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MODELLING OF THE DEGREE OF DEVELOPMENT OF WORKING SURFACE DETAILS USING THE MULTIFACTOR SYSTEM ALGORITHM AND EXPERIMENT PLANNING MATRIX

In the work, research was conducted on modeling the degree of activation of the working surfaces of parts using the multifactor system algorithm and the experiment planning matrix. The dependences of the mass loss of protective coatings with appropriate strengthening technologies were obtained, taking into account load modes, pressure in the tribo contact zones and the load cycle.
***Keywords**: algorithm, modeling, multifactorial system, experiment planning matrix, strengthening technological processes, coating, car.*

У роботі проведено дослідження з моделювання ступеня активації робочих поверхонь деталей за допомогою алгоритму багатофакторної системи та матриці планування експерименту. Отримано залежності втрати маси захисних покриттів з відповідними технологіями зміцнення з урахуванням режимів навантаження, тиску в зонах трибоконтакту та циклу навантаження.
***Ключові слова**: алгоритм, моделювання, багатофакторна система, матриця планування експерименту, технологічні процеси зміцнення, покриття, автомобіль.*

Formulation of the problem

The use of automotive equipment in modern operating conditions requires a significant increase in loads, speed and temperature regimes of the main nodes, mechanisms with simultaneous diagnosis and forecasting of the operating resource of the relevant units.

Up to 30% of the destruction of car parts is due to friction processes in contacting pairs of mechanisms. Therefore, special attention is paid to the condition of the surface layer of tribocontacting pairs, namely to the simulation of friction processes and strengthening technologies. The life expectancy of cars, the wear resistance of the surface layer with various technological methods of strengthening depends on the complex of formed properties.

Analysis of the latest sources of research and publications

Many technologies for strengthening the surface layer of parts have been implemented in machine-building production. The main criteria for choosing strengthening methods are high wear-resistant, physico-mechanical, operational properties of coatings and total costs for the technological process, equipment, consumables, environmental friendliness and safety. The mechanisms of formation of wear-resistant structures are highlighted in many works of famous scientists [1—3].

A promising direction of research is the modeling of the degree of activation of the working surfaces of parts using the algorithm of a multifactor system and the matrix of the planning of the experiment, which will significantly reduce the time when choosing technological processes of strengthening and with a high probability will provide a theoretically grounded forecast for the selected technological process of strengthening. In the handbooks, processing regimes and the final result of the most common technological processing methods are provided, where it is guaranteed that when certain operations are performed consistently, appropriate microstructures with specified indicators of microhardness and wear resistance are obtained on test steels. A significant breakthrough in the field of strengthening treatments was the use of high-energy energy sources, which made it possible to expand the spectrum of modification of surface layers, significantly increase the strength and wear-resistant characteristics of coatings [4—8].

Formation of the purpose of the research

Based on the analysis of the use of the latest methods of strengthening, develop a technique for modulating tribological processes occurring in contact interaction zones with the possibility of predicting the work of pairs and friction and determining the service life of parts.

Presenting main material

The disadvantage of most methods of modeling and forecasting of technological methods of strengthening the surface layer is the length of time of research and the impossibility of fully reproducing the influence of many factors: controlling the surface roughness of the part, the processes of structure formation, the concentration of alloying elements in the surface layers in the laser processing zone, the inhomogeneity of the treated surface, the microhardness fluctuations of individual local processing zones, a significant violation of the microgeometry and the need for additional finishing treatments. In production practice, quite often the processes of restoration and strengthening of the surface layer consist of the following successive operations: restoration of the geometry and shape of the surface due to surfacing with electrodes; blade processing to ensure the geometric parameters of the product; strengthening of the surface with the formation of superhard structures; special treatment for surface modification; finishing treatment.

The process of wearing parts is carried out by gradually changing the size and shape of the body. The intensity of operation of test samples is classified by kinematic characteristics and determined by the formula:

$$I_h = \frac{\Delta \mathrm{m}}{\rho \cdot \mathrm{S} \cdot \mathrm{Q}},$$

Δm — loss of material mass, g; ρ — material density, g/cm^2; S — friction path, mm; Q — geometric contact area, mm^2.

The general nature of the distribution of random variables can be presented on the basis of the measurements. The probability of estimating the mean of the normal distribution can be determined using the quantiles of the normalized normal distribution. The exact mathematical dependence for determining the degree of operation of I_h on the influence of operating parameters is possible only with the help of the method of planning the experiment. In a separate case, an orthogonal central composition plan of the second order is used. The experiment investigates the value of Δm — loss of mass of the material of the part in the process of friction and activation. The following parameters affect the activation process: $H_{\mu 50}$, MPa (X_1); P(X_2), H; speed of movement of mutual friction contact surfaces V (X_3), m/s and activation time τ (X_4), min. Fig. 1 shows a graph of the mass loss of friction surfaces with corresponding coatings, depending on the types and modes of loading. The degrees of variation of the factors that have a direct influence on the operation of the experimental samples are shown in Tabl. 1. When checking the results of the experiment, the dispersion of observation errors was found at S=1 and the degree of freedom $f = 2$. Designation of the regression coefficients according to the Student's test for the level $q = 0.05$ and the degree of freedom $f = 2$ and the degree of freedom $\overline{X}_1, \overline{X}_2, \overline{X}_3, \overline{X}_4$, as well as their interaction $\overline{X}_1 \cdot \overline{X}_2, \overline{X}_1 \cdot \overline{X}_3, \overline{X}_1 \cdot \overline{X}_4, \overline{X}_2 \cdot \overline{X}_3, \overline{X}_2 \cdot \overline{X}_4, \overline{X}_3 \cdot \overline{X}_4$.

When solving a problem, we have a recall function:

$$y = -3.752 - 0.777\overline{X}_1 + 0.196\overline{X}_2 + 0.054\overline{X}_3 + 0.585\overline{X}_4 - 0.0025\overline{X}_1\overline{X}_2 - 0.019\overline{X}_1\overline{X}_3$$
$$-0.03\overline{X}_1\overline{X}_4 + 0.02\overline{X}_2\overline{X}_3 + \overline{0.038X_2}\overline{X}_4 - 0.032\overline{X}_3\overline{X}_4.$$

With $\overline{X}_1, \overline{X}_2, \overline{X}_3, \overline{X}_4$ are determined by formulas:

$$\overline{X}_1 = \frac{2(\ln H_{\mu 50} - 9.138)}{9.138 - 8.102} + 1;$$
$$\overline{X}_2 = \frac{2(\ln P - 3.912)}{3.912 - 3.4} + 1;$$
$$\overline{X}_3 = \frac{2(\ln V - 1.099)}{1.099 - 0.875} + 1;$$
$$\overline{X}_4 = \frac{2(\ln \tau - 1.099)}{1.099} + 1.$$

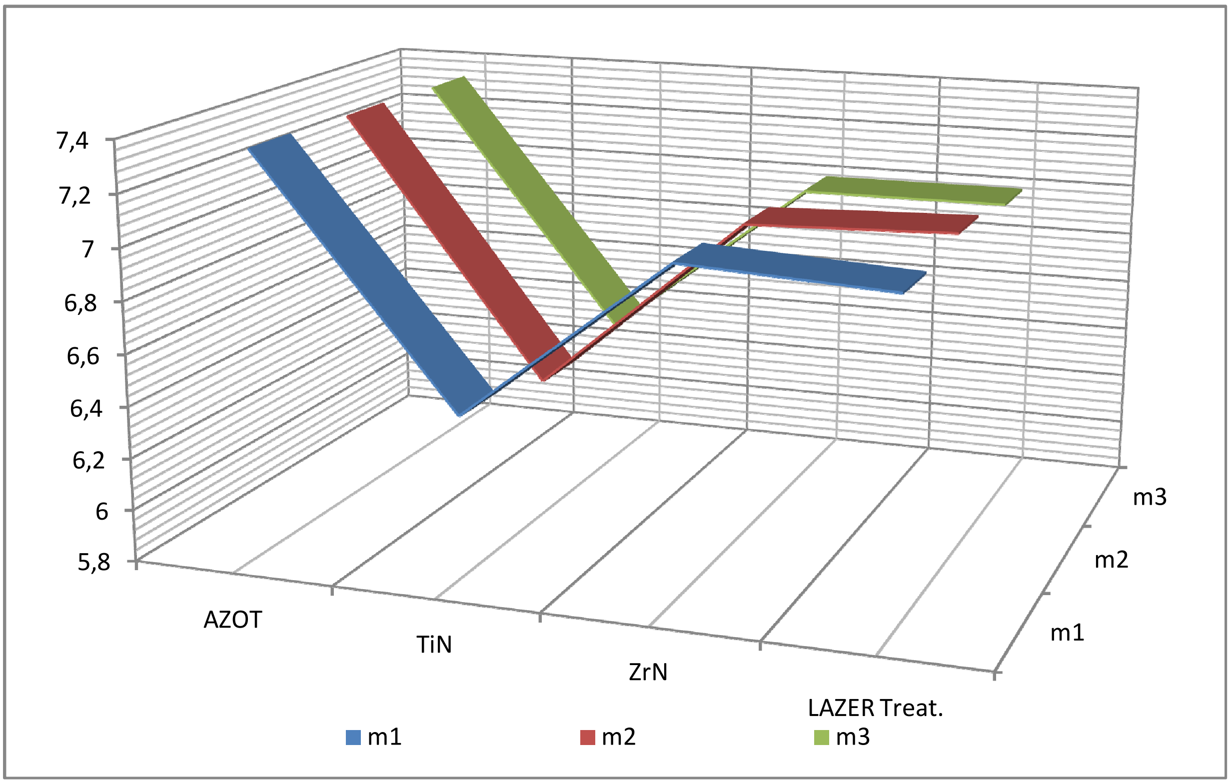

Fig. 1. Graph of dependence of mass loss of friction surfaces with corresponding coatings depending on the types and modes of loading

Table 1. Degrees of variation of the factors of activated parts

№	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
$(X_1)H_{\mu 50}$	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	0	0	0	0
$(X_2)P$	-	-	-	-	-	+	+	+	-	-	-	-	+	+	+	+	0	0	0	0
$(X_3)V$	-	-	+	+	-	-	+	+	-	-	+	+	-	-	+	+	0	0	0	0
$(X_4)\tau$	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	0	0	0	0
Δm	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9	Y_{10}	Y_{11}	Y_{12}	Y_{13}	Y_{14}	Y_{15}	Y_{16}	Y_{17}	Y_{18}	Y_{19}	Y_{20}

where + - highest parameter value; - - smallest parameter value; 0 - average value of the parameter

Checking the adequacy of values y= Δm, showed that according to Fisher's criterion $F_p = 15.27$ with tabular value $F_p = 19.42$. In this way, an adequate mathematical model was obtained. For the convenience of calculations, coded variables are replaced by valid physical quantities

$$\Delta m = 5.1 - 1.151 \ln H_{\mu 50} + 1.584 \ln \tau + 1.313 \ln V + 0.11 \ln P - 0.357 \ln H_{\mu 50} \ln V -$$
$$-0.115 \ln H_{\mu 50} \ln \tau + 0.696 \ln P \ln V + 0.271 \ln P \ln \tau - 0.518 \ln \tau \ln V - 0.02 \ln H_{\mu 50} \ln P.$$

The distribution curves of the wear resistance of the coating group under the specified conditions are shown in Fig. 1. To achieve these goals, tribological studies of plates made of 50XFA steel (tabl. 2.) were carried out, where the load modes, the type of strengthening of the working surfaces, the mass consumption of the samples depending on the cyclic period of action on the contacting pairs are indicated.

Table 2. Tribological studies of plates made of 50XFA steel

Coating	Initial mass$m_п$, g	Load conditions: speed V=2,4 м·с$^{-1}$; pressure on the contact surface P=30H; time of controlled load 3 hours.						
		m_1, g	Δm_1,g 1 hour	m_2, g	Δm_2,g 2 hour	m_3, g	Δm_3,g 3 hour	Δm_Σ, g
АЗОТ	7.35	7.35	0,009	7,341	0,009	7,332	0,009	7,323
TiN	6.42	6.42	0,022	6,398	0,022	6,376	0,023	6,353
ZrN	7.05	7.05	0,026	7,024	0,026	6,998	0,027	6,971
ЛО	7.01	7.01	0,005	7,005	0,005	7,000	0,005	6,995

The planning matrix and the results of a fully factorial experiment taking into account the parameters $H_{\mu 50} = 3600 - 9300\ MPa$, P=30–50 N, V=2.4–3 m·s^{-1}, T=1…3 h,given in the tabl. 3. As a result of processing the data of the experiment, estimates of the effect of factors, their squares, and their interaction on the value were obtained Δm.

Table 3. Significance of factors and their interaction options

Factors	Designation of factors	$\overline{x_i} = -1{,}414$	$\overline{x_i} = -1$	$\overline{x_i} = 0$	$\overline{x_i} = 0$	$\overline{x_i} = 1{,}414$
Microhardness $H_{\mu 50}, MPa$	X_1	2420	3600	6450	9300	10479,9
Contact pressure, P= H	X_2	25,86	30	40	50	54,14
Speed of movement of the sample, V= m·s^{-1}	X_3	2,28	2,4	2,7	3,0	9,12
Time T, h	X_4	0,586	1,0	2,0	3,0	4,414

The calculated value according to Fisher's criterion F_p=15.27 when checking the adequacy at $y = \Delta m$has a table value of F_p=19.42. In this way, an adequate mathematical model was obtained.

Conclusions

1. Research was conducted on modeling the degree of activation of the working surfaces of parts using the multifactor system algorithm and the experiment planning matrix.
2. The graph of the dependence of the mass loss of protective coatings with the appropriate strengthening technologies is derived, taking into account the load modes, pressure in the contact tribo coupling zones and the load cycle.
3. As a result of checking the results of the experiment, the dispersion of observation errors was found to be S=1 with the degree of freedom $\mathfrak{f} = 2$. Checking the significance of the regression coefficients according to the Student's test for the q=0.05level.
4. An adequate mathematical model of the estimated value according to Fisher's criterionF_p=15.27.

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МОДЕЛЮВАННЯ СТУПЕНІ СПРАЦЮВАННЯ РОБОЧИХ ПОВЕРХНЕЙ ДЕТАЛЕЙ ЗА ДОПОМОГОЮ АЛГОРИТМУ БАГАТОФАКТОРНОЇ СИСТЕМИ І МАТРИЦІ ПЛАНУВАННЯ ЕКСПЕРИМЕНТУ

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Реферат

В роботі проведені дослідження по моделюванню ступені спрацювання робочих поверхней деталей за допомогою алгоритму багатофакторної системи і матриці планування експерименту. Виведений графік залежності втрати маси захисних покриттів при відповідних технологій зміцнення з урахуванням режимів навантаження, тиску в зонах контактного трибо сполучення і циклу навантаження

В результаті перевірки результатів експерименту найдена дисперсія помилок спостережень S=1 при ступені вільності $f = 2$. Перевірка значимості коефіцієнтів регресії за критерієм Ст’юдента для рівня q=0.05 при ступені вільності $f = 2$ показала значимість факторів

$\overline{x_1}, \overline{x_2}, \overline{x_3}, \overline{x_4}$, а також їх варіанти взаємодії $\overline{x_1 x_2}, \overline{x_1 x_3}, \overline{x_1 x_4}, \overline{x_2 x_3}, \overline{x_2 x_4, x_3 x_4}$. Проведені дослідження по моделюванню ступені спрацювання робочих поверхней деталей за допомогою алгоритму багатофакторної системи і матриці планування експерименту. Отримана адекватна математична модель розрахункового значення за критерієм Фішера F_p=15.27.

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