VIACHESLAV TARELNYK[1], VASYL MARTSYNKOVSKYY[2],
ALEKSEY ZHUKOV[3], IEVGEN KONOPLIANCHENKO[1],
ANREY BELOUS[1], MYKHAILO DOVZHYK[1],
[1] Sumy National Agrarian University, Sumy, Ukraine
[2] TRIZ Ltd, Sumy, Ukraine
[3] Sumy Scientific Production Association, Sumy, Ukraine

New method of working surfaces wear-resistance increase of impulse face seal metal rings

Nowa metoda zwiększenia odporności na zużycie roboczej powierzchni metalowego pierścienia w impulsowym uszczelnieniu czołowym

1. Introduction

Explosive technology development is followed not only by operating machine parameters increase but also by the existence of new, cheaper but not less reliable composite materials, combining surface protective properties with mechanical base strength.

Search for less scarce and cheap materials but not less reliable, applied in manufacture of noncontact face seals, is essential and currently important.

2. Analysis of basic achievements and publications

Face seal with impulse balancing of the axially moving element has comparatively recent history- 1974 [1].

Traditional schematic construction of the impulse face seal (IFS) is shown in Fig.1. Closed chambers 2 are located at the working surface of the axially moving ring (sliding block); several approach channels 4 are located at the surface of the bearing disk 3. The approach channels connect chambers 2 with sealed cavity A in the course of bearing ring rotation.

The functional principle of the impulse seal is based on the fact that approach channels 4 regularly signal the chambers with high-pressure cavity5 in the course of rotor rotation. As a result pressure surges (impulses) occur, causing change of the axial forces balance.

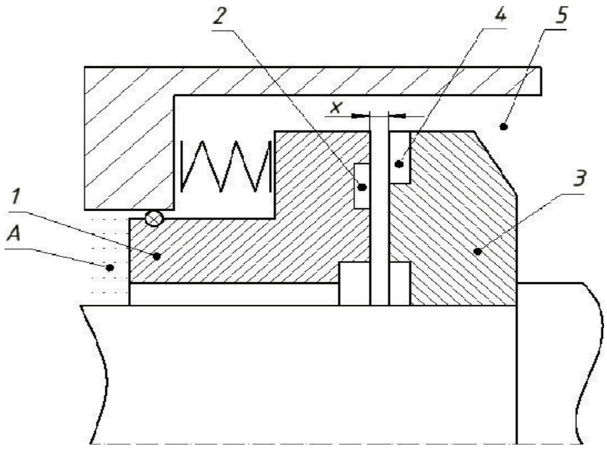

Fig. 1. Traditional schematic construction of IFS

The forces effect on the axially moving ring, resulting in separation of the sealing surface of the end pair couple in a thin layer of the operating environment, its thickness depends on the chamber size and feed channels.

IFS refer to the self-adjusting type, where the end clearance value is automatically set up. Clearance self-adjusting is based on the fact that average pressure for the period between the subsequent injections of pressure-seal environment in each chamber 2 is higher, if the end clearance is less and the rotor speed is higher. End clearance increase causes average pressure release in these chambers and force disbalance, effecting on the axially moving element. As a result the ring moves to the bearing disk and the end clearance decreases till the pressure rises in order to recover the balance of the axial forces. In case of the rotor failure to rotate and high pressure occurrence of pressure-seal environment, the end clearance is closed resulting in seal operation as the parking one.

The significant peculiarity of IFS consists in micro-gaps capability to be achieved in friction couple due to macrogeometry of the end bands, meaning that the dimensions (width, depth and length) of the chambers and feed channels are calculated in mm and exceed the clearance sizes many times. Meanwhile resizing of the chambers and feed channels as a result of erosion and abrasive wear does not effect on the clearance width and on the leakage as well.

Traditionally the rings of IFS were manufactured of silicified graphites that imposed restrictions on the range of their application, sliding speed and pressure value. These materials are expensive, possess impact resistance and subject to cracking under power and thermal load [2].

Liquid lubricated IFS were examined in a wide range of the mode parameters: differential pressure up to 16.0 MPa, sliding speed up to 100 m/s. Owing to its high operational capabilities the seals operate in high-speed feeding pumps at nuclear power and thermal power stations. On the average their runlife between the scheduled repairs of pumps comprises not less than 8000 hours, herewith their rate of wear remains in the range of 1-2 micron for 10^6 km, characterized as zero wear of friction assemblies. Under typical operating conditions (pressure 2.0- 4.0 MPa, the rotation speed is 40-60 m/s) the leakage level comprises 1-2 l/h [3].

The analysis [4] of the locking impulse seal operation was made. It was noted that the application of such impulses provided energy and resource conservation, including ecological safety improving of the pump and compressor equipment.

In some aggressive environments, where application of non-metallic seals is limited or impossible, metal seals are used.

Reliability and service life of IES depends on clearance width between friction surfaces and on the surface alignment of the end friction couple.

The clearance between the friction couples depends on many factors:operation conditions (rotation frequency and differential pressure), contraction ratio, and thermal-physical properties of sealed fluid, material performance, geometry of O-rings, force and temperature deformations.

Change of protective and tribological properties of workpiece surfaces can be achieved through formation of the special surface texture of friction pairs [5, 6].

Extension of the application range of impulse seals to the mode parameters increase has made necessary to create new composite materials of "base-coating", combining protective coating peculiarities with mechanical base strength.

The advanced way of wear-resistance increase of IFS rings may be the formation of quasimultilayer coatings with lubricating and antiwear properties on the working surfaces using electroerosion alloying. Such coatings may be combined electroerosion coatings, combining solid wear-resistant and soft antifriction materials.

A new method of electroerosion alloying is proposed, which is different: the coating layer is applied firstly with antifriction low-melting metal with the purpose of wear resistance increase and surface roughness decrease, and afterwards the coating layer of wear resistant highly rigid metal is applied [7].

In order to increase the coating thickness and uniformity, the quasimultilayer combined electroerosion coatings (QCEC) were proposed, formed in the sequence of BK8+ Cu+ BK8.

The most preferable is QCEC, where the first and the last layers of solid alloy BK8 are applied for Wu= 0.2 J, Copper- 0.08 J. In this case the thickness of the hardened layer increases up to 30-40 micron, microhardness remains 8740 MPa,uniformity comprises 100% [8].

However the coating thickness 3-40 micron is also not enough for majority of face seal rings. According to [9] it is preferable to manufacture the rings of the friction couple of cheap metals for the purpose of seal cost reduction; herewith it is necessary to lay down the antifriction wear- resistant coating of the friction surfaces. The coatings are commonly applied with plasma powder spraying of aluminum or chromium oxides, tungsten or chromium carbides. Thickness of these coatings is commonly a tenth millimeter. Besides spraying the rings coatings are made electrodeposit or with heat treatment: chroming, oxidation, nitriding, etc. Tungsten carbide with cobalt as a binding substance has limited application, especially for abrasive-carrying environment. Cobalt has low chemical resistance- it is highly soluble in distilled water, that's why it must not be used in food-processing industry. Cobalt rings of tungsten carbides are subject to heavy corrosion in sea water. Herewith a small quantity of cobalt (8%) in the coating may adversely affect its wear-resistance under certain specific conditions.

One of advantages of electroerosion alloying method is a capability to change mechanic, thermal, electric, thermionic and other properties of the work surfaces in wide range [10]. This provides seal operational capability in highly corrosion and highly reactive environments.

The quality of the formed surface layer depends on the various parameters: process conditions of the equipment, materials of the basis and electrode, time of processing, etc. In its turn, the stated above factors determine such qualitative parameters of the surface layer as microhardness, depth of the hardened layer, surface roughness. However achievement of the required precision parameters of the work surface, roughness parameter is possible under application of the additional processing methods, two methods of final polishing: polishing and ultrasonic processing with nonabrasive ultrasonic final polishing.

Consequently the work objective is the improvement of working surface parameters of steel rings of the impulse seals effecting on their wear-resistance.

3. Research techniques

Coating layer thickness was measured with micrometer, and the surface roughness- with profilograph- profilometer 201 "Kalibr" by means of profilograms reading and processing.The structures of the surface layer were examined at the optical microscope "Neofot-2", where the layer quality assessment was performed, including its uniformity, thickness and sublayer structure. At the same time the durometer analysis for microhardness distribution in the surface layer and along the section depth to the surface was made using microhardness tester PMT-3.

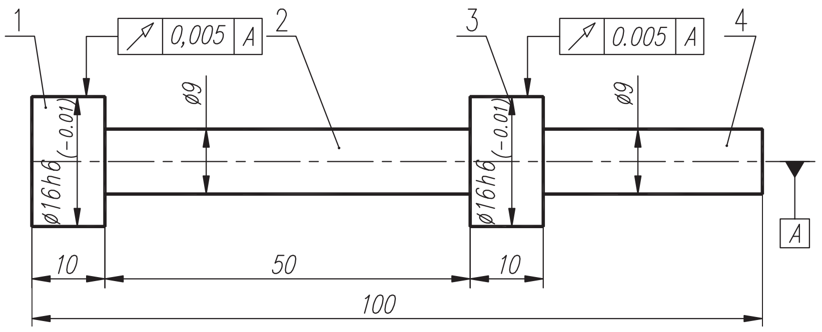

Fig. 2. The sketch of sample for testing the cementation with electroerosion alloying:1, 3- sample working surfaces; 2,4- sample technologic surfaces

In order to study the effect of alloying time on the qualitative parameters of the surface layer in case of cementation by electroerosion alloyingthe samples (Fig.2) of various materials were used: armco iron, steel 12X18H10T, steel 30X13 and 40X.

Further sample processing was carried out according to scheme Fig.3. Carbon (graphite EG-4) was used as anode.

Nonabrasive ultrasonic final polishing was performed using screw lathe 16K20 with magnetostrictor PMS-39 and ultrasonic generator UZU-030, its specification is stated in Table 1.Cementation with electroerosion alloying was carried out at “EIL-8A” and “EIL-9” for discharge energy 0,6; 2.6 and 4,6 J. The setup mode 6.8 J was not applied due to great roughness values.

The roughness was measured using profilograph- profilometer 201 “Kalibr” by means of profilograms reading and processing.

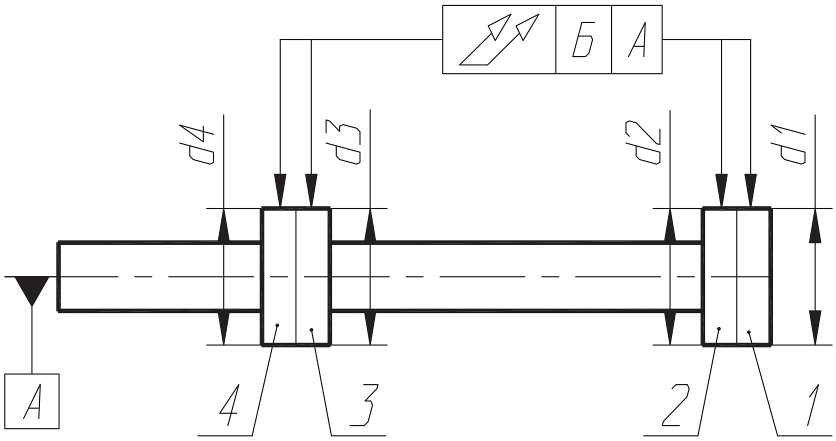

Fig. 3. The scheme of integrated technologies application for each sample: 1- Cementation with electroerosion alloying+nonabrasive ultrasonic final polishing; 2-Cementation with electroerosion alloying+nonabrasive ultrasonic final polishing+polishing; 3- Cementation with electroerosion alloying+polishing; 4- Cementation with electroerosion alloying

Table 1. Specification for ultrasonic generator UZU-030

Parameter	Output value
Ac mains supply with nominal voltage, V	220 ±10 %
Power consumption, W	300
Output waveform	square
Power output, W	500
Operating frequency, kHz	18.6
Oscillations amplitude of the ultrasonic waveguide, micron	10
Dimensions, mm	400x450x280
Weight, kg	25.4

4. Evaluation

In order to solve the specifies engineering problem the method of wear-resistance increase of the steel rings working surfaces of the impulse face seals was proposed, including as in [8] the application of quasimultilayer combined electroerosion coatings (QCEC), formed in the sequence of BK8+ Cu+ BK8, where the layers of QCEC are applied with reduced energy charge indexes; and before QCEC application the working surfaces are processed with cementation with electroerosion alloying with discharge energy in the range of 0.036…4,6 J, furthermore the hardened layer thickness shall be increased by the layer thickness with cementation with electroerosion alloying. Herewith, the process of cementation with electroerosion alloying may be carried out in case of discharge variation in the range of 0.036…1.41 J without additional processing, in case of discharge variation in the range of 1.41…2.83 J with additional processing using nonabrasive ultrasonic final polishing, also in case of discharge variation in the range of 2.83…4.60 J with additional processing using nonabrasive ultrasonic final polishing and polishing. Besides, the first and the last layers of solid alloy BK8 may be applied if energy discharge Wu= 0.1, and copper layer- Wu=0.04 J.

Application of cementation with electroerosion alloying if graphite (carbon) is used as electrode provides:

- 100% uniformity of the surface layer hardening;
- Hardening of the workpiece surface layer due to diffusion and hardening processes;
- Alloying shall be carried out in strictly specified places not protecting the rest of the workpiece surface;
- No extreme heating of the workpiece, consequently no warping and buckling [11].

The use of the stated above method provides the formation of work surface layers of steel rings of the hardened impulse end seals with the thickness of 4-5 to 320-350 micron, variating the discharge in the course of cementation with electroerosion alloying in the range of 0.036…6.8 J.

The Table 2 beneath show the results of research.

The surface roughness increments with energy discharge regardless of the test material (Table 2). Besides, the Tables show the data of the general depth of the hardened layer and maximum microhardness on the surface of the test specimen according to energy discharge.

Increase of energy discharge causes increase of the hardened layer depth. Regardless of the test material and mode of cementation with electroerosion alloying the microhardness of the hardened layer, maximum on the surface, smoothly decreases and achieves the value of supporter microhardness.

Table 2. Research results of samples

Energy dischargeW$_{п}$, J	Time of alloying, min	General layer depth, micron	Microhardness, HV	Roughness, Ra, micron
1	2	3	4	5
Steel 12X18H10T				
0,5	1	30	950	0,8-0,9
1,41		71	900	1,0-1,6
2,83		96	840	5,5-6,3
3,4		101	870	8,3-8,5
6,8		115	900	11,9-14
0,5	5	48	1013	0,9-1.0
1,41		134	1101	1,2-1,7
2,83		200	974	5,8-6,7
3,4		210	960	8,6-8,8
6,8		250	1100	11,9-14.1
0,5	10	51	1006	0,9-1.1
1,41		145	995	1,4-1,9
2,83		220	930	5,8-6,9
3,4		230	1001	8,6-9.1
6,8		275	1050	12.3-15
Steel 40X				
0,5	1	35	950	0,8-0,9
1,41		146	900	1,0-1,6
2,83		215	980	5,5-6,3
3,4		230	960	8,3-8,5
6,8		270	1010	11,9-14
0,5	5	50	987	0,8-0,9
1,41		377	993	1,1-1,7
2,83		658	1001	5,6-6,5
3,4		722	997	8,7-8,9
6,8		910	1050	11,9-14.1
0,5	10	55	1002	0,9-1.0
1,41		424	989	1,2-1,8
2,83		757	1100	5,7-6,8
3,4		833	1050	8,5-9.0
6,8		1060	1001	12.1-14.3
Armco-iron				
0,5	1	30	950	0,8-0,9
1,41		71	900	1,0-1,6
2,83		96	840	5,5-6,3
3,4		101	870	8,3-8,5
6,8		115	900	11,9-14

Table 2 continuation

0,5	5	37	985	0,9-1.0
1,41		163	970	1,2-1,6
2,83		245	1002	5,7-6,7
3,4		262	1006	8,6-8,9
6,8		310	1070	11,9-14.1
0,5	10	38	991	0,9-1.1
1,41		173	1006	1,5-1,9
2,83		261	1050	5,7-6,9
3,4		281	959	8,7-9.1
6,8		333	1040	12.4-15
Steel 30X13				
0,5	1	34	1050	0,8-0,9
1,41		134	978	1,1-1,5
2,83		196	909	5,8-6,3
3,4		209	1072	8,0-8,5
6,8		245	1027	11,9-14
0,5	5	48	1020	0,8-1.0
1,41		358	1005	1,2-1,7
2,83		623	1100	5,9-6,7
3,4		684	993	8,7-8,8
6,8		860	1000	11,9-14.1
0,5	10	50	995	0,9-1.1
1,41		405	1002	1,4-1,8
2,83		720	1040	5,8-6,8
3,4		795	1080	8,6-9.0
6,8		1006	1100	12.3-14.9

It should be noted that uniformity of the hardened layer of all the tested samples is 100%. It is well-known that the original surface roughness should not exceed Rz< 6.3 micron that equals Ra≈1.2 micron for the purpose of formation the qualitative surfaces in the course of cementation with electroerosion alloying [12]. Consequently cementation with electroerosion alloying as preliminary operation, according to the method proposed, may be carried out without additional processing only with energy discharge in the range of 0.036-1.4 J. Research results of the qualitative surface parameters of samples are stated in Table 3-4.

Table 3- Research results of samples after cementation with electroerosion alloying

Energy discharge$W_{п}$, J	Time of alloying, min	General layer depth, micron	Microhardness, HV	Roughness, Ra, micron
Steel 40X				
0,6	5	50	987	0,8-0,9
2,83		658	1000	5,6-6,5
4,6		910	1050	11,9-14,1
Steel 12X18H10T				
0,6	5	48	1013	0,9-1,0
2,83		200	974	5,8-6,7
4,6		250	1100	10,0-14,5

Table 4. Qualitative surface parameters of samples using integrates technologies

Energy discharge$W_{п}$, J	Method of sample processing	General layer depth, micron	Microhardness, HV	Roughness, Ra, micron	General layer depth, micron	Microhardness, HV	Roughness, Ra, micron
		Steel 40X			*Steel 12X18H10T*		
1	2	3	4	5	6	7	8
0,6	Cementation with electroerosion alloying + ultrasonic processing	50	980	0,2	50	880	0,2
	Cementation with electroerosion alloying + ultrasonic processing + polishing	40	920	0,6	48	841	0,6
	Cementation with electroerosion alloying + polishing	10	780	0,6	18	723	0,6
	Cementation with electroerosion alloying	50	987	0,8-0,9	48	1013	0,9-1,0
2,83	Cementation with electroerosion alloying + ultrasonic processing	657	920	0,8	210	970	0,8
	Cementation with electroerosion alloying + ultrasonic processing + polishing	635	895	0,8	195	950	0,8
	Cementation with electroerosion alloying + polishing	580	770	0,8	130	790	0,8
	Cementation with electroerosion alloying	658	1000	5,6-6,5	200	974	5,8-6,7
4,6	Electroerosion cementation + ultrasonic processing	908	854	0,8	244	985	0,8
	Cementation with electroerosion alloying + ultrasonic processing + polishing	895	840	0,8	220	875	0,8
	Cementation with electroerosion alloying + polishing	856	824	0,8	110	670	0,8
	Cementation with electroerosion alloying	910	1050	11,9-14,1	250	1100	10,0-14,5

Thus it is preferable to perform cementation with electroerosion alloying before coating application BK8+Cu+BK8 with the following energy discharges:

- up to 1.41 J- without additional processing;
- up to 2.83 J with additional processing using nonabrasive ultrasonic final polishing;
- up to 4.6 J with additional processing using nonabrasive ultrasonic final polishing plus polishing.

If energy discharge exceeds 4.6 J the cementation with electroerosion alloying is not preferable because of surface quality degradation, exactly, high roughness, low uniformity of the processed surface, etc. and fast electrode damage.

In order to improve the qualitative characteristics of the formed surface layers the QCEC were tested, formed according to scheme BK8+Cu+BK8. The coatings were applied on samples of steel 40X, which were subject to cementation with electroerosion alloying with energy discharge Wu= 0.6 J.

Roughness of the layer formed in the course of cementation with electroerosion alloying significantly depends on the value of the initial surface roughness, herewith the higher the initial value the more the finite one. Considering the fact that after cementation with electroerosion alloying the surface roughness of samples increases and comprises Ra= 0.8- 0.9 micron, and on exposure to layer in the heat-affected zone temper hardening may occur, that effects negatively (microhardness and the hardened layer thickness decrease); the first layer of solid alloy BK8 was applied with energy discharge Wu=0.1 J, less than [8], where Wu=0.2 J. The second layer (copper) and the third (solid alloy BK8) was applied at various modes (Table 5).

Table 5. Results of metallographic studies of QCEC

Electrode material	Energy discharge, Wu, J	Thickness, micron		Microhardness, MPa		Roughness, Ra, micron
		layer	transient zone	layer	transient zone	
BK8	0,1	Up to 15	60-65	6500…9600	7500…9800	0,5
Cu	0,04					
BK8	0,1					
BK8	0,1	Up to 15	60-65	6420...7570	7500...9580	0,5
Cu	0,08					
BK8	0,1					
BK8	0,1	Up to 15	Up to 60	5520...6970	6480…9300	0,8
Cu	0,08					
BK8	0,2					
BK8	0,2	Up to 20	Up to 60	6330...8740	6030...9500	0,7
Cu	0,08					
BK8	0,2					

For comparison, QCEC were applied at the modes [8].

The data of the Table 10 prove that the most preferable is QCEC, where the first and the last layers of solid alloy BK8 were applied with energy discharge Wu= 0.1, and the interlayer (copper)- if Wu=0.04 J.

5. Conclusions

1. A new method of working surfaces wear-resistance increase of impulse face seal metal rings was proposed, which includes QCEC application of the alloy formed in the sequence of BK8+Cu+BK8, herewith the working surfaces before the application are processed with cementation with electroerosion alloying with energy discharge in the range of 0.036…4.6 J, provided that the hardened layer thickness is increased by layer thickness processed with cementation with electroerosion alloying.
2. Metalographic studies of QCEC have shown that the most preferable for steel supports is the coating BK8+Cu+BK8, where the first and the last layers of solid alloy BK8 are applied with energy discharge Wu= 0.1 J, and the copper with Wu=0.04 J. The surface layer microhardness of such coatings is high enough (H_μ= 6500...9600 MPa), low roughness (Ra= 0.5 micron), the microhardness smoothly decreases from the maximum as penetration increases to hardness of the base metal.

LITERATURE:

[1] End seal with controlled leakage: A.c. 446695 USSR, MKH 23 P 1/12 /K.V. Lisitsyn, V.A.Martsynkovskyy, N.V.Periderii (USSR).-№ 1827549/25-8; Applied 11.09.72; Publ. 22.06.74, Bul. № 7.- 2 p.

[2] End seals for chemical machinery. / G. V. Antipin, M.T.Bannikov, A.D. Domashnev, etc. – M.: Machine building, 1984.-112 p.

[3] Moskalenko V.V., Lisitsyn K.V., Martsynkovskyy V.A. Characteristics and experience of impulse end seals operation// Materials of the 6th technical conference «Seals and vibration reliability of centrifugal machines». - Sumy- 1991.- P. 41.

[4] Martsynkovskyy V., Zahorulko A. , Gudkov S., Mischenko S. Analysis of buffer impulse seal // Procedia Engineering, Volume 39, 2012, pp. 43-50.DOI: 10.1016/j.proeng.2012.07.006.

[5] Bogdan Antoszewski. Influence of Laser Surface Texturing on Scuffing Resistance of Sliding Pairs //Advanced Materials Research, V. 874, 2014, pp. 51-55.

[6] Błasiak S., Kundera Cz. Numerical analysis of the grooved surface effects on the thermal behavior of a non-contacting faceseal // Procedia Engineering, V.39,2012, pp. 315-326.

[7] Method of electroerosion alloying of steel workpiece surfaces: Pat. 2524471. The Russian Federation. MPKV23N9/00 / Martsynkovskyy V.S.Tarelnyk V.B.; Publ. 27.07.14, Bul. № 21.-10 p.

[8] Tarelnyk V.B. Development of upgrading technology of the surface layers of impulse end seals, operating in different environments, using electroerosion alloying// Materials electronic processing.- 2000.- № 4.- p. 7-11.

[9] Melnik V.A. End seals of shafts: reference book.-M.: Machine building, 2008.- 320 p.

[10] Electrospark alloying of metal surfaces/ Gitlevich A.E., Mikhailov V.V., ParkanskiiN.Ya, Revutskii V.M./Kishinev: Shtintsa, 1985.- 196 p.

[11] Patent of Ukraine for invention № 82948, 23C 8/00. Cementation method of steel workpieces using electroerosion alloying/ V.S.Martsynkovskyy,V.B.Tarelnyk, A.V.Bilous/ Publ. 25.03.2008, Bul. № 10.

[12] Lazarenko N.I.Electrospark alloying of metal surfaces.-M.: Machine building, 1976.- p. 46.

Summary

Presented in the article technical solution relates to the field of electrophysical and electrochemical machining, particularly to electroerosion alloying, and can be used for surface processing of impulse face seal (IFS) elements.

Set the way of the IFS steel rings working surfaces wear resistance increase, which consists of coating of quasi-multilayers combined electroerosion covering (CEC). The covering composition formed in sequence WK8 + Cu + WK8, while before CEC coating, working surfaces processed by method of graphite electrode electroerosion alloying carburization (EEAC) with discharge energy of 0.036 ... 4.6 J. The thickness of the high hardness layer is increased by the thickness of the EEAC layer. Besides, during the CEC formation the first and last layers from WK8 hard alloy coating with discharge energy Wu = 0.1 J and copper layer at Wu = 0.04 J.

Abstrakt

Przedstawione w artykule techniczne rozwiązanie dotyczy dziedziny elektrofizycznej i elektrochemicznej obróbki, a szczególnie elektroerozyjnego wytwarzania stopu, który może być stosowany do przetwarzania powierzchni elementów impulsowego uszczelnienia czołowego. Przedstawiono sposób zwiększenia odporności na zużycie powierzchni roboczej pierścieni stalowych polegający na nakładaniu quasi-warstw podczas złożonego elektroerozyjnego pokrywania(CEC). Kompozycję powłoki uformowano w kolejności pokrywania stopem WK8 + Cu + WK8 , podczas gdy przed pokrywaniem (CEC), robocze powierzchnie przetwarza się przy pomocy grafitowych elektrod podczas nawęglania w trakcie elektroerozyjnego wytwarzania stopu (EEAC) przy energii wyładowania 0,036….4,6 J. Grubość warstwy o podwyższonej twardości wzrosła o grubość warstwy wytworzonej w procesie (EEAC). Poza tym, podczas procesu CEC pierwsza i ostatnia warstwa z twardego stopu WK8 nałożono przy energii wyładowania Wu = 0,1J a warstwę z miedzi przy Wu = 0,04 J.