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THE MECHANISM OF VIBROMECHANICAL TREATMENT AND REFINING OF THE THRUST RACES

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ABSTRACT

The article considers the application of the mechanism of stress relaxation in the rings and refining their working surfaces by applying graphite lubricant by the application of the spherical tool acting on the treated surface at an ultrasonic frequency. The article presents the movement diagram of the working part of the inductor tool relative to the processed surface. The calculations conducted allow for an analysis of the anti-friction surface creating process. It is revealed that at the sequential application of instantaneous heat sources, the heat flux due to the instantaneous heat removal becomes even over the entire working area rather than increases in a selected point. It is evident from calculations that the theoretical values of coating thickness are within the confidence limits of the experimental values that confirms the adequacy of the proposed mathematical model.

Keywords: residual stress, relaxation, indenter, antifriction coating, diffusion, ultrasound.

1. INTRODUCTION

There are numerous known studies in the field of ultrasonic hardening and refining treatment [1-5] *et al*. As a positive effect of ultrasonic strengthening treatment, most authors note the increase in hardness and wearability of the surface [6-12]. Unfortunately, important properties of ultrasonic treatment such as the removal of residual stresses of the first kind out of the part's material and the possibility of applying the solid anti-friction coating to the surface remain virtually unnoticed.

2. MATERIALS AND METHODS

The design of rolling bearings, whose rings running surfaces are manufactured from the small-sized rolled products [13, 14], allows application of high-effective strengthening treatment methods in the manufacturing process, combined with the application of antifriction coatings. This is facilitated by the fact that under the action of ultrasonic instrument, the graphite powder, which plays a role of solid lubricant, can penetrate between the rolled coils. This technology is aimed at improving the quality of the bearings, because as compared with conventional consistent grease, solid lubricant is not squeezed out from the contact zone of the roller paths and balls, does not leak from the bearing during its operation, does not offer resistance to the rotation of the bearing, and protects the working surfaces of the bearing against corrosion. Working surfaces of the rings are hardened, and residual stresses are removed from the roller paths decreasing the surface roughness. Furthermore this technology is simple to implement and reduces the cost of bearings manufacture.

The mechanism of stress relief in the rings and application of graphite lubricant on their working surfaces under the action on the treated surface of a high frequency vibratory spherical tool at an ultrasonic frequency is illustrated on the following example of vibratory stress relief treatment of thrust races.

Figure-1 shows a movement diagram of the working part of tool relative to the work surface.

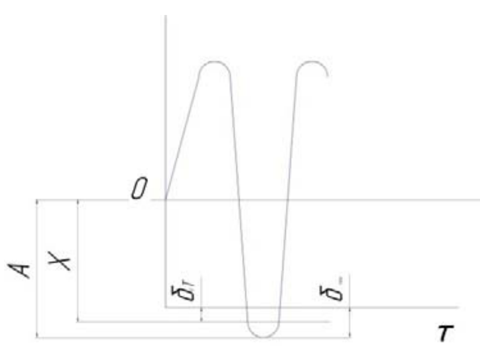

Figure-1. Movement diagram of the indenter's working part.

We introduce a Cartesian coordinate system. The OX axis is positioned along the indenter oscillations direction, while 0τ axis is directed along the rotation of the processed surface. The center of the Cartesian system is positioned in the center of symmetry of the vibrational motion of the indenter. Oscillations of the indenter can be represented in the form of sustained harmonic oscillations in time with the amplitude A.

In accordance with the harmonic vibrations law we can write

$$x = A \cdot \sin \cdot 2 \cdot \pi \cdot \frac{\tau}{T} \quad (1)$$

where x – is the distance from the axis 0X, m; T – is the period of indenter oscillations, s; τ – is the time of indenter displacement, s; A – is the amplitude of indenter oscillation, m.

Periodically, the indenter interacts with the processed surface and penetrates into it to a depth of

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$$\delta_\tau = A\cdot\sin(2\cdot\pi\cdot\frac{\tau}{T}) - A + \delta_m$$

at $\frac{T}{2\cdot\pi}\cdot\arcsin(1-\frac{\delta_m}{A}) + T\cdot i \le \tau \le \frac{T}{4} + T\cdot i$ (2)

where δ_τ – is the penetration depth of the indenter into the processed surface at the timepoint τ, m; δ_m – is the maximum penetration depth of the indenter into the processed surface of the work piece, m; i – is the ordinal number of the oscillation cycle of the instrument *(i=0,1,2...)*.

Three types of energy are consumed at the penetration of the indenter into the proceeded surface [14, 15]:

$$U = U_{def} + U_{dyn} + U_a \quad (3)$$

where U_{def} – is the deformation component J; U_{dyn} - is the dynamic component, J; U_a – is the adhesion component, J. The adhesion component is neglected due the availability of the separating layer of antifriction material. The shape of the working part of the indenter is assumed to be spherical. The shape of the roller path of a rolling thrust bearing corresponds to the torus.

Then the deformation component of energy consumed over time τ is:

$$U_{def} = 0{,}988\cdot F^{\frac{5}{3}}\cdot\eta^{\frac{2}{3}}\cdot\left(\sum\rho\right)^{\frac{1}{3}}\cdot f\cdot\tau \quad (4)$$

where τ – is the treatment time, s; f – is the frequency of the indenter oscillations, Hz; F – is the force exerted by the indenter on the processed surface;

$$\eta = \frac{1-m_1^2}{E_1} + \frac{1-m_2^2}{E_2}$$

Here m_1 и m_2 – are the Poisson's coefficients of the indenter material and the processed work piece; E_1 and E_2 – are the elasticity modules of the bodies materials, Pa; and $\sum\rho$ – is the sum of the principal curvatures of body surfaces in place of their initial contact, 1/m.

It is easy to show that during the time τ from the beginning of treatment, the total dynamic component of the impact energy will be equal to:

$$U_{dyn} = \frac{1}{T^2} m\cdot A^2\cdot\pi^2\cdot\cos^2(2\cdot\pi\cdot\frac{\tau_u}{T})\cdot f\cdot\tau \quad (5)$$

The obtained equalities (4) and (5) allow for an analysis of the anti-friction coating creation process on the surface of the work piece. It should be noted that the coating layer consists of two layers: the top layer of the coating, formed by the indenter through the indentation of the coating material into microscopic irregularities of the treated surface, and the lower coating layer formed by diffusion of the coating material into the work piece material.

The thickness of the top layer of the coating we find from the equation:

$$h = \delta_m = 0{,}655\cdot\left(F\cdot\eta\cdot\sqrt{\sum\rho}\right)^{2/3} \quad (6)$$

where h – is the coating thickness, m; F – is the pressing force of the indenter to the work piece, N.

In the general case the diffusion applies in all possible directions. Though, we are interested in a diffusion process conducted in the direction perpendicular to the treated surface. Therefore, as a basic law describing the diffusion of carbon into the work piece surface, we take Fick equation, written in the following form:

$$J(\tau,x) = -D\frac{dC(\tau,z)}{dz} \quad (7)$$

where, J_c – is the specific mass flux of the substance passing through the unit area per time unit, kg/(s m^2); D - is the diffusion coefficient, i.e., the diffusion-current density of the material at a unit gradient of concentration, m^2/s; $\frac{dC(\tau,z)}{dz}$ – is the concentration gradient of the diffusant impurity in the direction of diffusion at a distance z away from the work piece surface at a timepoint τ from the beginning of the diffusion process, kg/m^4.

The temperature dependence of the diffusion coefficient has the form:

$$D = D_0\exp(-\frac{U}{R\cdot T^o}) \quad (8)$$

where, D_o – is the frequency factor, which characterizes the frequency of atoms jumps in the lattice at infinite temperature, m^2/s ; U – is the activation energy, J; R – is the Boltzmann constant, J/K; T^o– is the absolute temperature, K.

On the basis of the so-called equation of continuity, taking into account the boundary conditions, we find the diffusion process speed. Integrating further the determined velocity over time we find the proportion of the coating material diffusing through the unit area of the treated surface during the diffusion time τ :

$$w(\tau) = 2C_O\cdot\sqrt{\frac{D_o\tau}{\pi}}\cdot\exp\left(-\frac{U}{R\cdot T^o}\right) \quad (9)$$

A deformation of treated surface due to impact of an indenter at ultrasonic treatment results in heat generation. Since the length of contact between the indenter and treated surface in the cross section of the roller path exceeds by more than an order the size of the contact patch in the direction of work piece rotation, we assume heat source as instantaneous flat source of heat. Therefore the temperature conditioned by heat release

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during each exposure of indenter on the treated surface can be calculated by the following equation:

$$\theta = \frac{u}{4\cdot\pi\cdot\alpha\cdot c\cdot\rho\cdot(\tau-t)} exp\left(-\frac{(x-x_1)^2+(z-z_1)^2}{4\cdot a\cdot(\tau-t)}\right) \quad (10)$$

where t – is the initial timepoint, s; τ – is the time from the initial moment of heat release, s; u – is the specific amount of heat released by instantaneous heat source at the initial timepoint , $\tau = t$, J/m; ρ – is the density of the work piece material, kg/m^3; α – is the thermal diffusivity coefficient, m^2/s; c – is the specific heat capacity, J/(kg K).

The heat from each impulse instantly transfers deep into the metal; therefore the temperature on the treated surface is instantly lowered. Though, in the treatment area, the high frequency oscillations of the indenter create a lot of instantaneous heat sources, whose heat fluxes are superimposed on each other. At sequential application of instantaneous heat sources, the heat flux due to the instantaneous heat removal becomes even over the entire working area rather than increases in a selected point.

From the equality (10) we find the average temperature during one oscillation cycle of the indenter:

$$\theta_o = \frac{u}{4\cdot\pi\cdot\alpha\cdot c\cdot\rho\cdot T}\int_0^T \frac{1}{\tau} exp\left(-\frac{(x-x_1)^2+(z-z_1)^2}{4\cdot\alpha\cdot\tau}\right)\cdot d\tau \quad (11)$$

The duration of this temperature is equal to:

$$\tau_u = \frac{2\cdot a}{\pi\cdot d\cdot n} \quad (12)$$

where d – is the diameter of the treated roller path, mm; n - is the rotation frequency of the work piece, Hz.

Substituting the found values of temperature (11) and corresponding time (12) in equality (9) we determine the required amount of diffusing substance per single revolution of the work piece. Knowing the rotation frequency of the work piece it is easy to determine the total amount of substance diffused during the whole time of treatment.

3. RESULTS AND DISCUSSIONS

The calculation results are in good agreement with the experiment [17]. As an example, Fig. 2.10 shows the theoretical and experimental values of coating thickness depending on the impact strength on the treated surface.

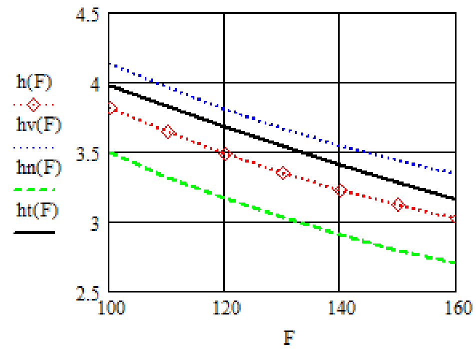

Figure-2. Calculated $ht(F)$ and experimental $h(F)$ correlations of the coating thickness (μm) depending on the impact strength F(N) of the indenter.

The symbols are experimental values, while solid line corresponds to the theoretical calculation. Dotted lines indicate confidence limits of the experimental values.

As is obvious, the theoretical values of coating thickness are within the confidence limits of experimental values that confirms the adequacy of proposed mathematical model.

4. CONCLUSIONS

The coating of graphite lubricant on the surface under the action of the spherical instrument applied on the surface at an ultrasonic frequency allowed strengthening working surfaces of thrust races, reducing surface roughness, and removing the residual stresses from roller paths. This mechanism has shown that as compared with conventional consistent grease, solid lubricant is not squeezed out from the contact zone of the roller paths and balls, does not leak from the bearing during its operation, does not offer resistance to the rotation of the bearing, and protects the working surfaces of the bearing against corrosion. This technology is simple to implement, reduces the cost of bearings manufacture, and is aimed at improving the quality of the thrust races.

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