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Research of wear resistance of the composite coverings applied by a method of electric contact sintering

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Abstract. Intensity of wear process is one of the basic characteristics defining durability of mobile connections. To study wear resistance of a «roller pin», conditions close to real conditions of operation of the given unit should be recreated. Axes of running gears of wood machinery are subject to wearing due to abrasive friction. Friction is one of the most widespread processes; it accompanies any relative movements of adjoining bodies or their parts. The purpose of the present research is the substantiation of application of composite coverings for enhancement of running gear unit durability.

1. Introduction

To study wear resistance of a «roller pin», conditions close to real conditions of operation of the given unit should be recreated. Axes of running gears of wood machinery are subject to wearing due to abrasive friction. Friction is one of the most widespread processes; it accompanies any relative movements of adjoining bodies or their parts.

The purpose of the present research is the substantiation of application of composite coverings for enhancement of running gear unit durability.

2. Research Method

Contact friction occurs at relative movement of two contacting bodies. It depends on interaction of exterior surfaces of these bodies nearby to contact areas; it does not depend on the state of internal parts of bodies. Contact friction and wearing process consists of three consequent stages: surface contact, surface layer material deformations due to friction, and surface destruction. As for the roller pin, a bearing made of pure bearing-grade steel is subject to friction [1, 2, 3]. The key aspect of a solid body surface is microrelief, which has the following attributes: shape, undulation, and roughness. It could be concluded that structure change during friction takes place at specific contact patches. This is why the structure and properties of the surface layer differ from the structure and properties typical for volumetric deformation and thermal treatment. The key aspect of a solid body surface is microrelief, which has the following attributes: shape, undulation, and roughness [4, 5].

In the present case, roughness of both units is Ra = 2.5, which minimizes the impact of this factor. During contact friction process studying, three groups of factors must be considered (see table 1) [6, 7, 8].

Table 1. Factors Affecting Contact Friction of Solid Bodies.

Input Factors	Internal Factors	Output Factors
Properties of Contacting Bodies Lubricating Material Load Speed Temperature	Roughness Change Surface Film Properties Change Heat Release Structure Change Mechanical Properties Change	Friction Force Wear Process Intensity

DM-15 machine is used to recreate natural friction conditions. This machine recreates abrasive friction through introducing abrasive elements into the contact area (sand, ground, etc.). A pair «roller pin— inner race» is used as a friction joint. "UNIOL-1"lubricating material (GOST 1033-79) is used for pre-test greasing of units [8, 9, 10, 11].

Units were marked at measurement places. Conjugate diameters were measured after micrometer and inside gage treatment with the accuracy of up to 0.001 mm in two mutually perpendicular surfaces and in tree points, in the center and at the edges, while the wearing rate was taken as the average of the two mentioned parameters [12, 13].

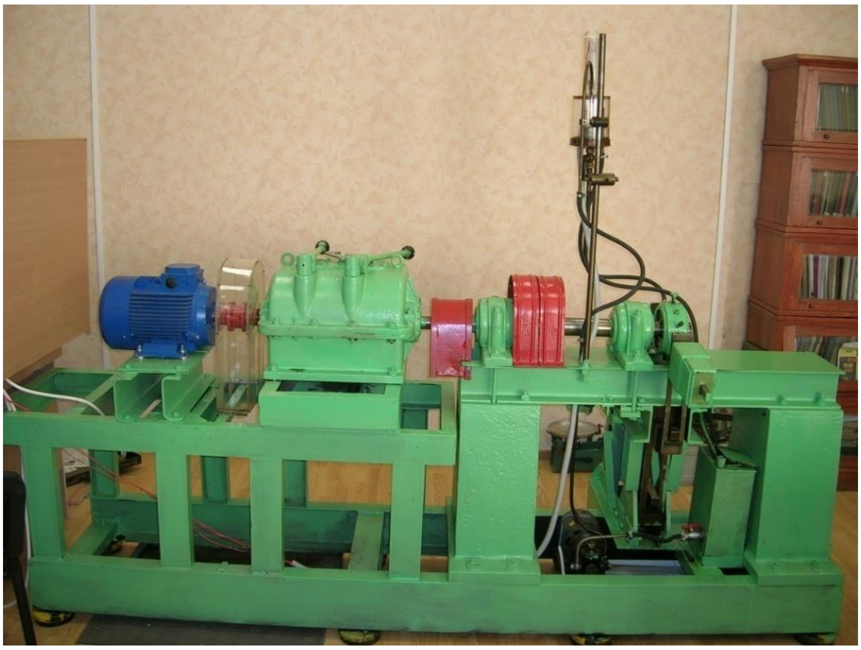

Figure 1. DM-15 Machine.

The load on the contacting units is taken based on the real value P = 15.000 N set by the force gage DOSM-5-1 (TU25.06.629-74). The following conditions were kept: rotative movement, max sliding speed at the friction pair V_{max}=0.07 m/s at the output shaft speed n = 30 min^{-1} received by the electric motor [14, 15, 16]. Before the tests for each friction pair, preaging (at P = 5.000 N and V = 0.01 m/s) was conducted. During the studying, temperature in the friction zone was measured by means of a temperature gage installed in the aperture prepared in the bearing race[17].

The following relationships were accepted to evaluate the wearing rate:

$$I_i = \frac{U}{t} \quad (1)$$

Where U is the wearing rate of contacting units, mm;
tis the time of the test, h

$$I_w = I_{pin} + I_{bear} \tag{2}$$

Where I_w is the total wearing rate of the joint, mm/h;
I_{pin} is roller pin wearing rate, mm/h;
I_{bear} is bearing wearing rate, mm/h.

Wearing rate of the uncovered roller pin is taken as the nominal wearing rate I_{nom}. During preliminary research, it was found that nominal wearing rate is 0.014 mm/hour. Through studies of nominal wear process intensity, tests were conducted in the same conditions as during studies of wear resistance of covered axes [18, 19].

The following are sintering factors affecting the wearing rate: current intensity (A), voltage (U), and electrode pressing force (P). Factor levels and varying intervals thereof are given in table 2.

Table 2. Factor Levels.

Factor Level	I, kA		U,V		P, kN	
	x_1	$\ln x_1$	x_2	$\ln x_2$	x_3	$\ln x_3$
Lower (-1)	10	2.30	2	0.69	0.5	-0.69
Main (0)	12	-	3	-	1	-
Upper (+1)	14	2.64	4	1.39	1.5	0.4
-α	7.85	-	1.57	-	0.285	-
+α	17.01	-	4.86	-	1.715	-

Following the table:

$X_1 = 2\times(\ln x_1 - 2.3)/[2.3-2.64]+1 = -5.88\ln x_1 + 14.5$
$X_2 = 2\times(\ln x_2 - 0.69)/[0.69-1.39]+1 = -2.86\ln x_2 + 5.83$
$X_3 = 2\times(\ln x_3 + 0.69)/[-0.69-0.4]+1 = -0.96\ln x_3 - 0.63$

There goes the regression analysis. Results of the test are coded and logged in table 3. For more accuracy, 8 main tests are complemented by 7 auxiliary ones.

Table 3. Test Matrix.

	X_1	X_2	X_3	$Forr_1$	$Forr_2$		
	code	code	code	I', mm/h	I'', mm/h	$\bar{I}$,mm/h	$\bar{Y} = ln\bar{I}$
1	+	+	+	0.008	0.009	0.0085	-4.77
2	-	+	+	0.015	0.017	0.016	-4.14
3	+	-	+	0.014	0.012	0.013	-4.34
4	-	-	+	0.019	0.021	0.02	-3.91
5	+	+	-	0.009	0.010	0.0095	-4.66
6	-	+	-	0.016	0.018	0.017	-4.07
7	+	-	-	0.015	0.017	0.016	-4.14
8	-	-	-	0.021	0.023	0.022	-3.82
9	-α	0	0	0.024	0.025	0.0245	-3.71
10	+α	0	0	0.013	0.014	0.0135	-4.31
11	0	-α	0	0.019	0.019	0.019	-3.96
12	0	+α	0	0.015	0.015	0.015	-4.20

13	0	0	-α	0.019	0.019	0.019	-3.96
14	0	0	+α	0.018	0.017	0.0175	-4.05
15	0	0	0	0.016	0.018	0.017	-4.07

By substituting b_i we get equation:

$$Y = -33.85-1.97X_1-1.43X_2-0.47X_3-0.47X_1X_2-0.15X_1X_3+0.11X_2X_3+0.07X_1X_2X_3- -0.06X_1^2-0.24X_2^2-0.09X_3^2 \quad (3)$$

Variance of reproducibility (error mean square) is found by the formula, and values are logged in table 4.

Table 4. Variance of reproducibility.

	$\overline{Y_u} - Y_{uq}$	$(\overline{Y_u} - Y_{uq})^2$		$\overline{Y_u} - Y_{uq}$	$(\overline{Y_u} - Y_{uq})^2$
1	-4.77+4.83=0.06	0.0036	5	-4.66+4.71=0.05	0.0025
1	-4.77+4.71=-0.06	0.0036	5	-4.66+4.6=-0.06	0.0036
2	-4.14+4.2=0.06	0.0036	6	-4.07+4.14=0.07	0.0049
2	-4.14+4.07=-0.07	0.0049	6	-4.07+4.02=-0.05	0.0025
3	-4.34+4.27=-0.07	0.0049	7	-4.14+4.2=0.06	0.0036
3	-4.34+4.42=0.08	0.0064	7	-4.14+4.07=-0.07	0.0049
4	-3.91+3.96=0.05	0.0025	8	-3.82+3.86=0.04	0.0016
4	-3.91+3.86=-0.05	0.0025	8	-3.82+3.77=-0.05	0.0025

$$S_y^2 = 0.0581/8\cdot(2-1) = 0.00726$$

$$S_y = 0.085$$

Homogeneity of variance is checked through the Cochran test:

$$G^{calc} = \frac{S^2_{yu\max}}{\sum S^2_{yu}} = \frac{0.0064}{0.0581} = 0.11$$

For N = 8; α = 0.05; f = r-1=1, following the table, the critical value of Cochran test is found: G_{CRIT} = 0,6798. As $G^{calc} < G_{CRIT}$, the hypothesis is accepted.

Testing the regression coefficient significance:

$$S_{bi}^2 = S_y^2/(N\times r) = 0.00726/(8\cdot 2) = 0.00045;\ S_{bi} = 0.021$$

The critical value of Student test is found from the table: $t_{CRIT} = 2.306$.

The half-length of the confidence interval is as follows:

$$\Delta b_i = t_{CRIT}\cdot S_{bi} = 22.327\cdot 0.019 = 0.42$$

The coefficient is significant if $|b_i| \geq \Delta b_i$. Without insignificant coefficients, the regression equation will look as follows:

$$Y = -33.85-1.97X_1-1.43X_2-0.47X_3-0.47X_1X_2 \quad (4)$$

Model adequacy test. Adequacy variance:

$$S^2_{AD} = 2/(8-5)\cdot 0.022 = 0.0147$$

Fisher Test is found as follows:

$$F = S_{AD}^2 / S_y^2 = 0.12 / 0.00726 = 16.5$$

Compare with critical value, $F_{CRIT} = 19.37 > 16.5$, which speaks for the model adequacy.

3.Research results

After switching to natural values and equation exponentiation, we get the following

$$I_w = 0.0455 - 0.00175I - 0.0025U - 0.00175P \quad (5)$$

This equation lets us state that all the factors of the technological process are significant.

Optimizing the model following Monte-Carlo method and using SPSS v.13. Gauss distribution graph is given in figure 2.

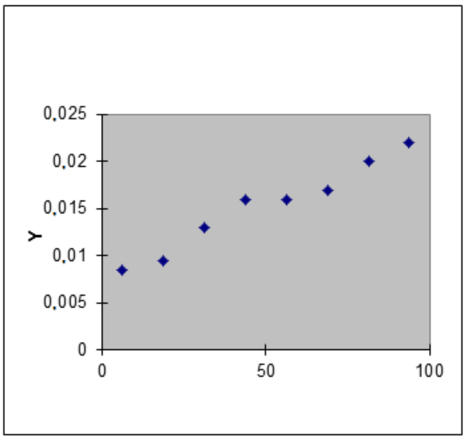

Figure 2. Gauss Distribution Graph.

The following technological parameters were found after optimization: I = 14 kA, U = 4V, and P = 0.5 kNtI_w=0.009 mm/h.

Considering that I_{nom} = 0.014 mm/h, the wear process intensity coefficient is as follows:

$$K_I = \frac{I_{nom}}{I_{\exp}} = \frac{0.014}{0.009} = 1.55 \quad (6)$$

4. Conclusions

Research result analysis may lead to a conclusion that a covering applied by a method of electric contact sintering of composite materials is by 1.5 times more wear resistant than steel 40X (of which a roller pin sample part is made). Therefore, durability and reliability of joints made or restored by means of composite materials, are significantly higher than those of standard joints in running gears of wood machines.

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