IMPROVED TRIBOTECHNOLOGY OF RUNNING-IN

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Introduction

Running-in is a process of change geometry of surface of friction and physical and mechanical properties of upper layers of material in an initial period of friction, showing up at permanent external terms in diminishing of friction force, temperature and intensity of wear. A concept "geometry of friction surface» is plugged in itself micro-roughness of surface and form (macro-geometry) of detail [1]. Conformities to the law of process of running-in is fullest studied depending on the roughness of surface [2]. A general conclusion is position about optimum micro-geometry of the running-in surfaces. During running-in the drastic alternations of characteristics of micro-relief of surface and structure-phase state of upper layer are taking place (process of structural adaptation goes). It does not depend on a size and character of roughness of surface in the initial state [3]. The roughness of surface of detail (height, form and direction of micro-roughness) is rendered by influence on wear resistance only in the period of running-in. Duration of this period also depends from roughness. It is necessary optimum to count a roughness. But Waletow specifies on that talking about the real optimization of micro-geometry of surface is possible only in case if only one micro-relief of surface can describe the set value of criteria (criterion) of its estimation with possible unimportant rejections [4].

Macrogeometry of units of friction considerably differs from correct. In many cases space tapering of surfaces is broken. A roughness after tooling frequently falls short of optimum values. It results in higher specific pressures in the area of contact, to the direct contact of metal surfaces and, as a result of it, to the teasers, grasping and enhance able wear of the running-in surfaces. Defects have an effect of increase of contact pressure on small area and further in more rapid tribological processes as compared to a contact without a defect.

For renewal of precision pairs, abrasive grinding in is used. At many positive moments, the abrasive grinding (polishing) has substantial failings. The conducted analysis allows exposing the following failings, related to the abrasive polishing of precision details: presence of technological contaminations; danger of caricaturing of abrasive particles in soft materials; disparity of roughness to the conditions of work; incomplete forming of actual area of spot of contact; negative gradient of mechanical properties on depth.

On this basis it is possible to conclude that the abrasive polishing does not allow to form necessary micro- and macro geometry, physical and mechanical properties that would allow shortening time of running-in and increasing quality of the recovered surfaces. In addition, a presence of technological contaminations is reason of enhance able wear of connections and decline of their technical and economical indexes of hydraulic aggregates.

Therefore, the details of connections of machines must not be exposed to abrasive grinding in. One possible type of grinding in, there is the chemical–mechanical planarization (CMP) [5…7] and another one is electrochemical–mechanical planarization (ECMP) [8…10]. ECMP found a wide use as method of clean (final) grinding in of details, workings in the conditions of friction, mechanical loadings, corrosions because this process is related to the change of micro roughness and physical and chemical state of surface. The electrochemical polishing provides the best friction properties of the ground pair, by comparison to the mechanical polishing; it is confirmed by a number of researchers.

ECMP requires application of special equipment (adaptation, instrument), exact maintenance of the mode of electrolysis, control and adjustment of solution, temperature condition of work of bath, careful cleaning of surfaces of details before treatment (chemical treatment is in organic solvents, electrochemical depriving of fat). For intensification of process, the electrochemical polishing must be conducted in a running electrolyte, and it requires more advanced equipment, than stationary baths. In addition, this method does not allow correcting macro geometrical defects.

The electrochemical-mechanical running-in (ECMR) is an improved tribotechnology of running-in. This method is used for running-in of basic units of engines and is one of perspective directions in research [20]. Application of the electrochemical - mechanical running-in has a number of substantial advantages before other types of final grinding in. Unlike the abrasive polishing in ECMR formation, abrasive particles are fully eliminated as products of wear. Affecting material is made by imposition of current on an environment and details and takes a place at ionic level. As a result, products of output are in an environment as atoms and molecules. As well as at the electrochemical polishing, at ECMR there is a removal of internal tensions both in micro- and macro-volume of surface of material. ECMR allows making the local output of metal, but the surface passivation, characteristic for electrochemical process, absent here. In addition, ECMR provides joint running-in of details without application of the special instruments unlike abrasive and electrochemical processes, due to it there is rapid structural, micro- and macro-geometrical adaptation of the surfaces under friction.

Presently the efficiency of ECMR is improved due to additions of oleic acid in an electrolyte. It enabled considerably to improve tribotechnical characteristics of the running-in surfaces at the different types of friction. Further research must be directed on opening of mechanism of forming of running-in surfaces of details of basic machines' units on the different types of friction.

Experimental

The aim of this paper was to study the influence of electrochemical mechanical running-in to change the nature of friction and wear in a pair of friction with reciprocating characteristic of the piston-liner pair, working in conditions with distortions of their axes. Changes in friction, temperature and rate of wear are commonly observed shortly after the start of sliding contact between fresh, unworn solid surfaces [11]. The studies were conducted on a model representing the slider-crank mechanism that mimics the friction pair of cylinder-piston sleeve. The design system is shown in Fig. 1(a). The experimental assembly was mounted on the friction machine. Drive of experimental assembly from the shaft friction machine. The effects of the friction in the slide were estimated friction torque, taken from the machine shaft potentiometer included with the machine. Friction torque recorded on graph paper plotter N-306. Two rings made of aluminum (outer diameter of 42 mm and a width of 11 mm) are pushed on slider. Frictional resistance created by these rings and the amount of wear and tear are estimated.

The moment of friction and wear rings were determined at different skew axis slide and barrel. Skewed axes provides a turn of the stage in the horizontal plane perpendicular to the plane of the swing rod, using a micrometer screw (Fig. 1(a)). For the initial value of the distortion, value was taken within the clearance between the piston and the sleeve length in mm/100 mm piston (Δ_n = 0.19 mm/100 mm length).

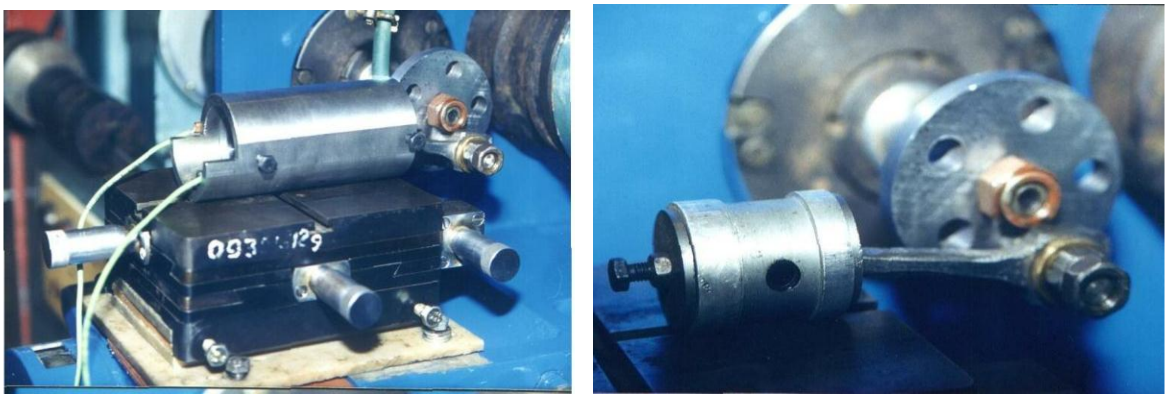

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Fig. 1. Device for study the effect of piston warps to ECMR of slider-liner pairing (a) and the slider with two rings (b)

Before the experiment the ring was cleaned, thoroughly washed, dried, weighed on an analytical balance WA-31 with an accuracy of 0.1 mg, and then mounted on a slide. The slide was collected from the liner. Slider joint movements were performed with sleeve liner along its axis together with the stage. An electrolyte was given in the area of friction. An alternative current (AC) was connected to the piston (slider) and liner (Fig. 1(a)). For comparison, experiments were carried out under the same conditions, but without current flow between the friction surfaces.

Results and discussion

In the latter case, the experiments showed that the time fixed by friction during operation without connecting current slide significantly depended on the tilt axis of slide and liner. The corresponding value of the friction torque was achieved almost immediately after starting the device for study the effect of piston warps to ECMR of slider-liner pairing and did not undergo further changes (Fig. 2).

The friction torque is increased with increasing bias. Changing the friction torque in time in connection with the current pair had a different character with a small warp (0.38 and 0.76 mm/100 mm of long slide). As in the previous case, immediately after the start time, friction increased sharply and then decreased at these distortions to patterns shown in the diagram. However, during the experiment, the friction torque is not reached the value corresponding to a zero skew. The greater difference the greater the resulting distortion was observed. When distortions 1.14; 1.52 mm, length 100 mm (curves 4 and 5, Fig.2 (a)) decreased friction torque was observed. Pattern is similar to that observed in friction without current. Character study of wear patterns energized and de-energized showed that more wear rings occurred in the experiments with the passage of current. This indicates that the action of the electrochemical process increases the material removal from rings, the removal increased with increasing bias to a greater extent than those without current. This phenomenon provides for fast burn-rings to the sleeve, which leads to a decrease in the friction torque. The passing current through the bearing surfaces provided them quickly (within 4 minutes) macro running-in. Changing the friction torque in time it is possible to explain of high speed of diminishing of macro-geometrical error of form of detail at ECMR.

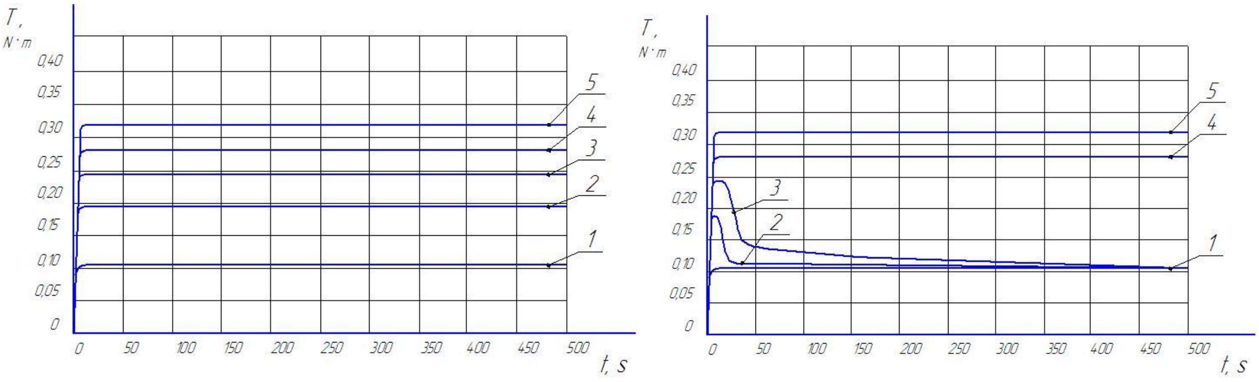

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Fig. 2. The change in the friction torque versus time during running by the standard method (a) and with ECMR (b): 1,2,3,4,5 - for piston misalignments 0; 0.38; 0.76; 1.14; 1.52 mm to 100 mm in length.

For analytical determination of the mode of friction, presence and thickness of electrolyte film between the ground details apply the criterion of Sommerfeld S_m [12]. Knowing that $S_m = 10^{-5}$ corresponds to the transient behavior of friction to set the change of types of lubrication at moving of piston. For a double piston movement, the detail surfaces operate at the different modes of friction: limiting mode, transitional and hydrodynamic.

It is possible to assert that at the hydrodynamic lubricating of running- in surfaces an electrochemical reaction flows cleanly: a current pass through details, part the layer of electrolyte. Investigation of it is an etched surface during their anodal polarization with frequency of alternating current. The mode of limiting and transitional friction, besides other, is activating surfaces that strengthen the effect of electrochemical reaction at a liquid friction.

From Fig. 3 it is evident, that any process macro running-in of two surfaces is possible to take to running-in of surface, inclined with the corner of defect γ, in relation to other one. For the running-in of sliding bearings, it is necessary to take into account frequency of rotation of shaft ω and presence of macro-geometrical rejections δ (Fig. 3).

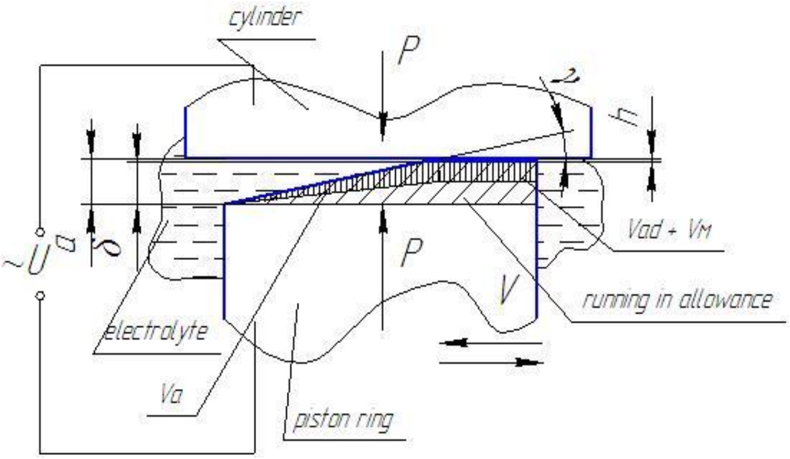

Fig. 3. Scheme of ECMR of details with reciprocal motion: δ – maximum size of a running-in allowance; V$_a$ – electrochemical etching rate of material from detail surface on a gap; V$_{ad}$ – electrochemical etching rate of material from detail surface at mechanical activation’s$_{м}$ – mechanical wear rate from detail surface; h – radial electrode gap at fluid friction; γ - angle of obliquity of running-in surfaces; a– joint gap, dependent on γ

To conduct error analysis, select factors, influencing on the change of size the error of form of detail $d\delta/dt$ and relation of speed of electrochemical output on an area with the depassivation of surface to speed of output on an area without a depassivation V_{ad}/V_a. Assume that material of detail on the area of the mechanical activating is taken off as micro-volumes of metal, then

$$V_{\max} = \frac{d\delta_{\max}}{dt} = V_m + V_{elc} = V_m + V_{a\partial} - V_a, \tag{1}$$

where V_m - speed of mechanical output; V_{elc} - speed of electrochemical output; V_{ad} - speed of anodal dissolution of metal with mechanical depassivations; V_a - speed of anodal dissolution of metal without mechanical depassivations.

It is possible to express constituent V_{ad} coming from laws Faraday and Ohm [13] taking into account the periodic breaking of anodal dissolution in the examined point of surface of ring because of pickoff at the mechanical activating (in the areas of limiting friction mode). By analogy with expression speed, output of metal will make on the area of anodal dissolution. After the calculation of the equation takes the form

$$V_{\max} = V_m + 0{,}5 \cdot (1 - k_1) \cdot \frac{\chi\varepsilon}{\rho} \cdot (\eta_{a\text{д}} \cdot (U - \varphi_{a\text{д}} + \varphi_k) / \sqrt{h_{\min}{}^2 + (1 - k_1)\frac{\chi\varepsilon}{\rho} \cdot \eta_{a\text{д}}(U - \varphi_{a\text{д}} + \varphi_k) \cdot t} -$$
$$- \eta_a \cdot (U - \varphi_a + \varphi_k) / \sqrt{(h_{\min}{}^2 + \delta\ )^2 + (1 - k_1)\frac{\chi\varepsilon}{\rho} \cdot \eta_a (U - \varphi_a + \varphi_k) \cdot t}\,) \quad , (2)$$

where *0,5*- coefficient, taking into account an alternating current; k_1 - coefficient, taking into account the limiting friction mode (S_m<10^{-5}) in general time of cycle (one turn of crankshaft); U - working voltage, V; φ_{ad} - anodal potential at mechanical activation, V; φ_k - cathode potential, V; η_{ad} - anodal current output at the mechanical activating, %; χ - specific conductivity of electrolyte, $Om^{-1} \cdot cm^{-1}$; ρ - density of material, g/cm^3; *c*- electrochemical equivalent of material of anode, g/A·h; *h* - a radial gap in the area of liquid friction, cm, η_a - anodal current output, %; φ_a - anodal potential, B; δ- maximal size of running-in allowance, см, *t*- time of ECMR process.

It is clear that speed of diminishing of running-in allowance depends, except for mechanical (V_m), geometrical *(δ)* and from electrochemical factors, such as specific conductivity χ, values of anodal potentials $\varphi_{ad,}$ φ_a and outputs on a current $\eta_{a\text{д},}$ η_a. The mechanical activating is reduced by anodal potential, and confirmation that an anodal output on current increases as a result of periodic mechanical influence, present in [14].

Thus, the choice of the modes of ECMR can be carried out on the basis of information about sizes φ_{ad} and φ_a, η_{ad} and η_a at the certain conditions of running-in.

Diminishing coefficient *k* accelerates the running-in details. The coefficient *k* depends on the criterion of Sommerfeld S_{m}.

Thickness of layer *h* is the function of piston speed *V* also and dynamic viscosityμ, however an increase of *h* will result in the increase of transitional resistance of layer of electrolyte. It is concordantly Eq. [2] necessary for the increase of speed of running-in details, that size *h* it was minimum, but the terms of the hydrodynamic lubricating would be provided here.

Knowing that the Sommerfeld criterion which is evened $S_m = 10^{-5}$ corresponds transient regime of friction, easily to set the change of types of lubrication at running-in surfaces. In an initial period of time there is mechanical elimination or driving back of plastic materials, forming an initial area of contact (I stage). With its growth, a transition is possible from a semi liquid friction to hydrodynamic (II stage), and at the hydrodynamic regime of friction the spot of contact is finally formed in examined tribosystem (III stage). The evident picture of terms of transition of one mode of friction f in other gives diagram of Gersi, in which the coefficient of friction is related to the parameter μV/P. This parameter is named description of the bearing mode. On diagram line $S_m = 10^{-5}$, passing through the point of a minimum of coefficient of friction, divides the areas of friction at a liquid and other types of lubricating (Fig. 4).

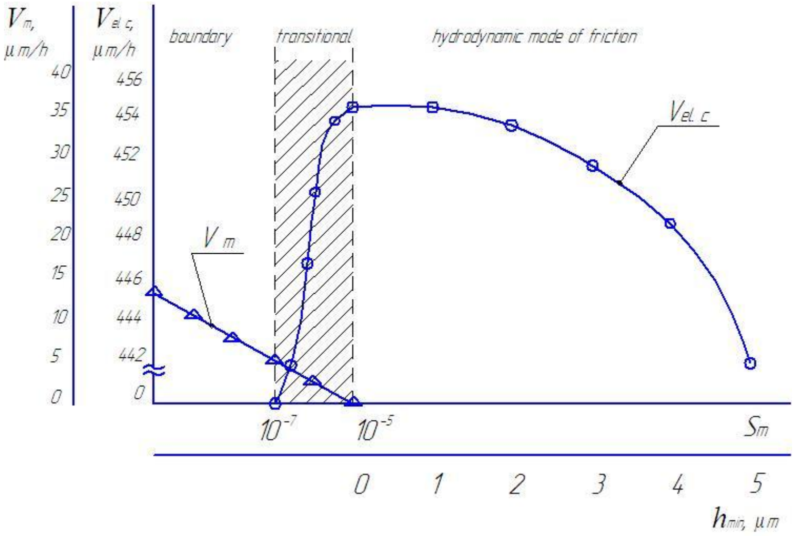

Fig.4. Speed of diminishing of macro-geometrical detail's form error at ECMR

As obvious from Fig. 4, diminishing of macro-geometrical form defection $d\delta/dt$ due to a mechanical wear $V_м$ possibly only at the dry and limiting types of friction. Thus, then more surfaces are divided the layer of lubricating, the less than influence of mechanical wear on the process of improvement of macro-geometry of details surface. The mechanical factor is absenting at a liquid friction.

Influence of electrochemical factor increases with the division of the running-in surfaces the layer of electrolyte (V_{ad} increases at a limiting friction). However, it is necessary to provide a minimum gap; because resistance of layer of electrolyte grows with its increase those results in deceleration of electrochemical reactions (V_a goes down at a liquid friction with growth of thickness of electrolyte layer). Experimental confirmation of improvement of tribotechnical descriptions of friction surfaces at ECMR is presented in [15]. The use of this high-efficiency method of forming of surfaces of details allows considerably increasing their resource.

Conclusions

1. An alternating electric current on the friction surface coupling a piston-cylinder accelerates the running-in of the contact surfaces at the misalignment of their axes. Most of the wear rate of the samples at an alternating current leads to a decrease in the friction torque at the investigated distortions 0.38 and 0.76 mm, which to some extent eliminates misalignment axes to macro-geometry burnishing.

2. ECMR of the basic conjugations of engines is the high-efficiency process of running-in of the running-in surfaces: except for mechanical influence, characterized $V_М$, the process of running-in is accelerated due to electrochemical processes.

3. Running-in can be accelerated with the proper selection of optimum composition of electrolyte. It must possess low conductivity, passive properties, and also to provide the hydrodynamic mode of friction. It is possible to control the processes of running-in due to the change of speed index are frequencies of crankshaft rotation and current parameters I and U. The mode of ECMR must provide a high output on a current η_{ad} and minimum gap h.

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