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INCREASING THE DURABILITY OF PRECISION PAIRS USING NANOCOMPOSITE ELECTROLYTIC IRON PLATING TECHNOLOGIES

Problem statement

Ensuring the operability of precision pairs at certain repair and maintenance costs is possible only on the basis of implementing a set of organizational and technical measures, as well as good preparation of repair production and compliance with the technological process of repair, material and technical and labour resources. Records of operation largely depend on the quality of operation of this system, to increase which it is necessary to improve the repair technologies of hydraulic system units [1-3].

The durability of hydraulic systems is determined by the resource of the most complex and responsible units - hydraulic distributor, hydraulic pump, power cylinder.

Large material and technical and labor resources are spent on maintenance of hydraulic systems. The performance of the equipment largely depends on the quality of this system, to increase which it is necessary to improve the repair technologies of the hydraulic system units [2-4]. During operation, the precision pair, which is the main working connection of the hydraulic distributor, is most intensively worn out, since the size of the gap in this pair determines the normal operation of the entire hydraulic system. The main defect, limiting the normal operation of the hydraulic distributor, is the presence of leaks of the working fluid through the diametrical gaps between the cylindrical holes in the housing and the spool belts, which increase during operation due to wear [2-4]. In connection with the written above, it is necessary to study the material, heat treatment, operating conditions, the type and degree of wear of the spool pair during operation, as well as existing methods of its restoration.

Analysis of current research.

The main damage to the working surfaces of parts of the hydraulic systems of equipment occurs under the action of abrasive mass. At the same time, abrasive particles close in size to the gap in the connection lead to local damage to the surfaces of micro-cut parts. Those particles, the size of which is significantly smaller than the radial gap of the connection, provoke the activation of hydroabrasive wear [3-5]. It is obvious that the working surfaces are prone to corrosion, and are also cut by a multitude of longitudinal grooves and scratches - traces of abrasive wear.

Fig. 1 Appearance of worn surfaces of hydraulic system parts

Due to the specific operating conditions of hydraulic equipment, increased requirements are imposed on dimensional stability, high wear resistance of working surfaces, strength and permissible thermal and assembly deformations of their parts. These requirements are achieved by various types of heat treatment: nitriding, cementation, artificial aging, cold treatment, surface hardening, etc. [3-5].

Nitriding is carried out to obtain high hardness and wear resistance of the surface layer of the part, increase the fatigue strength limit or corrosion resistance. The essence of the process is to saturate the steel with nitrogen, which at a temperature of 500 to 600°C is in an atomic state and forms chemical compounds with iron - nitrides, which give the nitrided steel hardness up to HV 698 [3-5]. During heat treatment at a temperature of 500 ° C, nitrogen diffuses into the metal at a rate of 0.01 mm/h. With high requirements for the mechanical properties of the core, the part before nitriding is subjected to high tempering.

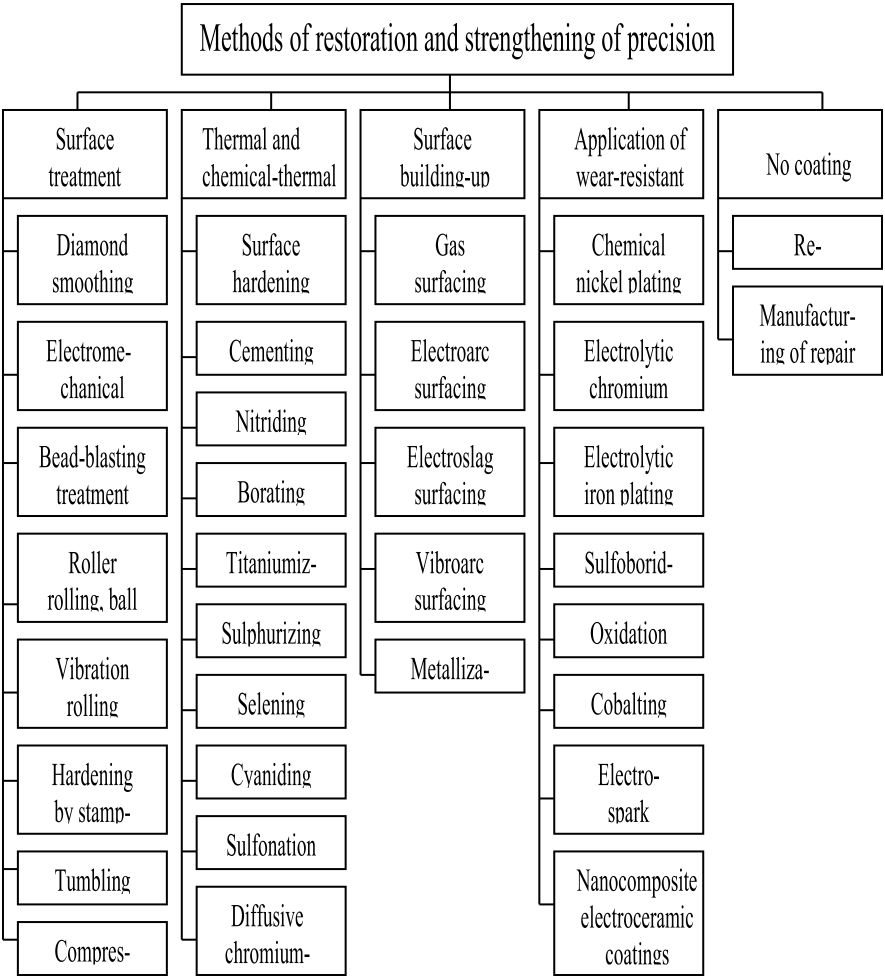

Fig. 2 Ways to increase the durability of precision pairs

Due to the high hardness of the nitrided layer and the presence of residual compressive stresses in it, the endurance limit of the part, especially those with stress concentrators, is significantly increased. Depending on the medium in which the process takes place, there are carburizing in a solid, liquid and gaseous carburizer. Carburizing in a solid carburizer is carried out by heating parts, most often packed in a mixture of activated charcoal in grains with a diameter of 3.5-10 mm. It occurs at a temperature of 900-950°C. To accelerate carburizing, from 10 to 40% barium carbonate and sodium carbonate, or from 5 to 20% cobalt nitrite, are added to the mixture. The depth of the carburized layer depends on the duration of the process. Liquid carburizing is carried out in baths of molten sodium carbonate salts from 75 to 85%, table salt from 10 to 15% and silicon carbide (5-10%). The bath temperature is maintained at 860°C. The machined parts in steel baskets or ladles are immersed in the bath and kept in it for 3 hours. Depending on the duration of cementation, the diffusion depth can reach from 0.2 to 1.0 mm. Heat treatment after the cementation process is double hardening and tempering:

- microwave hardening at a temperature of 1040°C;
- tempering with microwave heating to 700°C.

Hydraulic systems are inevitably operated in conditions of increased dustiness of the ambient air. Solid particles of contamination, getting into the gaps of precision joints, cause wear of the mating parts, and also, due to the appearance of increased friction forces, jam the parts of the distribution and control equipment. Reliable operation of hydraulic systems largely depends on the quality of the working fluid.

The main defects of the spool pair are dimensional wear and distortion of the geometric shape: for the body - ovality, taper and barrel shape, and for the spools - taper and saddle shape.

The working belts of the spool holes in the bodies wear out (Fig. 3).

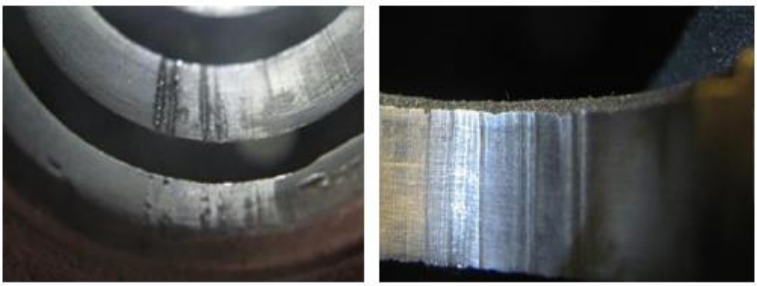

Fig. 3. Worn surface of the working belts of the holes of the hydraulic distributor housing

The maximum wear value of the holes in the housing for the spool usually reaches 0.09 mm, but there are scratches and marks on their surface with a depth of up to 0.12 mm. The spools wear out on the surfaces of the working belts (Fig. 1.3) connected to the housing holes. Shiny and matte zones of the belts are observed on the worn surfaces.

Scratches also appear along all belts, traces of surface seizure. The average value of spool wear is 0.014 mm, the maximum is 0.08 mm.

With slight wear of the holes for the spools of the housings (less than 0.01 mm), they are divided into size groups and restored by completing them with subsequent finishing together with the spool.

In case of significant wear of the housing spool holes (more than 0.01 mm), their geometric shape is restored by boring, reaming with subsequent finishing or diamond honing. Finishing of the housing holes is performed by manual lapping or on vertical finishing machines with fixing the lapping in the chuck. First, lapping is carried out with a 30-micron paste. For finishing, a 7-micron paste is used.

Measure the diameters of the restored holes with a pneumatic length gauge or an indicator inside gauge and divide the housing spool holes into 18 size groups in increments of 0.004 mm. Distortion of the geometric shape should not exceed 0.004 mm.

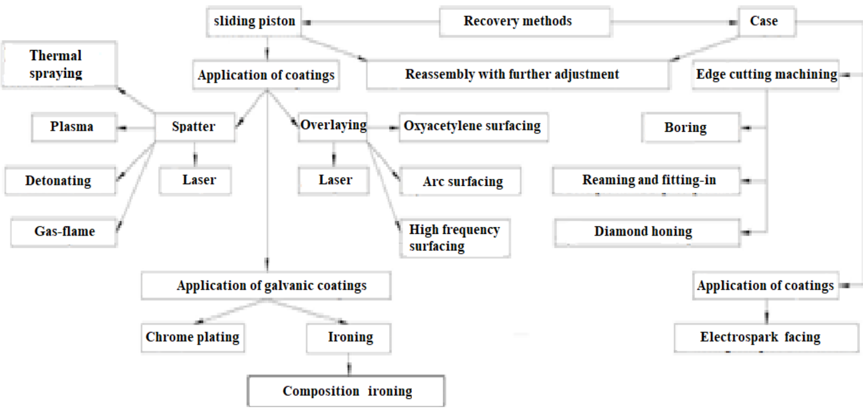

Fig. 4. Analysis of methods for restoring the working surface of the spool pair and hydraulic distributor

Recently, the method of restoring and strengthening parts with composite electrolytic coatings (CEC) based on iron has become quite widespread. Unlike classical electrolytic iron plating, this method involves introducing dispersed particles into the iron plating electrolyte. When modifying classical iron plating with dispersed materials, the physical and mechanical properties of the resulting coatings are improved and, most importantly, their microhardness, wear resistance, antifriction characteristics, thermal and corrosion resistance increase several times. Thus, we can conclude that the most preferable methods for restoring the spool pair are: for restoring the housing holes for the spools - diamond honing; for restoring and strengthening the spool belts - applying a composite electrolytic coating based on iron.

The purpose of the work is to substantiate the technologies for increasing the service life of precision machine parts using nanomaterials during electrolytic iron restoration.

Material and research methods

In recent years, methods of spraying powder and metal onto the restored surface have become quite widespread. In this case, the deposited layer exhibits special properties. The most promising methods include electric arc, plasma, gas powder and detonation spraying. Electric arc spraying does not require the use of complex technological equipment. The required chemical composition of the layer can be ensured by selecting special wires. At a current strength of 750 A, a steel coating is formed at a speed of 36 kg / h, which makes this method quite productive. The disadvantages of this method include overheating and oxidation of the sprayed material at low feed speeds of the spraying wire, poor adhesion of the deposited layer, high porosity of the coating, etc. In this case, the burnout of alloying elements occurs due to the release of a large amount of heat during the arc burning process. This method can be effective for large areas to be coated on massive parts. Plasma spraying, in comparison with electric arc spraying, has advantages. Strong noise, reaching 140 dB, during spraying requires the location of guns in a chamber with double walls, while observation is carried out through a viewing window. This method is low-performance and, in terms of ergonomics, is practically not used in repair production [4-6]. Electrolytic coating on worn spool rings is applied in two ways: by iron plating and chrome plating. The electrochemical equivalent of iron is 1.042 g / l-h, and chromium is 0.324 g / l-h, the current output when applying an iron-based coating is up to 5 times higher than when chrome plating, therefore a more productive and economical method of iron plating is more preferable. When ferrous plating, it is possible to obtain a coating layer thickness of 0.1 to 1.5 mm with an initial hardness of HV 406–495 units. Recently, the most widespread method has been the method of ferrous plating in hot chloride electrolytes, the temperature of which reaches 70...90 ° C. The process of restoring worn parts by ferrous plating has certain disadvantages that limit its application. These include low microhardness, insufficient wear resistance of the resulting coatings, which leads to a decrease in the resource of the restored connection. The method of restoring by chromium plating, unlike ferrous plating, allows you to obtain coatings that exceed the serial spool in many indicators, including wear resistance. For coating, electrolytes are used, the main component of which is chromic anhydride. Such coatings have the highest hardness - up to HV 1000. However, the use of this method is limited due to the fact that:

• the deposited layer of chromium coating contains tensile stresses, which, the greater its thickness, the more difficulties it causes in obtaining a high-quality coating layer with a thickness of more than 0.05 mm;

• parts restored with chromium coating have poor wear, which complicates the process of selective assembly with subsequent wear of the spool in the hydraulic distributor housing;

• the chrome plating process is expensive due to the high cost of chromic anhydride and the need to use additional treatment facilities that neutralize chromium-containing waste from galvanic production.

In the case of restoration of the spool pair of the hydraulic distributor, the thickness of the resulting coating is of particular importance due to significant wear of the spool and housing, reaching 0.2 mm. The chrome plating method cannot be used to solve the problem, since the thickness of the coating obtained with this method is limited to 0.05-0.06 mm. Recently, the method of restoring and strengthening parts with composite electrolytic coatings (CEC) based on iron has become quite widespread. Unlike classical electrolytic iron plating, this method involves introducing dispersed particles of iron into the electrolyte (Fig. 6). When modifying classical iron plating with dispersed materials, the physical and mechanical properties of the resulting coatings are improved and, most importantly, increase their microhardness, wear resistance, antifriction characteristics, thermal and corrosion resistance several times. The most appropriate for restoring the spool pair of a hydraulic distributor is: to restore the housing holes for the spools - diamond honing; to restore and strengthen the spool belts - applying a composite electrolytic coating based on iron.

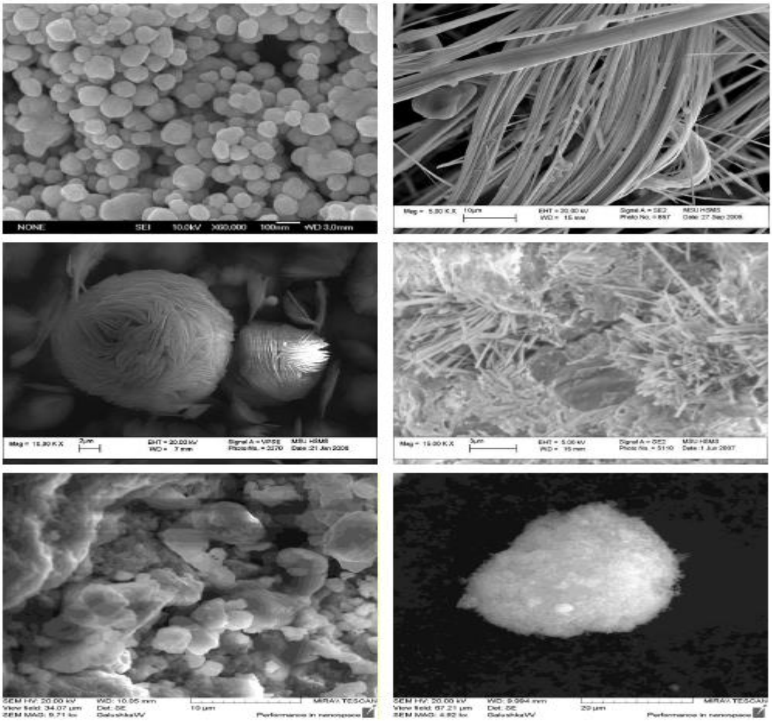

Fig. 5. Appearance of particles for modification of electrolytic coatings

Inclusion of dispersed particles in electrolytic coatings makes it possible to improve the mechanical and anti-corrosion properties of such coatings without changing the external shape of the products on which they are applied. CEC combine the properties of metals (electrical and thermal conductivity, plasticity, etc.) and non-metals (heat resistance, chemical resistance, high hardness, lubricating properties, etc.).

The advantages of such coatings:

- they are formed directly on the surface of the product and have a given size;
- the materials are obtained compact, practically without porosity;
- there is a possibility of regulating the physical and mechanical properties of the obtained coatings by the type and amount of addition of dispersed materials;
- economical electrolytic methods and techniques are used.

These very valuable properties of coatings create the prerequisites for their widespread use in various industries, including repair production. An important advantage of CEC, in comparison with hard electrolytic coatings, is the preservation of their increased hardness values over time, while conventional coatings with initial high hardness lose hardness in the first days after receipt [4-6].

Table 1. - Dispersed materials affecting the properties of electrolytic coatings

Coating properties	Disperse materials
Hardness and wear resistance	Al_2O_3, WC, AIN. ZrO_2, TIC, SiC TiO_2. ZrB_2. CrB_2 ZRC. ThO_2. TaC. HfC.WSi_2, SiO_2
Wear resistance in dry friction and elevated temperatures	$A1_2O_3$. TiB_2. SiC. amorphous carbon
Heat resistance	AI_2O_3. SiO_2. $TaSi_2$. B_4C. ZrO_2. amorphous carbon
Corrosion resistance	AIN. $Z1B_2$. AI_2O_3. SiC. $HfSi_2$.$TaSi_2$
Antifriction	WC. Mo **S_2,** graphite
Thermal resistance	Oxides, carbides
Self-lubrication	Graphite . MoS_2. WSi_2
Thermal conductivity	AIN. **$NbSi_2$**,WSi_2
Erosion resistance	Carbides
Strength	Al_2O_3. AlN

Presentation of the main material

Composite electrolytic coatings are metal matrices with a given distribution of various amplifiers in them, as which powders, fibers and materials with properties different from the matrix are used. Various combinations of matrix and dispersed phase materials allow obtaining hundreds of types of CEPs that combine the properties of electrolytically deposited metals (electrical and thermal conductivity, wear resistance, plasticity, etc.), as well as metals and non-metals (heat resistance, chemical resistance, hardness, etc.), which can be included in the coating when applying a polarizing current [5-7]. This significantly expands the capabilities of electroplating. The results of experimental studies have determined the use of CEPs in various areas, including in repair production. The introduction of boron carbide iron into the electrolyte contributed to a decrease in hydrogenation of the coating by 1.4-1.6 times, and the introduction of molybdenum disulfide reduced this indicator by 1.2-2.4 times. It was established that the presence of inclusions in electrolytic iron coatings does not affect the fatigue strength of the iron samples. The wear resistance of composite iron coatings with inclusions is 1.5-2.0 times higher than the wear resistance of pure iron [5-7]. The hardness of the dispersed phase and its proportion in the electrolyte determine the change in the polarization of the cathode. Moving particles prevent the formation of dendrites, pitting and pores caused by the accumulation and growth of hydrogen bubbles. A number of researchers [5-7] note these patterns in the deposition of iron, as well as nickel and other metals. The presence of the dispersed phase in the electrolyte makes it a participant in the process of electrical crystallization. Being at a distance from the cathode comparable to the diameter of the particle, it screens part of its surface. The most likely location of the dispersed particle in the immediate vicinity of the cathode or its migration to the centers of crystallization on the cathode surface. Screening changes the conditions of the growing coating [5-7]. If a particle is in close proximity to the cathode for a long time, this leads to the formation of a certain depression on its surface (Fig. 7, a), into which it gradually sinks and is subsequently overgrown with a coating (Fig. 7, b). The possibility of direct contact of particles with the cathode in the process of electrical crystallization of the metal depends on most factors, such as the properties of the dispersed phase, its adhesion, as well as on the charges of the particles and the charge of the cathode. If the thickness of the adsorption layers of the dispersed particle and the cathode is less than a certain critical distance (one of the conditions for the formation of a composite coating), the possibility of direct contact of the dispersed phase with the cathode increases significantly. In this case, a liquid layer is formed that firmly holds the particles at the cathode surface. Their contact with the cathode also contributes to the formation of oxygen and hydroxide compounds of metals in the process of electrolysis. Such compounds are intermediate products of electrochemical reactions and mediators in the mechanism of transformation of a hydrated ion into an atom and an ion of the crystal lattice. Hydroxide compounds are hydrophilic, have a positive charge and well retain negatively charged dispersed particles at the cathode [6-8].

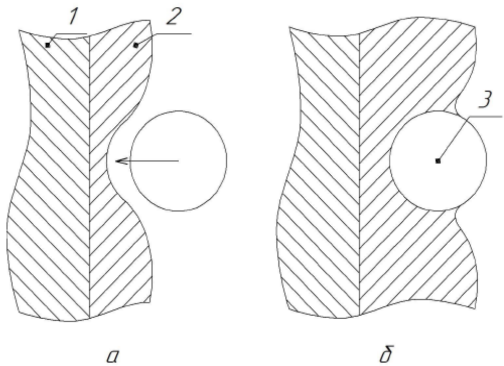

Fig. 6. Shielding by a nanoparticle of a coating: a - formation of a recess; b - overgrowth of a nanoparticle in a recess; 1 - detail; 2 - coating; 3 - nanoparticle

The positive effect of intermediate products of the electrochemical reaction is enhanced if the cathode charge is negative in the region of electrode potentials corresponding to the working density of the cathode current. Particles of the dispersed phase are well overgrown with a coating upon adhesion to the cathode. Conductive particles are able to overgrow both from the base and from the top, thereby increasing the roughness of the cathode surface. Non-conductive particles overgrow from the base; the coatings are obtained without porosity, dense, usually without pitting and dendrites, slightly affecting the roughness of the coating (Fig. 8).

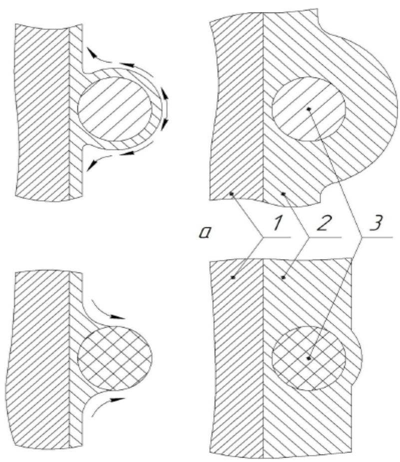

Fig.7. Scheme of overgrowth of nanosized particles: a - conductive; b - dielectric; 1 - part, 2 - coating, 3 - nanosized particles

Thus, for the formation of CEC, direct contact of the particle with the cathode is desirable. However, the appearance of CEC is quite possible in the presence of a liquid layer with a thickness of less than some critical distance. In this case, non-conductive particles are the most preferable, since they practically do not change the roughness of the resulting coatings. Dispersed particles included in the coating change the structure and physical and mechanical properties of the coating [6-8]. The kinetic stability of electrolytes depends on many factors, such as density and temperature, size and properties of the dispersed phase, its concentration [6-8]. To obtain CEC from suspensions with particle sizes of 0.01-0.02 mm, constant directional movement of particles to the cathode is necessary. However, if the particle size in the suspension is up to 0.001 mm, it is sufficient to pre-mix the suspension before depositing the coating. Particles with sizes larger than 10-4 mm are more difficult to introduce into the coating, they precipitate more easily, and therefore their formulation concentration is always higher than the active one, while the best sizes of the dispersed phase to maintain the kinetic stability of the suspensions and effective inclusion in the deposited coatings should be in the nanometer range and be from 10-5 to 10-4 mm. Coatings obtained with particles in the nanometer range have been little studied and are of great scientific and practical interest. In this regard, the study of the influence of nanosized particles on electrolytic coatings is an urgent task. The results of microhardness measurements are presented in Fig. 8. As can be seen from the data presented, the coatings deposited from electrolytic ferric iron with a concentration of nanosized aluminum nitride particles of 3 g/l have the highest microhardness of 682HV. The high microhardness of electrolytic coatings with the inclusion of aluminum nitride particles, compared to other nanosized particles, is most likely explained not only by their high hardness, but also by the chemical properties of nitrides. When interacting with acids present in the electroplating electrolyte, they release nitrogen, the introduction of which into the electrolytic coating further improves its physical and mechanical properties.

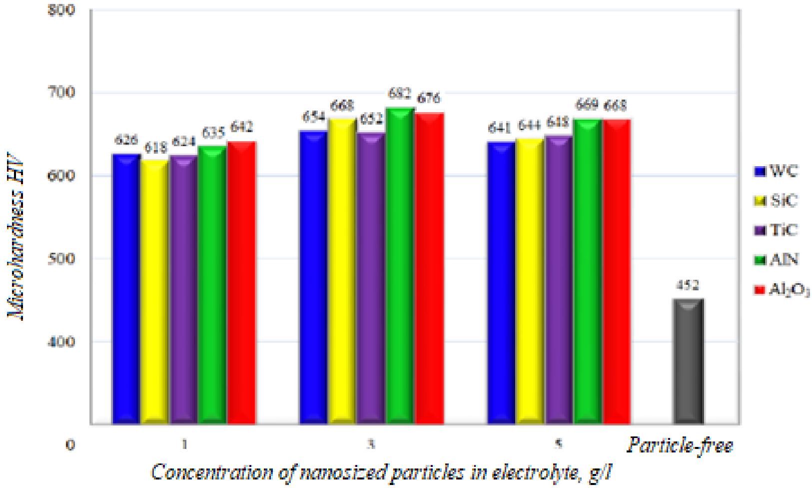

Fig. 8. Histogram of microhardness of NCEP depending on the type and concentration of nanosized particles in the electrolyte

As a result of the study of the microhardness of coatings, the most promising materials and their concentration were determined, which allowed to achieve the highest microhardness of the coating in comparison with other considered materials, in connection with which all subsequent experiments were carried out only with nanodispersed aluminum nitride powder [6-8].

The tests were carried out on samples without coating (material of the serial spool), with classical electrolytic coating (recovery using existing technology) and NCEC based on iron (recovery and strengthening using the proposed technology).

Fig. 9 shows that the minimum total wear by mass is observed in the friction pair, on the rollers of which an iron-based NCEC is applied, both during tests in a clean lubricating medium and during tests in a contaminated lubricating medium. During tests in a clean lubricating medium, the total wear by mass of the friction pair, on the rollers of which the studied coating is applied, was 0.0436 g, which is 1.7 times less than that of the friction pair, on the rollers of which a classic iron coating is applied, and 1.3 times less than that of the friction pair made of 15X steel without coating. In a contaminated lubricating medium, the total wear by weight of the friction pair, on the rollers of which an iron-based NKEP was applied, was 0.0621 g, which is 1.6 times less than that of the friction pair, on the rollers of which a classic coating was applied, and 1.35 times less than that of the friction pair made of 15X steel without coating. During accelerated comparative tribological tests, a change in the friction torque was also recorded.

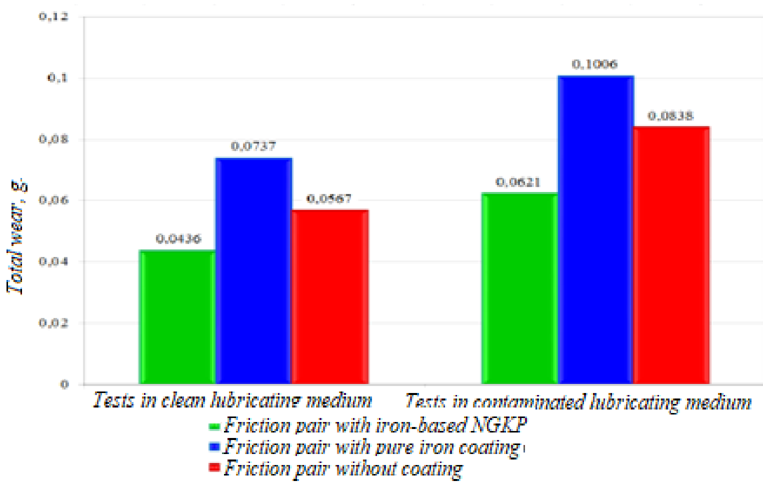

Fig. 9. Total wear by mass of friction pairs after accelerated comparative tribological tests

Thus, in samples with iron-based NKEP in a clean lubricating medium, the friction torque by the end of the tests reached a value of 4.4 Nm, which is 2% lower than that of samples made of 15X steel without coating. In a contaminated lubricating medium, the friction moment of samples with iron-based NCEP was 5.1 Nm, which is 4% less than that of samples with a classic coating and 2% less than that of samples made of 15X steel without a coating. From the above, it follows that iron-based NCEC has increased wear resistance compared to classic iron coating and 15X steel [6-8]. In addition to the general requirements for spool pairs, it is necessary to take into account the requirements imposed when applying electrolytic coatings to the spool, namely:

- mechanical processing of spools must exclude overheating, as well as the illumination of grooves and furrows on their belts;
- spool surfaces must not have deep scratches, scratches and traces of corrosion;
- technological openings before galvanic operations must be tightly closed to prevent the ingress of aggressive liquids inside the spool. All materials used in the application of iron-based NCEC must comply with

the declared purity and standards established for them. To increase productivity and safety, all restored and strengthening spools are suspended on special suspensions, to which the following requirements are imposed:

- suspensions are made of materials with high electrical conductivity;
- all sections of the suspension must be isolated from contact with electrolytes and solutions;
- the design of the suspensions must provide reliable fastening of parts and ensure the supply of electric current to them.

The ratio of the surface area of a single-use coating to the volume of electrolyte must be more than 1. The thickness of the coating must be within the tolerance for further mechanical processing. Poor-quality coatings are removed by grinding until the coating is completely removed on centerless grinding machines. The scheme of the technological process of restoring spool pairs using iron-based NCEC is presented in Fig. 10. In accordance with it, we will consider the technology of restoration and strengthening, the procedure for carrying out individual operations, and recommendations for their implementation.

When restoring spool pairs of hydraulic distributors, they are depersonalized, defecated and divided into groups according to the amount of wear. The belts in the housing holes are honed to remove traces of wear on a 3K833 vertical honing machine using an ASP-60/40 bar for rough honing and an ASM 20/14 bar for fine honing. Worn spool belts are processed on a centerless grinding machine S250 to remove traces of wear using an ASM 7/5 diamond wheel at the following modes: feed wheel rotation speed - 30 rpm, diamond wheel rotation speed - 1400 rpm. After processing the valve bands, iron-based NCEP is grown in a composite electrolytic coating system.

After washing in hot and cold running water, the spools are subjected to pickling in an electrolyte of 30% sulfuric acid to remove oxide films and more thorough degreasing of the surfaces. Processing modes: cathode current density - 20A/dm^2, electrolyte temperature 25°C, operation time 2-3min. After washing in hot and cold running water, NCEP is applied from an electrolyte of the following composition: ferric chloride 200 - 300g/l; hydrochloric acid 1-1.5g/l; manganese chloride 5-10g/l, nano-sized particles of aluminum nitride - 3.1g/l. Electrolysis modes: cathode current density - 21A/dm^2, electrolyte temperature 70°C, operation time - up to the required size of the applied layer. The rate of coating deposition is 100-150μm/h. After coating, the spools are washed sequentially in hot and cold running water and passivated in a 10% sodium hydroxide solution for 10 minutes.

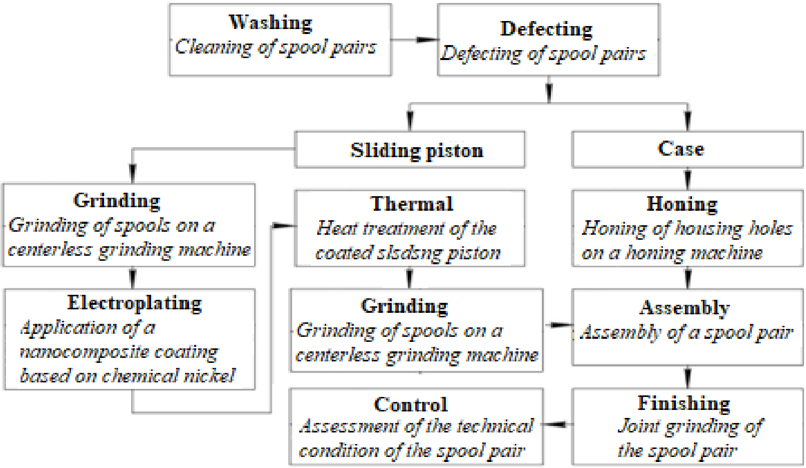

Fig. 10. Schematic of the technological process for restoring spool pairs of a hydraulic distributor

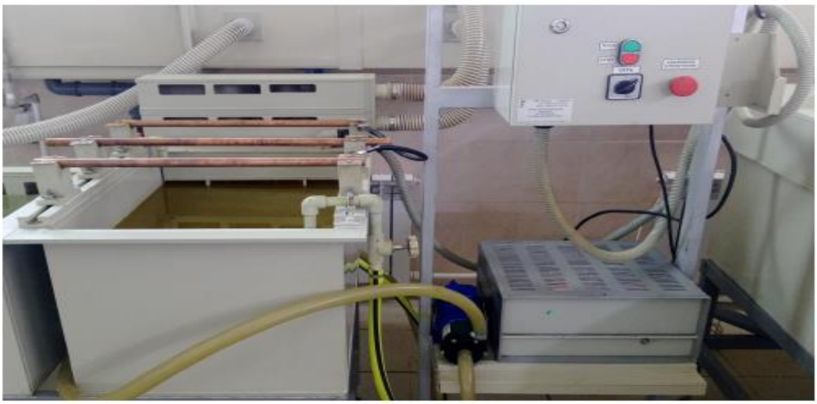

Fig. 11. Installation for applying composite electrolytic coatings

In the process of assembling hydraulic distributors, the depersonalization of the attached spool pairs is not allowed [6-8]. The operability of the hydraulic distributor was assessed by the amount of leakage in the spool pair. A hydraulic distributor is considered operable if the leakage does not exceed 40 cm^3/min.

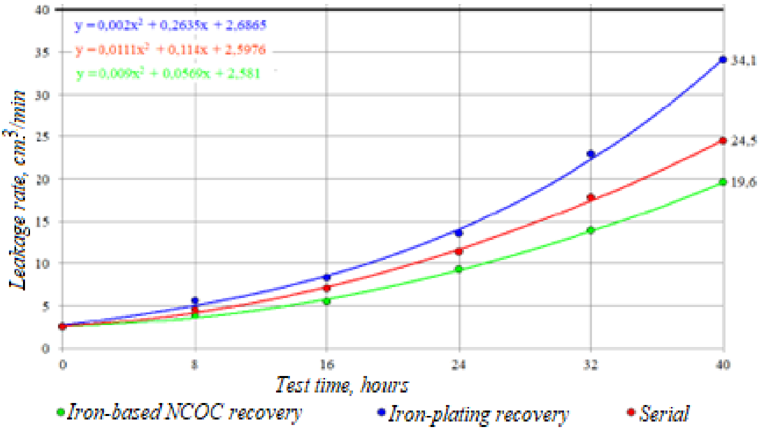

Fig. 12. Results of bench tests of hydraulic distributors

After bench tests, it was found that all hydraulic distributors did not reach the limit state. The leakage rate in hydraulic distributors, the spool pairs of which were restored using iron-based NKEP, was 19.6 cm3/min, which is 1.75 times less than in hydraulic distributors, the spool pairs of which were restored using existing technology, and 1.25 times less than in serial hydraulic distributors.

Conclusions

Precision pairs wear out most intensively during operation, the deterioration of which technical condition leads to disruption of the normal operation of the entire hydraulic system and an increase in the cost of the work performed. The analysis of restoration technologies showed that for the hydraulic distributor housing the most promising method of restoring worn belts is diamond honing, and for the spool - applying a nanocomposite electrolytic coating based on iron.

The modes and concentration of nanosized aluminum nitride powder for applying a nanocomposite electrolytic coating based on iron have been established, which allow obtaining a coating with a microhardness of up to 717 HV units, which is 1.6 times higher than that of a coating without the inclusion of nanosized particles.

Comparative tribological tests of friction pair samples showed that the total wear by mass of a friction pair with a nanocomposite electrolytic coating is 1.6-1.7 times less than that of a friction pair with a classic electrolytic coating, and 1.3-1.4 times less than that of a friction pair without a coating. Based on the results of theoretical research, a technological process for restoring precision pairs using a nanocomposite electrolytic coating based on iron has been developed.

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