Improving the Factor of Useful Action of Sliding Bearings for Workers in Dry Friction Sliding Modes

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ABSTRACT

This paper presents the technology to increase the efficiency of dry friction bearings, based on the impact on the working surface, highly concentrated energy flow, in order to reduce power consumption mechanisms and components of aviation equipment.

INTRODUCTION

Interest in bearings of dry sliding friction is relevant in some cases when special requirements are placed on the mechanism for size, weight and reliability, and also requires the use of linear bearings operating in aggressive environments: a sharp temperature difference of ± 60º, the presence of abrasive particles (sand), salt fog [1, 2]. Therefore, the task of reducing friction losses in dry friction bearings today is relevant in a number of modern industries.

THEORETICAL BACKGROUND

In this work, a pair of dry sliding friction was selected, where the aluminum alloy of the grade D16T acts as the base material. The basis of the friction layer of a friction pair is a coating based on silicon dioxide [3, 4]. In order to ensure the stability of the friction pair and the possibility of repair, the hardness of the friction shaft is 65 HRC, respectively, the hardness of the sleeve 60 HRC. For precision positioning and

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providing a gap of several microns, a final surface finish is required. As a rule, ceramic surfaces are subjected to diamond grinding (polishing is additionally performed for precision mechanisms), but during surface treatment, microcracks appear on the friction surface, which negatively affects the coefficient of friction, and also contributes to accelerated wear of the friction pair. As a result, the efficiency of the mechanism as a whole is reduced [5].

Modern technologies have made great strides with the emergence of highly concentrated energy flows. Namely, it is plasma and laser surface treatment of the friction pair under study with the purpose of quenching with and without melting. Highly concentrated energy fluxes allow the processing of refractory alloys and coatings [6, 7, 8].

In order to reduce the friction coefficient and increase the reliability of the dry friction bearings, as well as to avoid the formation of microcracks during the finishing treatment based on ceramic friction pairs, a method of "laser radiation finishing" was proposed [2, 9].

The manufacture of a friction pair has several stages:
1. Manufacture of the bearing housing (shaft and sleeve);
2. Application of friction coating;
3. Pretreatment of the obtained coating with diamond grinding, leaving a seam allowance;
4. Laser finishing.

RESULTS AND DISCUSSIONS

As a result, we get a better surface in which the concentration of stresses and microcracks is minimized, thereby reducing the time of running-in of a friction pair and increasing the resource by 1.5 times. In Figure 1, the relief (roughness) of the friction surface is conventionally represented before and after the finishing laser treatment.

![Figure 1. Friction surface relief](image)
a) surface after diamond grinding; b) surface after laser finishing.
The proposed method is based on the equation proposed by N.N. Rykalin, describing the process of heat propagation of a point source of constant power \( q \) moving at a constant speed \( V \), and having the form [10]:

\[
T(R, z) = \frac{q}{2\pi \lambda R} \exp \left( -\frac{V(R-x)}{2a} \right) + T_e,
\]

where \( T(R, z) \) is the temperature at the point A under consideration; 
\( \lambda \) is the thermal conductivity coefficient of the body, W/(m); 
\( a \) is the coefficient of thermal diffusivity of the body, m\(^2\)/s; 
\( R\sqrt{x^2 + y^2 + z^2} \) - the distance from the considered point A with the coordinates \((x, y, z)\) to the beginning \( O \) of the moving coordinate system associated with the moving heat source; 
\( T_e \) is the ambient temperature, i.e. the temperature of the object under study before exposure to a heat source [10].

The condition of heat balance [11]:

\[
q = q_{el} + q_{ref} + q_{hc} + q_{rt} + q_{c} + q_{d},
\]

where \( q_{ph} \) - the power of the point heat source; 
\( q_{el} \) - the loss of thermal capacity due to the absorption of the environment of the energy radiation heat source; 
\( q_{ref} \) - the heat loss due to partial reflection of the radiation energy of the heat source surface of the investigated object due to the fact that the investigated material has a coefficient of reflection different from zero. 
\( q_{hc} \) - the heat loss to the environment due to convective heat transfer; 
\( q_{rt} \) - the heat loss to the environment due to radiant heat exchange; 
\( q_{c} \) - the power distributed in the friction coating due to the conductive heat transfer; 
\( q_{d} \) - the power distributed in the body processed detail account conductive heat transfer.

Let us consider the components of equation (2) in more detail.

The loss of thermal power due to absorption by the environment of the energy radiation of the heat source is determined by the following expression [12]:

\[
q_{el} = q_{ph}[1 - \exp(-\theta l)] = q_{ph}[1 - \beta],
\]

where \( \theta \) is the indicator of environmental degradation, 1/m; 
\( l \) is the distance between the heat source and the object to be examined (distance from the part surface to the focal length), m; 
\( \beta \) - the coefficient of environmental transparency.

Power loss due to incomplete absorption of laser energy by the surface of the opaque body being studied, taking into account losses \( q_{el} \) [13] is:

\[
q_{ref} = r\beta q_{ph} = (1 - \alpha)\beta q_{ph},
\]
where \( r \) is the reflection coefficient; 
\( \alpha \) – the absorption coefficient.

It is known [13] that at the given temperature the emissivity of a body is equal to its absorption coefficient, i.e. \( \varepsilon = \alpha \). With this in mind, expression (4) has the form:

\[
q_{\text{ref}} = (1 - \varepsilon)\beta q_{\text{ph}}.
\] (5)

The loss of thermal capacity in the environment due to convective heat transfer, based on the theory of heat exchange [14], is determined by the following expression:

\[
q_{hc} = \alpha_{hc}(T - T_e)S,
\] (6)

where \( \alpha_{hc} \) – the coefficient of convective heat exchange, W/(m\(^2\)K);
\( T \) is the surface temperature of the heated body, K;
\( T_e \) – the ambient temperature, K;
\( S \) – the heat-transfer surface area, m\(^2\).

The loss of thermal power into the environment due to radiant heat transfer is determined by the following expression:

\[
q_{rt} = \alpha_{rt}(T - T_e)S,
\] (7)

where \( \alpha_{rt} = \varepsilon C_0 \left[ \left( \frac{T}{100} \right)^4 - \left( \frac{T_e}{100} \right)^4 \right] / (T - T_e) \) is the coefficient of radiative heat transfer, W/(m\(^2\)K);
\( C_0 = 5.67 \) is the Stefan-Boltzmann constant, W/(m\(^2\)K);
\( S \) – the heat-transfer surface area, m\(^2\).

The power \( q \) distributed in a heated body due to conductive thermal conductivity with a non-contact thermal effect on it from a fixed point heat source, according to expression (1) is determined as follows [11]:

\[
q = 2\pi \lambda R [T_m - T_e] \exp \left( \frac{\sqrt{V(R-x)}}{2a} \right),
\] (8)

where \( T_m \) - the melting point of the processed material.

The power \( q_e \); \( q_d \) is determined by expression (8).

The author of [11] found that the obtained expression describing the temperature field with \( R \geq 20r_0 \), (where \( r_0 \) is the radius of the point source) describes the temperature field acting on the body by a moving point heat source with an error of no more than 5%. But with \( R < 20r_0 \) values, the error exceeds 40%.

In this case, it is necessary to introduce a numerically calculated correction factor \( \gamma(R) \) in order to obtain sufficiently accurate calculated data up to \( R \sim 1 \). Then, with sufficient accuracy for practice, it is possible to calculate the effective absorbed power density [15]:
Using relations (3) - (8) for each of the terms of equation (9) after mathematical transformations, the expression describing the temperature thermal field in a semi-infinite thermal body under the action of its mobile point source of heat has the following form:

\[
q_{\text{ef}} = \gamma q = \gamma (q_{el} + q_{ref} + q_{hc} + q_{rt} + q_{c} + q_{d})
\]  

(9)

Thus, we determined the equation describing the working surface of the bearing, taking into account that the friction layer has distinctive characteristics of thermal conductivity and absorption of laser radiation, in comparison with the structural material. These mathematical calculations have become fundamental for the development of a mathematical model, laser micromelting, which is currently under active work.

The first experimental studies on steel surfaces showed an increase in the surface roughness class from 6 to 7 (it was Ra 1.6 microns and Ra 1.25 microns). Surface hardening was also observed on the steel surface.

Further studies are planned to be made with silica-based coatings. The result of the study should be the technology of finishing laser processing of refractory and ceramic coatings.

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REFERENCES

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327