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INFLUENCE OF MICROGEOMETRY OF CONTACT ON CHARACTERISTICS OF NON-ADHESION FRICTION OF SLIDING TRIBOSYSTEMS

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Considered theoretical and experimental dependences specify influence of microgeometrical parameters of surfaces roughness of details, which were not taken into account earlier, on operational efficiency of unit of friction.

The introduction

Operational efficiency of tribosystem depends on three groups of parameters: parameters of work of unit of friction, properties of the lubricant environment and parameters of contacting surfaces [1]. Operational efficiency is understood antiwear and antifrictional properties which determine work capacity, as reliability and profitability of tribosystem.

Some these work parameters of unit of friction are: speed of sliding, size of loading (pressure of one surface upon another) and speed of loading (speed from which one surface nestles on another).

The influence on operational efficiency of the lubricant environment is determined by such characteristics as: viscosity, the type of chemical interaction with a surface (strengthening or loosening), lubricant properties.

Parameters of contacting surfaces include parameters of roughness and property of a material of tribosystems details (hardness, a chemical compound and etc.).

$$E(f_w,I)=\phi(F_e,V,V_e)+\phi(M)+\phi(R,H_t), \qquad (1)$$

where $E(f_w, I)$ is efficiency of the lubricant environment (force of friction and size of deterioration);

$f(F_e, V, V_e)$ is the dependence on loading, speed of sliding, speed of loading; $f(M)$ is the dependence on the type of the lubricant environment; $f(R, H_t)$ is the dependence on parameters of contacting surfaces.

Any of the designated parameters influences efficiency tribosystem itself, or through any other parameter. It happens owing to physical and chemical interaction of all components of the tribosystem (details between itself and with the lubricant environment which also changes tribochemically during operation time).

The model of contact

The submitted model of contact of two surfaces are based on the following assumptions:

– contacting surfaces have identical hardness;

– contact of two details is linear; bottom sample is immovable, the top is the cylinder which turns around;

– axial loading is accepted constant, and roughness is determined;

– phenomenon of non-adhesion friction[2] takes place in the contact, (plastic deformation of micro- and submicroroughness is equal to zero, the waveness is deformed);

– choice of parameters of topography of surfaces is based on the real parameters determined by the laser scanning profilograph-profilometer;

– it is accepted, that all tops of roughness have an identical structure and height.

Thus the designated model of contact of two surfaces will be such as it is shown on fig. 1.

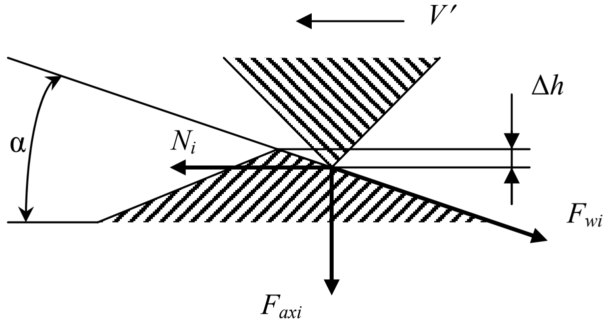

Fig. 1. Contact k_i

Thus, at increase α_i, necessary force N_i grows. The necessary work for a raising of a tooth up to Δh_i, is equal to:

$$\begin{cases} X: N_i - F_{wi}\times\cos\alpha_i = 0 \\ Y: F_{ax\,i} - F_{wi}\times\sin\alpha_i = 0 \end{cases} N_i = \frac{F_{wi}}{\mathrm{tg}\alpha_i},$$

$$A_i = N_i \times \left(\frac{\Delta h_i}{\sin\alpha_i}\right) = \left(\frac{F_{ax\,i}}{\mathrm{tg}\alpha_i}\right)\left(\frac{\Delta h_i}{\sin\alpha_i}\right).$$

The total work

$$A = \sum\left(\frac{F_{ax\,i}}{tg\alpha_i}\right)\left(\frac{\Delta h_i}{\sin\alpha_i}\right),$$

where

$$F_{ax\,i} = \frac{F_{ax}}{i}.$$

This formula shows, that with increase of the size Δh (actually, it is R_a, but in an operational direction), necessary work on shift grows.

During time Δt the number of contacts changes and therefore distribution of loading F_{axi} changes.

To prevent the calculation of each contact, it has been taken: Δh_i is the average resulted height which depends on R_a, α is an average angle of an inclination of the tops of roughness.

The law of distribution of a material through the height of roughness is taken from the formula.

$$A_c = 1{,}8 A_a K_w (r_w / R_w)^{2/(4+2\delta_w)} (q_a / E)^{2/(2+2\delta_w)}.$$

Theoretical calculation of dependence of the necessary work for the relative moving of the teeth of a roughness

Parameters of roughness for calculation (fig. 2):

$$\begin{cases} M \ddot{x}_c = \sum_{i=1}^{n} F_{X_i}^{e}; \\ M \ddot{y}_c = \sum_{i=1}^{n} F_{Y_i}^{(e)}; \\ I_C \dfrac{d\omega}{dt} = \sum_{i=1}^{n} M_C \left(\overline{F}_{X_i}^{(e)} \right); \end{cases}$$

$$M \ddot{x}_c = -F_w \cos\alpha - N \sin\alpha + X_C;$$

$$M \ddot{y}_c = -F + N \cos\alpha - F_w \sin\alpha + Y_C;$$

$Y_C = 0$;

$$I_C \frac{d\omega}{dt} = M_r - NR\sin\alpha - F_w R \cos\alpha;$$

$X_c = F_w \cos\alpha + N \sin\alpha$;

$M\ddot{y}_c = -F + N\cos\alpha - F_w \sin\alpha$, $F_w = fN$;

$M_r = NR \cdot \sin\alpha + F_w R\cos\alpha$;

$M\ddot{y}_c = -F + N\cos\alpha - fN\sin\alpha$;

$\ddot{y}_c = (1/M)\,[N\cos\alpha - (F + fN\sin\alpha)]$,

where M is the weight of contrbody; M_r is the moment enclosed to contrbody; R is the radius of contrbody; α is the corner of an inclination of the teeth of contrbody; F is the loading on the contact; h is the length of contact of two opposite peaks.

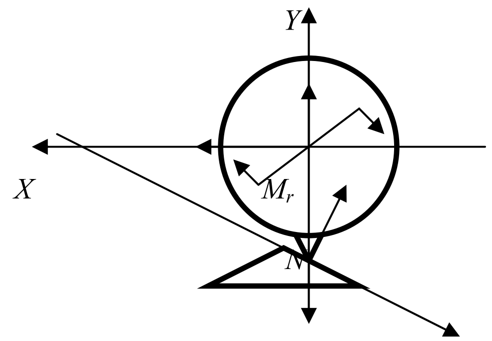

Fig. 2. The circuit of contact

In case $f = 0$, α=const, equation is:

$\ddot{y}_c = (1/M)\,[N\cos\alpha - F]$;

$\dot{y}_c = (1/M)\,[N\cos\alpha - F]\, t + C_1$;

$y_c = (1/M)\,[N\cos\alpha - F]\, 1/2\, t + C_1 t + C_2$;

$C_1 = 0$, $C_2 = -R$;

with $t \to 0$

$y_c = (1/M)\,[N\cos\alpha - F]\, 1/2\, t - R \geq 0$;

$M_r = NR\sin\alpha \Rightarrow N = M_r / R \sin\alpha$;

$X_c = N\sin\alpha \Rightarrow N\cos\alpha = X_c \operatorname{ctg}\alpha$;

$y_c = (1/M)\,[(M_r/R)\operatorname{ctg}\alpha - F]\; 1/2\, t^2 - R$;

$t^2 = f(h)$, $y_c = h$.

The spending work

$A^{(e)} = T_1 - T_0$;

$T_1 = t_1$, $T_2 = t_2 = 0$;

$$\frac{dT}{dt} = N^{(e)};$$

$$T = 1/2\, MV_c^2 + 1/2\, I_c W^2; \qquad (2)$$

$V_c = \dot{y}_c \Rightarrow T = 1/2\, M \cdot \dot{y}_c^2 + 1/2\, I_c W^2$;

$A = 1/2\, M \cdot [\dot{y}_c(t_1)]^2 + 1/2\, I_c W^2 -$

$-(1/2\, M \cdot [\ddot{y}_c(t_0)]^2 + 1/2\, I_c W^2) \Rightarrow A = 1/2\, M \cdot [\dot{y}_c(t_1)]^2$;

$$A = \frac{1}{2} M \left\{ \frac{1}{M} \left[\frac{M_r}{R} \operatorname{ctg}\alpha - F \right] t_1 \right\}^2.$$

Substituting t from the formula (2), we receive:

$$A = \frac{1}{2} M \left\{ \frac{1}{M} \left[\frac{M_r}{R} \operatorname{ctg}\alpha - F \right] \sqrt{2hM \frac{1}{\frac{M_r}{R}\operatorname{ctg}\alpha - F} + R} \right\}^2;$$

$$A = \left(\frac{M_r}{R} \operatorname{ctg}\alpha - F \right) h.$$

Experimental researches

Two cases were considered:

1) dependence of the necessary work on Δh $A = f(\Delta h)$ which in turn, depends on size of roughness R_a, at constant angle of roughness inclination, with α =const;

2) dependence of the necessary work from an angle of roughness inclination α $A = f(\Delta\alpha)$, with Δh=const.

The quantity of teeth in contact was received on profilograph-profilometer. Then the two dependences were built.

Knowing the border of durability of the tested material, it is possible to calculate the size of roughness or the inclination of the teeth (accordingly to distribution of a material in plane of a cutting formula (1) non-wear friction will finish and the cut or wear will begin. It is necessary to take into account, that in a mode of non-adhesion friction the adhesion-compound force of friction is equal to zero, and the general force depends only on the elasto-plastic properties of a material of samples.

The plane of contact consists of the summary contact planes of separate teeth.

The contact can maintain the loading which depends on the amount of separate contacts between teeth of roughness.

Also as smaller is the size of roughness, the more teeth are in contact.

Thus it is necessary to "cut" less amount of material for endurance loading level without exaggeration of the border of durability of materials.

The experiments were carried out by the technique described earlier. And the influence of the teeth sharpness on the antifrictional properties of the tribosystem were received (fig. 3).

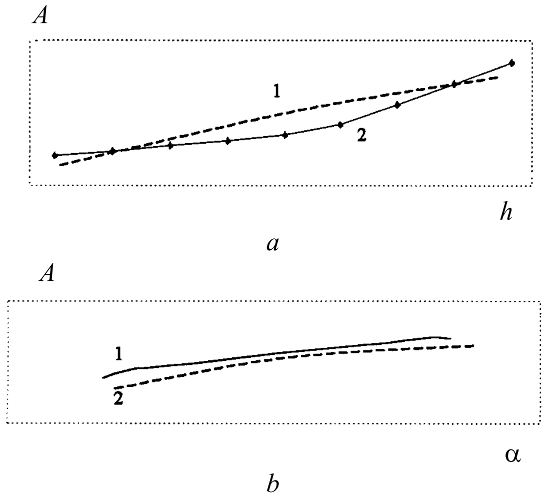

Fig. 3. Theoretical (*1*) and experimental (*2*) dependences of the necessary work for relative moving of teeth from an angle of the inclination (*a*) and the size (*b*) of this teeth of roughness

The realization of the phenomenon of non-adhesion friction was provided during experiment.

The line 2 on fig. 3, *b* shows the experimental dependence of the necessary work for relative moving of teeth. The necessary work was defined depending on the force of friction at identical 3D configuration and various size of roughness by R_a.

Divergence of theoretical and experimental curves depends on: errors at measurements; the influence of heat removal on parameters was not taken into account in the theoretical calculations. Namely, at increase of temperature viscosity of the lubricant environment decreases, and heat removal grows, that improves characteristics of tribosystem. As influence of temperature is rather significant, and it is visible from the constructed curves, this question demands additional, deep theoretical and experimental researches.

Conclusion

According to results of theoretical calculations and the confirmed experimental data it is possible to make a conclusion, that not only the size of roughness, but also a corner of an inclination of a teeth of roughness which is not supervised in a modern production, influence on the operational properties of the tribosystems.

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Вплив мікрогеометрії контакту на характеристики безадгезійного тертя трибосистем ковзання

Розглянуто теоретичні та експериментальні залежності, що вказують на вплив просторових мікрогеометричних параметрів шорсткості поверхонь деталей трибосполучень, які не враховувались раніше, та на експлуатаційну ефективність вузла тертя.

А.Ю. Сидоренко

Влияние микрогеометрии контакта на характеристики безадгезионного трения трибосистем скольжения

Рассмотрены теоретические и экспериментальные зависимости, указывающие на влияние микрогеометрических параметров шероховатости поверхностей деталей трибосистем, не учитываемых ранее, и на эксплуатационную эффективность узла трения.