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RESEARCH OF MODERN TECHNOLOGIES FOR THE RESTORATION OF STRUCTURAL ELEMENTS OF MINING PUMPS: ADVANTAGES AND DISADVANTAGES, PROMISING TECHNOLOGIES

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Abstract

The scientific article is devoted to the study of modern technologies for restoring the internal surfaces of critical parts of the structural elements of oil and gas pumps. By the method of critical analysis of defects, it was found that paraffin deposits and mechanical impurities are in the list of the main complicating factors leading to abrasive wear of the working surface of the parts being contacted. Asphalt-resin-paraffin deposits together with mechanical impurities are distributed unevenly, for example, along the diameter of the cylinder of the injection column, narrowing the passage section of the rod in different stroke length intervals. This phenomenon causes the rod to deviate from the design axis of the trajectory of movement and forms sections of the cylinder working under shock loads with maximum wear. Therefore, it is necessary to restore the degraded surface in places where maximum dynamic loads are applied. The patent search method and the evaluation of the claims allowed us to establish that the generally accepted methods of restoring internal surfaces are reduced to nitriding and chrome plating. Due to known technological shortcomings, these methods are limited in application, and it is impossible to restore the phase structure by these methods. To solve the technological problem of restoring the structure and modifying the inner surface of a small cylinder diameter, it is proposed to apply a coating with a ceramic protective layer based on nickel alloys of the carbide class, which has high hardness and inert properties. To restore the surface of worn parts in conditions of a limited coordinate space of long-dimensional elements of the RDP structure (pump and compressor pipes, a pair of cylinder-plunger and others), the authors propose a promising laser spraying.

Keywords*:* *restoration, oil pump, small diameters, wear resistance, failure, aggressive environment.*

Introduction

The development of energy and mechanical engineering of extractive industries, through the diversification of oil-producing complexes, is the basis of industrial and innovative development of countries with oil fields [1,2].

In the extractive industry, for more complete extraction of hydrocarbons in conditions of small and medium-sized wells, rod deep pumps (RDP) are the main complex for lifting oil. The effectiveness of this equipment is limited by the insufficient reliability of its elements, large losses of deep oil and leaks of associated petroleum gas [3,4]. The overhaul period of the RDP recommended by the manufacturer is 4,000 – 4,500 hours, but the actual working period is 1,800 – 2,900 hours, which is 45 – 64% lower than planned.

The collection of analytical and statistical information, processing, generalization and analysis of defect maps and failures of oil producing wells made it possible to form the main types of RDP

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defects and the complex nature of their wear with a simultaneous combination of hydromechanical and chemical factors of influence [4,5,6]. The variety of wear is caused by the action of an aggressive environment, the complex composition of oil and the influence of various types of inhibitors on metal products at the atomic level. The study of the types of RDP failures required to establish a causal relationship between failures, types of defects and the composition of the oil fluid [5]. The results of the conducted studies allowed us to conclude that the main factors that have a significant impact on RDP failures include the properties of the extracted liquid [7,8,9]:

– the amount of free gas in the operational flow;
– work in an aggressive environment;
– removal of mechanical impurities;
– deposits of salts and ARPD on the working nodes of RDP;
– high viscosity of the produced reservoir fluid.

Investigation of the reasons for the failure of the RDP allowed us to establish that the inner surface of the cylinder of the rod pump is more susceptible to wear compared to other parts of the parts being contacted (a pair of cylinder-plunger).

A wide variety of factors that catastrophically reduce the durability of deep rod pumps necessitates the development of an optimal universal method for restoring critical internal surfaces (a cylinder-plunger pair) of small diameter and long length. Thus, there is a complex scientific and technical problem of developing a unique method for restoring the inner surface of a small-diameter rod pump that provides high physical and mechanical properties of the coating and manufacturability. The problem of restoration is focused on the elimination of mechanical wear in the form of a change in the design geometry of the surface and the restoration of the phase structure of a carbide material with corrosion-resistant properties.

To solve this problem, it is necessary to solve the main tasks:

– to investigate the technological features of existing methods of RDP recovery;
– to develop a design for restoring the physical and mechanical properties of metal pump products;
– to develop a technology for restoring the internal surfaces of small diameter RDP;
– to justify the optimal modes of laser recovery technology;
– to substantiate optimal materials that provide high physical and mechanical properties of the modified surface.

Research of modern technologies of recovery of mining pumps

The main requirements for RDP of low-flow wells are their compliance with the requirements of drawings, high physical and mechanical properties (strength, fatigue resistance, fretting resistance, erosion and corrosion resistance), specified productivity [10 – 13].

Researchers Yu.I. Blinov and others have developed a method for manufacturing a rod pump [14, 15] by applying a system of recesses before the final operation of finishing, removal of damaged material, thermal and mechanical stress treatment.

The disadvantage of the method is the unacceptability of applying depressions by chemical methods, the technical complexity of processing the inner surface of long cylinders of high-strength nitrided steel 38Cr2MoAlA, and mechanical methods of depressions lead to the formation of burrs and swellings, reducing the quality and operability of the rubbing surfaces of parts, increasing the running-in time.

The method of manufacturing a pumping rod [16 – 20], proposed by O.R. Valiakhmetov and others, includes the use of blanks made of steel of different grades for the body and heads of the rod, thermal and mechanical processing of the blanks is carried out separately, then by friction welding to the ends of the rod, the heads are welded.

The disadvantages are poor quality and stress concentration in the rod. Due to the high heterogeneity of the structural and phase composition at the welding site, the rods break off. The method is not inferior in labor intensity and energy intensity to the method [16], which requires special equipment that welds long parts Ø8 – 30 mm with a force of 10 tons.

Tensile stresses reduce the fatigue resistance of the material, and the structural-phase heterogeneity of the material reduces its corrosion resistance, since the combination of sites with different electrode potential forms many microgalvanopares.

Problems with the hardening of the plunger are currently being solved by spraying a hard alloy with high chemical and mechanical wear resistance on its surface. The experience of operating domestic RDP has shown that nitriding and chrome plating give the best results in wear resistance of cylinders.

Hardening coating — spraying of the outer surface with carbide powders. The base of the powder is nickel (70%), which causes high corrosion resistance. The chromium content in the powder (15 – 18%) determines the high hardness of the coating 56 – 65 HRC. Therefore, these plungers are used in various environments, both with the content of abrasive particles (sand, scale, etc.), and corrosive environments with the presence of hydrogen sulfide (H_2S), and carbon dioxide (CO_2). The thickness of the coating should be at least 0.35 mm, to maintain hardness during wear during work. At the same time, a significant increase in the thickness of the coating (more than 0.6) will lead to its low adhesion to the substrate and chips during operation.

The advantage of chrome plating is in the high hardness and wear resistance of the coating, as well as in the absence of warping (bending) of the cylinder when applying this coating. The disadvantage is the porosity of any chrome coating and the small thickness of the layer. Corrosion tests of the chrome coating show that according to the existing defects, intensive etching occurs, both in width and depth (Figure 1). In addition, the chromium plating process is dangerous to health, 6-valent chromium causes oncological diseases [15,21,22].

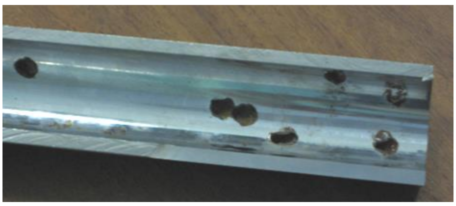

Fig. 1. Foci of corrosion of the base metal of the inner surface of the cylinder as a result of the chrome plating process

The advantages of nitriding include the high hardness and wear resistance (including corrosion) of the nitride layer, the absence of porosity under certain conditions, and the relatively large thickness of the nitrided layer. However, when restoring the cylinder, warping takes place – its transverse bending. This is due to the difference in the thickness of the cylinder itself and the unevenness of the nitrided layer along the diameter of the channel (Figure 2).

The traditional technology of ion-vacuum nitriding (IVN) with a depth of 0.25 – 0.30 mm increases the non-straightness of the axis of the cylinder section with a length of 1 m to an average of 0.2 mm, which exceeds the tolerance for this parameter by 2 times. To ensure a tolerance of 0.1 mm regulated by API standards and GOST, a transverse bending correction is required, after which cracks of 2 – 5 microns appear on the nitrided surface.

In addition, after editing, to ensure a guaranteed clearance between the cylinder and the plunger of 0.025 mm, honing with multi-row honing heads having a rigid body is necessary. Such honing ensures straightness of the channel axis, but removes part of the nitrided layer up to 0.03 – 0.1 mm deep.

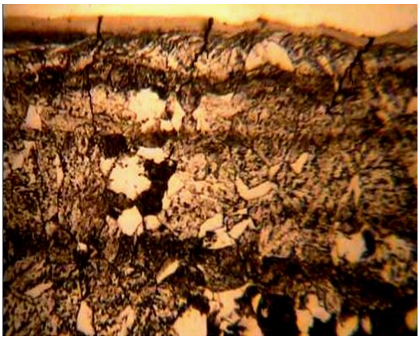

Fig. 2. The appearance of cracks on the nitride surface after bending correction

The advantages of chrome plating are high hardness (Figure 3) and wear resistance of the coating, as well as the absence of warping (bending) of the cylinder when applying this coating.

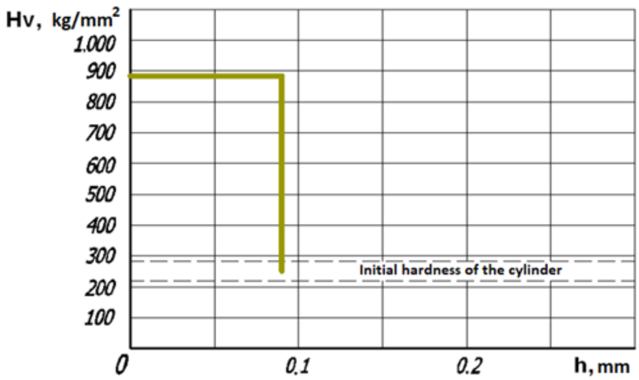

Fig. 3. Hardness distribution over the depth of the chrome layer of the cylinder

The disadvantage is the porosity of any chrome coating and the small thickness of the layer. Corrosion tests of the chrome coating show that according to the existing defects, intensive etching occurs, both in width and in depth of the metal (Figure 4).

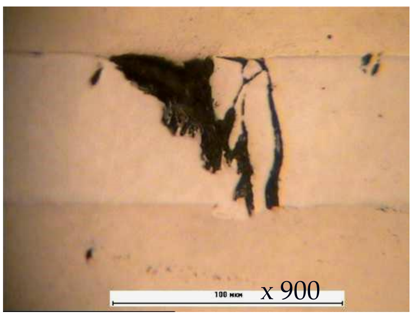

Fig. 4. The state of the chrome coating of steel samples after exposure in reservoir water for seven days at T = 60 °C

After seven days, the dimensions of the defects in depth exceed the thickness of the coating, that is, corrosion of the base metal begins. Comparative corrosion tests of the nitrided layer with the removal of an allowance of 2 – 3 microns and 50 microns showed an increase in the corrosion rate by 3 times, from 0.12 g/m^2h to 0.37 g/m^2h.

Therefore, an important scientific and technical task is the development of an energy-efficient technology for manufacturing a pumping complex with high physical and mechanical properties of the parts of the RDP well.

Plasma technologies for the manufacture of oil-producing equipment using ionized gas, multicomposite powders and wires are widely used in Europe [22 – 25].

Strict requirements for the RDP of low-flow wells are regulated by corrosion-resistant, wear-resistant nickel and cobalt alloys ZMI-ZU, ZhS-6, U-5,000, Fsx-414, etc. The alloy structure consists of a Y-matrix and a uniformly distributed reinforcing fine g/-phase in it. As a result of high rates of abrasive-erosive wear, the alloy undergoes structural transformations, with coagulation, changes in the morphology of the strengthening Y/-phase and carbides in the body and along the grain boundaries. Further operation of RDP is impossible, although the resource of their work is not exhausted [23, 24].

The main disadvantage of the mining complex is a decrease in the physical and mechanical properties of the surface and corrosion destruction of the structure, as well as high roughness, which, when the oil fluid interacts with the released acid-salt radicals of the metal, degrades the structure of the RDP. A.G. Gazarov, L.A Nagirny, and T.V. Prikhodko high mechanical properties of nickel alloy products have been achieved by electrolytic deposition technology [15,16,26]. The main problem is the need to control the microstructure, porosity and compliance with the balance of tensile and compressive stresses. Consequently, in the CIS, the technologies of designing and manufacturing mining complexes lag far behind modern realities. An actual method is manufacturing using highly concentrated sources of laser-plasma energy.

Studies of V.N. Ivanovsky, O.Yu. Elagina, Ya.I. Frenkel, V.N. Dovbysh [27, 28] and the authors of the project showed that laser technologies allow controlling the granularity of the microstructure and controlling the martensitic and austenitic medium of the material, modifying surfaces, and not limiting the stresses in the details, but using their effect (compression–stretching). Scientific and technological needs are concentrated in the absence of energy-efficient technology for laser modification of the inner surface of a small diameter. An important problem that needs to be solved is not only the development of a unique technology for restoring the structure and properties of the pump metal, but also to develop an original installation that ensures the restoration of the inner surface of the pump with a diameter of up to 44 – 50 mm over the entire length of the pump 4 – 6 m. Existing analogues provide hardening of the contact surface, but do not have technical solutions for creating and modifying the structure of the base material and the design geometry of the plunger parts of the complex with its partial loss. Thus, the fundamental difference of the research idea lies in the development and justification of a unique technology for laser modification of the structure and design geometry of RDP with specified physical and mechanical properties.

The motive for the development of innovative recovery technology was the shortcomings of the method of manufacturing a deep pumping complex of low-flow wells. The market of production and restoration services is poor in the supply of high-quality manufacturing of mining complexes due to strict requirements.

The scientific problem is to substantiate the optimal material with high adhesive and corrosion-wear properties, providing phase modification of the coating depending on the modes of laser modification.

Scientists A.A. Al-Taq, V.N. Arbuzov, S.M.A. Zeid, M.L. Galimullin, D.A. Shock, J.O. Sudbury, J.J. Crockett proved that deposits in different wells differ from each other in chemical composition depending on the group hydrocarbon composition of different types of oil [29 – 31].

The authors of the research have established the scientific novelty of the interaction with certain types of metals, quartz compounds and zirconium dioxide. Paraffin molecules participate in co-crystallization with alkyl chains of asphaltenes, forming a point structure. As a result, the paraffin does not form a solid lattice, being redistributed between many small centers and the release of paraffins on the surface is significantly weakened.

The solution to the problem of cylinder wear is proposed to cover the inner surface of the hole with a ceramic protective layer based on nickel alloys of the carbide class, high hardness and inert properties. Plasma and laser spraying technologies are used for spraying ceramic powder. The small diameter (Ø38 – Ø44 mm) and the length of the cylinders (up to 6 m or more) limits the use of plasma spraying technology. The dimensions of the plasma spraying unit are 1.5 – 3 times larger than the possible installation based on laser spraying technology. When using laser spraying technology, the lenses for focusing the laser beam and the light guides can be positioned separately from the feeding device of the deposited material (powder) or in some cases outside the working device. Also, during plasma spraying, in a limited space, the gas jet affects a large area (compared to a laser beam), as a result of which it is possible to melt the sprayed layer, its separation from the part and a change in the structure of the surface layer of the part, which worsens its strength. In turn, the laser beam acts pointwise on the surfacing site and does not cause overheating of the part with deterioration of strength characteristics [32, 33].

Conclusion

From a critical analysis of modern technologies for restoring critical parts of the mining pump design, it can be seen that for surfacing in conditions of a limited coordinate space, laser spraying is more effective than plasma spraying. Modern laser installations exceed the efficiency of plasma installations in terms of weight and dimensions, and unit costs are also reduced due to the low energy intensity of the technology and high efficiency.

An actual solution is to modify the working surface of the cylinder with ceramic materials based on zirconium (ZrO_2 – zirconium dioxide). Zirconium dioxide has a wide range of useful properties (Table 1): high corrosion resistance; high crack resistance among ceramic materials; low thermal conductivity; preservation of strength over a wide temperature range; antifriction properties; inertia to oil products. Mechanical processing in order to bring to the exact dimensions (grinding, honing) of metal-ceramic alloys does not differ from the processing of ordinary metals and alloys.

Table 1. Ceramic alloys based on zirconium dioxide

Properties	**Metal-ceramic alloys**			
Composition	$ZrO_2 + Y_2O_3$	ZrO_2 + MgO	ZrO_2 + CaO	$ZrO_2 + Al_2O_3$
Density, [g/cm^3]	5.8-6.05	5.6-5.7	5.6-5.7	5.4-5.6
Open porosity, [%]	0	0	0	0
Hardness, [HRC]	72	72	72	72
Flexural strength, [MPa]	300 – 1,000	500 – 600	500 – 600	1,900 – 2,100
Compressive strength, [MPa]	2,000 – 2,200	1,800 – 1,900	1,800 – 1,900	1,900 – 2,100
Thermal conductivity at 20 – 100 °C, Вт/мК [W/mK]	2.0 – 2.5	2.0 – 2.5	2.0 – 2.5	5 – 7
Coefficient of linear thermal expansion at 20 – 1000 °C	10 –11	10 –11	10 –11	5 –7
Maximum operating temperature, [°C]	1,000	1,000	1,000	1,000

For the successful implementation of laser recovery technology, it is necessary to develop an original design of an adaptive installation for restoring the physical and mechanical properties of metal products of the inner surface of a small diameter pump. The scientific and practical task is also to determine the physical principle of the formation of internal stresses in the zone of thermal influence of the laser.

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