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METALLOPHYSICS OF DETERIORATION DURING FRICTION SLIDING IN THE PRESENCE OF ABRASIVE MATERIAL

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Suggested new physical conception of wearing charge surface.

Introduction

During deterioration of friction surfaces of initially free abrasive particles, which are in the conjugation space [1], it is observed charging effect fixation of the abrasive material on one of the friction surfaces. In that conjugations of friction sliding, where movable surface is made of more tough metal than fixed one, usually charge last. Due to this effect, the deterioration ability of movable surface appreciably reduces. Never the less, deterioration of fixed friction surface under heavy load is very considerable [2]. The deterioration mechanism of charging surface is not completely elucidated.

Theoretical concept and its analysis

The result of study of this problem [3; 4] showed that structure because of charging fixed surface gets composite. Abrasive deterioration of such "composite" represents fatigue disruption under low-cycle loading. Frictional low-cycle fatigue takes place at the fixation points of the abrasive particles on the friction surface and the destruction has a viscous character. This process occurs because of abrasive particles enforced vibration which charges into metal under action of changeable forces or forced by movable surface. Due to vibration of particles in the places of their fixation deformations will appear and tensions which are in accord with them. Scheme of powered action of friction movable surface on the abrasive particle which is fixed on fixed surfaces depicted in fig. 1.
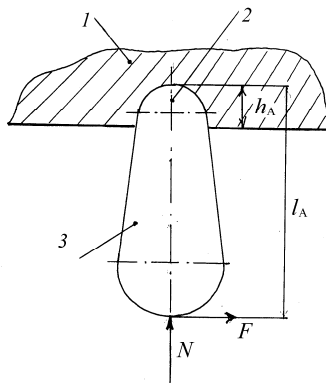
According to [5] it can be assumed take that speed of deterioration of fixed surface is

$$V_i = \frac{h_A}{\tau} = \frac{h_A \omega}{N},\qquad(1)$$

where h_A is penetration of abrasive particle on the fixed surface; τ is material durability at the place of abrasive particle fixation with penetration h_A; ω is enforced vibration frequency; N is quantity of cycles till material destruction at the place of abrasive particle fixation with penetration h_A.

Charging layer can be regarded as the enforced vibrations source from which in the depth of fixed surface amplitude vibrations will be spread.

Due to such vibrations in the fixed surface metal acoustic waves spread which with at distant from the surface disappear. As charging layer is the source of acoustic vibrations are spread lower layer then for flat external surface it's possible to take acoustic wave as flat (fig. 2) wave with finite value of shift:

$$A = A_m \sin\omega\left(t - \frac{x}{a}\right),\qquad(2)$$

where A is source shift from equilibrium position; A_m is vibrations amplitude; t is time interval; x is wave front coordinate; a is speed or sound (phase velocity):

$$a = \sqrt{E/\rho_i},$$

E is metal resilience module of the fixed friction surface; ρ_i is metal particle of the fixed friction surface.

Fig. 1. Scheme of power action of mobile surface of friction on abrasive particle, that:
1 – immobile surface of friction; *2* – center of oscillation of the particle; *3* – abrasive particle
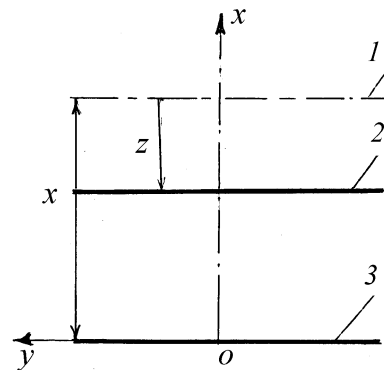

Fig. 2. Scheme of spreading flat wave in immobile surface of friction:
1 – front of wave; *2* – immobile surface of friction; *3* – source of oscillation

Due to enforced constant frequency, intensity of sound depends on amplitude vibration am only. It is possible to find Am formula on the basis of solution of the expression of energy consumption process in the body with unbounded external surface, which moves in the deterioration process.

After the solution of this equitation the following formula for amplitude vibrations (2), a has been obtained

$$A_m = A_{m_0} e \chi \rho (-V_i b^{-2} z), \qquad (3)$$

where A_{m_0} is amplitude of enforced vibrations on the fixed friction surface; b is temperature conductivity of metal:

$$b^2 = \frac{\lambda}{c\rho};$$

λ is heat conductivity of metal; c is heat capacity; z is depth on which enforced vibrations are spread inside the metal; V_i is metal deterioration rate.

If in the equation (3) instead of deterioration rate V_1 its expression is put from (1) we will get a well known from vibration theory formula for finding amplitude of fading vibrations.

$$A_m = A_{m_0} \exp\left(-\frac{\pi\varepsilon}{a} \omega z \right), \qquad (4)$$

where ε is acoustic loss factor [6]; $\frac{\pi\varepsilon}{a}$ is metal physical constant of an immovable surface.

From equalizations (3) and (4) for suppression velocity V_1 will have

$$V_i = \frac{\pi\omega b^2}{a} \varepsilon. \qquad (5)$$

Acoustic loss factor is recommended [5] to determine from the following correlation:

$$\varepsilon = \frac{8\pi}{3} \frac{\omega(1+l)}{E} \eta, \qquad (6)$$

where $l = Ta = \frac{2\pi}{\omega} a$ is wave length; T is vibration period; η is metal viscosity of immovable surface.

In general, viscosity of immovable surface η is determined through its connection with inner metal friction. But the approach exists [6], that the notion of inner friction includes energy losses of different types which have no direct relation to the notion of viscosity. It is reflected negatively on the exactness of viscosity estimation.

The analysis of new relations with high-level characteristics is necessary for increasing exactness. Besides, if to take into account the interaction, fact of friction tensions with electronic system of metal, the approach from the position of electronic relaxation is to be considered perspective [7].

According to this approach, sound fading is a result of a sound wave interaction, that is spread with electronic gas of metal.

The gas, that electrons create in metal, is highly degenerated (i.e. has quantum character of interaction between electrons) and is a subject of Fermi-Dirac statistics [8]. Quantum state of electron is described by wave vector K, directed toward the side of spreading electronic wave in metal.

One of the most important characteristics of the metal electronic system is the Fermi surface – the surface of constant energy at a K-sphere, which answers Fermi's energy. In the metal conductivity only conductivity electrons which are on the Fermi's surface take part. According to [7] electrons may be regarded as effective viscous environment, viscosity of which

$$\eta = \frac{N_e m_e l_e \overline{V}}{3}, \qquad (7)$$

where N_e is quantity of electrons in a volume unit:

$$N_e = \frac{N_A \rho_\Pi}{\mu},$$

N_A is Avocado's number; $\rho_{\bar{I}}$ is metal viscosity; μ is metal molecular weight; m_e is electron mass; l_e is average length of electron free run; $\overline{V}$ is average velocity of electrons conductivity.

Because of this viscosity, sound wave transfers a pulse and energy to the electronic gas and as a result of this fades.

Taking into account, that near the Fermi's surface $\overline{V} = V_F$ equitation (7) can be written as follows

$$\eta = \frac{N_e m_e l_e V_F}{3} = \frac{N_e m_e V_F^2 \tau}{3}, \qquad (8)$$

where τ is relaxation time:

$$\tau = \frac{m_e}{N_e e^2 \rho};$$

e is electron charge; ρ is specific electric resistance of metal; V_F is velocity of electrons near the Fermi's surface:

$$V_F = \sqrt{\frac{2 E_F}{m_e}};$$

E_F is Fermi's energy:

$$E_F = \frac{\hbar^2}{2 m_e} (3\pi N_e)^{2/3};$$

$\hbar = \frac{h}{2\pi}$ is Plank's constant; h is Plank's constant.

After the introducing all these correlations in to the formula (8) and correspondent transformations.

We obtain

$$\eta = \frac{\hbar^2 \left(3\pi \dfrac{N_A \rho_n}{\mu}\right)^{2/3}}{3e^2 \rho} . \tag{9}$$

If we take into account (9) formula (6) looks like

$$\varepsilon = \frac{2\hbar^2(\omega + 2\pi a)\left(3\pi \dfrac{N_A \rho_{\ddot{I}}}{\mu}\right)^{2/3}}{9\pi^2 e^2 \rho E} . \tag{10}$$

And now, returning to the formula (5), after the substitution (10) we definitely have

$$V_i = \frac{2}{9}\left(\frac{h}{e}\right)^2 b^2 \frac{\omega(\omega + 2\pi a)}{\rho E a}\left(3\pi \frac{N_A \rho_{\ddot{I}}}{\mu}\right)^{2/3} . \tag{11}$$

Using known correlations of quantum mechanics, i e de-Broil's formula

$$\lambda_e = \frac{h}{m_e V_F} \Rightarrow h = \lambda_e m_e V_F ,$$

where λ_e is de-Broil's wave length, and also formula of gyro magnetic ratio of election spin moments

$$g_s = \frac{e}{m_e}$$

equalization (11) can be rewritten form which is in a more comfortable for subsequent analyses form:

$$V_i = (\lambda_e V_F)^2 \left(\frac{N_e^{2/3}\gamma}{g_s^2}\right)\left(\frac{\lambda}{C}\right)\left(\frac{1}{\rho_{\ddot{I}} E}\right)\left(\frac{1+l}{a}\right)(\omega). \tag{12}$$

Single out in the equation (12) six groups of factors, which characterize:

1) quantum characteristics of electrons

$$K = (\lambda_e V_F)^2 ; \tag{13}$$

2) electronic system

$$E_e = \frac{N_e^{2/3}\gamma}{g_s^2} , \tag{14}$$

where $\gamma = \dfrac{1}{\rho}$ – conductivity of metal;

3) thermal characteristics

$$T = \frac{\lambda}{C} ; \tag{15}$$

4) mechanical characteristics

$$M = \frac{1}{\rho_i E} ; \tag{16}$$

5) acoustic characteristics

$$3 = \frac{1+l}{a} ; \tag{17}$$

6) the soiree of oscillations

$$D = \omega . \tag{18}$$

After substitution (13)–(18), the equation (12) may be written in the following form

$$V_i = KE_e TM3D . \tag{19}$$

Results from (19), show that increase of all six groups of factors favours the increase of wearing ability. The most influence is exerted by parameters λ_1, V_F, g_s – so as they are pouts of equation (12) with index of power 2. The smallest influence has parameter N_1 which has index of power 2/3. The rest of parameters have the index of power 1, so their influence should be considered as essential.

Conclusion

The equation (12) revels the nature of wearing ability, defines ways of regulation by this tribological characteristics, and also it is an instrument for calculation of wearing ability. So as it is evident the amplitude Am is not a part of this equation, the for application in tribotechnical calculations it is necessary to know temperature of fiction (defined experimentally or by calculation way), as well as temperature dependences on all parameters.

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Металофізика зношування при терті ковзання в присутності абразиву

Запропоновано нову фізичну концепцію зношування шаржованої поверхні тертя.

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Металлофизика изнашивания при трении скольжения в присутствии абразива

Предложена новая физическая концепция изнашивания шаржированной поверхности трения.