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MODELLING AND FORECASTING OF WEAR RESISTANCE OF FRICTION UNITS OF MACHINES WITH LUBRICANTS

MODELOWANIE I PROGNOZOWANIE ODPORNOŚCI NA ŚCIERANIE SMAROWANYCH ELEMENTÓW MASZYN

A b s t r a c t

The wear test methods with lubrication under three schemes, with the definition of parameters of multi-factor wear process models have been offered. The tests have been designed by means of Solid Works program. The numerical algorithm for the solution of research task was based on MathCad program.

Keywords: *four-ball wear test, lubrication, contact pressure, speed of sliding, computational model*

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

W artykule przedstawiono metody badań na zużycie ze smarowaniem według schematów o wyznaczonych parametrach modeli zużycia. Przyrząd dla badań zaprojektowano za pomocą programu Solid Works. Otrzymane dane z badań poddano obróbce komputerowej, stostując program MathCad.

Słowa kluczowe: *badania na zużycie według schematu czterech kul, smarowanie, ciśnienia kontaktowe, szybkości ślizgania, modele rozrachunkowe*

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1. Introduction

The main cause of failure of machines friction units is wear. Lubrication is the most effective way to increase wear resistance of these units. Therefore the first basic task for researchers, designers and technologists is to create conditions of preservation and restoration of lubrication in contact. The success of research on the wear process of lubricated surfaces is determined by test methods.

Among the known test methods of friction units with lubrication tests under four-ball scheme are most efficient. This is a standard method and it is widely applied all over the world [1] (in Russia – ГОСТ 9490-75; in USA – ASTMD 2596, ASTMD 2783; in Germany – DIN 51350; in Poland – PN-76/C-04147; in England – IP 300; in Bulgaria БДС 14150-77). In this scheme the main defect of the test is the lack of mathematical description of the wear process. Besides, the four-ball test uses only standard material for the steel balls. But the scheme of external contact of two balls does not adequately prototype the contact of the real interfacing of friction units.

The present paper is an attempt to produce a quantitative description of the wear process for samples of different tests and materials schemes. The basic problem is the direct and inverse wear-contact tasks for contact and wear samples of different form [2–4]. Solving this problem results in mathematical models of the wear process, using calculation programs.

2. Technique of wear process models construction on an example of four-ball scheme

In the scheme of tests the top ball rotates and exerts pressure on three motionless bottom balls (Fig. 1). As a result of tests for the bottom balls a circular surface of wear process of radius α is formed. The influence of elastic deformations of the contact area formation was neglected. The contact area between the top and bottom balls is filled with a lubricant.

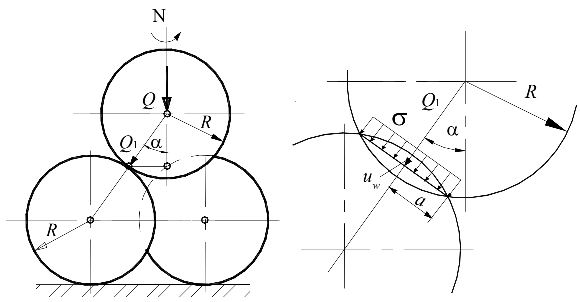


Fig. 1. Scheme of four-ball wear test

Rys. 1. Badania na zużycie według schematu czterech kul

To describe the wear process of the bottom balls under the adopted test scheme a model in the form of dependence of wear process intensity on two parameters is assumed: loading and speeds of sliding

$$I = \frac{du_w}{dS} = k_w \left(\frac{\sigma}{E^*} \right)^m \left(\frac{VR^*}{\nu} \right)^n \quad (1)$$

where:

σ	–	contact pressures,
E^*	–	the resulting module of elasticity of materials of contacting balls,
V	–	the relative speed of sliding,
R^*	–	the radius of contacting balls,
ν	–	the kinematic viscosity of lubricant (at 100°C),
u_w	–	the linear wear of the bottom balls,
S	–	friction mode for the bottom balls,
K_w, m, n	–	the parameters of wear process model.

Dependence of linear deterioration u_w on radius of the wear process surface a of the bottom balls is defined by the geometry of balls surfaces intersection (Fig. 1)

$$u_w(S) = \frac{a(S)^2}{2R} \quad (2)$$

From the tests it is possible to receive the dependence of the wear circular surface radius on the friction mode in the form of approximation

$$a(S) = cS^\beta \quad (3)$$

where c, β are the parameters of approximation.

At uniform distribution of contact pressure on the contact surface the equilibrium in balls contact is obtained from the condition

$$\sigma = \frac{0{,}4082Q}{\pi a^2} \quad (4)$$

After substitution (2–4) in (1) and integration, we shall receive

$$\frac{c^2 S^{2\beta}}{2R} = K_W \left(\frac{0{,}4082Q}{c^2 \pi E^*} \right)^m \left(\frac{VR^*}{\nu} \right)^n \frac{S^{1-2\beta m}}{1-2\beta m} \quad (5)$$

From the condition of feasibility of equation (5) at any S m will be determined

$$m = \frac{1-2\beta}{2\beta} \quad (6)$$

To find parameter n tests are run for two values of sliding speed V_1 and V_2 and two groups of data are received

$$a = c_1 S^{\beta_1} \quad a = c_2 S^{\beta_2} \tag{7}$$

At constant test specifications for wear process $\beta_1 = \beta_2 \approx \beta$ is adopted.

Substituting expressions (7) in (5), we shall receive a system of two equations

$$\left.\begin{aligned} \frac{c_1{}^2 S^{2\beta}}{2R} &= K_W \left(\frac{0{,}4082Q}{c_1{}^2 \pi E^*}\right)^m \left(\frac{V_1 R^*}{\nu}\right)^n \frac{S^{1-2\beta m}}{1-2\beta m} \\ \frac{c_2{}^2 S^{2\beta}}{2R} &= K_W \left(\frac{0{,}4082Q}{c_2{}^2 \pi E^*}\right)^m \left(\frac{V_2 R^*}{\nu}\right)^n \frac{S^{1-2\beta m}}{1-2\beta m} \end{aligned}\right\} \tag{8}$$

To define parameter n we shall divide the first equation by the second and after transformations we shall receive

$$n = (2m+2)\frac{\lg(c_1/c_2)}{\lg(V_1/V_2)} \tag{9}$$

To find factor K_w we shall take advantage of one of the equations (8)

$$K_w = \frac{\beta c_1^{2m+2}}{R}\left(\frac{2\pi E^*}{0{,}4082Q}\right)^m \left(\frac{\nu}{V_1 R^*}\right)^n \tag{10}$$

3. Results of wear process modelling in tests under schemes: a ball-ring, a cone-ring

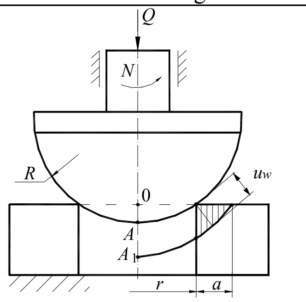
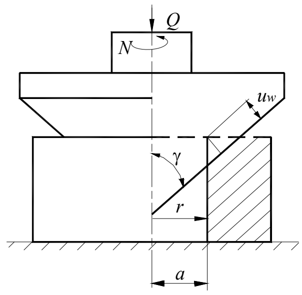
The scheme of contact of four balls is used for tests of the interaction between different forms from steel materials (gears, cam mechanisms, bearings, etc.) For testing materials of sliding bearings, including polymeric materials for the interaction of similar forms (sliding bearings, hinges, etc.) the ball-ring scheme is suggested. To extend the types of tests of structural materials a third test scheme: a cone-ring is offered. Manufacturing of a conic sample is simpler than manufacturing of a ball.

Form (1) is used as the general form of wear process model.

The schemes for calculation and results of definition of wear process models parameters are shown in Table 1.

Table 1

Schemes of tests and parameters of wear process models

Parameters	Ball-ring	Cone-ring
		
m	$m=\dfrac{1-\beta}{\beta}$	$m=\dfrac{1-\beta}{\beta}$
n	$n=(m+1)\dfrac{\lg(c_1/c_2)}{\lg(V_1/V_2)}$	$n=(m+1)\dfrac{\lg(c_1/c_2)}{\lg(V_1/V_2)}$
K_w	$K_w=\dfrac{\beta c_1^{m+1} r^{m+1}}{R}\left(\dfrac{2\pi E^*}{Q}\right)^m\left(\dfrac{\nu}{V_1 R^*}\right)^n$	$K_w=\beta c_1^{m+1}\cos\gamma\left(\dfrac{2\pi r E^*}{Q}\right)^m\left(\dfrac{\nu}{V_1 R^*}\right)^n$

4. The test stand

For quantitative definition of wear process models parameters by the results of laboratory tests a test stand on the basis of four-ball machine of friction has been designed by means of Solid Works program (Fig. 2).

The basic unit of the stand is the working unit (Fig. 2). The top ball 1 is placed in a holder at the end of the spindle. Palpation of the ball sphere at rotation is not assumed. The three bottom balls of diameter of 12,7 mm (2) are installed on tempered surface of a support 4. The top plane of the nut 3 is used as measuring base for measuring the range of wear. The wear is measured without disassembly of the stand. For measurement of the sizes of spots of wear process on the bottom balls a microscope МПБ-2 resolution of 0,05 mm is used. After the measurements of wear process the tests proceed along the adopted program.

Exception of skews at contact of the balls is provided for ball bearings 5.

For measurement of the moment of friction a different type of bearing 6 is used. The top ball is loaded by means of the lever with the transfer ratio k = 3,25.

The thermometer of ЭТП-М is mounted to control the temperature in the balls friction zone. The sensitive element of the thermometer (9, Fig. 2) is placed in the support under the bottom spheres. During the tests the temperature of lubrication over the zone of friction is under continuous control.

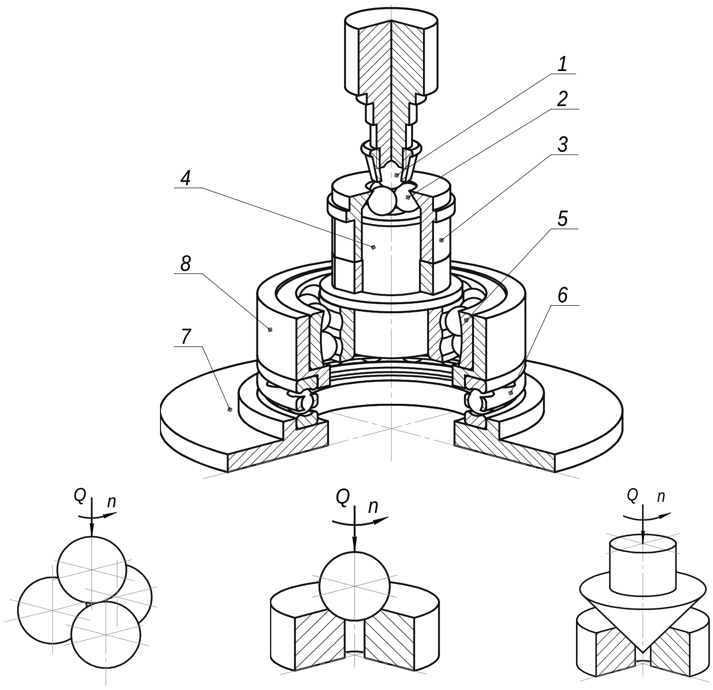


Fig. 2. The test stand (Solid Works)

Rys. 2. Przyrząd do badań (*Solid Works*)

5. Results of tests of lubricant and constructional materials

Initial data:
Scheme 1. Four balls.
1. R = 6,35 mm.
2. Q = 65 N.
3. N_1 = 200 rev/min (V_1 = 0,077 m/s), N_2 = 600 rev/min (V_2 = 0,19 m/s).
4. Material of balls: steel ШХ-15 ГОСТ 801-78 (52100 steel balls).
5. Lubricant: motor oil М6$_3$/12 – Г$_1$, ν = 12 mm^2/s (API-SJ/CD, SAE-15W/40).

Scheme 2. Ball-ring.
1. R = 6,35 m, $r = 3$ mm.
2. Q = 65 N.
3. N_1 = 200 rev/min (V_1 = 0,063 m/s), N_2 = 600 rev/min (V_2 = 0,19 m/s).
4. Material of ball: steel ШХ15; rings – aluminium.
5. Lubricant: motor oil М6$_3$/12 – Г$_1$, ν = 12 mm^2/s (API-SJ/CD, SAE-15W/40).

Scheme 3. Cone-ring.
1. $\gamma = 30°$, $r = 3$ mm.
2. $Q = 65$ N.
3. $N_1 = 200$ rev/min ($V_1 = 0{,}063$ m/s), $N_2 = 600$ rev/min ($V_2 = 0{,}19$ m/s).
4. Material of a cone: steel 45; rings: bronze Бр ОФ10-1.
5. Lubricant: motor oil М6$_3$/12 – Г$_1$, $\nu = 12$ mm^2/s (API-SJ/CD, SAE-15W/40).

The results of tests under the three schemes have been shown in Table 2.

Table 2

Dependence of wear process surface size *a* (mm) on duration of tests (numerator – 200 rev/min, a denominator – 600 of rev/min)

№ scheme	30 min	60 min	90 min	120 min	150 min	180 min
1	0,35	0,4	0,43	0,48	0,5	0,51
	0,48	0,54	0,63	0,65	0,67	0,68
2	0,125	0,2	0,25	0,275	0,35	0,4
	0,25	0,35	0,4	0,475	0,5	0,5
3	0,125	0,2	0,225	0,25	0,275	0,3
	0,225	0,325	0,375	0,4	0,425	0,45

The test results have been processed by means of programs Exel and MathCad. The calculated parameters of wear process models for three test schemes have been given in Table 3.

Table 3

Models of wear

Four balls	$I = 0{,}025\left(\frac{\sigma}{E^*}\right)^{1,62}\left(\frac{VR^*}{\nu}\right)^{0,135}$
Ball-ring	$I = 4{,}7 \cdot 10^7\left(\frac{\sigma}{E^*}\right)^{4,19}\left(\frac{VR^*}{\nu}\right)^{0,441}$
Cone-ring	$I = 2{,}19 \cdot 10^8\left(\frac{\sigma}{E^*}\right)^{4,37}\left(\frac{Vr}{\nu}\right)^{0,403}$

In Fig. 3 the dependencies of wear process intensity on contact pressure (1) and sliding speed (2) for three test schemes have been presented.

The presented technique of wear process models construction can be used for designing units of friction and optimisation of their parameters.

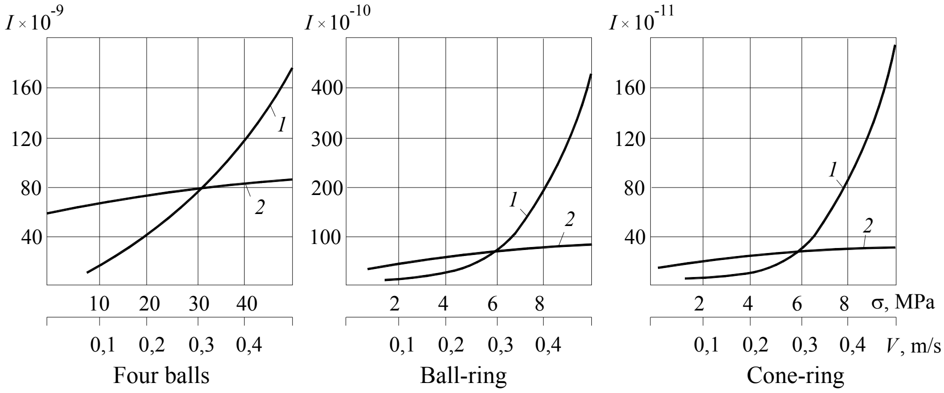


Fig. 3. Dependencies of wear process intensity on contact pressure – 1 and sliding speed – 2

Rys. 3. Zależność zużycia od ciśnienia kontaktowego – 1 i szybkości ślizgania – 2

6. Conclusions

1. Test of lubrication by the four-ball machine with no definition of wear process models has only a qualitative character. Consequently, it can be used only for limited types of materials and forms of interactions.

2. The wear test methods are offered for three schemes, including the definition of parameters of multi-factor wear process models. It is designed by means of Solid Works program.

3. The numerical algorithm is developed for calculation of models parameters together with a comparison of properties of lubricants for friction units obtained by means of MathCad program.

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