

## **Improvement of tribotechnical characteristics of the main engine's pairings at electrochemical-mechanical running-in**

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**Summary.** One of the running-in processes is the electrochemical-mechanical running-in (ECMR). The processes of ECMR pass in the environment of electrolyte, which influences efficiency of process, mode of friction at running-in pair and speed of electrochemical reactions. The essence of ECMR consists of the following: working motion for details of mechanism is given, between details an electrolyte is pumping and cutoff alternating current. Due to joint electrochemical-mechanical influence there is a rapid adaptation of one surface to other. The most effective factor of ECMR is electrochemical, at which it is easy to electrochemical stripping of material from the run-in surface due to anodal dissolution at the hydrodynamic lubrication rate.  
**Key words:** running-in, electrochemical-mechanical running-in (ECMR), engines, friction torque

### **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 [12]. Conformities to the law of process of running-in of the ground interfaces are most full studied depending on the roughness of surface [18]. 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). After running-in termination there is an "even roughness of surface". As Kragel'skiy marks, it does not depend on a size and character of roughness of surface in the initial state [13]. 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, near to «even roughness of surface ". But Valetov 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 [19]. For sufficient self-reactance description of micro-geometry of the real surfaces, 3 to 25 criteria can be required. The standardized parameters of roughness of such description do not give and offered approach non-parametric to the estimation and control of micro-geometry of surface.

It follows from the formulated hypothesis of forming of roughness in the process of running-in flows out, that "even roughness " a roughness can be attainable, when surfaces of friction will be family of equidistant surfaces, and that is why the final running-in on a micro-level is possible only after macro-running-in of units [12, 13].

Unfortunately, macro-geometry 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 enhanceable 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 example, by the result of the unlubricated contact of surface on a ring, in which warped steel on bronze, diminishing of the time of running-in with the increase of defect was marked. It talks about complication of flowing processes and necessity of further study of influence of defects on running-in of the grinding in surfaces.

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) [3-10, 14, 16]. 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.

One direction in polishing and reduction of time of running-in is a key-in of electric current directly through connections of details, part the layer of electrolyte which is give working motion. The electrochemical-mechanical running-in (ECMR) method is used for running-in of basic units of engines and is one of perspective directions in research [1].

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.

Present efficiency of ECMR is enhanceable 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.

A research object is choosing the process of the electrochemical - mechanical running-in of surfaces of details of basic machines' units. The most ground surfaces at ECMR pass three basic stages of running-in process. Knowing that the

Sommerfeld criterion which is evened  $Sm = 10^{-5}$  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 semiliquid friction to hydrodynamic (II stage), and at the hydrodynamic regime of friction the spot of contact is finally formed in examined tribosystem (III stage).

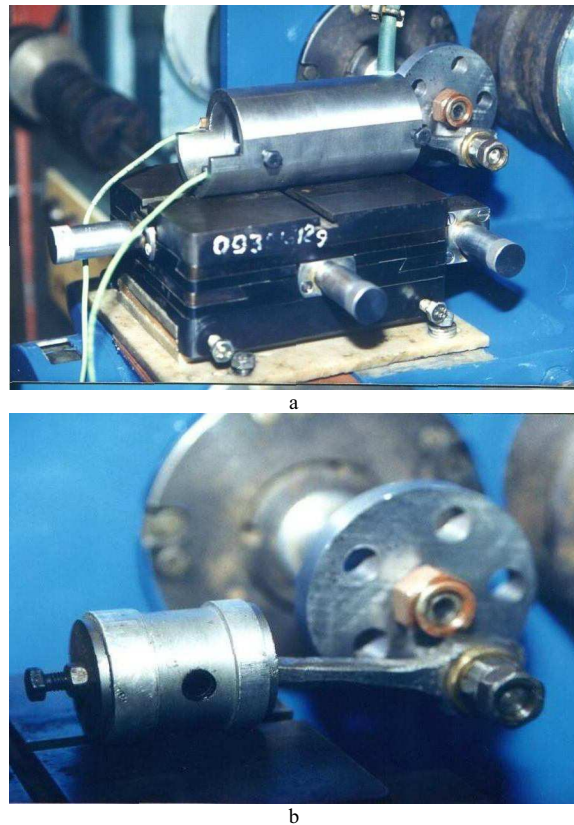
Examining factors, influencing on a friction resistance and intensity of output of material, it is possible to see at ECMR, that on an intensity of wear influence: form of area of contact, type of friction, properties of the surfaces and factors of external influence. Obviously, that flowing process of running-in of the surfaces depends on initial geometry of surfaces. At ECMR tribotechnical characteristics of the running-in surfaces at the different types of friction are improved. Thus the change of surfaces takes place on all of three stages of running-in that is impossible at ordinary methods, being based on a mechanical wear or creation on the grinding surfaces of different type of tapes. Surface forming at ECMR takes place due to electrochemical and mechanical influence. Influence of different factors allows forming top surface relief of roughness of surfaces. The mechanical strengthening is instrumental in the etching of tops of ledges, and the presence of superficial tapes and gasification is diminished by creation of cavities.

## OBJECTS AND PROBLEMS

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 interface, 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, unworm solid surfaces [2]. 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). Installation was mounted on the friction machine. Drive installation 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. For the initial (zero) value of the frictional moment taken its value corresponding to the time of friction with the shaft of the machine impaled on it without a crank rod. Assessing the friction and wear of the slide were performed on samples-rings, to strengthen it from both sides (Fig. 1(b)). 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 ( $\Delta n = 0.19$  mm/100 mm length).

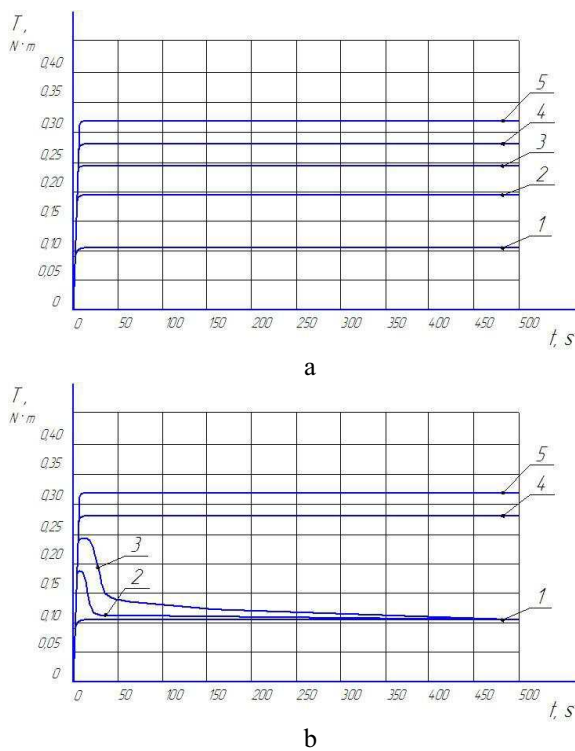


**Fig. 1.** Device for study the effect of piston warps to ECMR of slider-liner pairing (a) and the slider with two rings (b)

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.

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).



**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

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 a 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.

It is known that the basic pair of friction of machines has different character of the mutual moving. The tribounits of piston-cylinder group are working at crank motion (fig. 3), and the sliding bearing – at rotator movement (fig. 4). Obviously in first case, speed of the mutual moving of details changes from zero to the maximum speed, determined the structural parameters of knot and frequency of rotation of crankshaft. In the second - speed depends only on frequency of rotation and on the set modes is constant.

For analytical determination of the mode of friction, presence and thickness of electrolyte film between the ground details apply the criterion of Sommerfeld  $S_m$  [17] For running- in of details of type of piston-rings in the interfaces of rings-liner (with the recurrently-forward mutual moving) it is equal:

$$S_m = \frac{\mu \cdot V}{P \cdot b}, \quad (1)$$

where:  $\mu$  - dynamic viscosity of lubricating material (electrolyte), MPa·s;  $V$  - moving speed of piston, m/s;  $P$  - pressure of ring to the cylinder face from forces of resiliency, MPa;  $b$  - height of ring, m.

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.

Following the hydrodynamic theory of lubricating the thickness of tape, dividing a ring and cylinder, is based on formula [18]:

$$h = \sqrt{S_m} \tag{2}$$

It is possible to assert that at the hydrodynamic lubricating of running-in surfaces an electrochemical reaction flows cleanly: a current passes 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 and 4 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  $\gamma$ , in relation to other one. For the running-in of sliding bearings, it is necessary to take into account frequency of rotation of shaft  $\omega$  and presence of macro-geometrical rejections  $\delta$  (fig. 3).

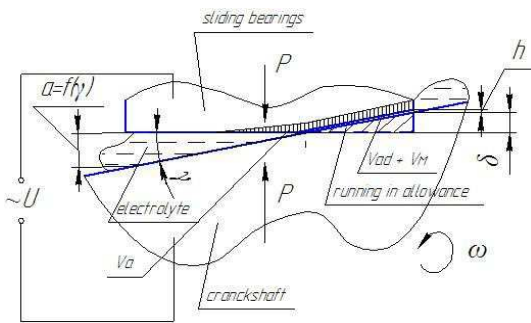


Fig. 3. Scheme of ECMR of details with rotation motion

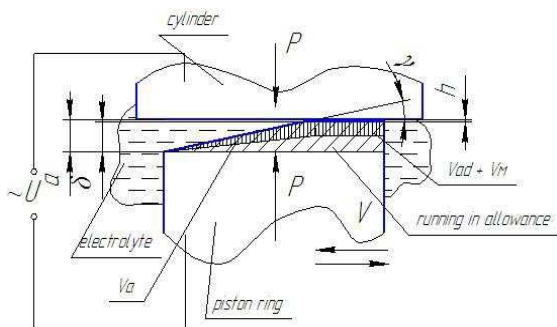


Fig. 4. Scheme of ECMR of details with reciprocal motion:  $\delta$  – maximum size of a running-in allowance;  $V_a$  – electrochemical etching rate of material from detail surface on a gap;  $V_{ad}$  – electrochemical etching rate of material from detail surface at mechanical activation;  $s_m$  – mechanical wear rate from detail surface;  $h$  – radial electrode gap at fluid friction;  $\gamma$  – angle of obliquity of running-in surfaces;  $a$  – joint gap, dependent on  $\gamma$

According to the hydrodynamic theory of friction, the thickness of tape between a shaft and journal bearing depends on frequency of rotation

of crankshaft. Except for it, important parameters are properties of lubricating environment and geometrical parameters of journal bearing. The laws of the hydrodynamic lubricating allow describing the minimum thickness of oily tape of the freely rotated crankshaft based on the formula:

$$h_{min} = \frac{d^2 n \eta}{18,36 k S c}, \tag{3}$$

where:  $d$  – diameter of shaft, mm;  $n$  – frequency of rotation of shaft,  $\text{min}^{-1}$ ;  $\eta$  – dynamic viscosity of oil, Pa·s;  $k$  – loading on a shaft, Pa;  $S$  – gap, mm;  $c$  – amendment of Glyumbel.

By formula (3) it is possible to define the minimum thickness of electrolyte layer at ECMR in the area of direct contact of the running-in surfaces of shaft and bearing without the account of macro-geometrical rejections (fig.2).

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:

$$V_{max} = \frac{d\delta_{max}}{dt} = V_m + V_{elc} = V_m + V_{ad} - V_a, \tag{4}$$

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 [15] 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:

$$V_{max} = V_m + 0,5(1-k_1) \frac{\chi \epsilon}{\rho} \cdot \eta_b \cdot (U - \varphi_a + \varphi_c) / \sqrt{h_{min}^2 + (1-k_1) \frac{\chi \epsilon}{\rho} \cdot \eta_b \cdot (U - \varphi_a + \varphi_c) \cdot t} - \eta_b \cdot (U - \varphi_a + \varphi_c) / \sqrt{(h_{min}^2 + \delta)^2 + (1-k_1) \frac{\chi \epsilon}{\rho} \cdot \eta_b \cdot (U - \varphi_a + \varphi_c) \cdot t} \tag{5}$$

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;  $\varphi_{ad}$  - anodal potential at mechanical activation, V;  $\varphi_k$  - cathode potential, V;  $\eta_{ad}$  - anodal current output at the mechanical activating, %;  $\chi$  - specific conductivity of electrolyte,  $\text{Om}^{-1}\cdot\text{cm}^{-1}$ ;  $\rho$  - density of material,  $\text{g}/\text{cm}^3$ ;  $c$  - electrochemical equivalent of material of anode,  $\text{g}/\text{A}\cdot\text{h}$ ;  $h$  - a radial gap in the area of liquid friction, cm,  $\eta_a$  - anodal current output, %;  $\varphi_a$  - anodal potential, B;  $\delta$  - maximal size of running-in allowance, cm,  $t$  - time of ECMR process.

It is clear that speed of diminishing of running-in allowance depends, except for mechanical ( $V_m$ ), geometrical ( $\delta$ ) and from electrochemical factors, such as specific conductivity  $\chi$ , values of anodal potentials  $\varphi_{ad}$ ,  $\varphi_a$  and outputs on a current  $\eta_{ad}$ ,  $\eta_a$ . The mechanical activating is reduced by anodal potential, and confirmation that an anodal output on a current increases as a result of periodic mechanical influence, present in [11].

Thus, the choice of the modes of ECMR can be carried out on the basis of information about sizes  $\varphi_{ad}$  and  $\varphi_a$ ,  $\eta_{ad}$  and  $\eta_a$  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 viscosity  $\mu$ , however an increase of  $h$  will result in the increase of transitional resistance of layer of electrolyte. It is concordantly Eq. [5] 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. Decline of bearing strength of electrolyte, with the purpose of diminishing  $h$ , possibly due to gasification. At electrochemical-mechanical running-in electrolyte is filled gas bubbles due to electrochemical processes, flowing on the surfaces of pair of friction. It is known that gasification depends on current parameters. A gas stream with a liquid provides a high degree of compressibility that can be used for diminishing  $h$  in the process of running-in with the use of ECMR. Several gas bubbles will be useful in localization of process of anodal dissolution, which is widely used in many processes of electrochemical size treatment of details of machines.

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  $\mu V/P$ . 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. 5).

As obvious from Fig. 5, diminishing of macro-geometrical form defection  $d\delta/dt$  due to a mechanical wear  $V_m$  possibly only at the dry and limiting types of friction. Thus, than more surfaces is 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 absents 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 [20, 21]. The use of this high-efficiency method of forming of surfaces of details allows considerably increasing their resource

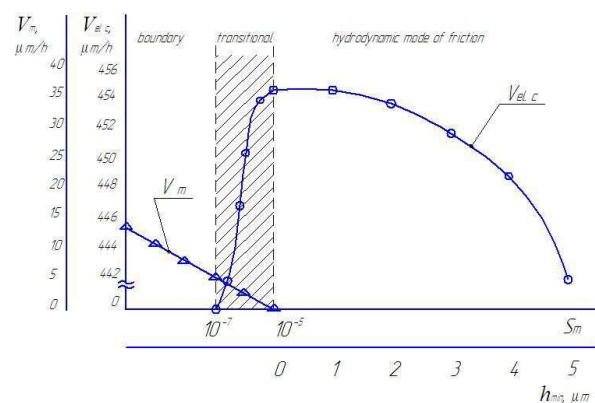


Fig. 5. Speed of diminishing of macro-geometrical error of form of detail at ECMR

Research of anodal output on a current  $\eta_{ad}$  in the pair of friction with the rotatory mutual moving present in [22].

Most intensively process of ECMR tribosystem shaft and journal bearing will be flows at outputs on a current  $\eta_{ad}$  near to 100%. Such values were observed at the closeness's of current less  $1000\text{A}/\text{m}^2$ . At the high-current density efficiency of process is minimal, a wear takes a

place due to a mechanical factor and an output on a current does not exceed 10%.

### 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. With increasing tilt axis of piston and sleeve increases the friction torque.

2. 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.

3. Biases of the piston and the cylinder axis of 1.14 and 1.52 mm did not provide running-surface even when applying current.

4. 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  $V_M$ , the process of running-in is accelerated due to electrochemical processes.

5. Macro 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.

6. 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  $\eta_{ad}$  and minimum gap  $h$ .

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УЛУЧШЕНИЕ ТРИБОТЕХНИЧЕСКИХ  
ХАРАКТЕРИСТИК ОСНОВНЫХ  
СОПРЯЖЕНИЙ ДВИГАТЕЛЯ  
ЭЛЕКТРОХИМИКО-МЕХАНИЧЕСКОЙ  
ПРИРАБОТКОЙ

*Тарас Замота, Виктор Аулин*

**А н н о т а ц и я .** Одним из способов приработки является электрохимико-механическая приработка (ЭХМП). ЭХМП осуществляется в среде электролита, который влияет на эффективность процесса, режим трения и скорость электрохимических реакций. Сущность ЭХМП следующая: деталям механизма придается рабочее движение, между ними прокачивается электролит и пропускается переменный электрический ток. Благодаря совместному электрохимико-механическому воздействию происходит быстрая приспособляемость одной поверхности к другой. Наиболее эффективным фактором является электрохимический, благодаря которому происходит стравливание металла поверхности при гидродинамическом режиме трения.

**К л ю ч е в ы е с л о в а :** электрохимико-механическая приработка, двигатели, момент трения