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MICRO STICK–SLIP REGIME FOR DYNAMIC FRICTIONAL CONTACT

ZJAWISKO TYPU STICK-SLIP PRZY DYNAMICZNYM KONTAKCIE CIERNYM

A b s t r a c t

Indirect measurement of fretting amplitude, as a difference of displacement between specimens, in many cases is not in accordance with the facts. And this discordance is more, than less amplitude of a tangential displacement. A complex operation of an adhesion, the elasticity of a contact layer and dynamic phenomena of a system "contact – subsurface layer – body as a whole", do not give point significance of slip amplitude for usual method of a measurement. Our interest for friction has two main principles: the law of friction with low velocities (Stribek effect) and dynamics of a system "contact layer – body as a whole". Thus, presented two-dimensional model consists of three bodies: one of which makes oscillatory movement, second – elastic element with a mass and third body – movement of all element. The performance of stick-slip regime is represented by ratio between a mass of an elastic layer and all elements, friction laws, stiffness and frequency of oscillations.

Keywords: stick-slip mixed contact, fretting, damage

S t r e s z c z e n i e

Pośredni pomiar zużycia ciernego, jako różnicy przemieszczeń badanych elementów w wielu przypadkach jest niezgodny ze stanem faktycznym. Niezgodność jest tym większa, im mniejsza jest amplituda przemieszczenia stycznego. Złożone procesy adhezji, sprężystości i dynamiczne zjawiska zachodzące w układzie „styk – warstwa podpowierzchniowa – urządzenie" nie pozwalają uzyskać wiarygodnej amplitudy przemieszczenia przy standardowych metodach pomiaru. Tematyka artykułu dotyczy dwóch zjawisk: tarcia przy małych prędkościach (efekt Stribeka) i dynamiki układu „warstwa kontaktowa – urządzenie". Stąd, model 2D układu ma trzy składniki: pierwszy wykonuje ruch oscylacyjny, drugi jest elementem sprężystym z masą natomiast trzeci reprezentuje ruch całego układu. Zjawisko stick-slip modelowane jest za pomocą stosunku masy warstwy sprężystej do masy całego układu, praw tarcia, sztywności i częstotliwości oscylacji.

Słowa kluczowe: zjawisko stick-slip, zużycie cierno-korozyjne, uszkodzenie

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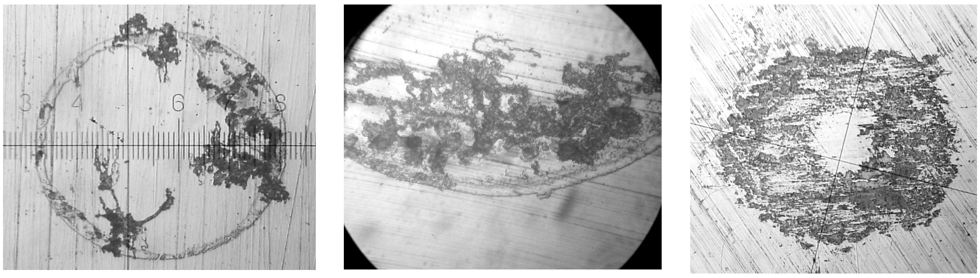
1. Introduction

Fretting processes are determined by complex mechanical, natural and chemical processes, which occur into zone of contact of two surfaces at the presence of tangential contact stresses. Recently increasing attention of the researches is given to quasi-static contact in conditions of dynamical loading. It is possible to state, that the given condition of contact is characteristic in most cases for real operate nominal – fixed joints, when there is no visible relative displacement [1, 2, 3]. The last description requires detail discussion with the purpose of definition of parameters of small amplitude fretting. The difficulties for certain state of stress and deformation of surface the amplitude-frequency characteristic of oscillations of two bodies practically is identical, that, a priori excludes relative displacement of surfaces. It is possible to assume, that the elastic interaction of two bodies in a tangential direction suffices for initiation fretting. In this case configuration of separate spots of contact both in scale of roughness, and in the boundaries of contour area of contact allows occurring of relative micro-displacement up to several micron. It is enough for intensive evolution of fretting in the boundaries of surfaces (Fig. 1).



a b c

Fig. 1. Initiation of fretting-processes on an edge of nominal – fixed contact (a, b) and further development of process (c) for N = 107 cycle, Ω = 100 Hz, diameter sphere Ø 12 mm

Rys. 1. Początek procesu zużycia ciernego na krawędzi kontaktu (a, b) oraz dalszy rozwój tego procesu (c) dla N = 107 cykli, Ω = 100 Hz, średnica kuli Ø 12 mm

Depending on kinetics of surface damage due to fretting, the evolution of a spectrum of oscillations occur. As a results of mentioned oscillation there is a modification of amplitude and velocity relative slip, forces of friction, moment installation of an equilibrium roughness.

Fretting which do not exceed the limit of force of friction ($Q < \mu P$) leads to significantly smaller amplitudes of a relative displacement in partial area of contact, as compared to traditionally fretting (20 … 100 μm). Other part of contact is deformed as agreed and is named as a zone of stick. From the general equation [4]:

$$Q = \mu P \left[1 - \left(\frac{c}{a} \right)^3 \right] \tag{1}$$

let's receive ratio for sizes of zones of stick and slip:

$$\frac{c}{a} = \left(1 - \frac{Q}{\mu P}\right)^{1/3} \tag{2}$$

The relative displacement of two bodies for diameter of ring area of contact a is determined by expression:

$$\Delta = \frac{3\mu P}{16 \cdot a}\left(\frac{2-\nu_1}{G_1} + \frac{2-\nu_2}{G_2}\right)\left[1 - \left(1 - \frac{Q_x}{\mu P}\right)^{2/3}\right] \tag{3}$$

Disregarding slip moment:

$$\Delta = \frac{Q_x}{8a}\left(\frac{2-\nu_1}{G_1} + \frac{2-\nu_2}{G_2}\right) \tag{4}$$

There was investigated geometric performance of spot of contact for sphere and flat from the point of view of development of small amplitude fretting on the boundary of contact.

2. The equipment

The scheme of test station for studying the frictional contact in conditions of fretting is presented in a Fig. 2.

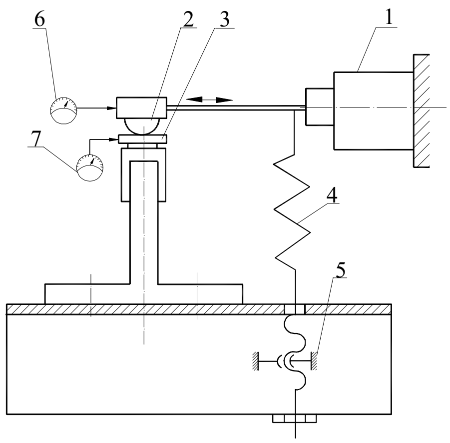


Fig. 2. The scheme of test station used for a studying of frictional contact in fretting conditions

Rys. 2. Schemat ideowy stanowiska do badania kontaktu ciernego w warunkach zużycia

On an elastic beam with a sufficient rigidity in a tangential direction ($2 \cdot 10^6$ H/m) the flat specimen 3 is placed. The ball 2 is fixed on a shaker 1. Frequency of vibration is 100 Hz.

The displacement of each element of contact pair is checked by indicators (6, 7), which probes are rigidly fixed. It excludes inertia micro impacts between a probe of the gauge and checking body. The normal load in to contact formed by an elastic element 4. Visual monitoring for oscillations and the digital information processing was made because of software product, developed by us, Dual ADC [5].

Optic research carries out on microscope MIM-10 and measurements of geometric parameters of contact on tool microscope IMC-10. Counter specimen is ball-bearing steel with a diameter 12 mm.

3. Configuration of contact

Let's consider a picture of micro displacement from the points of two bodies, which are characterized as nominally – fixed contact. In the boundaries of a contact zone, all points of a surface test have identical tangential location and the point K_1 coincides with C_1, K_2 with C_2. Having set transition of the upper body x_1, the body 2 is shifted on x_2. The coordinates x_1 and x_2 are inspected immediately by displacements' sensor (Fig. 3a). The difference $\Delta x = x_1 - x_2$ gives a relative displacement of two bodies (Fig. 4).

Since points K_2 and C_2 the ring slip zone for points K_3 and C_3 (Fig. 3b) begins. The points K and C are mean points on a surface of contact which coincide before appendix of tangential force. The points A_1 and B_1 are located in sufficient distance from contact, that it would be possible to place the displacements' sensor.

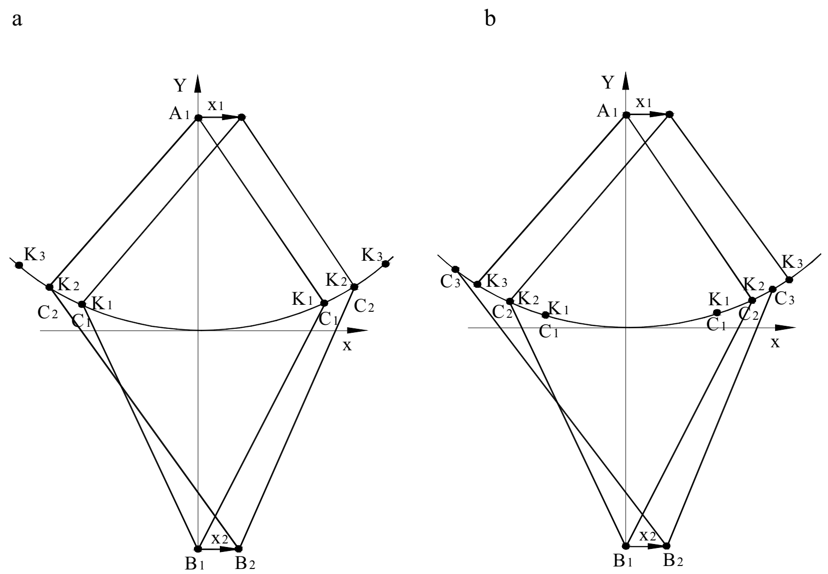


Fig. 3. Displacement in a zone of sticking (a) and slipping (b)

Rys. 3. Przemieszczenie w strefie przywierania (a) i poślizgu (b)

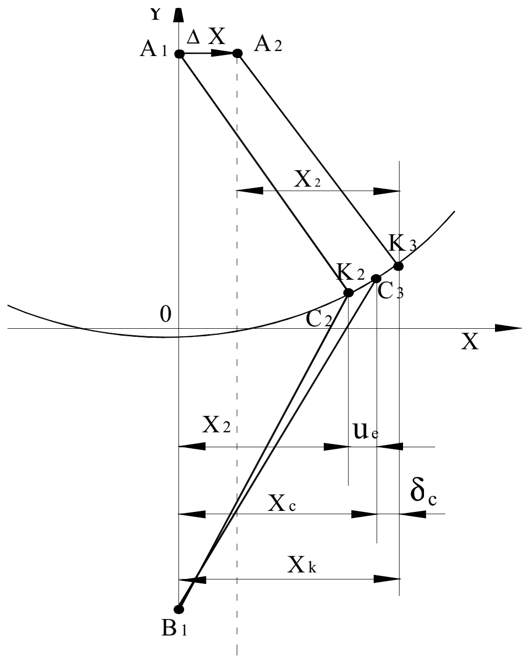


Fig. 4. The scheme of a displacement of points contact of rigid sphere and planes

Rys. 4. Schemat przemieszczania się punktów kontaktu sztywnej sfery i płaszczyzn

Let's consider a rigidity of a ball absolute. Then displacement Δx coincides with displacement of points of contact of ball $\Delta x = K_1K_2$. And point C tests elastic tangential displacement distinct from Δx.

Significances of slip will be:

$$\delta_s = x_k - x_c = \left(\Delta x + x_2\right) - \left(x_2 + u_e\right) = \Delta x - u_c \tag{5}$$

The conditions of absence slip˙ are equality of displacement in a tangential direction of all points of contact. If the difference of displacement of two bodies Δx, which is inspected by the gauge of displacement, does not exceed an elastic displacement of points of contact, is satisfied condition: $\mu\sigma_c < \tau_c$,

where:

σc – distribution of normal stress in zone of stick,

τc – distribution of tangential stress.

The relation of difference of points of contact in directions of axis's x and y a little also is possible to neglect displacements in a vertical direction $\nu/\left(4-2\nu\right) \approx 0{,}09$ [4],

where:

– Poisson's constant.

Magnitude slip˙ in a ring $c \le r \le a$ we determined from the equation:

$$s = \frac{3\mu P}{16Ga}(2-\nu)\left[\left(1-\frac{2}{\pi}\arcsin\frac{c}{r}\right)\left(1-2\frac{c}{r}\right)+\frac{2c}{\pi r}\left(1-\frac{c^2}{r^2}\right)^{1/2}\right] \tag{6}$$

Relative tangential displacement [4]:

$$\delta_x = \frac{3\mu P}{16a}\left(\frac{2-\nu_1}{G_1}+\frac{2-\nu_2}{G_2}\right)\left[1-\left(1-\frac{Q_x}{\mu P}\right)^{2/3}\right] \tag{7}$$

Dissipation of energy for a cycle of oscillations:

$$\Delta W = \frac{9\mu^2 P_0^2}{16a}\left(\frac{2-\nu_1}{G_1}+\frac{2-\nu_2}{G_2}\right)\times\left\{1-\left(\frac{Q_x}{\mu P}\right)^{5/3}-\frac{5Q_x}{\mu P_0}\left[1-\left(1-\frac{Q_x}{\mu P_0}\right)^{2/3}\right]\right\} \tag{8}$$

Settlement dependence of magnitude of slip˙ of area $c \le r \le a$ depending on coefficient of friction is shown in a Fig. 4. Significance of a breadth of a ring zone and normal gain are taken from experiment. It is visible, that maximum slip takes place on the boundary of area of contact and their magnitude is small enough.

a) b)

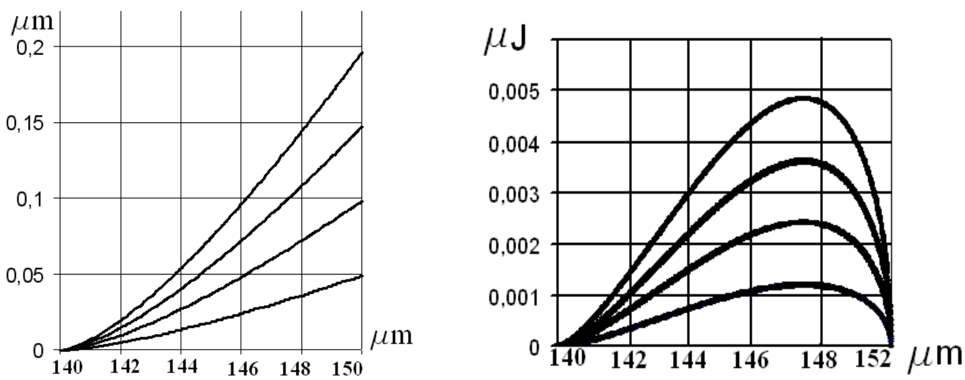


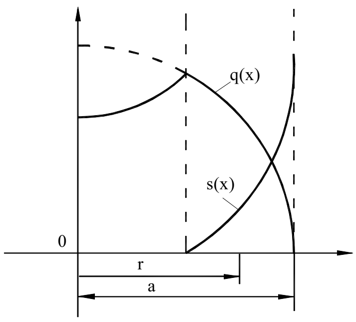
Fig. 5. Tangential displacements of points of contact in ring area (a) and work of friction in slip zone (b) depending on of friction coefficient at $0{,}1 \le f \le 0.4$, c = 140 µm, a = 150 µm, P = 40 H, Ω = 100 Hz

Rys. 5. Przemieszczenie styczne punktów kontaktowych w obszarze pierścienia (a) i wpływ tarcia w strefie poślizgu (b) w zależności od współczynnika tarcia dla $0{,}1 \le f \le 0.4$, c = 140 µm, a = 150 µm, P = 40 H, Ω = 100 Hz

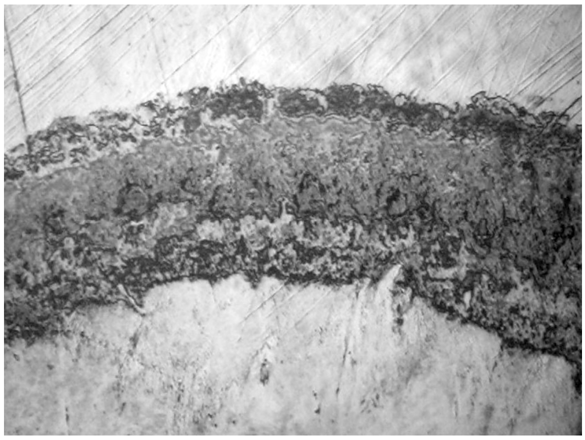
Distribution of tangential stress, at condition of absence slip for only two points of a ring zone in the (beginning and the end contact) extreme is determined by a ratio:

$$q = \mu P_0 \left(1 - \frac{r^2}{a^2}\right)^{1/2} = \mu \frac{2P}{\pi a}\left(1 - \frac{r^2}{a^2}\right)^{1/2} \tag{9}$$

The work of forces of friction in slip area is described by a configuration of two association's $q(x)$ and $s(x)$ (Fig. 6).



a



b

Fig. 6. A configuration of tangential stress $q(x)$ and relative displacements in a zone slip $s(x)$ (a). Structures of a zone slip in a result of small amplitude fretting (b)

Rys. 6. Rozkład naprężeń stycznych $q(x)$ i względne przemieszczenia w strefie poślizgu $s(x)$ (a). Struktura strefy poślizgu ukształtowana w wyniku zużycia ciernego o małej amplitudzie (b)

4. Conclusions

1. Intensive fretting-corrosion develops for very small peak tangential displacement.
2. The greatest fretting damage 1/3 breadths of a ring zone of a sliding from edges of contact are expected inside slip area.
3. The origin fretting – fatigue crack is possible inside area of slipping.
4. The frictional processes on a start stage of oscillations and accompanying by them adsorption phenomenon on a surface call flocculation of molecules of water and iron, that observes as a congestion of oxide particles.

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