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The analysis of ways to increase the durability of shut-off valves loaded elements

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Abstract: This review analyzes the problems caused by heavy wear of loaded friction elements of structures, which is typical of almost all industries. This implies the importance of solving problems of increasing their durability. Of particular relevance is the need to solve the problem of improving wear resistance of contact surfaces of special-purpose shut-off valves, being an irreplaceable component of technical equipment used in the oil and gas industry as well as processing industries, nuclear energy, and medicine. It is shown that the effectiveness of solving problems of increasing durability of equipment is largely associated with additional standard processing of loaded friction elements of such structures, and with the improvement of technologies for increasing wear resistance and strength characteristics of their contact surfaces. The analysis of the possibilities of increasing wear resistance by mechanical methods of surface treatment, as well as by methods of surface modification through various functional coatings has been made. It is substantiated that the vacuum-arc method of ion-plasma spraying of a multilayer nanocomposite coating is the most promising way of creating a functional coating to increase the wear resistance of valves. Widespread industrial introduction of the method of beam surface modification of materials makes it possible to obtain such structural-phase states of materials, which are not possible with traditional methods.

Keywords: shut-off valves; friction; wear resistance; ion-plasma spraying; vacuum arc method; beam surface modification of materials; nanocomposite coatings; multilayer functional coatings.

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Анализ способов повышения долговечности нагруженных элементов запорной арматуры

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Аннотация: В настоящем обзоре выполнен анализ проблем, связанных с наличием высокого износа нагруженных фрикционных элементов конструкций, характерного практически для всех отраслей промышленности. Отмечена важность решения проблем, связанных с повышением их долговечности. Показана особая актуальность решения задачи обеспечения износостойкости контактных поверхностей запорной арматуры специального назначения, которая является незаменимой составляющей технического оборудования, используемого в сферах нефтегазодобывающей и перерабатывающей промышленности, атомной энергетики, медицины. Показано, что эффективность решения проблем, связанных с обеспечением долговечности различной техники и оборудования в значительной степени связана как с проведением дополнительной типовой технологической обработки нагруженных фрикционных элементов таких конструкций, так и совершенствованием технологий повышения износостойкости и прочностных характеристик их контактных поверхностей. Выполнен анализ возможностей повышения износостойкости механическими способами обработки поверхностей, а также способами модификации поверхности за счет нанесения различных функциональных покрытий. Дано обоснование того, что вакуумно-дуговой метод ионно-плазменного напыления многослойного нанокомпозитного покрытия является наиболее перспективным способом создания функционального покрытия для повышения износостойкости элементов запорной арматуры. Показаны потенциальные возможности широкого внедрения в промышленность способа пучковой поверхностной модификации материалов, позволяющего получать такие структурно-фазовые состояния материалов, которые при традиционных методах не реализуются.

Ключевые слова: запорная арматура; трение; износостойкость; ионно-плазменное напыление; вакуумно-дуговой метод; пучковая поверхностная модификация материалов; нанокомпозитные покрытия; многослойные функциональные покрытия.

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1. Introduction

Most products, assemblies, and parts are subject to wear and tear, i.e. a gradual destruction and degradation of properties caused by changes in shape, size and physicochemical characteristics. The resulting changes usually accumulate gradually, but can also lead to an avalanche-like degradation and subsequent destruction of loaded structural elements. Often, the main reason for these phenomena is associated with the processes of friction of loaded structural elements [1].

In mechanical engineering, the problem of intensive wear of loaded friction elements of various structures, such as the contact surfaces of valves, cutters of cutting tools, friction clutch disks, bearings, shafts, axles, liners, etc. is quite acute. They are subjected to various types of wear, among which one should note adhesion, abrasive and fatigue types of wear caused by molecular adhesion on the surface of contacting bodies and the subsequent destruction of the formed bonds, the surface damage by small particles of other materials and the changes in the structure of the material [2, 3]. In particular, the main type of wear of shut-off valve elements (O-rings of valves, spindles and slide nuts in their threaded connection, shafts in slide bearings, plungers and seats of control valves, etc.) is adhesive wear, which manifests itself during the friction of any hard surfaces [4, 5]. Serious breakdowns can also be caused by the results of abrasive wear of the shut-off valve parts with debris that gets inside the pipeline during installation, as well as the results of erosion, cavitation and chemical wear, as well as thermal wear of polymer parts [5, 6].

Due to continuous technical improvement, accompanied by an increasing range of operational capabilities and loads, as well as the need for special equipment to work in extreme conditions, the solution to the problem of providing wear resistance and durability of technical tools and equipment remains an urgent scientific and technical problem [7].

Shut-off valves are increasingly used in the construction of systems, assemblies and equipment involved in industrial technological processes under conditions of high pressure at both high and low temperatures. They are designed for installation on pipelines for specialized and medical purposes, such as transportation of various liquid and gaseous media, including chemically aggressive ones: acidic, alkaline, salt, abrasive, etc. high requirements in terms of reliability and durability. A general view illustrating a typical design of shut-off valves is shown in Fig. 1, in which the following parts are numbered: *1* – body; *2* – branch pipe; *3* – plug; *4* – spindle; *5* – outlet flange; *6* – seat; *7* – nut; *8* – stud; *9* – valve flange; *10* – valve nut; *11* – valve stud.

The effectiveness of solving problems of improving durability of technology and equipment is largely associated with the improvement of technologies for increasing wear resistance and strength characteristics of contact surfaces. In this regard, the purpose of this paper is to review and analyze effective methods of increasing wear resistance of loaded elements of shut-off valves.

2. Analysis of the main processing methods of increasing wear resistance of products

An increase in durability and reliability of products is closely related to an increase in their wear resistance. It is advisable to use scientifically grounded approaches at the design stage of friction units for an effective solution of this urgent problem. The rational choice of materials for wear resistance, the optimal design of friction units and the optimization of the operating conditions of the designed products are important for an increase in their service life [8].

With regard to the solution of the problem of ensuring the deceleration or preservation of the speed and degree of wear of products currently used in various areas of the mechanical engineering, it is necessary not only to meet the requirements for

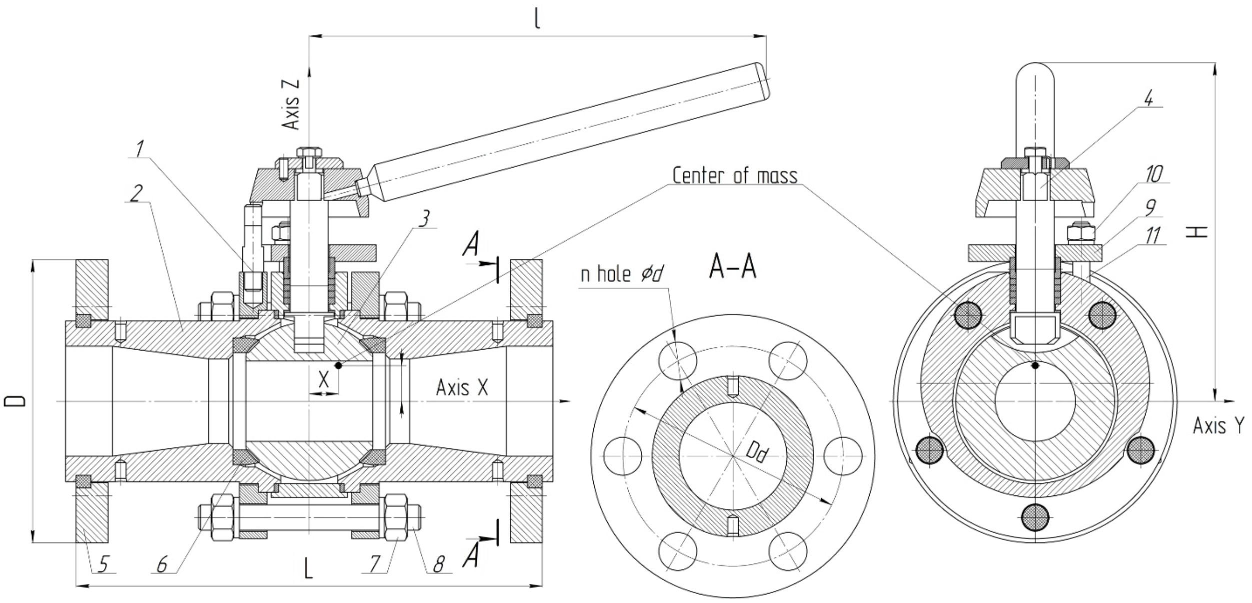


Fig. 1. General view drawing of a flanged valve

operating conditions, timely maintenance and scheduled preventive maintenance, but also use effective lubricants and a wide range of practical processing methods aimed at increasing wear resistance of mating surfaces of technical tools and equipment. The main purpose of lubricants is to reduce frictional resistance and reduce wear on friction surfaces. Liquid (oils, water, high concentration sulfuric acid, emulsions and other liquids), gaseous (air and gas lubricants), plastic and solid (talc, graphite, molybdenum disulfide, etc.) lubricants have found wide application [8].

To increase durability and wear resistance of friction units for various purposes, a number of processing methods such as cutting, surface plastic strain hardening, heat treatment, thermomechanical processing and chemical treatment, application of wear-resistant coatings, surfacing, gas-flame spraying, plasma spraying, electric arc spraying, detonation spraying, sprayfusing, etc. are used [8–10].

The cutting method is based on the action of the cutting tool, causing the compression of the metal layer being cut off. The resulting deformations in the cutting zone contribute to an increase in the hardness of the surface layer and a decrease in its plasticity. For example, as a result of such strain hardening of the surface layer of a part made of aluminum, its microhardness increases in comparison with the initial one by 90–100 %, while the increment for steel is 40–50 %.

The method of surface plastic strain hardening is aimed at increasing the fatigue resistance and hardness of the surface layer of the metal and the formation of compressive strain in it, and surface roughness [8]. For example, hardening of natural steel occurs due to structural and substructural changes (changes in grain structure, density and interaction of dislocations and vacancies, etc.), the occurrence of additional microstrains.

Also, in order to change the structure and properties of metal without changing its chemical composition, various methods of heat treatment are used [11, 12]. These are associated with heating and cooling of metal in the solid state, such as annealing, normalization, quenching, tempering, as well as thermomechanical processing. Annealing makes it possible to reduce internal stress, and achieve grain refinement. Such processing gives the steel plasticity, brings its structure into a more equilibrium state. Normalization also contributes to the elimination of the coarse-grained structure of the metal and the leveling of its mechanical properties, as a result of which the hardness and strength of the steel become higher than that during annealing. The most common type of hardening heat treatment of medium and high carbon steels is quenching followed by tempering. Surface hardening (high-frequency heat treatment, contact hardening, plasma hardening, electrolytic hardening, laser hardening, etc.) contributes to reaching high hardness in the surface layer while maintaining the viscous core of the part [13], while tempering (low, medium and high types) results in reduction of quenching stresses and reduction of hardness in order to obtain required mechanical properties.

Low and high temperature thermomechanical treatment comprises a series of operations of plastic deformation and heat treatment combined in one *t* process: heating, plastic deformation and cooling. The optimal combination of plastic deformation and phase transformations leads to an increase in density and to a redistribution of imperfections in the crystal lattice of the metal, that is, to a structural state that provides a significant increase in mechanical properties. For example, as a result of thermomechanical treatment, the tensile strength of steel increases by up to 1.5 times compared to conventional heat treatment, while the ductility doubles.

Due to its simplicity, accessibility and high efficiency, various types of chemical-thermal treatment have become very widespread. They involve the process of surface saturation of the material with various elements in order to give the desired properties to the surface and the subsurface layer. Among such methods, one can distinguish carburizing, nitriding, low-temperature and high-temperature cyanidation, aluminizing, chromium plating, siliconizing, boriding, etc. They differ from other types of heat treatment because they cause not only structural changes, but also changes in the composition and structure of the surface due to diffusion of elements in an atomic state from the external environment at high temperatures [14].

To impart heat resistance, corrosion resistance, hardness, wear resistance and other properties to the surface of steel parts, the technology of diffusion metallization is used. It involves the process of diffusion saturation of the surface with metals. Diffusion metallization can be carried out in solid (using ferroalloys with the addition of ammonia chloride), liquid (immersing parts in molten metal) and gaseous (chlorides of various metals) media within a fairly wide range of technological processes, in particular, such as siliconizing, aluminizing, chromium plating, nickel plating, oxidation, iron plating, etc.

Surfacing is used in restoration of worn-out and manufacture of new parts of machines and mechanisms. A layer of metal or alloy is applied to the surface of the product by fusion welding. The surfacing of functional coatings is used to obtain a layer with the desired properties on the surface of products [15]. The base metal provides the required structural strength. The deposited metal layer gives the part special specified properties: wear resistance, fire resistance, heat resistance, corrosion resistance, etc.

Anti-friction non-abrasive finishing treatment is also used in a number of processes. It implies the friction surfaces of parts that are covered with a thin layer (1–3 microns) of bronze, brass or copper, as a result of which they acquire high antifriction properties and contact stiffness. As a result of this procedure, the friction coefficient is reduced by 1.5 times, and the wear resistance is increased by 2–3 times.

Various methods of thermal spray of surfaces are used to create wear-resistant, corrosion-resistant, antifriction, heat-resistant, thermal barrier functional coatings in the form of thin films on the surface. There are a lot of such methods, including gas flame spraying, high-speed flame spraying, detonation spraying, fusion spraying, electric arc metallization and activated electric arc metallization, plasma spraying, etc. All of them are based on the processes of heating, dispersion, and transfer of condensed particles of the sprayed material onto a substrate by a gas or plasma flow [15].

The features of thermal spraying of surfaces are:

– the possibility to apply coatings from various melting materials;

– no mixing of the base material and the coating material;

– slight heating of the surface during coating;

– the possibility of applying several layers, each of which has its own function (for example, corrosion-resistant and thermal barrier layers).

A wide range of problems related to the need to maintain and slow down the speed and degree of wear of parts in various areas of machine-building industry will be solved with the help of rational use of the above and a number of other processing methods. For example, galvanization and coating with special antifriction materials based on solid lubricants that provide chemical resistance are widely used methods of protection against damage and corrosion of threaded elements of valves [16]. Compared to electroplated coatings, such coatings are more resistant to wear and tear and continue to operate after multiple cycles of assembly and disassembly of valves. In Russia, a line of anti-friction solid lubricating coatings with the addition of polytetrafluoroethylene of MODENGY 1010, 1011 and 1014 grades is widely used for threaded fasteners of shut-off valves (the latter also contains molybdenum disulfide).

To reduce the intensity of chemical wear to which parts of valves are exposed under the impact of working media (i.e. total corrosion – across the entire metal surface, crevice corrosion, intergranular corrosion and pitting corrosion), corrosion-resistant metal and non-metallic coatings are used in accordance with the Russian Standard 9.301–86. Some of them, such as the MODENGY coatings that have already been mentioned above have very high anti-corrosion properties and are easy to use.

The effectiveness of other coatings is not always clear enough. For example, the results of a number of experiments have shown that traces of corrosion damage are possible on galvanic and gas-thermal coatings, and corrosion of the base metal was found on the laser-plasma coating [17–19].

Traditional processing methods (galvanic treatment, chemical-thermal treatment, painting, applying polymer coating, etc.) used for treatment of gate valve assembly elements or more modern ball valves and other elements do not fully provide an increase in wear resistance of friction surfaces in valves.

Thus, a significant increase in wear resistance of the loaded friction elements of the shut-off valve structures becomes possible as a result of the development and implementation of new technologies for surface modification of materials, based, among other things, on the use of various methods of thermal spraying of protective coatings.

3. High-strength protective coatings

The structural-phase state of a thin surface layer has a significant and, in many cases, a dramatic impact on the wear and fracture of high-strength materials [19, 20]. The absence of a part of interatomic bonds at the surface atoms determines the special structure of the surface layer and its energy state. This state should be considered not just as a weakened crystal, but as a system of nanoclusters, whose behavior is fundamentally different from an equilibrium crystal with translational symmetry. As a consequence, the surface layer under loading of a solid more intensively loses its shear stability in comparison with the volume of the crystal, exhibiting specific mechanisms of plastic flow of a non-dislocation nature [21].

In this regard, the further development of technologies for the deposition of high-strength coatings, which provide a decrease in contact pressures by increasing the bearing capacity of the surface and reducing the adhesive interaction on the spots of actual contact, is an extremely urgent task.

It should be noted that at present many industries have already introduced a number of varieties of vacuum deposition technologies, which imply the creation of a directed flow of particles of the sprayed substance (atoms, molecules or clusters) in a vacuum medium in the form of condensate, and its subsequent deposition on the treated surface. There are several methods of such spraying, for example, resistive thermal evaporation, electron beam evaporation, ion-plasma spraying, and others. In all these methods, processes in a vacuum chamber can take place in a reaction gas environment, with additional ionization, bias voltage, or without the listed conditions. Different metals (titanium, aluminum, copper, nickel, chromium, etc.), their alloys (NiCr, Cr–Ni–Si, TiO_2, Al_2O_3, etc.), chemical compounds (oxides, carbides, etc.), as well as cermet and composite glasses are used as spraying materials.

The high performance thermal evaporation method allows for deposition of a wide range of materials, including organic and inorganic polymers and metals. The method of electron beam evaporation makes it possible to deposit refractory materials or dielectrics on a substrate. In this case, the film is also clean and homogeneous.

Vacuum ion-plasma methods are of great importance among the methods of applying protective coatings through the action of high-energy particle and quantum fluxes on the surface of the part. Their characteristic feature is structural-phase transformations in the condensate deposited on the surface and in the very surface layer of a part placed in a vacuum chamber [22].

The main advantages of these methods are the ability to create a high level of physical and mechanical properties of materials in thin surface layers; application of dense coatings of refractory chemical compounds that cannot be obtained by traditional methods.

The most widely used in mechanical engineering are two fairly universal methods of ion-plasma spraying of coatings: magnetron sputtering and vacuum-arc deposition [19].

In the process of magnetron sputtering, a feature of which is a relatively high gas pressure in the chamber, high-energy particles moving in the plasma collide and separate atoms from the surface of the target material, which then condense in the form of a film on the substrate. The spraying process takes place at a high speed. The resulting film coating, the composition of which is identical to the target material, has high adhesive properties. The magnetron sputtering method makes it possible to deposit films on substrates with low heat resistance.

The method of vacuum-arc deposition of coatings utilizes the movement of ions in a vacuum thin-film technology resulting in formation of thin films on a substrate (product, parts) by condensation of material from plasma flows generated on the target cathode in the cathode spot of a vacuum arc of a high-current low-voltage discharge (current strength 150–300 A at a voltage of 20–30 V), which develops exclusively in the vapors of the electrode material. A wide range of superhard and nanocomposite coatings can be synthesized using this technology, including TiN, TiAlN, CrN, ZrN, AlCrTiN and TiAlSiN. Also, this technology is widely used for the deposition of diamond-like carbon films. Since the deposition of this type of coatings is especially sensitive to parasitic inclusions (macroparticles), the equipment for this technology necessarily uses plasma beam filtration. The vacuum arc can also be used as a source of metal ions/plasma for ion implantation or combined plasma immersion ion implantation with coating deposition.

The high-performance method of vacuum-arc evaporation is used to spray refractory metals and complex alloys; the resulting coatings have high adhesion to the substrate, dispersed structure and low porosity.

One of effective ways of changing the structure and tribomechanical properties of steels and alloys involves ion-beam modification of the surface layer with high-energy ion fluxes. When the material is exposed to a powerful pulse of an ion beam, a surface layer with a thickness of the order of the path of particles in the material (10–100 μm) is rapidly heated to the temperature of phase transitions, i.e. to the melting temperature. If a layer of material heated in this way is rapidly cooled by removing heat into the thickness of the material by means of thermal conductivity, then the microstructure and phase composition of the surface layer change [23]. For example, the grain size is reduced from hundreds of microns to fractions of a micron. The phase composition is homogenized; for example, carbides are crushed and uniformly distributed in steels. With a change in the phase composition, the appearance of metastable phases and compounds is possible, which cannot be formed by conventional methods of heat treatment of materials [24].

The method of beam surface modification of materials is based on ion sputtering, ion implantation, as well as implantation by recoil atoms or ion mixing. As part of these procedures, the following processes take place – cleaning and surface preparation of substrates before spraying coatings to improve adhesion; introduction of high-energy ions into the surface layer of the material during its bombardment; introduction of recoil atoms rather than primary high-energy ions into the doped material, including those removed from a thin film previously deposited onto the workpiece [19].

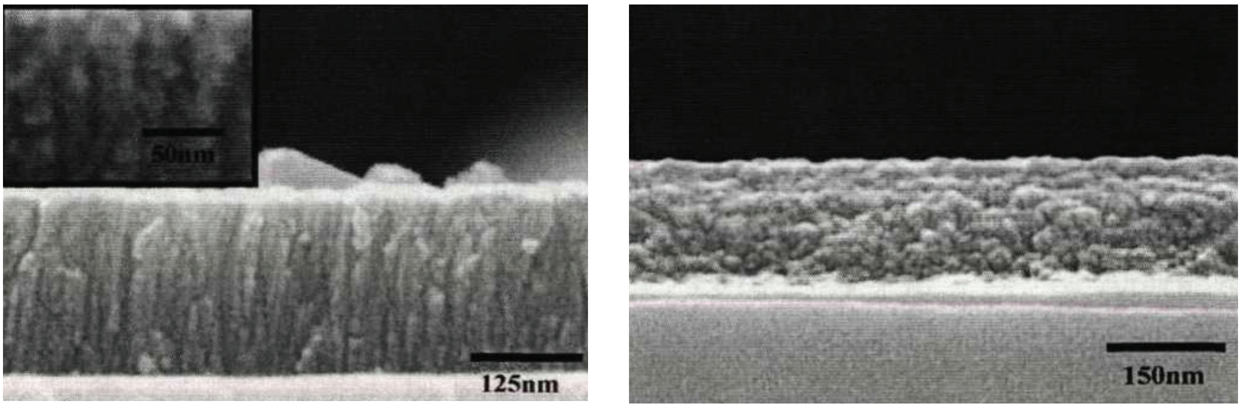
The maximum sputtering effect is possessed by the ions of those elements that have filled *d*-shells (Pb, Sb, Sn, Cd, etc.), as well as ions of elements with filled *p*-shells (ions of inert gases). The maximum yield of emitted atoms is also observed from metals with filled *d*-shells.

It should be noted that the hardening effect is characterized by a number of phenomena that have a certain effect, the value of which depends on the temperature and type of the processed material, ion irradiation regimes and the type of ions. Possible mechanisms for modifying surface properties include hardening caused by the formation of solid solutions (in this case, an energy barrier slows down the movement of dislocations), the pinning of dislocations by an embedded impurity (atoms, complexes, precipitates) and radiation defects, a decrease in the grain size, an increase in the area grain boundaries that prevent the movement of dislocations and slip bands, blocking of dislocations by internal elastic stresses caused by the volume mismatch of the interstitial atoms and the occurrence of pore precipitates. They also include the formation of structures with hardening phases that cause precipitation hardening. Thin layers of oxides, sulfides, or carbon-rich layers formed during ion bombardment often act as a solid lubricant that reduces the coefficient of friction and wear of materials. At the same time, as a result of spraying, a significant smoothing of the surface occurs, and micropoints disappear. This process is essential for wear and friction.

The medium-energy area of ion implantation has received the most intensive development and widespread practical application so far. When using the method of implantation by recoil atoms and ion mixing, effective doping and mixing is achieved at lower doses and radiation energies than in the method of direct implantation [19]. A significant drawback of implantation with recoil atoms is sputtering of the surface film during bombardment; it is overcome by developing the method of dynamic mixing, when the surface is bombarded with a high-energy ion beam, simultaneously with the deposition of alloying substance atoms on it.

Using the method of beam surface modification of materials, it is possible to form alloys and an amorphous layer on the working surfaces, increase the wear resistance of friction parts of mechanisms by 2–4 times, increase the dynamic strength of products by 2–4 times, and more than double the corrosion resistance of the working surfaces of parts from steels and alloys.

A significant increase in the mechanical properties of the near-surface regions of metals and alloys during ion implantation, by methods of ion-plasma and ion-beam spraying of coatings, is influenced not only by the ion energy (Fig. 2), but also by the type and dose of ions, the composition of the coating, the gas pressure, material, substrate temperature and other parameters [25].

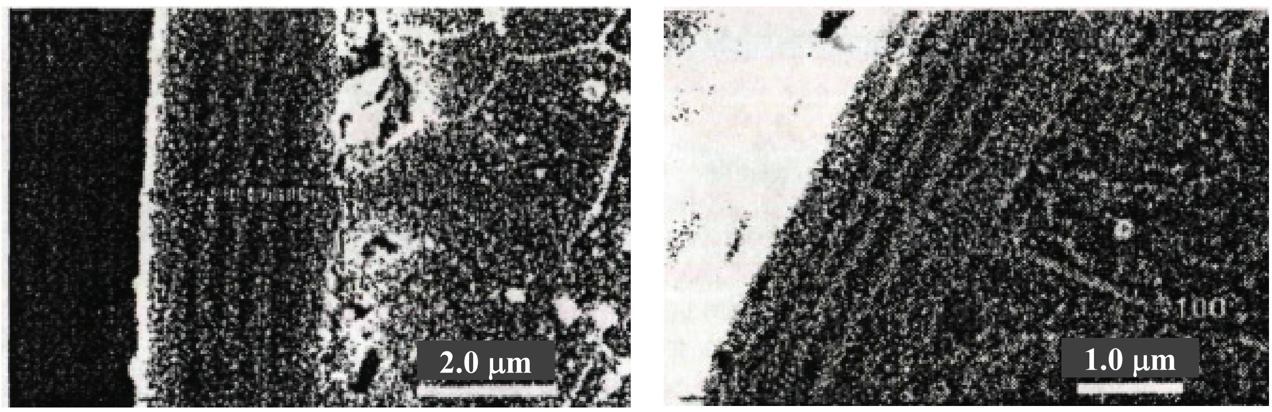


(*a*) (*b*)

Fig. 2. SEM images of the cross-section of TiN coatings obtained at a substrate temperature of 500 °C and a bias potential of –200 V (*a*) and –500 V (*b*) [26]

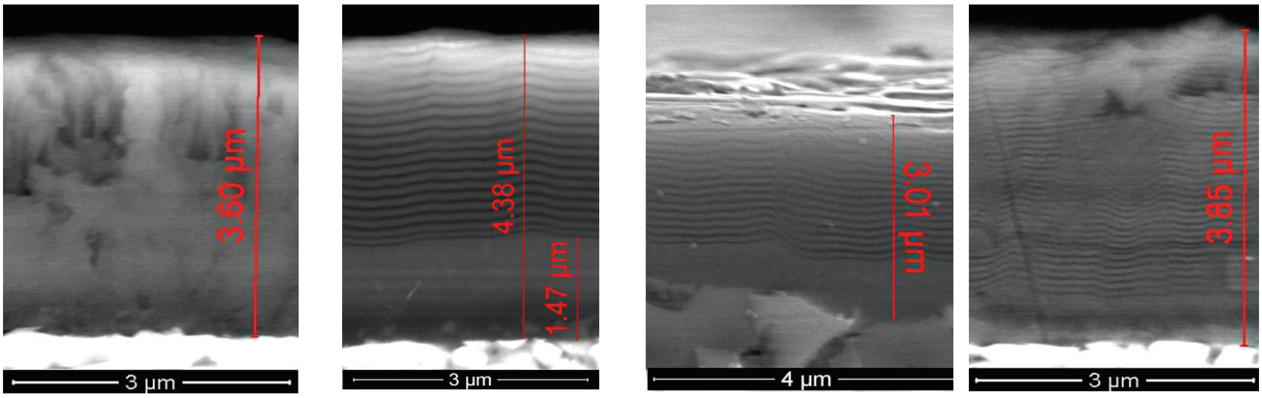
It should be noted that refractory compound as a coating does not always meet the requirements for protective wear-resistant coatings operating under high thermo-mechanical loads. In this regard, when using the methods of ion-plasma and ion-beam spraying, multicomponent coatings are being increasingly used [19, 26] (Fig. 3). It was found [27–30] that when adding one or more chemical elements, which are insoluble in the base substance or have limited solubility, to the base material of the coating, its grain structure is refined. The added elements segregate along the grain boundaries of the main component in the form of a very thin nanocrystalline or amorphous layer, which acts as an obstacle to further grain growth. As a result of this mixing process, it is possible to obtain single-layer two-phase solid and superhard composite coatings, in which the solid grains of the main phase are separated by thin layers of atoms of another phase, segregated along the boundaries of the first [19].

A number of scientific and practical works on the development of technologies for obtaining multilayer coatings (including those based on the possibilities of methods of ion-plasma and ion-beam spraying of coatings), in which microlayers, consisting of materials differing in composition and structure, with a thickness of 0.05–0.5 microns alternate [32, 33]. Thus, in [34], the use of a multicomponent multilayer composite coating (Zr–ZrN–($Cr_{0.58}Zr_{0.20}Al_{0.22}$)N) with a nanoscale structure, developed through the experimental studies, and consisting of three functional layers (wear-resistant layer, intermediate barrier layer, adhesive sublayer), the practical research problem of increasing the durability of the cutting tool during end milling of the titanium alloy VT20 was solved. In this case, coatings were used as alternatives, the microstructure of which is shown in Fig. 4 [34].



(*a*) (*b*)

Fig. 3. SEM images of the cross-section of a microlayer coating on a 7KhNM steel substrate (*a*) and the distribution of the concentration of Ti, Cr, Fe elements in it (*b*) [31]



(*a*) (*b*) (*c*) (*d*)

Fig. 4. SEM images of the microstructure of various coatings:
a – Ti–TiN; *b* – Ti–TiN–(Ti, Cr, Al)N; *c* – Zr–ZrN–(Zr, Al)N; *d* – Zr–ZrN–(Cr, Zr, Al)N

A comprehensive analysis of the experience of using and the research findings of methods for applying high-strength protective coatings (including layered ones, with layers alternating from different materials at the nano- and micro-level), gives reason to believe that when solving the problems of developing coatings with unique mechanical characteristics for critical high-load elements of shut-off valves, it is extremely promising to use and develop technological solutions implemented in the framework of the ion-plasma spraying technology, and, first of all, the vacuum-arc method of ion-plasma spraying of a hardening material based on a multicomponent nanocomposite material.

To date, a certain scientific and technical groundwork has already been accumulated in terms of solving this problem. For example, in the Russian Federation, an innovative environmentally friendly ion-plasma technology has been tested for increasing the tribological characteristics, resource and wear resistance of pipeline systems for transporting working media. According to estimates, the surface hardening process using this technology does not change the structure and properties of the base metal at a coating thickness of 10 to 30 μm. The friction coefficient decreases 3–5 times, and the corrosion resistance of materials in aggressive media increases 4–6 times.

4. Conclusions

The operational characteristics and reliability of valves, including ball valves with a ball-seat tribointerface, have a significant impact on the efficiency of technological processes in these areas. There are many industries in which parts and mechanisms of various technical tools and equipment are subject to intense wear and tear, including due to extreme working conditions. This also applies to pipeline valves, which are an irreplaceable component of technical equipment used in the fields of oil and gas production and processing industries, nuclear energy, medicine, etc.

The effectiveness of solving problems of increasing durability (not only physical, but also functional, and economic) of technologies and equipment is largely associated with both additional typical technological processing of loaded friction elements of such structures, and with the improvement of technologies, increasing wear resistance and the strength characteristics of their contact surfaces.

To increase the durability and wear resistance of friction units for various purposes, a number of traditional technological methods of machining are used. The service life and reliability of the protective surfaces obtained in this case, due to their irregularity and randomness, from the point of view of both microgeometry and work hardening, and induced technological residual stresses, are insufficient.

To reduce the negative factors of mechanical processing, various methods of surface modification are used by applying various thin-film coatings. Even films with a thickness of 10–100 nm may be sufficient to significantly increase wear resistance. High requirements for products operating under extreme conditions lead to the need to create new, more promising materials, some of which are nanocomposite and multicomponent materials. Their use makes it possible to meet the specified requirements for plasticity with increased hardness and rigidity of parts.

The results of the comprehensive study showed that to effectively increase the wear resistance of highly loaded critical elements of shut-off valves for special and medical purposes, the most suitable method for applying protective coatings based on a multicomponent nanocomposite material is the vacuum-arc method of ion-plasma deposition of a hardening material. The technological process of applying multicomponent nanocomposite coatings to wear-resistant structural elements of valves includes four successive stages: preparatory; ionic cleaning and heating; application of multicomponent nanocomposite coatings; cooling products. The preparatory stage is the preparation and adjustment of all units and assemblies of the installation for the application of multicomponent nanocomposite materials and the preparation of the processed products. The start-up stage includes preliminary cleaning of the working surfaces of the processed products with a glow discharge for further application of multicomponent nanocomposite coatings. The stage of applying multicomponent nanocomposite coatings is ionic treatment and deposition on coatings on the working surfaces of the processed products. The final stage of application is the termination of the deposition of multicomponent nanocomposite coatings on the working surfaces of the processed products and smooth cooling of the processed product in the chamber of the installation.

Being a promising technological approach used in industry instead of traditional ones, the method of beam surface modification of materials deserves attention, which makes it possible to obtain such structural-phase states of materials that, in traditional methods (heat treatment in furnaces, quenching in acid and salt solutions, galvanic coating) are not implemented. It has ample opportunities in terms of saving electricity, increasing production efficiency, and reducing environmentally harmful effects.

It is advisable to recommend the named methods of creating functional modifying coatings to increase the wear resistance of the contact surfaces of the tribo- interface in special-purpose shut-off valves designed for operation in aggressive conditions.

5. Funding

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6. Conflict of interests

The authors declare no conflict of interest.

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