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INVESTIGATION OF INTERACTION OF CARBONITRIDED TEETH FRICTION SURFACES IN GEAR WHEELS

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ABSTRACT

This paper presents the results of the study of interaction of gear wheels carbonitrided surfaces in parallel-shaft reducers. The study was carried out on an experimental four-square torque loop device. The conducted experiment allowed to establish the dependence of the electric current intensity consumed by an electric motor to overcome friction force in gearings and frictionless bearings on the load intensity taken by a test stand. Using this dependence, we determined the rule according to which friction coefficient is altered depending on nominal pressure on the gearwheel contacting surfaces. The research proves that, firstly, a resilient contact is formed between the friction surfaces if they are treated with carbonitride. Secondly, an increase in surface roughness parameter and the nominal pressure leads to a decrease in friction coefficient.

Keywords: carbonitration of surfaces, gearing, friction coefficient, test stand, resilient contact.

INTRODUCTION

During recent years the method of thermochemical treatment – carbonitration – has been used to enhance operating characteristics of steel friction surfaces. This method allows to increase surface hardness, alter roughness parameter and friction surfaces [1 - 5]. The testing of carbonitrided samples on a friction test machine showed a significant decrease in friction coefficient in comparison with untreated samples not only in the samples with highly increased hardness, but also in the samples with practically unchanged hardness [6]. This means that one of the reasons for a decrease in friction coefficient during the interaction of carbonitrided surfaces is the alteration in the type of contact between them. It is known that according to loading conditions and macro- and micro-characteristics of the surfaces, different types of contacts, which determine friction coefficient, are formed [7 - 9].

The aim of our research is to establish the dependence of friction coefficient on normal force in gearing of carbonitrided gearwheels, which allows to determine the formed type of contact in gearing.

EXPERIMENTAL

The experiment was carried out at Metallurgical Machines and Machinery Design and Operation Department of Nosov Magnitogorsk State Technical University. The experimental device [10] is made up of four-square torque loop with two reducers 1 and 3, connected by two drive shafts 2 and 5, in which a reducer support 3 is 4 a bearing assembly. A loading bar is fixed on the reducer support 3, on which loads are hung to alterated pressure in gearing (Fig. 1).

The friction force in gearing is calculated by measuring the power needed for the motor to overcome friction forces in gearing and frictionless bearings from the following relation,

$$\sqrt{3}U(J_{l.c.} - J_{i.c.})cos\varphi = 2V_{rs} * P_{gear} * f + N_{fbf} \quad (1)$$

and the friction coefficient amount is calculated from the relation

$$f = \frac{\sqrt{3}U(J_{l.c.} - J_{i.c.})cos\varphi - Nfbf}{2V_{rs} * P_{gear}} \quad (2)$$

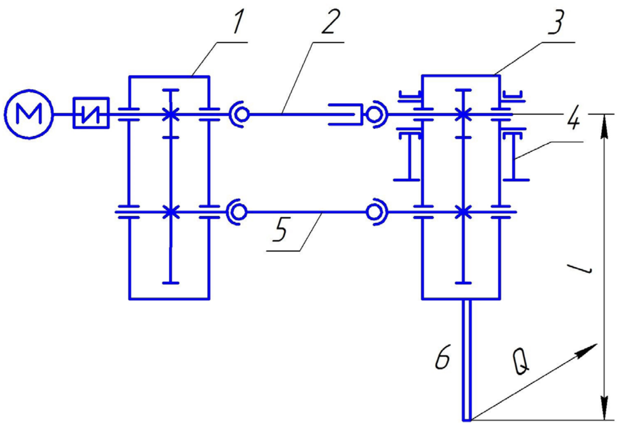

Fig. 1. Kinematic scheme of experimental installation of reducers with four-square torque loop for friction coefficient measuring. 1 - Rigidly fixed reducer; 2, 5 - drive shafts; 3 - reducer fixed on bearing assembly 4; 6 - loading bar.

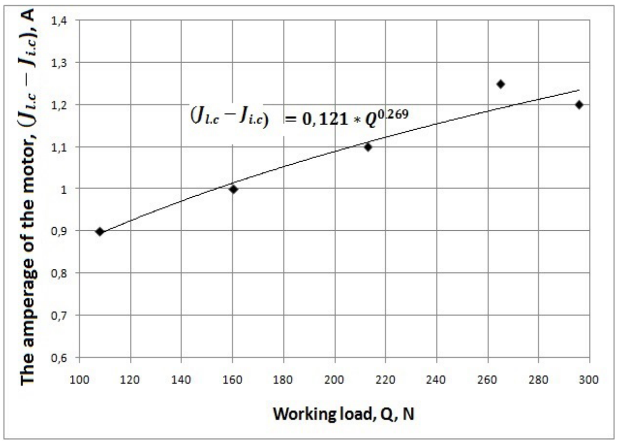

Fig. 2. Graph of dependence of motor current strength from the load.

where: U - electric line voltage, U = 380V;

$J_{l.c.}$ - load current, A;

$J_{i.c.}$ - idle speed current, A;

N_{fbf} - motor power to overcome friction forces in frictionless bearings, W;

V_{rs} - the sliding speed at the contact, m/s;

P_{gear} - peripheral force in gearing, N (Fig. 2)

$$P_{gear} = \frac{Q \cdot l}{R_{gp}}$$

The rubbing speed in gearing was calculated from the relation

$$V_{rs} = 0.3 \cdot \left[\xi (u+1) - a_w \cdot \sin\alpha \right] \cdot \omega_2 \quad (3)$$

$$\xi = a_w \cdot sin\alpha - \sqrt{2 \cdot d_{gp}} + 0.3m \quad (4)$$

where ω_2 – angular speed of the gearwheel,

m – gearing module.

Load on frictionless bearings in supports a, b, c, d.

$$P_{н} = Pgear/cos \propto$$

The initial load of four-square torque loop was made by weight of a reducer.

Force from reducer weight was brought to the arm end with length (at the points of load hanging), (Fig. 1), Q_p = 108 N.

Later loads were fixed sequentially at the point of load hanging on arm $Q_p, Q_p + Q_1, Q_p + Q_1 + Q_2$, $Q_p + Q_1 + Q_2 + Q_3$,$Q_p + Q_4$,(load Q_1 = 52,5 N, load Q_2 = 52,5 N, load Q_3 = 52,8 N, load Q_4 = 188 N).

After the motor was started loads were added sequentially every five minutes and current strength was recorded every minute.

The experiment was repeated three times. The motor current strength measurements are shown in Fig. 2 as functional dependence $J_{l.c.} - J_{i.c.} = f(Q)$.

As a result of processing of experiment results in Excel 2016 approximation dependence was derived

$$J_{l.c.} - J_{i.c.} = 0,2111Q^{0,2692} \quad (5)$$

which was later used to calculate friction coefficient f, as a function of nominal force in gearing - P_{gear}.

RESULTS AND DISCUSSION

It is necessary to exclude the effect of friction forces in frictionless bearings to evaluate the effect of carbonitration on force interaction of contact surfaces in gearings.

The power used to overcome friction force in frictionless bearings includes gear pinion frictionless bearings power – N_{gpfb} and gearwheels frictionless bearings power

$$N_{fbf} = N_{gpfb} + N_{gwfb} \quad (6)$$

$$N = M \cdot \omega \quad (7)$$

The moment of friction in frictionless bearings according to work [11]

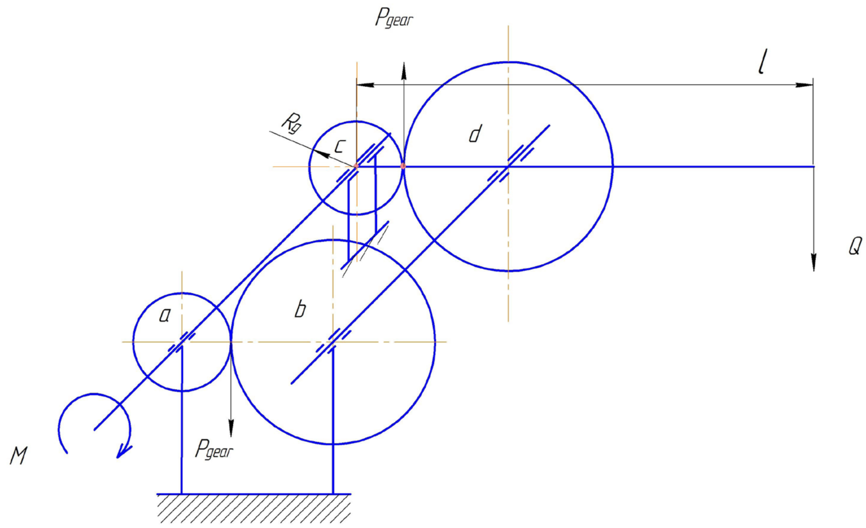

Fig. 3. Scheme of force activity in four-square torque loop experimental device.

$$M = M_0 + M_1 \tag{8}$$

$$M_0 = 1 * 10^{-7} * f_0 * (\nu_p * n)^{2/3} * D_0^3 \tag{9}$$

$$M_1 = f_1 * P_{gear} * D_0 \tag{10}$$

where: $f_0 = 4$, $f_1 = 5 \cdot 10^{-4}$ - tabulations for the given types of bearings;

D_0 - average diameter of bearing, mm;

ν_p - kinematic viscosity of lubricant at the operating temperature at the contact points, mm^2/s.

$$\nu_p = \nu_{t=40} \left(\frac{40}{t_p}\right)^{2.3} \tag{11}$$

The nominal force of gearing P_{gear} is calculated according to the scheme of force influence (Fig. 3).

The actual temperature at the contact points is calculated according to work [12] from dependence

$$t_p = 86 + 9{,}74 \cdot U_\Sigma - 5.72 \cdot \lambda \tag{12}$$

$$\lambda = j \cdot t_{ent}{}^{Y}$$

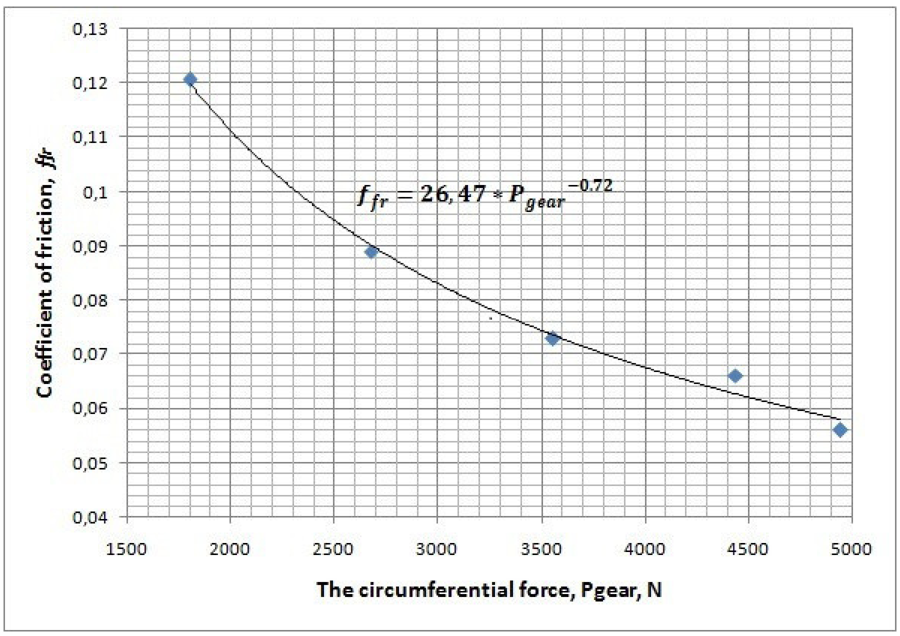

Fig. 4. Graph of friction coefficient dependence from rated pressure in gearing.

Table 1. Ratings of friction power in frictionless bearings.

Q, N	108	160,5	213	265.8	296
P_{gear}, N	1803	2680	3556	4438	4942
N_{fbf}, W	57,9	72,95	88,47	102,81	111,39

$$Y = -0.3 \cdot \ln(VC) - 0{,}57$$

$$j = 0.076 \cdot VC^2 - 1{,}12 \cdot VC + 283{,}4$$

$$U_\Sigma = \frac{\pi \cdot D_0 \cdot n}{60}(1 - \gamma^2)\ ; \quad \gamma = \frac{D_w}{D_0}\cos\beta \tag{13}$$

where t_{ent} is temperature of lubricant at the entrance to friction zone, 25°C, VC - 68 viscosity category of lubricant.

Calculation results are given in Table 1.

According to dependence (2) ratings of friction coefficient in gearing are derived, which are used to get functional dependence $f_{fr} = f(P_{gear})$, shown in Fig. 4.

Corresponded approximation dependence is developed.

$$f_{fr} = 26{,}47 \cdot P_{gear}^{-0{,}72} \tag{14}$$

CONCLUSIONS

The dependence (14) shows that while rated pressure increases friction coefficient decreases, which is typical for resilient contact in interaction zone of teeth friction surfaces. So, carbonitration of gear wheel teeth is an effective strengthening treatment, especially for high-pressure gearings. It not only increases surface hardness, but also forms a resilient contact, that decreases surfaces wear intensity.

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