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Development of a Technological Process for the Production of Diesel Engines with Wear-Resistant Metallized Coating of Piston Heating Units.

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ABSTRACT: The article shows that in most cases the reason for rejecting piston compression rings and cylinder liners is reaching the limit wear of the working rubbing surfaces and a conclusion is made about the advisability of applying a coating of a mixed steel-bronze pseudo-alloy to the working surface of the piston rings. The results of tribotechnical tests of a number of pseudo-alloys are presented, on the basis of which the optimal coating of piston rings is selected. The advisability of chemical-thermal treatment of metallization coatings is proven and the technological process of manufacturing piston compression rings with a wear-resistant coating is presented. In the water transport system, ship repair enterprises are faced with the tasks of improving quality, reducing the repair time of ship equipment, manufacturing replacement and spare parts in the required quantity, reducing the costs of raw materials, energy and materials.

KEY WORDS: improving quality, reducing equipment repair times, reducing costs for raw materials, energy and materials.

The current trend of re-equipping river vessels for work in coastal sea navigation requires high reliability of their operation over a long period of time, which is largely determined by the technical condition of the main and auxiliary diesel engines. In turn, the experience of operating marine engines shows that the timing of routine and medium repairs, economical and reliable operation of engines are determined by the technical condition of the cylinder-piston group (CPG) parts. These parts, especially piston compression rings (PCR) and cylinder liners, operate under extreme conditions of boundary and dry friction, high temperatures, significant mechanical and thermal stress, and exposure to aggressive environments.

In the works [3, 17, 38, etc.] it was established that on the rubbing surfaces of the cylinder "mirror" and piston rings, the processes of mechanical, abrasive, adhesive, hydrogen, fatigue wear occur simultaneously, which are intensified by the phenomena of chemical, electrochemical and gas corrosion.

As a result, the CPG parts, especially the cylinder liners and the piston rings, are rejected mainly due to reaching the maximum wear of the working rubbing surfaces [20], which in most cases does not exceed 1.5 ... 2 mm [14]. Thus, the problem of developing an industrial technology for the manufacture of piston rings with high wear resistance of the working rubbing surface becomes relevant. In this case, it is necessary to take into account the need to reduce the wear value of the cylinder liner.

In this regard, the most rational way to increase the service life of the piston rings is to use surface hardening methods and increase the wear resistance of the rubbing surfaces of the parts. Currently, a large number of such methods are known - thermal, chemical-thermal, electrical (electric spark), mechanical (abrasive jet) processing, plastic deformation and coating.

Of greatest practical interest are the methods of gas-thermal spraying (gas flame, plasma, detonation spraying, electric arc metallization (EAM) p, 15, 16, 18, 19, 21, 31, 35, etc.).

In the conditions of diesel building and ship repair production, the most rational application of the EAM method, which has the following advantages over the methods of plasma, gas flame and detonation spraying [2, 8, 13, 15, 33]: low level of heat input - with EAM, the metallized surface does not heat up above 700C; the productivity of the method reaches 100 kg / h; the cost of equipment and consumables (wire) for EDM is an order of magnitude lower than when using other spraying methods; small dimensions and weight of the equipment.

Of particular interest is the possibility of obtaining mixed pseudo-alloys - coatings obtained by simultaneous spraying of dissimilar materials (for example, steel - copper, aluminum - zinc; aluminum - lead; copper - lead, etc.). As a result, coatings are formed on the surface of the part, which are a mechanical mixture of metals and have high tribotechnical characteristics. The optimal ratio of hardness and the number of applied components makes it possible to form coatings whose microstructure fully complies with the "Charpy principle" [9].

Antifriction pseudo-alloys obtained by gas-thermal spraying were used in the USSR as early as 1936 and consisted of a mixture of aluminum, lead and copper and were used only in plain bearings. This development was further developed in the works of VNIIAVTOGENMASH, Rostov Institute of Agricultural Engineering and the All-Union Design and Technological Institute of Heavy Engineering "Giproneftemash" [1].

Currently, pseudo-alloys are used only in plain bearings; there is practically no information on the use of pseudo-alloys as a wear-resistant material for CPG parts in the technical literature. Nevertheless, in our opinion, the use of such materials in marine engineering is very promising.

Domestic industry produces a wide range of various steel, copper and bronze wires. For spraying by the EDM method, it is advisable to use spring class wires [2].

The work investigated coatings applied by the EDM method to the surface of samples made of gray cast iron PKK SOD (SPChF) 6 (8) CHRN 32/48, 6 CHRN 36/45.

The coatings were sprayed using a stationary electric arc metallizer EM-12 [2]. Before spraying, the surface of the samples was subjected to jet-abrasive treatment to a roughness of Rz = 40...80 µm. The following grades of spring-class steel and bronze wires were used as initial materials for spraying the coatings: ZOKhGSA, 51KhFA, 60S2 (GOST 14955-77) and Br. KMC-Z-1 (GOST 5222-72).

Three pseudo-alloys were selected for the studies, differing in the grade of the steel wire used (Table 1):

Table 1: Studied pseudo - alloys

Pseudo -alloy components	
steel	bronze
зохгСА	Б . КМц-3-1
51ХФА	Б . кмц-з-1
60С2	Б . КМц-3-1

During the spraying process, partial burnout of the alloying elements included in the initial materials occurs. The change in the percentage of chemical elements in the coating (carbon, manganese, silicon, etc.) can be quite significant and depends on the coating application modes and the wire materials used.

To determine the chemical composition of pseudoalloys, spectral and atomic absorption analysis methods were used according to GOST 20068.1-79 "Tin-free bronzes. Spectral analysis methods for metal standard samples with photographic recording of spectra" and GOST 27809-95 "Cast iron and steel. Spectrographic analysis methods". The result was estimated by averaging the data of three measurements - sulfocyanated cast iron SPChF (OOO Metmash,) and galvanic chromium (OAO RUMO,). The friction coefficient of tribounits was determined with a change in the load within the limits of УШа (100...2000 N) and a sliding speed of 0.05...2.62 m/s. Based on the test results, the total power consumption for overcoming friction forces was determined, Wt:

$$W=\sum(P\cdot f)\frac{L}{t}=\sum P\cdot f\cdot V \qquad ;(1)$$

where P - is the load, N;
f - is the friction coefficient;
L - is the friction path, m;
t - is the operating time, s;
V - is the sliding speed, m/s.

The wear of the materials and coatings of the piston ring and cylinder liner was determined by the artificial base method (GOSG 17534-74) under a load of 7 MPa and sliding speeds of 0.26...2.62 m/s. The friction path at each stage of the tests was Ш 000 m. The results are shown in Table 2 and Figure 1.

Table 2: Wear rates and relative wear of the studied materials of friction pairs

Materials of friction pairs									
СЧ25- СПЧФ		СЧ25-		сч 253ОХГСА + .КМц-3-1		СЧ 25-51ХФА+ Бр.кмц-з-1		сч 25-60С2 + Бр КМЦ-3-1	
	pad-				pad-	disk	pad-	disk	pad-
Wear rate,мкм! 1000 м at sliding speeds: 0,26; 1 ()5• 1 83• 2 62 м/с									
0,301 0,218 o 179	0,514 0,413 o 354	0,259 0,193 o 145	0',039 0,029 0026	0:062 0,056 o 059	0,328 0,227 0,240	0,140 0,125 o	0,295 0,193 0,135 0 111	0,116 0,086 0,076 o 067	0,140 0,074 0,052 0039
Average wear rate, w ¯ 4 . wear, мкм/ ООО м									
0,382	0.526	0,242	o 040	0,063	0318	0,145	o 184	o 086	0,076

Total wear on friction path 40()()() м, И" , мкм									
15,28	21,03	9,69	1,59	2,52	12 72	5,79	7,34	3 45	3,05
Relative wear, E %									
72 70	1000	46 O	7 60	1200	60,50	27 50	34,90	16,40	1450

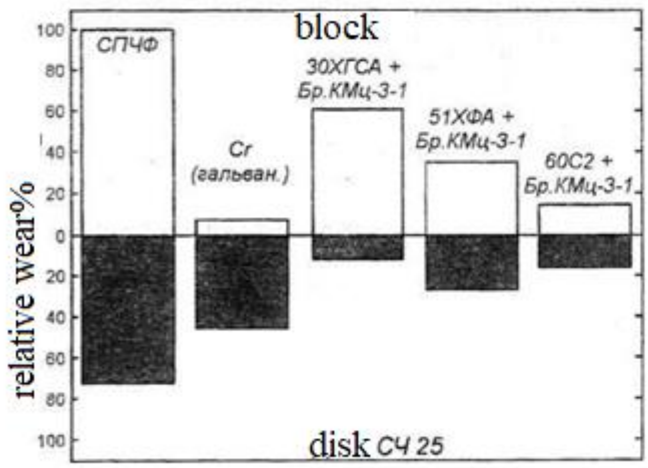


Fig. 1. Relative wear of the studied materials and wear of piston rings and cylinder liner

Based on the test results, the relative wear resistance of the friction units was determined:

$$I = \frac{1}{\frac{1}{2}\left(\sum W_{диск} + \sum W_{колодка}\right)},$$

(2)

where $\sum W_{диск}$, $\sum W$, block — wear of the disk and pad, respectively, on the friction path of 40,000 m.

The resistance of the friction pair materials to scuffing was estimated by the scuffing load Pз and the operating time N of the friction unit under dry friction conditions.

The quantities determined by formulas (1) and (2), the values Pз and N were reduced to a dimensionless form:

$$w_{отн} = \frac{W}{W^*};\quad i_{отн} = \frac{I}{I^*};\quad n_{отн} = \frac{N}{N^*};\quad p_{отн} = \frac{P_з}{P_з^*}$$

where W^*, I^*, N^*, $P_з^*$ — similar indicators of the tribocoupling of the SPCHF — SCH 25.

Finally, the performance of the tribocoupling was determined by the value of the generalized criterion K — as the geometric mean of four indicators:

The results are summarized in Table 3 and are shown in Figures 2, 3 and 4.

Table 3: Generalized performance characteristics of the tribocoupling

Indicators -	Materials of screw rings				
			Pseudoalloy		
	СПЧФ	st	ЗОХГСА + .кмц-з-1	51ХФА+ Б .КМЦ-3-1	60С2 + Бр.КМц-3-1
Щ кВт	13,12	в,32	6 15	12,67	11,28
мкм-	0,55		1,31	1,52	3,08
N, циклов	36700	46030	51	64940	101670
	800	800	800	1000	[400
		1,02	0,47	0,97	0,86
			2,38	2,77	5,59
		1 25	! 39	77	2 77
		1,00	1,00	1 25	1 75
		41	1 63	59	2,37

Based on the results of comparative tribological tests, it was established that in all tribological characteristics the studied pseudoalloys are superior to the material of piston rings (sulfocyanated cast iron SPChF), and in a number of characteristics - even to galvanic chromium. According to the generalized criterion of tribocoupling performance, the coating with the best tribotechnical characteristics was selected - pseudoalloy 6OC2 + Br.KMts-Z-1,

The experience accumulated to date in the application of thermal spraying processes indicates a significant influence of the coating application parameters on their tribotechnical and physical-mechanical properties. With a relatively narrow range of variation of the parameters of plasma, gas-flame or detonation spraying, such properties of thermal spray coatings as adhesive and cohesive strength, porosity, hardness, wear resistance can change by 1.5 ... 3 times [4, 14, 20, 26, 29].

At the same time, information on similar studies for the EDM method is currently practically absent in the technical literature. The results presented in the work - [2, 8, 13, 15] recommendations for the selection of pseudoalloy spraying modes were obviously obtained on the basis of a number of single-factor experiments and do not take into account the specifics of metallization processes, when the significance of the effects of the interaction of factors can be quite significant. At the same time, it remains unclear what is taken by the authors as the optimization parameter.

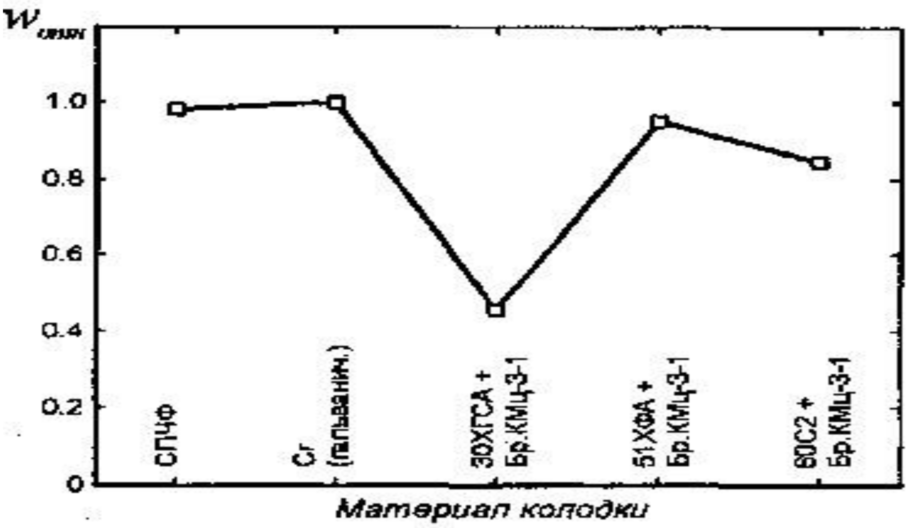


Fig.2. Relative power consumption to overcome friction forces

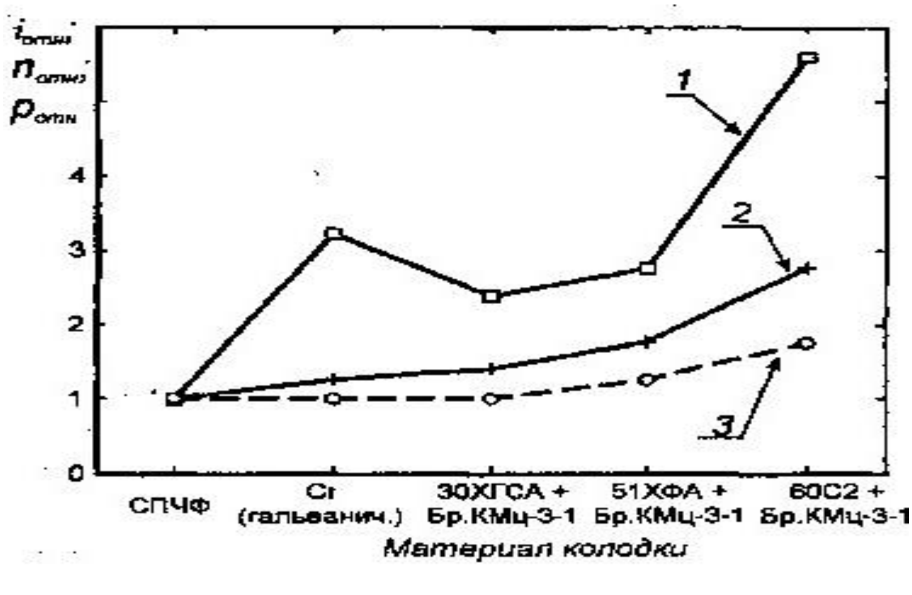
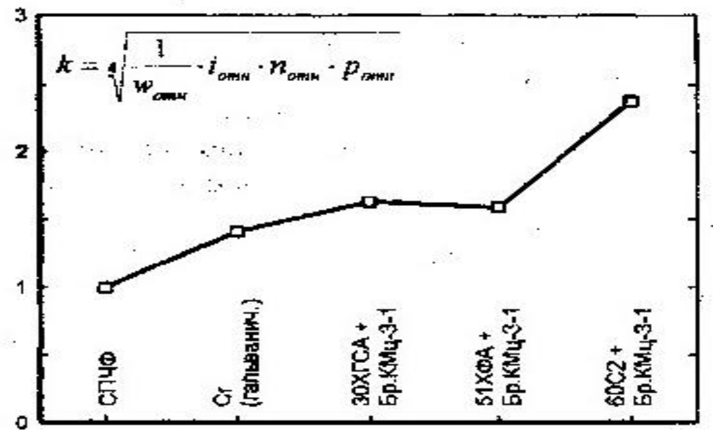


Fig.3. Relative performance parameters of tribounits: 1 - wear resistance of tribounits: 2 - number of cycles before scuffing: 3 - scuffing load



Material of the kolobok

Fig. 4. Values of the generalized criterion of the performance of the studied tribounits

Thus, the problem of optimization of spraying modes, being very relevant, still does not have a satisfactory solution.

To solve this problem, at the first stage of research it is necessary to select the optimization parameters.

As the accumulated experience of using thermal spraying processes shows, the performance of coatings is primarily affected by the adhesive strength, which, depending on the area of application, should be at least 25 ... 35 Ruta [3 At the same time, for coatings operating under friction and wear conditions, the next important parameter is the tribochemical properties (wear resistance, friction coefficient, running-in, resistance to scuffing and seizure). The studies indicate high values of scuffing resistance of the selected pseudoalloy, more than 2.5 times exceeding the similar characteristic of the base material of piston rings. As an optimization parameter characterizing tribotechnical properties, we take relative wear resistance.

The coating properties were optimized by varying four factors: arc voltage; spraying distance; compressed air pressure; feed per minute (takes into account the part rotation frequency and the metallizer movement speed). The limits of their variation were selected based on the passport characteristics of the available equipment.

The implementation of the central-composite rotatable orthogonal experimental design made it possible to obtain adequate regression equations linking the optimization parameters with the coating application modes, and using the mathematical analysis apparatus ("ridge analysis"), optimal metallization modes for the steel-bronze pseudoalloy 60S2 + Br.KMts-Z-1 were obtained.

As a result, two spraying modes were established, one of which ensures strong adhesion of the coating to the base, and the second - its high tribological properties. In this case, the original coating materials are absolutely identical. The optimization of the spraying mode allows obtaining coatings with an adhesive strength of 36...38 MPa and high wear resistance (wear rate of the tribocoupling is 0.137...0.141 µm./1,000 m).

Spare parts of the CPG for marine diesel engines 6 ChRN 36/45, 6 (8) ChRN 32/48, 6 ChSPN 18/22, 6 ChRN 27.5/36 are manufactured by OOO Metmash (Bor), OAO RUMO, therefore, technological preparation of production and development of technological processes are carried out in relation to the existing production sites and equipment of these enterprises, taking into account the specifics of their work. However, the proposed technical solutions can be successfully used and applied at other plants in various industries both for repairs and for the manufacture of new parts. In this paper, the pilot production process for manufacturing piston rings with a wear-resistant coating was developed in relation to the existing production of Metmash LLC. The process diagram (using the example of the PKK of the 6(8) ChRN 32/48 marine diesel engine) is shown in Figure 5.

The pilot technological process for manufacturing PKK can be conditionally divided into the following groups of operations:

1) obtaining blanks - a standard production technological process of casting oil (by centrifugal method or casting into earthen molds) from the SPChF material is used;

2) preliminary mechanical processing;

3) application of a coating to the working surfaces of piston rings;

4) subsequent mechanical processing;

5) technical control.

During preliminary mechanical treatment the following technological operations are performed: on lathes the oil is turned with subsequent cutting off of rings, then on a surface grinding machine the end face of each ring is ground, after final boring along the inner diameter the rings are assembled into a pack on a special mandrel on which the grooves for the coating are turned, abrasive jet processing, spraying and final mechanical treatment of the working surface of the rings are carried out. Abrasive jet processing of the piston ring pack is carried out in a abrasive jet chamber in accordance with OST 5.9229-81. To prevent oxidation of the prepared surfaces and moisture from getting on them, the operation of applying the 60C2 + Br.KMts-Z-1 coating is carried out immediately after surface activation of the working surfaces of the piston rings, the permissible break between these operations is no more than 2 hours [2].

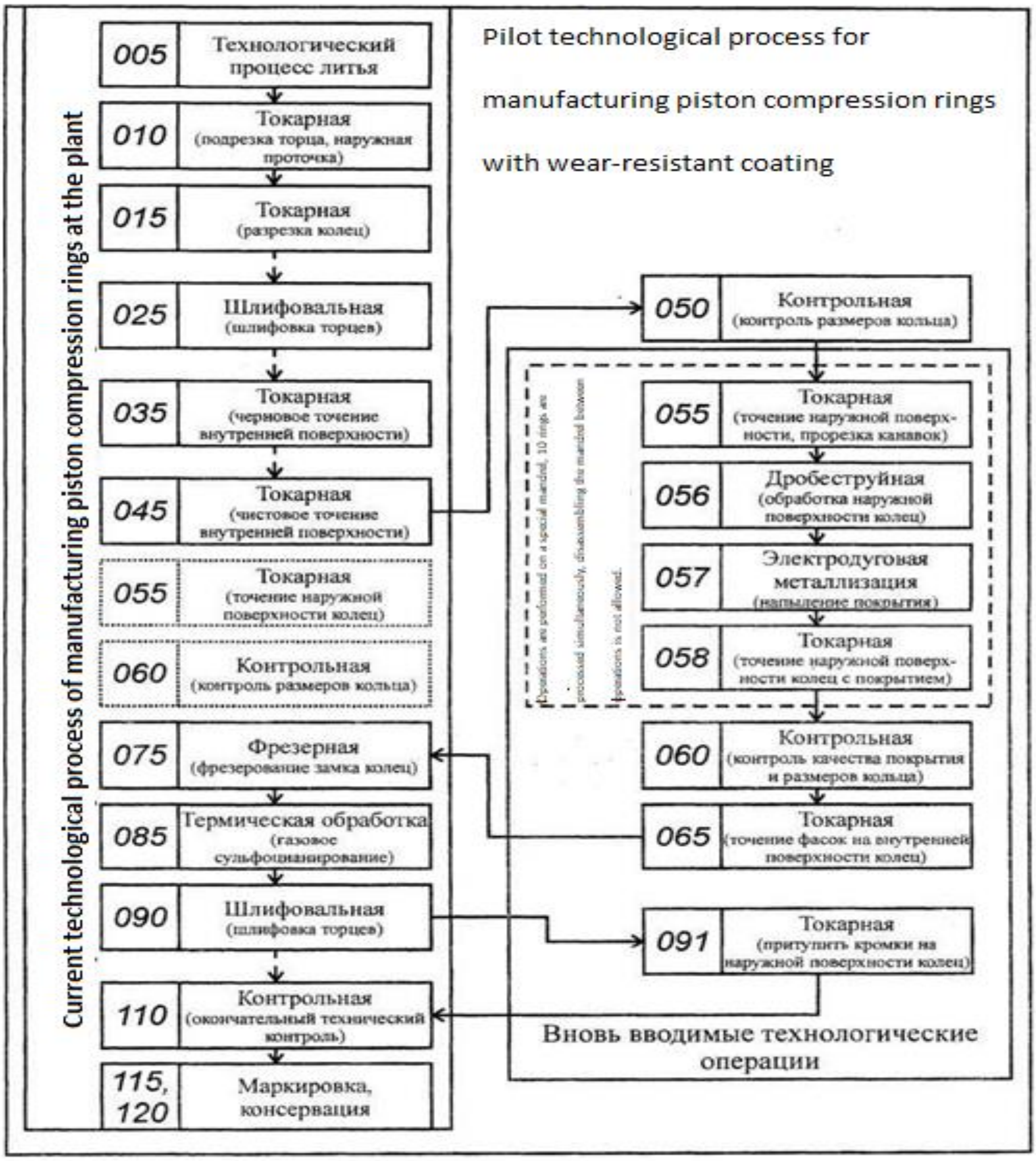
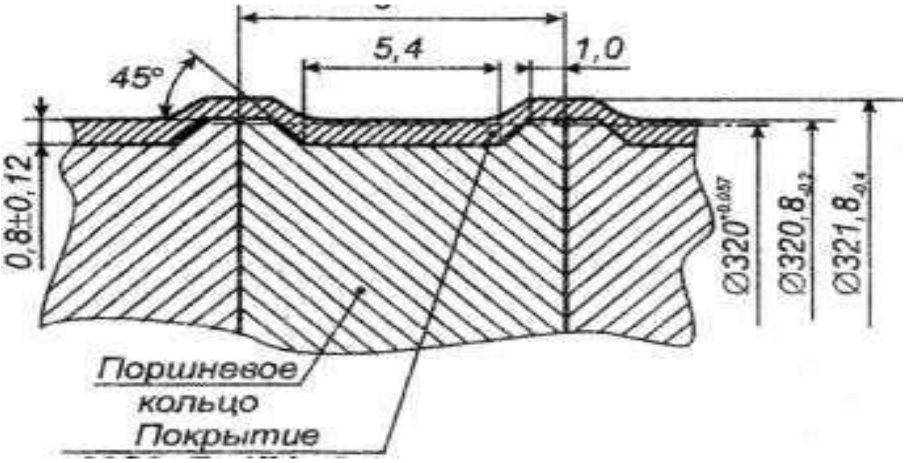


Fig. 5, Scheme of the manufacturing process for manufacturing piston compression rings for diesel 6(8) ЧРН 32/48 with application of a wear-resistant coating

It is recommended to apply the pseudoalloy to the prepared surfaces using stationary electric arc metallizers EM-12, EM-17 or EM-19 designed by VNIIAvtogenmash. As a power source, it is possible to use DC welding transformers with a power of 20...30 kW, with a voltage change range of 35...50 V (KDM-2, VDU-504, VDU-5O6).

Before applying the coating, the metallizer is installed in the support of the lathe so that its axis is located to the surface of the ring pack at an angle of 900±10C. When applying the working coating, wires with a diameter of 2 mm of the 60S2 GOST 14955-77 and Br.KMts-Z-1 GOST 5222-72 grades should be used. In this case, the bronze wire should be connected to the positive electrode, and the steel wire to the negative electrode. Initially, an adhesive "sublayer" with a thickness of 0.08 ... 0.12 mm should be applied to the working surface of the rings. Then the main layer with a thickness of 0.7 mm with high tribotechnical characteristics is formed. The geometric characteristics of the ring package are shown in Figure 6, the general view of the PUSK mandrel with a sprayed coating is shown in Figure 7.



БОС2+Бр_КМц.3.1

Fig. 6. Geometric characteristics of the PKK marine diesel engine 6 (8) ЧРН 32/48 after application

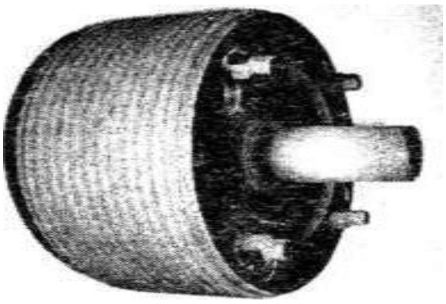


Fig. 7. Marine diesel piston ring pack coating and final mechanical 6(8) ЧРН 32/48 after spraying wear-resistant coating processing

After spraying the coating, the rings are thoroughly checked for possible defects (cracks, peeling) and for uniformity of coating thickness. It is recommended to perform a qualitative assessment of the adhesive strength using an ultrasonic method.

The subsequent mechanical processing - turning the outer surface of the piston rings - is performed on a mandrel without the use of cutting fluids with a straight turning cutter (VKB grade tool material). Coating mechanical processing modes: cutting speed V = 20.. .3O m/min; feed - So = mm/rev; cutting depth - t = 0.3 mm.

After processing the outer surface by turning to the nominal size, the piston ring pack is disassembled and the "lock" milling operation is performed. In this case, it is necessary to use down-cut milling to prevent chipping or peeling of the applied coating. Upon completion of the milling operation, the piston rings are processed in accordance with the current production process. In this case, the ring grinding operation is excluded.

From the practice of diesel engine operation, it has been established that the wear process of the cylinder liner - piston ring friction pair is greatly influenced by the shape of the ring edges. Sharp edges contribute to the oil-scraping action of compression rings, which often worsens the distribution of the lubricant over the surface of the liner and increases the wear rate, especially during the running-in period. In this regard, it is necessary to provide edge radius chamfers with a radius of 0.5 ... 1 mm on all rings. In the current technological process for manufacturing piston rings SOD at OOO Metmash and OAO GSRMZ, the operation of heat-fixing of the PCC is combined with chemical-thermal treatment — sulfocyanation — simultaneous saturation with carbon, nitrogen and sulfur.

To test the efficiency of sulfocyanation of the metallized coating, the friction force values were determined at a changing specific load of MPa on a reciprocating motion stand. The conducted studies made it possible to obtain the friction force values in the tribocoupling "piston ring - cylinder liner" every 20 crankshaft turns (Figure 8).

The conducted tests showed the feasibility of combining the operations of heat-fixing piston rings with a metallized coating with chemical-thermal treatment — sulfocyanation. A reduction in the friction work of sulfocyanated piston rings by 64% was experimentally confirmed. According to the developed technological process, a pilot batch of piston compression rings SOD 6(8) CHRN 32/48 with a wear-resistant metallization coating 60S2 + Br.KMts-Z-1 was manufactured at Metmash LLC.

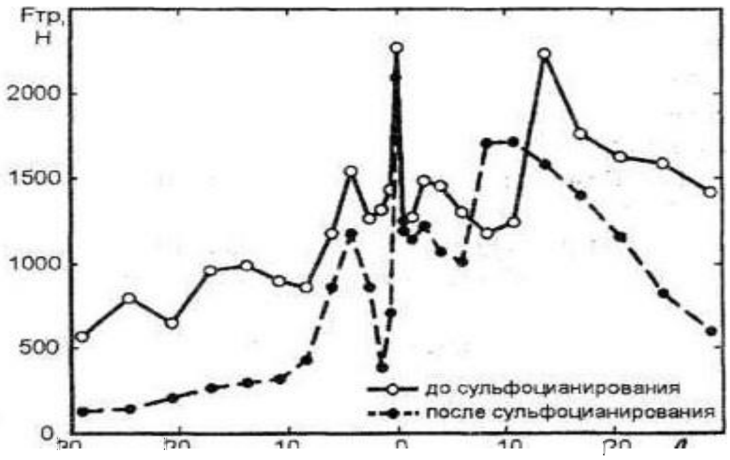


Fig. 8. Change in friction force along the piston stroke during the compression-expansion stroke for piston compression rings with a metallization coating 60S2 + Br.KMts-Z-1 before and after sulfonic etching

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