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METHOD FOR CALCULATING THE FRICTION SURFACES WEAR BASED ON MULTI-PARAMETRICAL OPTIMISATION

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ABSTRACT
Currently numerous empirical dependencies and linear statistical models are developed in order to describe a process of surfaces wearing in friction units. Common disadvantage is a lack of required flexibility and impossibility of fulfilling exact calculations under changing a number of factors. A more advanced approach is to investigate different regularities of friction surfaces wear within a single model. The goal of this study is to describe the required model on the basis of statement and solving the problem of multi-parametrical optimization.
Keywords: friction, surface wear, multi-parametrical optimisation

1. INTRODUCTION
The wear resistance of machine parts is one of important characteristics making an impact on a quality of mechanical products. It defines the ability of surface layers to resist to the destruction as the result of machine parts rolling friction, sliding friction and vibration action. Depending on reasons influenced on deformation and destruction of work surfaces the different mechanisms of friction and wear such as adhesion, oxidation, metal fatigue, heat and others are investigated [1,2,3]. However the interaction of these mechanisms is usually not studied in developing empirical or theoretical dependences, i.e. parameters introduced are considered as independent variables that are not interrelated with each other. In this case, it is very difficulty to conduct the complex analysis of changes occurred in surface layers of machine parts. Therefore a real wear remains as before unclear and hard-guided process.
Partly, the problem of decreasing the wear intensity of machine parts in friction units can be solved mathematically by means of variation and optimization of main parameters introduced in developing the model of friction surfaces wear. The description of such model based on the problem statement of multi-parametrical optimisation is presented in the next section. Finally, the case study referred to the evaluation of influence of roughness parameters on wear intensity subject to hard contact and dry friction is discussed.

2. COMMON MODEL OF MULTI-PARAMETRICAL OPTIMISATION
Formally the problem of multi-parametrical optimization can be stated by the following way. It is necessary to find the vector $\overline{X}^* = (x_1^*, x_2^*, \ldots, x_n^*)^T$ of parameters that minimizes the function $Y = F(X)$ at the given accuracy ε, where $X \in R^n$ and R^n is area of varied values of vector parameters. It means that:

$$F(x_1^*, x_2^*, \ldots, x_n^*) = \min F(x_1, x_2, \ldots, x_n), \qquad (1)$$

subject to:

$$a_1 \leq x_1 \leq b_1 \; ; \; \ldots..; \; a_n \leq x_1 \leq b_n \qquad (2)$$

In order to describe mechanical interaction of surfaces in friction units we should introduce parameters that define the surface roughness (e.g. R_a, S_{m1}, S_{m2}), physic-mechanical properties (e.g. E, H, μ), frictional-fatigue properties (e.g. σ_o, e_o, f, t_y) and some construction features (e.g. A_a, A_c, q,), where:
R_a is average height of surface imperfections;
S_{m1}, S_{m2} are average step of surface imperfections across and along friction respectively;
E is ductility module;
H is hardness of surface material;
μ is Poisson's coefficient;
σ_o, e_o are breaking pressure and lengthening respectively;
f is friction coefficient;
t_y is index of fatigue curve;
A_a, A_c are nominal and outline contact square respectively;
q is specific pressure.

According to detailed set of parameters and research results reported in [4] the goal function of wear intensity subject to hard contact and dry friction can be represented by the product of three constituents as follows:

$$F_1(X) = (R_a / S_{m2})^{\,ty+1}; \quad (3)$$

$$F_2(X) = K_F \cdot F^1{}_2 (X,\gamma) = K_F \cdot (S_{m1} \cdot q \cdot \theta_\Sigma / K_y \cdot R_a); \quad (4)$$

$$F_3(X) = (4\cdot (2\pi)^{1/2} \cdot f \cdot (1 + \mu_1)) / \sigma_o \cdot \theta_1)^{\,ty} \cdot (A_c / A_a), \quad (5)$$

where $F^1{}_2(X,\gamma)$ is tabulated function; K_F specifies relationship between functions $F^1{}_2(X,\gamma)$ and $F_2(X)$ depending on the layer γ of deforming the friction surface; K_y is correction factor depending on surface anisotropy; θ_1, θ_Σ - ductility constants referred to materials of machine parts in friction pair.

$$\theta_1 = (1- \mu_1^2) / \pi\cdot E_1 ; \;\; \theta_\Sigma = (1- \mu_1^2) / \pi\cdot E_1 + (1- \mu_2^2) / \pi\cdot E_2 \quad (6)$$

Each of constituents (3)-(5) allows evaluating influence of certain parameters on surface wear taking no into account its interaction. In order to connect them functionally it is necessary to fulfill transformations as follows:

- To select controlled variables (called decision variables) from a common set of detailed parameters;
- To derive empirical / theoretical dependences for establishment of relationship between uncontrolled and controlled variables;
- To express the goal function of surface wear intensity through the vector of decision variables.

3. DESCRIPTION OF EMPIRICAL DEPENDENCES

It was proved by conducting many experiments that roughness parameters of surfaces influence strongly on wear intensity under given conditions of hard contact. We can detail, for instance, such of them as R_{max}, R_a, S_m, and surface anisotropy c described by ratio:

$$c = S_{m1} / S_{m2} , \quad (7)$$

where $S_{m1} \approx 35 \cdot e^{Ra}$. (8)

Taking these parameters for decision variables and relying on tabular data shown in Fig.1 one can represent correction factors K_F and K_y in form of approximate equations as follows:

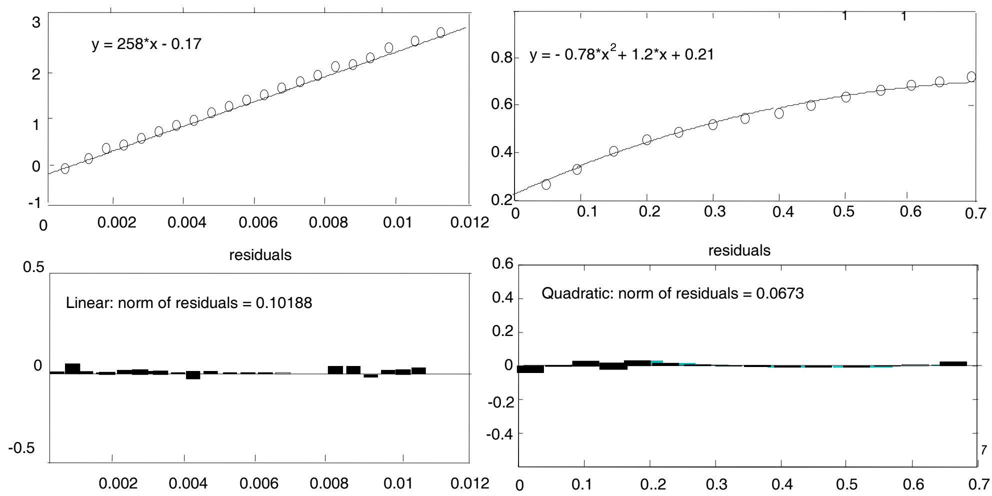

Figure 1. Approximate curves K_F and K_y.

$K_F = 258\ (S_{m1} \cdot q \cdot \theta_\Sigma / K_y \cdot R_a)$ subject to $2 \leq \gamma \leq 3$, (9)

$K_y = -0.78c^2 + 1.2c + 0.21$ (10)

Also relation between the friction coefficient f and parameter R_a can be detailed. According to the theory of friction [1] this relation for conditions of resilient contact is expressed by equation:

$f = 2.1 \cdot \tau_o\ \theta_l^{0.8} / q^{0.2} \cdot R_a^{0.4} + \beta,$ (11)

where τ_o is shear resistance of adhesion link; β is coefficient of strengthening adhesion link.
Here equation (11) involves only adhesion constituent of friction and omits deformation constituent because of its smallness in case of small loading.
Usually $\tau_o = (2.5 \div 30)$ MPa and $\beta = (0.08 \div 0.1)$ for friction units like "metal – metal" (without lubrication). These ones and other parameters referred to description of material resilience and durability are further taken for constants. Thus, according to dependences (6) ÷ (11) we enable to regenerate description of goal function of wear intensity in form of vector with two decision variables R_a and c.

4. EXPERIMENT

In order to evaluate the influence of decision variables R_a and c on wear intensity the friction unit "disc (alloyed steel) – finger (chill cast iron)" has been tested. The finger to be rubbed is characterized by following properties:
$E_1 = 1.3 \cdot 10^5$ MPa; $\mu_1 = 0.25$; $\sigma_o = 1600$ MPa; $t_y = 6$. Specific pressure $q = 0.6$ MPa; $\theta_\Sigma = 0.37 \cdot 10^{-5}$ MPa; profile imperfections are equal to $A_c / A_a \approx 0.1$.
Based on using these data the goal function $F(X)$ of wear intensity represented before by the product of multipliers (3) - (5) is transformed to the form as follows:

$$F(X) = \min\left(\frac{R_a \cdot c}{35 \cdot e^{R_a}}\right)^7 \cdot \left(\frac{0.02 \cdot e^{R_a}}{R_a(-0.78c^2 + 1.2c + 0.21)} - 0.17\right) \cdot \left(\frac{8.5 + 306 R_a^{0.4}}{R_a^{0.4}}\right)^6$$

In solving this equation, roughness parameters of finger were varied in intervals $R_a \in [0.2, 0.3]$ and $c \in [0.1, 0.5]$. For a search of optimal solution, genetic algorithm was used.

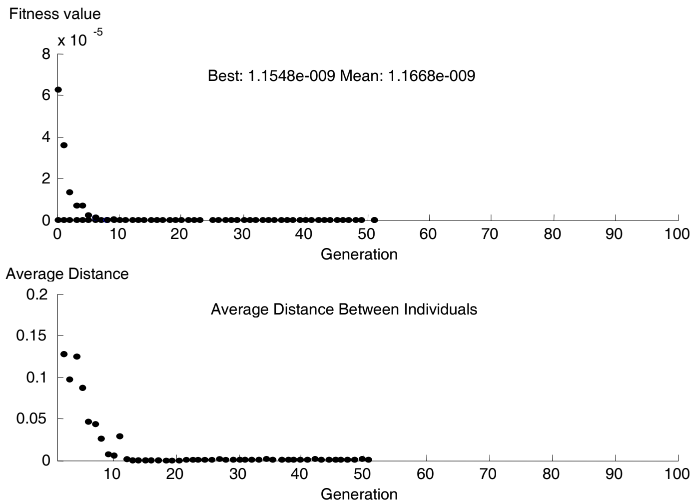

Figure 2. Search of optimal solution

As shown in Fig.2 the convergence of algorithm with minimal residuals reaches after 50 iterations under R_a = 0.202 and c= 0.1 that corresponds to wear intensity $F(X) = 1.15 \cdot 10^{-9}$. Because average velocity of sliding finger was 0.27 m/s, the linear wear h for 1000 working hours can be calculated according to: $h = 1{,}15 \cdot 10^{-9} \cdot 97.2 \cdot 10^{10} \cdot A_c / A_a = 112$ mkm.

5. CONCLUSIONS

Results of conducted research confirm that one of possible reserves for decreasing wear of friction units is variation and optimization of surface roughness parameters. In particularly, the wear can be decreased provided that the best combination of these parameter values is found for given operation conditions. From this it follows both constructional and technological requirements made for coupling friction surfaces.

The method of multi-parametrical optimization with using genetic algorithm enables to conduct analysis of wear including far larger number of decision variables. It is especially useful under existence of nonlinear dependencies between parameters.

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