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STRENGTHENING OF FACE IMPULSE SEALS RINGS BY ELECTROEROSIVE ALLOYING METHOD

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The results of the metallographic and durametric studies of the samples made of steel 40X (40H), 12X18H10T (12H18N10T) and 38X2МЮА (38H2MUA) steel grades; nickel alloy ХН58МБЮД (HN58MBUD) and beryllium bronze БрБ2 (BrB2) with combined electroerosive coatings are presented. It has been found that the most preferable coatings for the steel substrates are the strengthening coatings having the composition of ВК8 + Cu + ВК8 (WC8+Cu+WC8), and those for the nickel alloy of ХН58МБЮД (HN58MBUD) are the ones having the compositions of ВК8 + ВК8 + Cu (WC8+ WC8+Cu) and ВК8 + ВК8 + Ni (WC8+WC8+Ni) that are formed on the surfaces previously cemented by the electroerosive alloying method (CEEA). To strengthen beryllium bronze, there is recommended the method of electroerosive alloying (EEA) by a chromium electrode with preliminary and final CEEA.

Key words: *steel, nickel alloy, beryllium bronze, coating, electroerosive alloying, cementation.*

Introduction. The creation of reliable sealing units that ensure long-term tightness under condition of a wide range of temperature and pressure changes is one of the main problems arising at designing pump and compressor machines and packages.

Face impulse seals allowed increasing the level of reliability and tightness of modern rotary machines. They are widely applied in high-speed pumps and high-pressure compressors. The face impulse seals working surfaces are in contact with each other for a very short period of time, only at the moment of a machine starting and/or shutting down.

Face impulse seal rings are designed to form a friction pair operating as a main sealing element; therefore, they should be made of special materials selected from a group of proper ones depending on operating conditions. Correctly selected materials for the face impulse seal rings provide for the reliable, safe and trouble-free operation of the sealing unit and, therefore, the whole package.

Continuous development and improvement of technology is accompanied not only by increasing operation condition parameters of machines and mechanisms, but also by an appearance of new, cheaper but no less reliable composite materials that combine protective properties of the coatings with the mechanical strength of the base.

The investigations aimed at searching less-scarce, cheaper but no less reliable materials to be used for manufacturing face impulse seals are relevant and well-timed.

Analysis of Main Achievements and Publications. The seals operability is affected by design, technological and operational factors. The most important ones are properties of working and environmental media, operating conditions, properties of materials for joint to be sealed and also for sealants, permissible leakage limits, resource, service life, toxicity and chemical aggressiveness of the media [1].

The face seals with impulse balancing of the axially moving element have comparatively recent history - 1974 [2].

Traditional schematic construction of the face impulse seals is shown in Figure 1. Closed chambers 2 are located at the working surface of the axially moving ring 1; several feeding channels 4 are provided at the surface of journal disk 3. The feeding channels successively connect closed chambers 2 with cavity A to be sealed in the course of the thrust ring rotation.

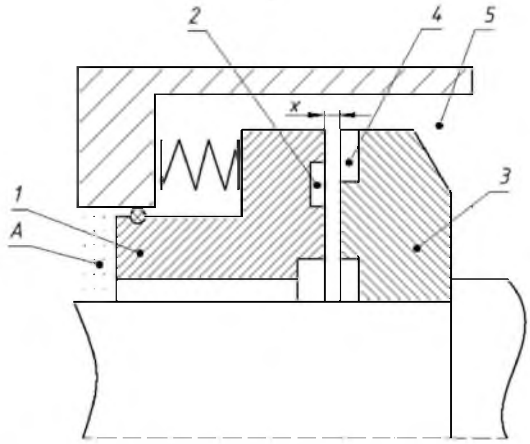


Fig.1 – Traditional schematic construction of face impulse seal

The functional principle of the impulse seal is based on the fact that feeding channels 4 regularly connect the chambers with high-pressure cavity 5 in the course of the rotor rotation. As a result, pressure surges (impulses) occur there in the chambers, causing a change of the axial force balance.

The forces act on the axially moving ring, and, as a result of the fact, there is occurred separation of the face pair sealing surfaces by an operating medium thin layer, which thickness depends on the dimensions of the chambers and feeding channels.

Liquid lubricated face impulse seals have been studied in a wide range of parameters of operating condition, namely, compressible pressure drop up to 16.0MPa and sliding speed up to 100 m/s. Due to their high performance, such seals successfully operate in high-speed feed pumps at nuclear and thermal power plants. On average, their operating time between scheduled repairs of pumps is at least 8,000 hours, while the degree of wear at the path of 106 km remains within 1 - 2 µm, which is characterized as zero wear for friction units. Under typical operating conditions (pressure of 2.0 to 4.0 MPa, circumferential speed of 40 to 60 m/s) the leakage level is only of 1 to 2 l / h [3].

In [4], there is analyzed operation of gate pulse seals. It is noted that the use of such seals can save energy and resources, as well as improve the ecological safety of pump and compressor equipment.

In some corrosive media, wherein the use of seals made of non-metallic materials is limited or impossible for detachable joints, there are used metal seals [5-7].

Until recently, it had been believed that the face impulse seals were operable only in liquid media. However, theoretical and experimental studies have shown that those seals work both in liquids and gases.

The unique studies of impulse seals were performed at ultrahigh operating condition parameters, namely, pv > 400 MPa · m/s in a cryogenic liquid (nitrogen liquid, t = -195 °C). Those ones showed that such seals were not very sensitive to thermal physical properties and temperature of working medium. This suggests the universality of the face impulse seals and the great practical value thereof [8].

Considering the fact that under operating condition of high and ultra-high pressures, extreme temperatures (from high to cryogenic ones), corrosive environments, etc., where the use of the seals made of non-metallic materials in detachable joints is limited or impossible, it is advisable to use metal seals, for which there are no restrictions, except the strength of the sealing material itself and also the thermal resistance of the coating material [9].

In our opinion, taking into account the short contact time required for the faces of the rings of the face impulse seals, it is not necessary to make them entirely from scarce and expensive materials, it is enough to ensure the proper wear resistance of the working surfaces by applying a wear-resistant coating thereon. Moreover, it is possible to provide the proper operability for the seals having high corrosive and chemical activities by changing the chemical compositions of their coatings.

In recent years, to improve the quality of the surface layers of machine parts, the method of electroerosive alloying (EEA), namely, the process of transferring a material to a surface of a product using a spark electric discharge, has become increasingly important. Its specific features that attract technologists are the followings: locality of action, low energy consumption, lack of volumetric heating of the material, strong bonding of the applied material to the base [10].

Thus, the purpose of the work is to improve the quality of the working surfaces of the face impulse seals made of qualitatively different materials by applying wear-resistant coatings being formed thereon using the EEA method.

Research Technique. The EEA process was executed at EIL-8A and EIL-9 installations in an automated mode with the discharge energy range (Wp) of 0.04 J to 6.8 J. Strengthening was carried out with the use of screw-cutting lathe of model 16K20 (Figure 2). The electrode was run by the lathe mechanisms. The choice of automatic strengthening modes (spindle speed, feed rate) was made based on the specified process performance.

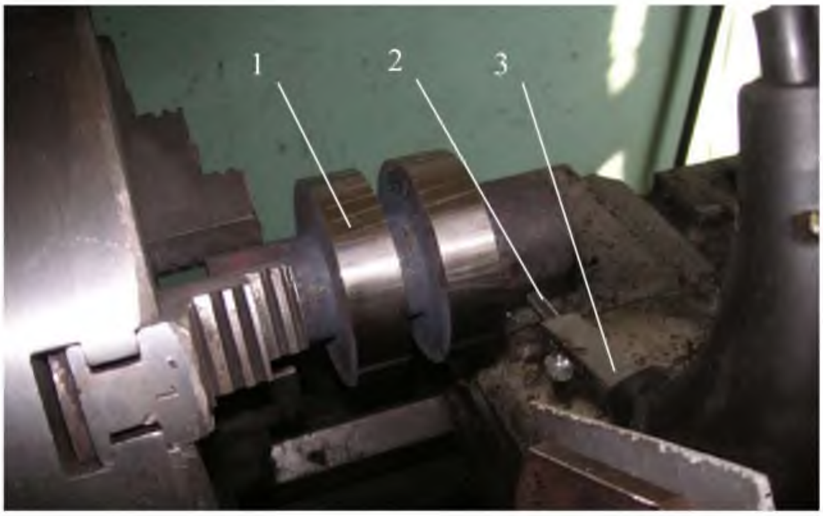


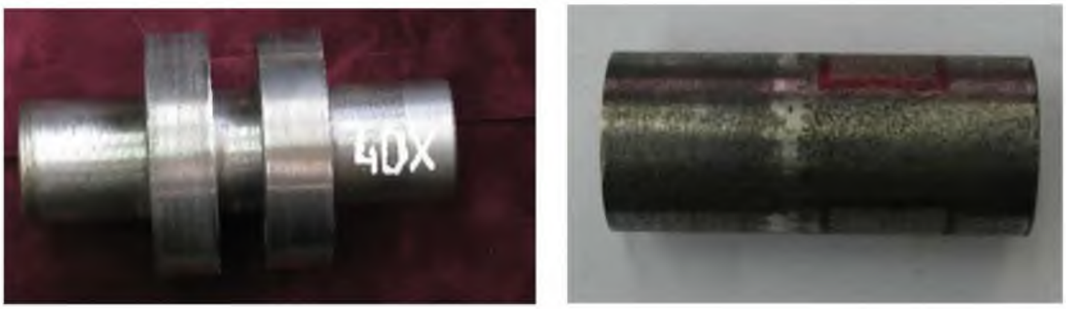
Fig.2 – Scheme of strengthening surface by the EEA method in automated mode:
1 - sample; 2 - electrode; 3 - vibrator

To conduct research, there were used special round samples made of 40H, 12H18N10T and 38H2MUA steel grades and HN58MBUD nickel alloy each designed in the form of a coil consisting of two disks being 50 mm in diameter and 10 mm in width, which are connected to each other by a spacer being 15 mm in diameter and having two technological sections of the same diameters, and also a sample in the form of a cylinder being 50 mm in diameter and 100 mm in length (Figure 3: a; b)

The surfaces of the disks and the cylinder were ground up to Ra = 0.5 μm. The samples were fixed in the chuck of the lathe, and further they were carburized using the EEA method (CEEA), coated and processed with the help of the method of non-abrasive ultrasonic finishing.

The CEEA method was carried out at such values of discharge energies as 0.6; 2.6, and 4.6 J. The installation mode of 6.8 J was not applied because of the significant values of the surface roughness. As an electrode, there was used the graphite electrode of MPG-6 grade.

The method of non-abrasive ultrasonic finishing was carried out on the basis of the screw-cutting lathe of 16K20 model (Figure 4) with the use of PMS-39 magnetostrictive converter and UZU-030 ultrasonic generator.



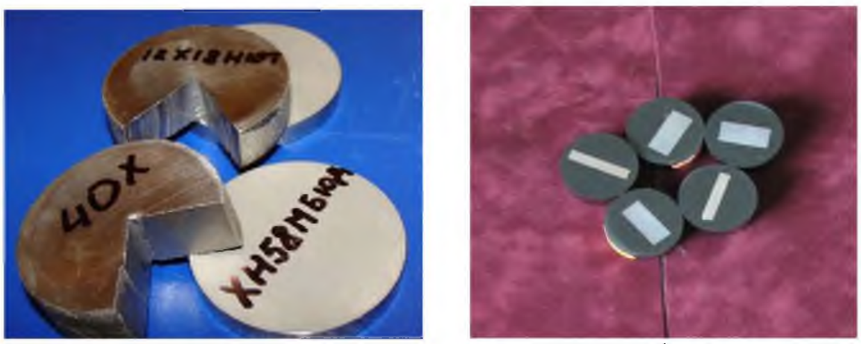
a b

Fig.3 – Round samples: a - in the form of a coil, b - in the form of a cylinder

Fig.4 – Using the method of non-abrasive ultrasonic finishing after CEEA and EEA y

To improve the quality of the surfaces of the elements for the face impulse seals for chemical and petroleum mechanical engineering, as well as the food industry, stainless steel, highly alloyed with chromium and nickel, was used as a cathode. This is 12H18N10T steel of austenitic class having 140 to 170NV hardness after final heat treatment. To develop a technology for strengthening component parts working at low temperatures and high pressures (pumps in refrigeration units, face impulse seals for turbine pumps of liquid rocket engines), there were performed the studies of the alloys on nickel and copper bases, respectively, HN58MBUD and BrB2 beryllium bronze having hardness of 400 and 370 NV, respectively. 38H2MUA heat-resistant and relaxation-resistant steel was used for manufacturing the component parts operating under high temperature conditions. 40H constructional alloyed steel is one, which is widely used in mechanical engineering for manufacturing improved component parts of increased strength. Copper, nickel, chromium and WC8 hard alloy were used as electrodes.

To perform metallographic and durametric studies, individual segments were cut from circular samples, and the samples in the form of parallelepipeds were obtained from the flat ones. After that thin sections were made thereof (Figure 5). Before manufacturing of the thin section, to eliminate edge effect while alloying, the sample face was milled to obtain a depth of at least 2 mm. To prevent crushing the coating layer and also lowering of the edge, the sample was fixed with a counterbody in a clamp.



a b

Fig.5 – Producing thin sections for metallographic and durametric studies:
a - disks with cut segments, b - obtained thin sections

Then the thin sections were subjected to chemical etching in order to reveal the structure in a reagent. The obtained thin sections were examined with the help of Neofot-2 optical microscope, where the quality of the layer, its continuity, thickness and structure of the sublayer zones, namely, the diffusion zone and the zone of thermal influence, were evaluated. Simultaneously, a durametric analysis was carried out to determinate the microhardness distribution in the surface layer and in the zone all over the depth of the thin section from its surface. The process of the microhardness measurement was carried out on PMT-3 microhardness meter by pressing a diamond pyramid under the load of 0.05 N, according to GOST 9450-76.

At all the stages of processing the thin sections, there was measured the surface roughness using the profilograph-profilometer, model 201 of the Caliber plant production. At the same time, the obtained results in the form of graphs were transmitted through a special device to a computer monitor.

The discussion of the Results. A promising way to increase the wear resistance of the rings for the face impulse seals is an EEA formation of the quasi-multilayer combined electroerosive coatings on the face operating surfaces, which coatings should combine lubricating and anti-wear properties. Such coatings are represented by the quasi-multilayer combined electroerosive coatings comprising hard and wear-resistant materials and also soft anti-friction ones.

As a result of our previous studies, it had been found out that the most preferable coatings were the quasi-multilayer combined electroerosive coatings of WC8+Cu+WC8 composition, wherein the first and the last layers of WC8 hard alloy were deposited at Wu = 0.2 J, and the layer of copper was deposited at Wu = 0.08 J, when the microhardness was at the level of 8740 MPa, and the continuity was 100% (prototype) [7]. However, the thickness of the formed coating (30-40 μm) is not sufficient for most of the rings designed for the face seals.

To improve the qualitative characteristics of the surface layers being formed, there were investigated the quasi-multilayer combined electroerosive coatings formed according to the scheme of WC8+Cu+WC8. The coatings were applied onto the 40H steel samples that were subjected to the CEEA process at the discharge energy of Wu = 0.6 J.

The roughness of the EEA formed layer significantly depends on the value of the initial roughness of the surface, and, the higher the initial roughness, the higher the final one. Taking into account the fact that after the CEEA process the surface roughness of the samples increases and reaches up to Ra = 0.8-0.9 μm, and also that, with the CEEA process, in the heat affected zone, there can be occurred the process of tempering, the first hard alloy layer of WC8 was applied at the discharge energy of Wu = 0. 1 J, which is smaller than in the prototype, where Wu = 0.2 J. The second layer (copper) and the third one (hard alloy WC8) were applied at different operating conditions (see Table 1).

The data of Table. 1 indicate that the most preferable quasi-multilayer combined electroerosive coatings are those ones, wherein the first and last layers of the hard alloy BK8 were applied at the discharge energy of Wu = 0.1 and copper - at Wu = 0.04 J.

Thus, to increase the wear resistance, the reliability and durability of the steel rings of the face impulse seals, there is proposed a new method, which, like a prototype, comprises the stage of applying the quasi-multilayer combined electroerosive coatings of the composition formed in WC8+Cu+WC8 sequence, wherein the above said layers are applied at lower energy values (the first and last layers of the hard alloy WC8 are applied at Wp = 0.1, and the copper layer is deposited at Wp = 0.04 J), and before applying the quasi-multilayer combined electroerosive coatings, the working surfaces of the rings are subjected to the CEEA process at the discharge energy values in the range of 0.05 to 4,6 J. As a result, the thickness of the layer of the increased hardness is increased by the depth of the cemented layer.

Table 1

Results of metallographic studies of quasi-multilayer combined electroerosive coatings

Electrode material	Wu, J	Thickness, μm		Microhardness, MPa		Ra, μm
		layer	transition zone	layer	transition zone	
WC8	0.1					0.5
Cu	0.04					
WC8	0.1					
WC8	0.1	up to 15	60-65	6420...7570	7500...9580	0.5
Cu	0.08					
WC8	0.1					
WC8	0.1	up to 15	up to 60	5520...6970	6480…9300	0.8
Cu	0.08					
WC8	0.2					
WC8*	0.2	12...20	up to 60	6330...8740	6030...9500	0.7
Cu*	0.08					
WC8*	0.2					

* - For comparison, the quasi-multilayer combined electroerosive coatings were applied under the prototype operating conditions.

While changing the energy of the discharge during the CEEA operation in the range of 0.05 to 4.6 J, the new method makes it possible to form the layers of the working surfaces of the face impulse seal steel rings, being of increased hardness from 4-5 to 320-350 μm in thickness

Taking into account the fact that to form qualitative coatings in the course of the EEA process, the initial surface roughness should not exceed the value specified as Rz < 6.3 μm (Ra ≈ 1.2 μm), the CEEA process as a preliminary operation, according to the proposed method, can be produced without additional processing but only at the energy of the discharge in the range of 0.05 to 1.4 J.

After the CEEA process, starting with 1.41 to 2.83 J, it is necessary to carry out an additional treatment using the method of non-abrasive ultrasonic finishing, and starting with 2.83 to 4. 6 J, it is necessary to treat using the method of non-abrasive ultrasonic finishing followed by grinding. At the discharge energy of more than 4.6 J, the CEEA process is not desirable to be carried out because of the deterioration of the surface quality, namely, high roughness, insufficient processing continuity, etc., and also because of rapid destruction of electrodes. For comparison, Table. 2 show the distribution of microhardness over the depth of the layer and the roughness of the surface layer for the following series of samples: 1 - EEA WC8+Cu+WC8; 2 - CEEA; 3 - CEEA + EEA WC8+Cu+WC8.

Figure 6 shows the microstructures and microhardness distribution over the depth of the layer of 40H steel samples strengthened, respectively, a-EEA WC8+Cu+WC8; b - CEEA; c-CEEA + EEA WC8+Cu+WC8.

The similar integrated coatings (CEEA + EEA WC8+Cu+WC8), formed under the same conditions as for 40H steel, were obtained for 12H18N10T and 38H2MUA steel grades (Figure 7).

Table 2

Distribution of microhardness of the surface layer of the samples made of 40H, 12H18N10T, 38H2MUA steel grades and HN58MBUD nickel alloy strengthened in various ways

Type of strengthening	Distribution of microhardness over the depth of the layer, MPa at a pitch of 15 μm							Ra, μm
40H Steel								
EEA WC8+Cu+WC8	8740	6030	3700	3200				0.5
CEEA	9870	7010	5010	3580	3150			0.8-0.9
CEEA+EEA WC8+Cu+WC8	9600	9800	8250	5490	5010	3580	3200	0.5
12H18N10T Steel								
CEEA+EEA WC8+Cu+WC8	8950	7300	4300	3050	1890	1750		0.5
38H2MUA								
CEEA+EEA WC8+Cu+WC8	9700	8890	7210	4300	3700	3250		0.5
HN58MBUD								
CEEA+EEA WC8+WC8+Cu	9270	8740	6300	4670	4300	4010		0.8
CEEA+EEA WC8+WC8+Ni	9850	8630	6240	4390	4400	3970		1.0

It should be noted that the quasi-multilayer combined electroerosive coatings on the samples of HN58MBUD nickel alloy formed in the sequence of WC8 → Cu → WC8 do not provide the desired microhardness in the surface layer.

To provide the required tribological and mechanical properties in the surface layers of the face impulse seal rings made of HN58MBUD nickel alloy, there is proposed a new process, which comprises the CEEA pretreatment of the surface and subsequent applying the quasi-multilayer combined electroerosive coating thereon, which coating being formed in the sequence of WC8 → WC8 → Cu or WC8 → WC8 → Ni.

It should be noted that, when applying the layer of WC8 hard alloy, due to the electrode adhesion, the surface continuity is low and lies in the range of 70-80%. To eliminate such an adhesion of the electrode and increase the continuity of the coating, the surface being strengthened was preliminarily treated with a graphite electrode at Wu = 0.1 J that was resulted in reaching the surface roughness of Ra = 0.6-0.8 μm.

To obtain the denser and less rough coatings, the process of alloying the surface with BK8 hard alloy was carried out in two stages. At the first stage, at Wu = 0.2 J, there was applied the more "hard" mode, which made it possible to introduce a large amount of reinforcing materials into the surface being treated. However, in this case, the roughness of the strengthened surface was unacceptably high, namely, Ra = 4.8 μm.

At the second stage, there was used the more "soft" mode at Wu = 0.04 J, wherein the most prominent vertices of the roughness of the coating, which was applied at the first stage, were smoothed and its continuity was increased. The roughness of the "ironed" surface was Ra = 1.6 μm.

The third layer, that is one made of copper or nickel, was also applied at Wu = 0.04 J. In this case, the roughness was further reduced to Ra = 0.8 ... 1.0 μm, the microhardness was at the level of 9270 and 9850 MPa, respectively, and the continuity of the layer reached made up100% (Figure 7 (c, d)).

In order to improve the quality of the face impulse seal rings made of beryllium bronze, there were carried out the metallographic studies of EEA of BrB2 copper alloy samples having the surface roughness of Ra = 0.5 mm and hardness after the final heat treatment of 370NV. EEA was carried out at the discharge energy of Wu = 0.42 J and the hard alloy of WC8, the alloy of 1M and chromium were used as the electrodes. As it is known from the previous studies, such coatings are of rather low quality [7]. And only at the EEA process by chromium, there is formed an uneven surface layer having the thickness of 10 ... 40 μm, the microhardness of up to 11020 MPa and the roughness of Ra = 1.2 μm. Below there is a transition zone (~ 25 μm) with the microhardness of 2100 ... 2500 MPa. The layer thickness is up to 90%.

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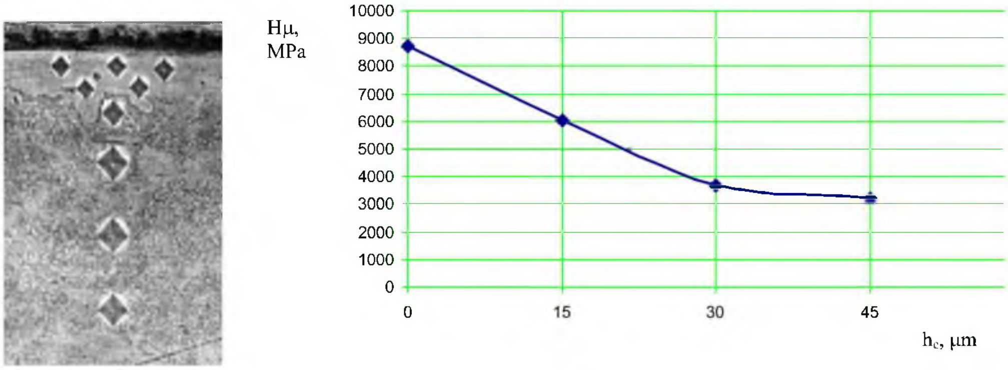

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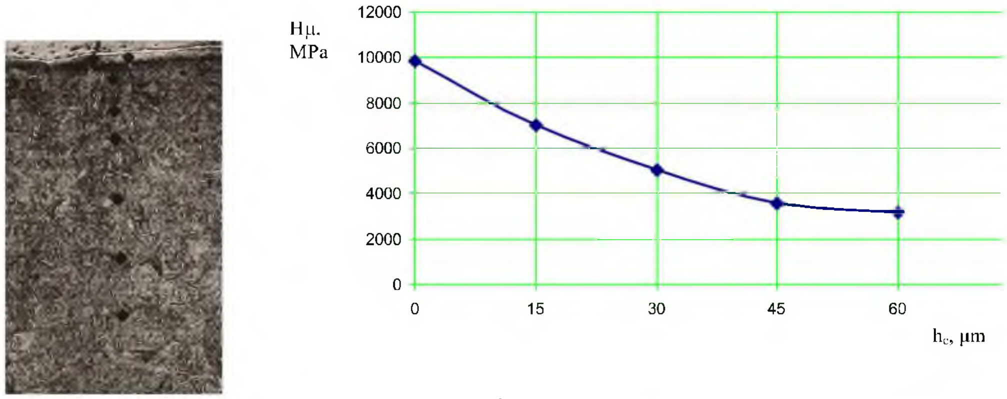

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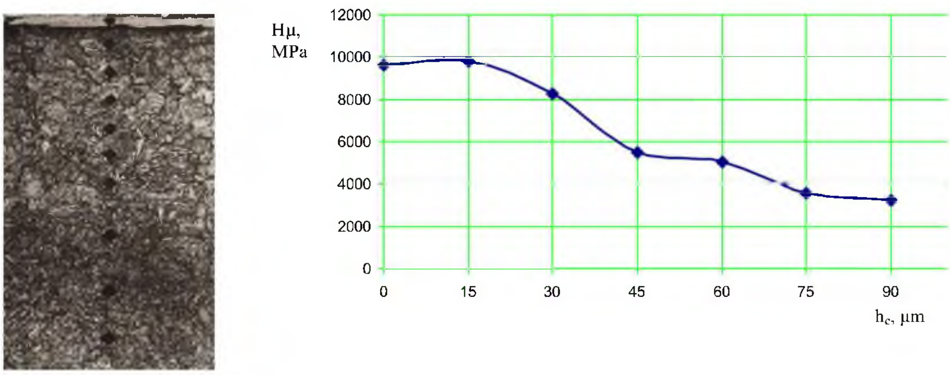
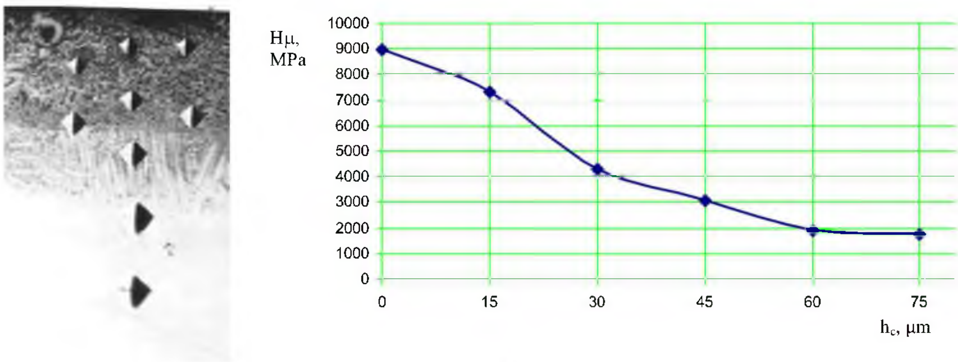


c

Fig.6 – Structure and distribution of microhardness over the depth of the layer of 40H steel samples after:
a - EEA WC8 + Cu + WC8; b - CEEL; c - CEEL + EEL WC8 + Cu + WC8



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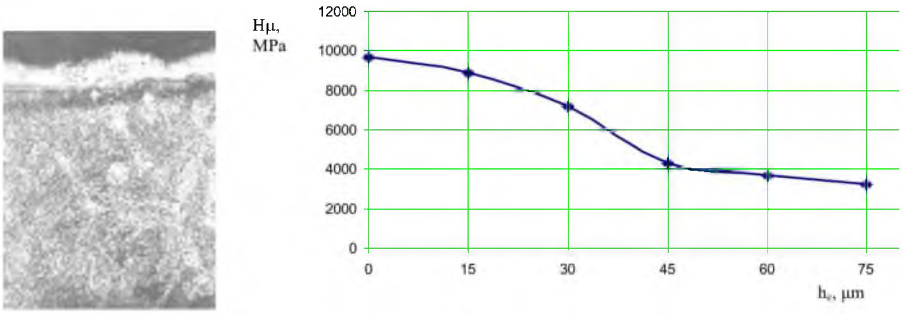

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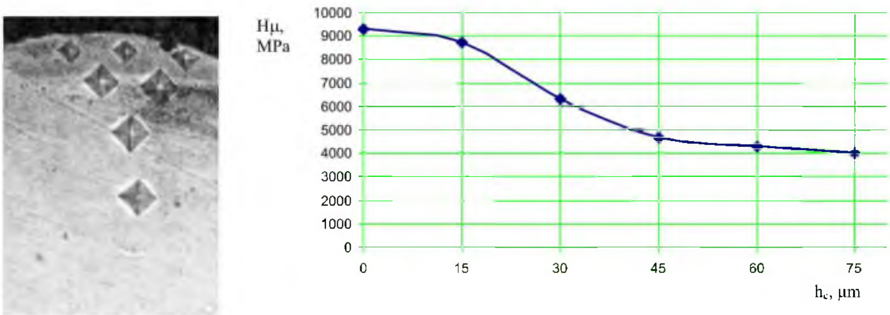

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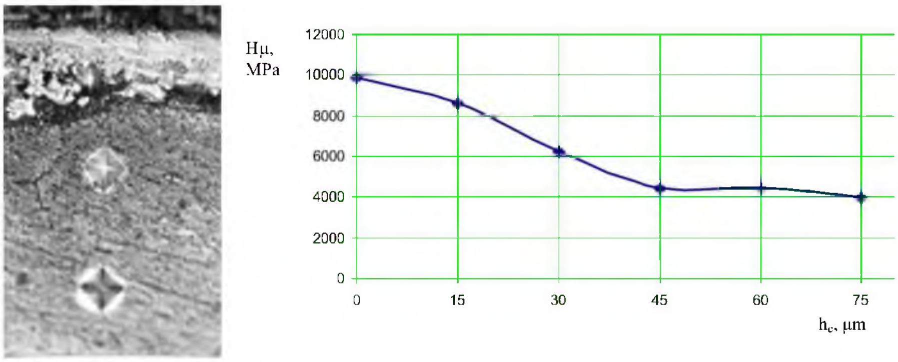

d

Fig.7 – Structure and distribution of microhardness over the depth of the layer of 12H18N10T (a), 38H2MUA (b) steel grades and HN58MBUD (c; d) alloy samples after: CEEA and EEA WC8 + Cu + WC8 (a, b); EEA WC8+WC8 + Cu (c) and EEAWC8+WC8+Ni (d)

Taking into consideration the significant increase in the microhardness of the surface of beryllium bronze at EEA processing the same by chromium, there were carried out the studies aimed at increasing the other quality parameters of the surface layer being formed (continuity, uniformity, roughness and microhardness "failure" in the transition zone). To this end, there has been proposed a new method, characterized in that the process of CEEA is carried out by chromium before and after EEA at Wu = 0.1 J

As a result, there increases the uniformity of the coating (the thickness of the layer is ~ 25 μm), the surface continuity increases up to 100% and the microhardness achieves 11020 MPa; the maximum microhardness on the surface decreases as deepened, and at the depth of 40 μm, it corresponds to the microhardness of the base.

Conclusions:

1. It has been experimentally set that the most preferred coating for the face impulse seal rings made of 40H, 12H18N10T and 38H2MUA steel grades is the coating of the composition of WC8 + Cu + WC8, formed on the preliminary CEEA processed substrates, when the microhardness of the surface layer is at a sufficiently high level, respectively, 9600, 8950 and 9700 MPa, the roughness is low (Ra = 0.5 μm), as deepened, the microhardness of the maximum value on the surface smoothly decreases to the hardness of the base metal.

2. To strengthen HN58MBUD nickel alloy, as for practical applications, there are recommended quasi-multilayer combined electroerosive coatings of the composition of WC8 + WC8 + Cu and WC8 + WC8 + Ni, which are formed on the preliminarily CEEA processed surfaces and having a low roughness (Ra = 0.8-1.0 mm), high microhardness (9270 and 9850 MPa, respectively) and 100% continuity.

3. To strengthen the rings of the face impulse seals made of beryllium bronze, it is possible to recommend the EEA process by a chromium electrode with preliminary and final CEEA processing. As a result, there increases the uniformity of the coating (the thickness of the layer is ~ 25 μm), the surface continuity (up to 100%), and the maximum microhardness of the surface (up to 11020 MPa), as deepened, decreases, and at the depth of 40 μm, it corresponds to the microhardness of the base.

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Аннотация

Жуков А.Н. Упрочнение колец импульсных терцевых уплотниений методом электроэрозионного легирования

Представлены результаты металлографических и дюрометрических исследований образцов, изготовленных из сталей 40Х, 12Х18Н10Т и 38Х2МЮА, никелевого сплава ХН58МБЮД и бериллиевой бронзы БрБ2 с комбинированными электроэрозионными покрытиями (КЭП). Установлено, что для стальных подложек наиболее предпочтительным является покрытие состава ВК8 + Cu + ВК8, а никелевого сплава ХН58МБЮД, составов ВК8 + ВК8 + Cu и ВК8 + ВК8 + Ni, сформированные на предварительно цементируемых методом электроэрозионного легирования (ЦЭЭЛ) поверхностях. Для упрочнения бериллиевой бронзы рекомендуется электроэрозионное легирование (ЭЭЛ) хромовым электродом с предварительной и окончательной ЦЭЭЛ.

Ключевые слова: *сталь, никелевый сплав, бериллиевая бронза, покрытие, электроэрозионное легирование, цементация.*