technological ways of raising the reliability of joints of line blocks of liner-tamper machines (LTM) are hold. In order to raise the reliability of line blocks of liner-tamper machines (LTM) was developed a method of forecasting of stable heat regime of metal polymeric bushes of bearing of sliding operating on Newton lubricant.

Analysis of works of domestic and foreign authors testifies about perspective use of composite materials in manufacturing bushes of bearing of sliding.

The choice of constructive size of bearing material and technology of manufacture of metal polymeric bushes is determined by maximum temperature in the zone of friction the size of which depends on condition of exploration. The greater influence in durability of metal polymeric bushes of bearing of sliding effects specific pressure, the speed of sliding and ratio of friction. However, the consideration of influence of these parameters doesn't let us to predict the service term of bearing of sliding in extreme conditions.

The calculation of three layered metal polymeric bushes in hydrodynamic fulcrums of sliding is connected with four basic peculiarities.

First, in hydrodynamic and heat calculation of such fulcrums it is necessary to take into account a multilayerness of this material.

Second, to take into account the condition of polymeric and metal component of antifriction layer for provision of heat resistance of work of considering unit of junction.

Third, during the dynamic contact of lubricating material with polymeric surface depending on structure and physical property of plastic on this surface doesn't fulfill the condition lubricants sticking.

Fourth, lubricant can't get tenacious properties.

Considering above mentioned circumstances the exact auto model decision of private task of hydrodynamic calculation of radial bearing of sliding with three layered metal polymeric bushes carries out in several stages.

On the first stage is decided a task in a full or partial filling of clearance by lubricant materials having Newton qualities. In the process of work in bearing of sliding may arise a hydrodynamic regime of friction which is caused by the following reasons:

- thickness of oil sheet is more or close to critical;
- the section of bush is in the zone of loading.

Lets consider the stream of non compressible sticky liquid on radial bearing with three layered metal polymeric bush. Journal rotates with angular speed ω, and circuit of supporting surface of bearing is heterogeneous and motionless.

In polar system of coordinate (r', Θ) with pole in the centre of bush such a task comes to the decision of system of dimensionless equation for thick layer.

$$\begin{cases} \dfrac{\partial^2 v}{\partial r^2} = \dfrac{\partial P}{\partial \Theta} \\ \dfrac{\partial u}{\partial r} + \dfrac{\partial v}{\partial \Theta} = 0 \\ \dfrac{\partial^2 T}{\partial r^2} = \left(\dfrac{\partial v}{\partial r}\right) \\ \dfrac{\partial^2 T_i}{\partial \tilde{r}^2} + \dfrac{\varepsilon}{\tilde{r}}\dfrac{\partial T_i}{\partial \tilde{r}} + \dfrac{\varepsilon^2}{\tilde{r}^2}\dfrac{\partial^2 T_i}{\partial \Theta^2} = 0, \quad i = 1, 2, 3 \ . \end{cases} \tag{1}$$

Schematic representation of journal in three layered metal polymeric bearing.

In expression (1) the transition to dimensionless parameters in lubricating layer is realized through formulae:

$$v_r = \omega\delta u, \; v_\Theta = \omega r_0 u, \; P' = P^* \cdot P, \; T' = T^* \cdot T, \\ r' = r_1 - \delta r, \; \delta = r_1 - r_0, \\ P^* = \frac{\mu\omega r_0^2}{\delta^2}, \; T^* = \frac{\mu\omega^2 r_0^2}{\lambda J}, \tag{2}$$

and in three layered bush

$$r' = r_1 + \tilde{\delta}\tilde{r}, \; T_i' = T_i \cdot T^{**}, \; \tilde{\delta} = r_i - r_1, \; i = 1, 2, 3, \tag{3}$$

where: r_0 – radius of journal, r_1 – inner radius of bush, v_r и v_Θ – components of speed vector, T' – temperature in lubricant layer, T_i' – temperature in layers of metal polymeric bush, μ – ratio of dynamic thickness, λ – conductivity, J – mechanic equivalent of heat, T^{**} – characteristic temperature.

System of equation (1.1) is solved with the following conditions:

$$u=-1,\ \upsilon=1 \text{ при } r=1-\eta\cos\Theta;\ u=u^{*}=0,\ v=v^{*}=0 \text{ при } r=0;$$

$$P(0)=P(2\pi)=0;\ \frac{\partial T}{\partial r}=0 \text{ при } r=1-\eta\cos\Theta;$$

$$T\big|_{r=0}=T_1\big|_{\tilde r=0},\ \lambda\frac{\partial T}{\partial r}\bigg|_{r=0}=\lambda_1\frac{\partial T_1}{\partial \tilde r}\bigg|_{\tilde r=0};$$

$$T_1\big|_{\tilde r=\eta 1}=T_2\big|_{\tilde r=\eta 1},\ \lambda_1\frac{\partial T_1}{\partial \tilde r}\bigg|_{\tilde r=\eta 2}=\lambda_2\frac{\partial T_2}{\partial \tilde r}\bigg|_{\tilde r=\eta 2};$$

$$T_2\big|_{\tilde r=\eta 3}=T_3\big|_{\tilde r=\eta 3},\ \lambda_2\frac{\partial T_2}{\partial \tilde r}\bigg|_{\tilde r=\eta 3}=\lambda_3\frac{\partial T_3}{\partial \tilde r}\bigg|_{\tilde r=\eta 3};$$

$$\frac{\partial T_1}{\partial \tilde r}\bigg|_{\tilde r=1}=\frac{\gamma_1\tilde\delta}{\lambda_3}\left(T_3-\frac{T_{\text{ср}}}{T^{**}}\right)\Theta^{*}\bigg|_{\tilde r=1}+\left(1-\Theta^{*}\right)\frac{\gamma_2\tilde\delta}{\lambda_3}\left(T_3-\frac{T_{\text{ср}}}{T^{**}}\right)\bigg|_{\tilde r=1}, \tag{4}$$

where: $\eta_2=\dfrac{r_2-r_1}{\delta}$, $\eta_2=\dfrac{r_2-r_1}{\delta}$, $\eta=\dfrac{\varepsilon}{\delta}$;

λ_i – ratio of layer's conductivity

$\varepsilon=\dfrac{\tilde\delta}{r_1}$ – eccentricity

γ_1 – ratio of temperature conducting of materials of metal constituencies of bushes supporting surface

γ_2 – ratio of temperature conducting of material of polymeric constituencies of bushes supporting surface

$\Theta^{*}\in[0,1]$ – quantity which characterizes presence of share of polymeric and metal constituencies (with $\Theta^{*}=0$ on fulcrum surface of bearing metal zones are absent).

Exact auto model decision of a problem determining the field of speeds and pressure in lubricant layer we search in form:

$$u=\frac{\partial\Psi}{\partial\Theta}+\tilde U(r,\Theta),\ v=\frac{\partial\Psi}{\partial r}+\tilde V,\ \Psi=\tilde\Psi(\xi),\ U=\tilde U(\xi)\eta\sin\Theta,$$

$$V=\tilde v(\xi),\ \xi=\frac{r}{h},\ h=1-\eta\cos\Theta,$$

$$\frac{\partial P}{\partial\Theta}=\frac{\tilde c_1}{(1-\eta\cos\Theta)^2}+\frac{\tilde c_2}{(1-\eta\cos\Theta)^3},\ u^{*}=0,\ v^{*}=\frac{c}{h}. \tag{5}$$

Substituting in two first equations of the system we get:

$$\Psi''=\tilde c_2,\ \tilde v''=\tilde c_1,\ \tilde u'-\xi\tilde v'=0, \tag{6}$$

$$\tilde u(0)=0,\ \tilde v(0)=0,\ \tilde u(0)=0,\ \tilde v(0)=0,$$

$$\tilde\Psi'(0)=c,\ \tilde\Psi'(1)=0,\ \int_0^1\tilde v(\xi)d\,\xi=0, \tag{7}$$

$$P(0)=P(2\pi)=0.$$

The solution of equation we get by direct integration. As a result we get:

$$\Psi'(\xi) = \tilde{c}_2 \frac{\xi^2}{2} + c_2\xi + c_3,\ \tilde{v}(\xi) = \tilde{c}_1 \frac{\xi^2}{2} + c_1\xi + c_4, \tag{8}$$

$$\tilde{u}(\xi) = \int_0^\xi \xi v'(\xi) d\xi,\ p = \tilde{c}_1 J_2(\Theta) + \tilde{c}_2 J_3(\Theta),\ J_k = \int_0^\Theta \frac{d\Theta}{h^k(\Theta)}.$$

Constant integration including (9) is determined from boundary conditions (8)

$$c_1 = 2,\ \tilde{c}_1 = 6,\ c_2 = -\frac{\tilde{c}_2}{2} - c,\ \tilde{c}_2 = \frac{-6J_2(2\pi)}{J_3(2\pi)},\ c_3 = c_4 = 0. \tag{9}$$

Solution of heat problem.

Using the obtained analytical expression (1.9) we find:

$$\left(\frac{\partial v}{\partial r}\right)^2 = \frac{(\tilde{c}_2\xi + c_2)^2}{h^4} + 2\frac{\tilde{c}_2\xi(\tilde{c}_1 + c_1) + c_2(\tilde{c}_1\xi + c_1)}{h^3} + \frac{\tilde{c}_1\xi + c_1}{h^2}. \tag{10}$$

The solution of system of equation in state of right part with considering we will search in form:

$$T(r,\Theta) = T(\xi,\Theta). \tag{11}$$

After double integration of equation (1.10) it will have a state:

$$T = -\frac{\tilde{c}_2^2 \frac{\xi^4}{12} + \tilde{c}_2 c_2^2 \frac{\xi^3}{3} + c_2 \frac{\xi^2}{2}}{h^2} - \frac{\tilde{c}_1\tilde{c}_2^2 \frac{\xi^4}{6} + \frac{\xi^3}{3}(\tilde{c}_2 c_1 + \tilde{c}_1 c_2) + c_1 c_2 \xi^2}{h} - \tag{12}$$

$$-\tilde{c}_1^2 \frac{\xi^4}{12} - c_1\tilde{c}_1 \frac{\xi^3}{3} - c_1^2 \frac{\xi^2}{2} - \Phi_1(\Theta)\cdot h^2\xi - \Phi_2(\Theta)\cdot h^2 \quad .$$

For determining the temperature in layers of bush lets use the forth equation of the system. Since in considering case $\varepsilon << 1$this equation with exactness up to the part of order of infinitesimal $O(\varepsilon)$ becomes simpler and gets the state:

$$\frac{\partial^2 T_i}{\partial \tilde{r}^2} = 0,\quad i = 1,\ 2,\ 3. \tag{13}$$

Integrating the equation we get:

$$T_i(r,\Theta) = M_i(\Theta)\tilde{r} + N_i(\Theta). \tag{14}$$

Using limited conditions for determining functions of integration $\Phi_1(\Theta),\ \Phi_2(\Theta),\ M_i(\Theta),\ N_i(\Theta),\ i = 1,\ 2,\ 3$, we get a system of equations.

$$\begin{cases} \frac{\tilde{c}_2^2}{3} + \tilde{c}_2 c_2 + c_2^2 + h\left(\frac{2\tilde{c}_2\tilde{c}_1}{3} + \tilde{c}_2 c_1 + c_2\tilde{c}_1 + c_2 c_1\right) + \\ + h^2\left(\frac{\tilde{c}_1^2}{3} + \tilde{c}_1 c_1 + c_1^2\right) + h^4\Phi_1(\Theta) = 0, \\ -h^4\Phi_1(\Theta) = N_1(\Theta), \\ -h^2\Phi_2(\Theta) = \frac{\lambda_1}{\lambda} N_1(\Theta), \\ M_1(\Theta)\eta_1 + N_1(\Theta) = M_2(\Theta)\eta_1 + N_2(\Theta), \\ M_1(\Theta) = \frac{\lambda_2}{\lambda_1} N_2(\Theta), \\ M_2(\Theta)\eta_3 + N_2(\Theta) = M_2(\Theta)\eta_1 + N_3(\Theta), \\ M_2(\Theta) = \frac{\lambda_3}{\lambda_2} N_3(\Theta), \\ M_3(\Theta) = \left[M_3(\Theta) + N_3(\Theta) - \frac{T_{\text{cp}}}{T^{**}}\right] \times \left[\frac{\gamma_1\tilde{\delta}}{\lambda_3}\cdot\Theta^* + \left(1-\Theta^*\right)\cdot\frac{\gamma_2\tilde{\delta}}{\lambda_3}\right]. \end{cases} \quad (15)$$

Solving the system of equations (15) we get

$$M_1(\Theta) = -\Phi_1(\Theta) h\frac{\lambda}{\lambda_1},\ M_2(\Theta) = -\Phi_1(\Theta) h\frac{\lambda}{\lambda_2},\ M_3(\Theta) = -\Phi_1(\Theta) h\frac{\lambda}{\lambda_3},$$

$$N_1(\Theta) = N_2(\Theta) + \Phi_1(\Theta)\eta_2 h\left(\frac{\lambda}{\lambda_1} - \frac{\lambda}{\lambda_2}\right),\ N_2(\Theta) = N_3(\Theta) + \Phi_1(\Theta)\eta_3 h\left(\frac{\lambda}{\lambda_2} - \frac{\lambda}{\lambda_3}\right),$$

$$N_3(\Theta) = \frac{-\Phi_1(\Theta) h\frac{\lambda}{\lambda_3}\left\{\left(\frac{T_{\text{cp}}}{T^{**}} - 1\right) \times \left[1 + \frac{\gamma_1\tilde{\delta}}{\lambda_3}\cdot\Theta^* + \left(1-\Theta^*\right)\cdot\frac{\gamma_2\tilde{\delta}}{\lambda_3}\right]\right\}}{\frac{\gamma_1\tilde{\delta}}{\lambda_3}\cdot\Theta^* + \left(1-\Theta^*\right)\cdot\frac{\gamma_2\tilde{\delta}}{\lambda_3}},$$

$$\Phi_1(\Theta) = -\frac{\tilde{c}_2^2}{3h^4} - \frac{\tilde{c}_2 c_2 + c_2^2}{h^4} - \frac{\frac{2}{3}\tilde{c}_1\tilde{c}_2 + \tilde{c}_2 c_1 + \tilde{c}_1 c_2 + 2c_1 c_2}{h^3} - \frac{\frac{1}{3}\tilde{c}_1^2 + c_1\tilde{c} + c_1^2}{h^2},$$

$$\Phi_2(\Theta) = -\frac{1}{h^2} N_1(\Theta). \quad (16)$$

It follows from expression (1.15) that the field of temperature both in lubricant layer and in layers of three layered metal polymeric bearing in hydrodynamic regime of friction essentially depends on following structural parameters:

- $\frac{\lambda}{\lambda_1}$, $\frac{\lambda}{\lambda_2}$, $\frac{\lambda}{\lambda_3}$ - describing the ratio of coefficient of heat conducting of lubricant composition to coefficients of heat conducting of layers of metal polymeric bush.

- η, η_1, η_2, η_3 - describing relative thickness of lubricant layer and relative thickness of layer of metal polymeric bush.

- Θ^* – dimensionless parameter describing volumetric parts of polymeric and metal constituencies of fulcrum surface of bush.

- $\frac{\gamma_1 \tilde{\delta}}{\lambda_2}, \frac{\gamma_2 \tilde{\delta}}{\lambda_3}$ – dimensionless parameters limited by different ratio of heat conducting of materials of metal and polymeric constituencies of fulcrum surface of bush.
- T_{cp}, T'' - dimensionless parameters described by ratio of medium's temperature to typical temperature.
- c_i, $i = 1, 2$ - dimensionless parameters limited by presence of polymeric layer on surface of bush.

Optimum choice of above mentioned parameters can be provided by stable temperature regime of bearing work. Results of numerical analysis given on fig 1, shows that the character of temperature changes and its quantity depends on parameter Θ^*: curve 1 – $\frac{\lambda}{\lambda_1}$ = 0,622, $\eta_1 = 0{,}5$, Θ^* = 1; curve 2 – $\frac{\lambda}{\lambda_2}$ = 0,00345, $\eta_2 = 9$, $\frac{\gamma_1 \tilde{\delta}}{\lambda_2} = 11{,}9 \cdot 10^{-6}$, Θ^* = 0; curve 3 – $\frac{\lambda}{\lambda_3}$ = 0,00345, $\eta_3 = 59$, $\frac{\gamma_2 \tilde{\delta}}{\lambda_3} = 42{,}9 \cdot 10^{-6}$, Θ^* = 0,5

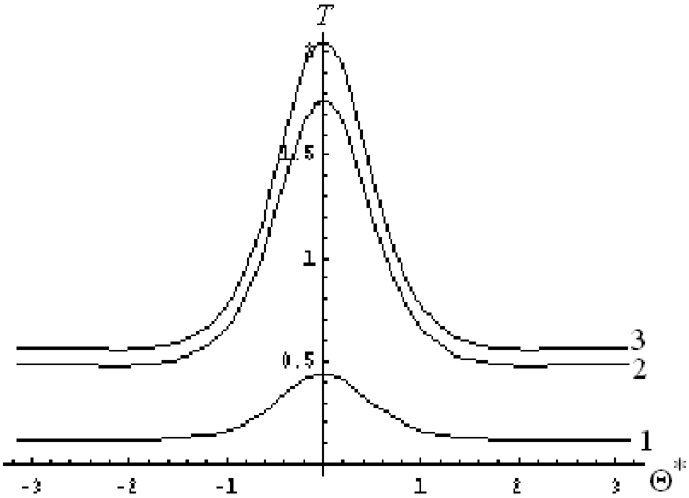

Fig. 1. Depends on dimensionless temperature on fulcrum surface of bush from parameter Θ^*

Рис. 1. Зависимость безразмерной температуры на опорной поверхности вкладыша от параметра Θ^*

CONCLUSIONS

Having conducted theoretical researches of influence of exploration conditions and geometrical size of contact on quality of temperature in zone of friction and boarding layers of three layered bush of metal polymeric bearing of sliding in conditions of liquid friction showed that in absence of polymer (Θ^*=1) or metal constituencies (Θ^*=0) can be observed a marked maximum. When a fulcrum surface consists of metal and polymeric zones occurs an improvement of temperature of journal located between its maximum significance for homogeneous polymeric and metal surface. Only in the case of equal correlation of metal and polymer (Θ^*=0,5) the length of area of bearing zone loading with equal temperature is the most. Temperature in non loading field reduces to the temperature of metal surface.

So the most stable temperature regime of bearing work is achieved through (Θ^*=0,5).

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