# LONGLIFE PROGNOSTICATION OF SLIDING TRIBOSYSTEMS WITH CONTOURS—A SLIGHT DIFFERENCE FROM CIRCULAR ONES

M.V. CHERNETS

*Drogobych Ivan Franko State Pedagogical Institute, 293720, Drogobych, I. Franka, 24 Str.*

## ABSTRACT

A method is suggested to investigate the kinetics of tribocontact effect in cylindrical conjugations of deformation bodies of cutting configuration haxing close radii. Its essentials are as follows: an equation of the sliding triboprocess, a method to calculate the tribocontact pressures in the inner contacts of bodies of cutting configuration, and a description of the cutting of cylindrical bodies, that results either from a production method or from wear. For the purpose of solving the problem of prognosticating the longlife of sliding tribosystems, a kind of decision functions has been determined of the tribocontact areas transformation, due to their element wear. For this purpose a method has been proposed, too, to determine the tribocontact pressure function, and, by applying the method, a calculation ratio of longlife has been obtained which takes into account the cutting configuration of the bodies, their kinematics, coatings, the unequal tensile properties of the materials. Numerical solution has been presented for cylindrical bearing.

KEYS WORDS

Tribocontact effect, degradation, calculation, longlife, wear.

Sliding tribosystems of cylindrical bodies find sufficient application in engineering (plain bearings, bearings and pilot bearings, rocker bearings, sliding socket joints and some other joints). In engineering practice, the existing methods of their longlife prognostications are, for some reasons, being restricted in application. In particular this is due to the assumptions and hypotheses that contact wear is directly proportional to contact pressure, that tribosystem elements are non-deformable or rigid, that their contours are not oval or of cutting configuration, of the Hertz contact.

This report gives an account of how the kinetics of deformation bodies tribocontact effect were investigated, on which basis has been realized the prognostic evaluation of the sliding tribosystems resource or wear of the bodies with the contours having a slight difference from the circular ones.

## RAISING THE PLANE TRIBOCONTACT PROBLEM

In a cylindrical conjugation of bodies with close radii (fig.1) under the external strain N any of the contact elements (or both) undergoes a relative travel (rotational, oscillating, alternating). In general, the contours of the bodies in contact have the starting $\delta_K(\alpha,0)$ or the degrading $\delta_K(\alpha,h)$ small disturbances shaped as cutting of diverse complexity, which is determined as follows:

$$\delta_K(\alpha,h) = (-1)^K\,[R_K(\alpha) \pm h_K(\alpha,t) - R_K],\quad K=1,2 \qquad (1)$$

where K - is numbers of the bodies; at K=1 the symbol "plus" is taken, and at K = 2 - "minus" is; $\alpha$ is the polar angle of the contour point; $R_K(\alpha)$ - the radii-vectors of the bodies contours at h = 0; $R_K$ - the radii of the bearing circles the one inscribed into the contour of body 2 at K = 2 and the escribed one, round the hole contour in body 1 at K = 1.

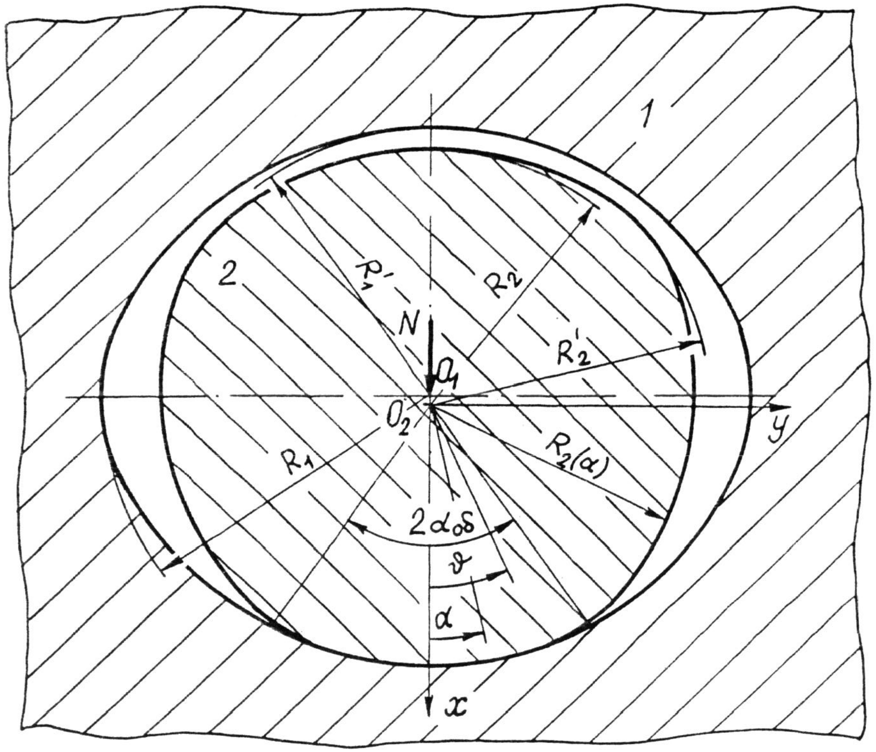


Fig.1. Calculation scheme tribosystem



It is assumed that there is a clearance $\delta=R_1-R_2$ in the conjugation. The materials of the bodies may have unequal elasticity characteristics.

The problem is to determine the resource $t_K$ of the tribosystem elements at reaching admissible wear $h_{*K}(\alpha,t)$ or to assess wear $h_K$ performance for the approved unit longlife $t_*$.

Tribokinetic equations system is taken of the kind (Andrejkiv and Chernets, 1991)

$$\frac{1}{V}\,\frac{dh_K(\alpha,t)}{dt_K}\,\Phi_K(\tau) = 1 \qquad (2)$$

where V is sliding velocity; $\Phi$ - the material wear root function determined from triboexperimental investigations ($\Phi$ = Vt/h); $\tau = \tau(\alpha,\delta,t,h) = fp(\alpha,\delta,t,h)$ - specific force of friction,calculated according to Coulomb; f - coefficient of sliding friction; $p(\alpha,\delta,t,h)$-tribocontact pressure.

For approximating the test results, the following correlation is used:

$$\Phi_K(\tau) = B_K\tau_K^{(0)}/\,[\tau - \tau_K^{(0)}]^{m_K}, \qquad (3)$$

where B, m, $\tau^{(0)}$ are characteristics of friction wear resistance of the material.

Determination of Tribocontact Pressures. For conjugations of bodies with cuttings the fundamental equation of the problem is as follows.

$$k_1\int_{-\alpha_{0\delta}}^{\alpha_{0\delta}} ctg\frac{\alpha-\vartheta}{2}\,p'(\vartheta,\delta,t,h)\,d\vartheta = k_2\,p(\vartheta,\delta,t,h) + k_3\int_{-\alpha_{0\delta}}^{\alpha_{0\delta}} p(\alpha,\delta,t,h)d\alpha$$

$$+ k_4\cos\alpha\int_{-\alpha_{0\delta}}^{\alpha_{0\delta}} p(\alpha,\delta,t,h)\cos\alpha\,d\alpha + \varepsilon/R_1R_2 - \sin\alpha\left\{2\,[f'_{1x}(\alpha,h)/R_1^2 - f'_{2x}(\alpha,h)/R_2^2] - [f''_{1y}(\alpha,h)/R_1^2 - f''_{2y}(\alpha,h)/R_2^2]\right\} + \cos\alpha \qquad (4)$$

$$\left\{2[f'_{1y}(\alpha,h)/R_1^2 - f'_{2y}(\alpha,h)/R_2^2] + [f''_{1x}(\alpha,h)/R_1^2 - f_{2x}(\alpha,h)/R_2^2]\right\}$$

where

$k_1 = [(1+\varkappa_1)/G_1R_1 + (1+\varkappa_2)/G_2R_2]/8\pi$, $k_3 = (1+\varkappa_1)/8\pi\,G_1R_1$,

$k_2 = [(1-\varkappa_2)/G_2R_2 - (1-\varkappa_1)/G_1R_1]/4$, $k_4 = [\varkappa_1/G_1R_1 + 1/G_2R_2]/2\pi$;

$f_{Kx}(\alpha,h) = x_K^{(\omega)}(\alpha,h) - x_K(\alpha)$, $f_{Ky}(\alpha,h) = y_K^{(\omega)}(\alpha,h) - y_K(\alpha)$. (5)

$\varkappa = 3-4\nu$ (plane deformation); $\varkappa=(3-\nu)/(1+\nu)$ plane strain); G, $\nu$ - shear module and Poisson coefficient of material; strokes denote derivatives with respect to $\alpha$; $x_K^{(\omega)}(\alpha,h)$, $y_K^{(\omega)}(\alpha,h)$ - parametric equations of the contours of bodies of cutting configurations of their bearing circles, where $A_1=R_1$ at K=1, $A_2 = R_2$ at K = 2.

Description of Cutting of Cylindrical Bodies. For this purpose generalized parameter equations are used

$$x_K^{(\omega)}(\alpha,h) = R_{Kl}^{(\omega)}(\alpha,h)\cos\alpha,\quad y_K^{(\omega)}(\alpha,h) = R_{Kl}^{(\omega)}(\alpha,h)\sin\alpha, \qquad (6)$$

where $R_{Kl}^{(\omega)}(\alpha,0) = 0.5\,[\delta_K^{+} - (-1)^{l}\,\delta_K\cos\omega\alpha]$,

$R_{kl}^{(\omega)}(\alpha,h) = 0.5\,([\delta_k^+ - (-1)^k \delta h_k] - (-1)^l [\delta_k + (-1)^{|k-l|} \delta h_k] \cos\omega\alpha)$ is radius-vector of the cutting contour; $\omega = 2,3,4,...$ -coefficient of the cutting ($\omega$=2 - ovality, $\omega$=3 - three- edge cutting, etc.); $\delta_k^+ = a_k + b_k$, $\delta_k = a_k - b_k$; $a_1 = R_1$, $a_2 = R_2'$, $b_1 = R_1'$, $b_2 = R_2$; l =1, 2 - index of relative position of bodies in conjugation; l = 1 at $x_k = a_k$, l = 2 at $x_k = b_k$; $\delta$ = 1 for x, $\delta$ = 0; 1 for y.

## GENERAL SOLUTION OF TRIBOCONTACT PROBLEM

Generally, if the kind of functions (5) is determined, the calculation of longlife parameters (of wear or resource) is done as the result of join of solutions - of tribocontact equations system (2) and equation (4) in assessing the following kind are obtained:

$$f_{kx}(\alpha,h) = 0.5(-1)^k \cos\alpha\, [\delta_k(1 \pm (-1)^l \cos\omega\alpha) - h_k(1+\cos\omega\alpha)],\qquad (7)$$

$$f_{ky}(\alpha,h) = 0.5(-1)^k \sin\alpha\, [\delta_k(1 \pm (-1)^l \cos\omega\alpha) - \delta h_k(1+\cos\omega\alpha)].$$

At rotational motion here $\delta$=1, at alternative - $\delta$=0, when the body is stationary - $\delta$=0; at K=1 the symbol "plus" is taken, and at K=2 - "minus".

A simpler solution of system (2) will be at a certain tribocontact pressure function $p(\alpha,\delta,t,h)$. Depending on the kind of cutting on kinematics of tribocontact, elements, on tensile properties of the materials, it may be represented as follows:

$$p(\alpha,\delta,t,h) = p(\alpha,\delta) \pm p(\alpha,h) =$$
$$= E_\delta \varepsilon_\delta \sqrt{tg^2(\tilde\alpha_o/2) - tg^2(\alpha_o/2)} \pm E_h \varepsilon_h \sqrt{tg^2(\tilde\alpha_o/2) - tg^2(\alpha_o/2)},\qquad (8)$$

$$E_\delta = e_4 R_2^{-1}\left\{\cos^{-2}(\tilde\alpha_o/4) - e_1\sqrt{tg^2(\tilde\alpha_o/2) - tg^2(\tilde\alpha_o/4)} - 2\sin^2(\tilde\alpha_o/4)\right. \times$$
$$\times \left.(e_2 \cos^{-1}(\tilde\alpha_o/2) + 2e_3\cos(\tilde\alpha_o/4))\right\};$$

$$\varepsilon_\delta = \varepsilon[1 - 0.5\varepsilon^{-1}\delta_1 D_1^{(\omega)}(\tilde\alpha_o/2) - 0.5\varepsilon^{-1}\delta_2 D_2^{(\omega)}(\tilde\alpha_o/2)] = \varepsilon\textstyle\sum_\delta,$$

$\tilde\alpha_o = \alpha_o$ at $\delta_k = 0$, $\tilde\alpha_o = \alpha_{o\delta}$ at $\delta_k > 0$;

$$D_k^{(\omega)}(\tilde\alpha_o/2) = 1 - (-1)^{k+l}(\omega^2 - 1)\cos\omega(\alpha_{o\delta}/2);$$

$e_1 = 2Z^{-1}[(1-\varkappa_1)(1+\nu_1)E_2 - (1-\varkappa_2)(1+\nu_2)E_1]$, $e_2 = 2Z^{-1}(1-\varkappa_1)(1+\nu_1)E_2$,
$e_3 = 4Z^{-1}[(1+\nu_2)E_1 + \varkappa_1(1+\nu_1)E_2]$, $e_4 = 4Z^{-1}E_1E_2$, $E = 2G(1+\nu)$,
$Z = (1+\varkappa_1)(1+\nu_1)E_2 + (1+\nu_2)(1+\varkappa_2)E_1$; $E_h \equiv E_\delta$ at $\alpha_{o\delta} \equiv \alpha_{o\delta h}$;

$$\varepsilon_h = \pm h_1 \pm h_2 = \pm \bar h_1 K_b^{(1)} \pm \bar h_2 K_b^{(2)} = h_k(\pm K_b^{(k)} \pm h_k');\quad h_1, h_2 = h_k(0);$$

$$h_1' = \frac{\bar h_2 K_b^{(2)}}{\bar h_1} = \frac{\Phi_1(\tau)}{\Phi_2(\tau)} = \frac{B_1[\tau_1^{(o)}]^{m_1}[\tau(0) - \tau_2^{(o)}]^{m_2}}{B_2[\tau_2^{(o)}]^{m_2}[\tau(0) - \tau_1^{(o)}]^{m_1}} K_b^{(2)},\ h_1 \neq h_2,\ \Phi_1 \neq \Phi_2,$$

$$h_2' = \frac{\bar h_1 K_b^{(1)}}{\bar h_2} = \frac{\Phi_2(\tau)}{\Phi_1(\tau)} = \frac{B_2[\tau_2^{(o)}]^{m_2}[\tau(0) - \tau_1^{(o)}]^{m_1}}{B_1[\tau_1^{(o)}]^{m_1}[\tau(0) - \tau_2^{(o)}]^{m_2}} K_b^{(1)};\ \tau(0) = fp(0,\delta);$$



$0 < K_b^{(k)} \leq 1$ - coefficient of relative overlapping of tribocontact elements, determined by their kinematics. With the parameter $\varepsilon_h$, the symbols are to be taken into account with $h_k$. If wear performance results in pressure increase, $h_k$ is positive, in the opposite case - $h_k$ is negative.

To determine the contact halfangle $\tilde\alpha_o$ or $\alpha_{o\delta h}$ the equilibrium condition is used

$$N = R\int_{-\tilde\alpha_o}^{\tilde\alpha_o} p(\alpha,\delta)\cos\alpha d\alpha = 4\pi\ RE_\delta\ \varepsilon_\delta\ \sin^2\frac{\tilde\alpha_o}{4}.\qquad (9)$$

In the other case $E_h \equiv E_\delta$, $\varepsilon_\delta \equiv \varepsilon_\delta + \varepsilon_h$, $\tilde\alpha_o = \alpha_{o\delta h}$.

By integrating the system of tribokinetic equations (2) taking account of (3), (8), (9) we get

$$t_k = \pm\frac{B_k[\tau_k^{(o)}]^{m_k}}{vS_h(K_b^{(k)} \pm h_k')(1-m_k)}\left\{\left[S_\delta \varepsilon \textstyle\sum_\delta - \tau_k^{(o)}\right]^{1-m_k} - \left[S_\delta \varepsilon \textstyle\sum_{\delta h} - \tau_k^{(o)}\right]^{1-m_k}\right\},\qquad (10)$$

where

$$S_\delta = fE_\delta\sqrt{tg^2(\tilde\alpha_o/2) - tg^2(\alpha/2)},\quad S_h = fE_h\sqrt{tg^2(\alpha_{o\delta h}/2) - tg^2(\alpha/2)}$$

$$\textstyle\sum_{\delta h} = \sum_\delta + \varepsilon_h S_h / \varepsilon S_\delta.$$

Wear performance $h_k$ of the conjugation elements are related to each other (one another)

$$h_1 = h_2,\ h_2 = h_1 h_1'.$$

The summational wear $h_\Sigma = h_1 + h_2$ of the tribosystem through wear performance $h_k$ and inversely in calculated as follows:

$$h_\Sigma = h_k(K_b^{(k)} + h_k')/K_b^{(k)},\quad h_k = h_\Sigma K_b^{(k)}/(K_b^{(k)} + h_k')\qquad (11)$$

It should be noted that in accordance with (10) the longlife calculation is restricted by the condition $S_\delta \varepsilon \Sigma_{\delta h} = \tau(0)_{min}$, where $\tau(0)_{min} \approx 0.637\ fN/R$ is specific friction force on the tribocontact at $\varepsilon$=0. At $\tau(0)_{min} > \tau_k^{(o)}$ the restricting condition is taken as follows: $S_\delta \varepsilon \Sigma_{\delta h} \approx \tau_k^{(o)}$. The longlife $\tilde t_k$ of this triboprocess period is determined by the equation

$$t_k = \frac{h_{k*}(0) B_k[\tau_k^{(o)}]^{m_k}}{v[\tau(0)_{min} - \tau_k^{(o)}]^{m_k}}.\qquad (12)$$

As an illustration, a sliding bearling resource has been calculated. The material of the rotary bushing 1 steel 45 heat-treated, for which by the result of triboexperimental investigations the friction resistance characteristics $B_1 = 21.4\cdot10^8$, $m_1 = 0.60$, $\tau_1^{(o)} = 0.13$ MPa; the material of axle journal 2 is protective coating, for which $B_2 = 42,8 \cdot 10^8$, $m_2 =$ 0,81, $\tau_2^{(0)} = \tau_1^{(0)}$. The journal is assumed to be circular or cutting (oval, there-edged), white the bushing is - circulpar. The initial data for calculation are: $N = 0,04$ MN, $\varepsilon = 0,001$ m, $v = 12$ $ms^{-1}$, $f = 0,15$, $R_2 = 0,1$ m; $E_1 = E_2 = 2,1 \cdot 10^5$ MPa, $\nu_1 = \nu_2 = 0,3$, $h_{2*} = 0,0005$ m, $\delta_1 = 0$, $\delta_2 = (0;\ 0,2;\ 0,4;\ 0,6) \cdot 10^{-3}$m, $K_b^{(1)} = \tilde{\alpha}_0 / \pi$, $K_b^{(2)} = 1$.

The calculation results are represented in Fig.2. Here curve 1 is built for the oval journal contour, and 2 - for the three edged one.

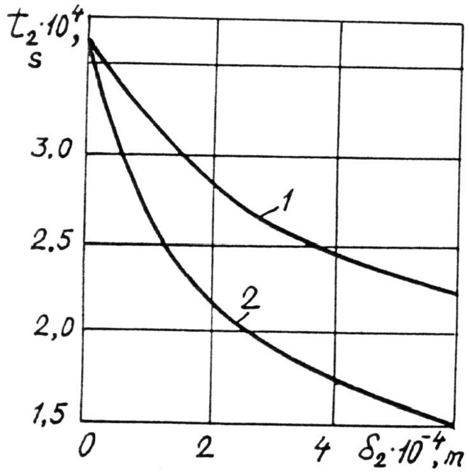


Fig.2. Resource coating one


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