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DETERMINATION OF THE DEGREE OF WEAR OF THE STUDIED PISTON RING SAMPLES

ВИЗНАЧЕННЯ СТУПЕНІ ЗНОСУ ДОСЛІДНИХ ЗРАЗКІВ ПОРШНЕВИХ КІЛЕЦЬ ДВЗ

In internal combustion engines, the wear of parts of the cylinder-piston group is associated with the interaction of the "piston ring - cylinder liner" tribosystem. The functioning of such a system significantly depends on the properties of friction surfaces, and reflects their interactions and depends on many factors: physical, mechanical, geometric, kinematic properties. Features of friction processes and wear processes are largely determined by the properties of the surface layers, their structural and strength connections with the base metal. In the process of operation, the surfaces of parts undergo significant changes in microgeometry and macrostructure. As a result of running-in, the roughness of the surfaces of the parts decreases. The irregularities formed during processing are replaced by the irregularities caused by wear processes due to intense thermal and mechanical effects. Parts of the cylinder-piston group (CPG) are simultaneously subject to molecular-mechanical and abrasive wear

[1]. The process of molecular-mechanical wear is most likely in the upper part of the cylinder, where, due to insufficient amount of lubricant, low piston speed, high temperatures and pressures, the integrity of the lubricating film is violated and local areas of the friction surfaces seize at certain points. On the second part of the cylinder, friction pairs interact in the environment of hydrodynamic lubrication. The intensity of molecular mechanical wear depends on the speed of movement of friction pairs, contact pressure and flash temperature of the combustible mixture. In case of their unfavorable combination, the intensity of coagulation increases sharply, and an eruption from the surface of the microparticles may occur. The process of corrosive-mechanical wear and electrochemical corrosion is observed during the operation of friction pairs in corrosive-aggressive environments, gaseous and liquid products of fuel combustion, oxidation of oils, water, weak acids and solutions that condense on the cylinder walls. When the thermal regime of the engine decreases, the intensity of corrosive-mechanical wear increases.

***Key words**: piston ring, cylinder liner, tribo system, cylinder-piston group, wear, surface friction, speed of movement.*

У двигунах внутрішнього згоряння зношування деталей циліндро-поршневої групи пов'язане із взаємодією трибосистеми «поршневе кільце - гільза циліндра». Функціонування такої системи суттєво залежить від властивостей поверхонь тертя, та віддзеркалює їх взаємодії та залежать від багатьох факторів: фізичних, механічних, геометричних, кінематичних властивостей.

Особливості процесів тертя та протікання процесів зношування в значному ступені визначаються властивостями поверхневих шарів, їх структурними та зв'язками міцності з основним металом. В процесі експлуатації поверхні деталей зазнають значних змін мікрогеометрії та макроструктури.

В результаті припрацювання шорсткість поверхонь деталей зменшується. Нерівності, що утворилися при обробці, замінюються нерівностями, спричиненими процесами зношування, внаслідок інтенсивних теплових та механічних впливів. Деталі циліндро-поршневої групи (ЦПГ) одночасно піддаються молекулярно-механічному та абразивному зношування [1]. Інтенсивність молекулярно-механічного зношування залежить від швидкостей переміщення пар тертя, контактного тиску та температури спалаху горючої суміші. При їх несприятливому поєднанні інтенсивність схоплювання різко збільшується та може виникнути вирив з поверхні мікрочасток.

***Ключеві слова**: поршневе кільце, гільза циліндру, трибо система, циліндро-поршнева група, знос, поверхня тертя, швидкість переміщення.*

Problem’s Formulation

The durability and reliability of cars, parts and mechanisms depend on many factors, the main of which is the quality of each individual part. As determined in many information sources, quality indicators have a multi-vector, complex composition — from the material, chemical composition, micro- and macrostructure, technologies, processing modes, the state of the surface layer, etc. to physical and mechanical properties. In the modern production of parts of the machine-building complex, it is necessary to take into account the steady increase in loads (speed, temperature, aggressive environment) on mechanisms and parts that make up a single product for machine-building purposes. The cylinder-piston group of internal combustion engine is shown in fig. 1

Fig. 1. Cylinder-piston group of internal combustion engine

Analysis of recent research and publications

The main percentage of breakdowns of parts (30 %) is attributed to friction processes in contacting pairs of mechanisms. Therefore, special attention is paid to the condition of the surface layer of friction pairs and strengthening technologies. The wear resistance of the surface layer, durability, reliability, and service life of cars depend on the set of properties formed when using different strengthening technologies. The mechanisms of formation of wear-resistant structures are given in many scientific sources [1—4]. In the experimental works, processing regimes and justified final results of the most common strengthening technologies were developed, and when performing certain operations, wear-resistant microstructures with specified indicators of microhardness and wear resistance on specified materials are guaranteed to be obtained. A set of ICT piston rings is shown in fig. 2

Fig. 2. A set of compression and oil piston rings

The wear rate of the test samples obtained as a result of tribological tests [88] can be determined from the relationship:

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

where Δm — is the mass loss of the material, kg; ρ — density of the material, kg/m^3; S — friction path, m; Q — geometric contact area, m^2.

It is possible to obtain an exact mathematical relationship for determining the degree of wear on the influence of operational parameters using the experimental design method, in particular, using a second-order orthogonal central compositional design.

In most physical experiments, the general nature of the distributions of random variables can be represented on the basis of preliminary measurements. The reliability of the estimate of the population mean can be described using quantiles of the normalization normal distribution.

The experiment examines the loss of mass of the piston ring during wear (X). The wear process is influenced by the microhardness of the piston ring coating material (X1), the contact pressure P(X2), the speed of the sample V(X3) and the time of the wear process (X4).

Experimental studies were carried out using a laboratory tribological machine with hourly recording of the mass loss of the samples.

The levels of variation of the factors that directly affect the degree of wear of the samples are given on next time. The influence factors can be taken as the following components:

– Microhardness, MPa (for $\overline{x}_i$ =-1.414 ,X_1=2420; when $\overline{x}_i$ =-1, X_1=3600; for $\overline{x}_i$ =0, X_1= 6450, when $\overline{x}_i$ =1, X_1=9300: for $\overline{x}_i$ =1.414, X_1=10479.9);

– Contact pressure, P, N(when $\overline{x}_i$ =-1.414 , X_2=25, 86;when $\overline{x}_i$ =-1, X_2=30; when $\overline{x}_i$ =0, X_2= 40, when $\overline{x}_i$ =1, X_2=50: when $\overline{x}_i$ =1.414, X_2=54,14);

– Sample movement speed, V, m/s(when $\overline{x}_i$ =-1.414 , X_2=2,2 8; when $\overline{x}_i$ =-1, X_2=2.4; when $\overline{x}_i$ =0,

X_2= 2.7, when $\overline{x}_i$=1, X_2=3,0: when $\overline{x}_i$=1.414, X_2=3.12);

– Time, τ, hour (when $\overline{x}_i$=-1.414 , X_2=0,59; when $\overline{x}_i$=-1, X_2=1; when $\overline{x}_i$=0, X_2= 2, when $\overline{x}_i$=1, X_2=3,0: when $\overline{x}_i$=1.414, X_2=4,4)

The planning matrix and there sults of the full-factor experiment taking into account the parameters H_μ= 3600..9300 MPa, P = 30..50 N, V = 2.4..3 m /s, τ= 1..3 hours are given in next time.

As a result of experimental data processing, we obtained estimates of the influence of factors, theirs quares, and the irinteraction on the value.Factor sand levels of the irvariation in the experiment by 4 parameters and planning matrix and results of a full-factor experiment is given next.

As a result of performing mathematical operations, we will obtain the following results:

*(1) – for microhardness X_1, ($H_{\mu 50}$=3600 -МПа,); X_2(P=30-, H); X_3(V=2,4-m/s); X_4 (τ=1-h, $\Delta m = 0.027 gr$;

∗ (2) – for microhardness X_1, ($H_{\mu 50}$=3600-МПа,); X_2(P=30- H); X_3(V=2,4- m/s); X_4 (τ=3+h, $\Delta m = 0.076 gr;$

∗ (3) – for microhardness X_1, ($H_{\mu 50}$=3600-МПа); X_2(P=30- H); X_3(V=3,.0+m/s); X_4 (τ=1-h, $\Delta m = 0.028 gr;$

∗ (4) – for microhardness X_1, ($H_{\mu 50}$=3600-МПа); X_2(P=30- H); X_3(V=3.0+m/s); X_4 (τ=3+h, $\Delta m = 0.078 gr;$

∗ (5) – for microhardness X_1, ($H_{\mu 50}$=3600-МПа); X_2(P=50+ H);X_3(V=2.4-m/s); X_4 (τ=1-h, $\Delta m = 0.027 gr;$

∗ (6) – for microhardness X_1, ($H_{\mu 50}$=3600-МПа); X_2(P=50+ H); X_3(V=2.4-m/s); X_4 (τ=3+h, $\Delta m = 0.127 gr;$

∗ (7) – for microhardness X_1, ($H_{\mu 50}$=3600-МПа); X_2(P=50+ H); X_3(V=3+m/s); X_4 (τ=1-h, $\Delta m = 0.43 gr;$

∗ (8) – for microhardness X_1, ($H_{\mu 50}$=9300-МПа); X_2(P=50+ H); ,X_3(V=3,0+m/s); X_4 (τ=3+h, $\Delta m = 0.136 gr;$

∗ (9) – for microhardness X_1, ($H_{\mu 50}$=9300-МПа); X_2(P=30- H); X_3(V=2.4-m/s); X_4 (τ=1-h, $\Delta m = 0.05 gr;$

∗ (10) – for microhardness X_1, ($H_{\mu 50}$=9300 +МПа); X_2(P=30- H); X_3(V=2.4-m/s); X_4 (τ=3+h, $\Delta m = 0.016 gr;$

∗ (11) – for microhardness X_1, ($H_{\mu 50}$=9300+МПа,); X_2(P=30 + H); X_3(V=3.0+ m/s); X_4 (τ=1-h, $\Delta m = 0.006 gr;$

∗ (12) – for microhardness X_1, ($H_{\mu 50}$=9300+МПа); X_2(P=30+ H); X_3(V=3.0+ m/s); X_4 (τ=3+h, $\Delta m = 0.17 gr;$

∗ (13) – for microhardness X_1, ($H_{\mu 50}$=9300+МПа); X_2(P=50+, H);X_3(V=2.4-m/s); X_4 (τ=1-h,, $\Delta m = 0.008 gr;$

∗ (14) – for microhardness X_1, ($H_{\mu 50}$=9300+МПа); X_2(P=50+ H); X_3(V=2.4-m/s); X_4 (τ=3+h, $\Delta m = 0.024 gr;$

∗ (15) – for microhardness X_1, ($H_{\mu 50}$=9300+ МПа); X_2(P=50+ H); X_3(V=3.0+ m/s); X_4 (τ=1- h, $\Delta m = 0.008 gr;$

∗ (16) – for microhardness X_1, ($H_{\mu 50}$=9300+ МПа); X_2(P=50+ H); X_3(V=3.0+ m/s); X_4 (τ=3+ h, $\Delta m = 0.025 gr;$

∗ (17) – for microhardness X$_1$, ($H_{\mu 50}$=6450o МПа); X$_2$(P=40o H); X$_3$(V=2.7o m/s); X$_4$ (τ=2o h, $\Delta m = 0.018 gr;$

∗ (18) – for microhardness X$_1$, ($H_{\mu 50}$=6450oМПа); X$_2$(P=40o H); X$_3$(V=2.7om/s); X$_4$ (τ=2o h, $\Delta m = 0.18 gr;$

∗ (19) – for microhardness X$_1$, ($H_{\mu 50}$=6450o МПа); X$_2$(P=40o H); X$_3$(V=2.7o m/s); X$_4$ (τ=2o h, $\Delta m = 0.018 gr;$

∗ (20) – for microhardness X$_1$, ($H_{\mu 50}$=6450o МПа); X$_2$(P=40o H); X$_3$(V=2.7o m/s); X$_4$ (τ=2o h, $\Delta m = 0.018 gr.$

Formation of the study purpose

As a result of checking the experimental results, the dispersion of observation errors $S = 1$ was found for the degree of freedom $f = 2$. The significance of the regression coefficients was checked using the Student's test for the level $q = 0.05$ and the degree of freedom $f = 2$ showed the significance of the factors $\overline{x_1}, \overline{x_2}, \overline{x_3}, \overline{x_4}$, as well as their interactions $\overline{x_1 x_2}, \overline{x_1 x_3}, \overline{x_1 x_4}, \overline{x_2 x_3}, \overline{x_2 x_4}, \overline{x_3 x_4}$.

The result is a response function

$$y = -3.752 - 0.777\overline{x_1} + 0.196\overline{x_2} + 0.054\overline{x_3} + 0.585\overline{x_4} - 0.0025\overline{x_1 x_2} - 0.019\overline{x_1 x_3}$$
$$-0.03\overline{x_1 x_4} + 0.02\overline{x_2 x_3} + 0.038\overline{x_2 x_4} - 0.032\overline{x_3 x_4}.$$

At the same time

$$\overline{x_1} = \frac{2(ln H_{\mu 50} - 9.138)}{9.138 - 8.102} + 1; \quad \overline{x_2} = \frac{2(ln P - 3.912)}{3.912 - 3.4} + 1;$$
$$\overline{x_3} = \frac{2(ln V - 1.099)}{1.099 - 0.875} + 1 \;; \quad \overline{x_4} = \frac{2(ln \tau - 1.099)}{1.099} + 1.$$

Presenting main material

Checking the adequacy of the observed values showed that the calculated value of the Fisher criterion is F_p = 15.27, and the tabulated value F_t = 19.42. Thus, the resulting mathematical model is adequate to the real-life and studied model. For convenience of calculations, coded variables are replaced by corresponding physical quantities

$$\Delta m = 5.1 - 1.151 ln H_{\mu 50} + 1.584 ln \tau + 1.313 ln V + 0.111 ln P - 0.357 ln H_{\mu 50}\, ln V$$
$$-0.115 ln H_{\mu 50}\, ln \tau + 0.696 ln P\, ln V + 0.271 ln P\, ln \tau - 0.518 ln \tau\, ln V - 0.02 ln H_{\mu 50}\, ln P$$

The resulting formula takes into account the influence of a multifactor system of tribological interaction of contacting surfaces and allows, by calculation using given parameters, to predict with high reliability the degree of wear resistance of coatings with various types of thermal hardening.

Conclusions

The developed technique of tribological tests with a change in the contact angle of the touching surfaces allows not only to determine the wear of the surfaces of the contacting pairs that rub, but also to study the dynamics of the abrasion process along the depth of the sample.

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