Hardening treatment of friction surfaces of ball journal bearings

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Abstract. The article presents the technology of finishing plasma hardening by the application of the multi-layer nanocoating Si-O-C-N system to harden the friction surfaces of the ball journal bearings. The authors of the paper have studied the applied wear-resistant anti-friction coating tribological characteristics, which determine the increase in wear resistance of the ball journal bearings.

1. Introduction
One of the new methods of surface hardening, which ensures the application of wear-resistant thin film coatings, is the process of finishing plasma hardening (FPH) based on the application of the plasma jet flowing at atmospheric pressure. The efficiency of this process derives from the compact and economical equipment, which allows for applying the hardening nanocoatings. This method belongs to the additive technologies [1].

The FPH technology fundamental principle of applying a thin-film wear-resistant coating based on the Si-O-C-N system is diffusion of the vapours produced by the liquid organoelemental agents, which are introduced into the plasma chemical reactor of the arc plasma gun, followed by plasma chemical reactions and formation of a coating on work pieces.

Argon is used as plasma-supporting gas as it provides the increased durability and reliability of the plasma gun components in the course of the long-term process. The vapours of volatile liquid reagents are used as the coating-formation materials. They are supplied into the reactor by a special feed-control device. The power for the plasma gun is supplied by a DC inverter with special current-voltage characteristics. The stable cooling of the reactor and the plasma gun is ensured by a cooler made from a refrigerating unit. The monitoring system of the process ensures monitoring and control of the treatment parameters and defines thickness of the applied coating in the course of its precipitation.

The main technologies of applying the wear-resistant nanocoatings, which are commonly used abroad, are chemical vapour deposition (CVD) and physical vapour deposition (PVD). In the aerated FPH technology, the coating is applied in 30...3 nm layers at typical speeds of the plasma jet movement of 10...100 mm/s.

Unlike the condensed coatings in vacuum performed in PVD and CVD processes, in this method the coating is formed locally, where the plasma jet contacts the base coat, and only for the multilayer coating, which is an important feature of the FPH technology. The FPH cyclic relative movement of the plasma jet and the hardened surface determines obtaining of a layered structure of the coating and allows reducing the thermal effect of the plasma on the base coat to the minimum, thus completely eliminating the softening drawing-back for all steels. The integral temperature of the hardened work...
pieces during the application of the coating is usually not more than 150 °C. The hardening coating is formed as a transparent film. On the polished surface it looks as an interference pattern with rainbow hues from purple-blue to green-red, depending on the thickness of the coating.

The choice of the material for the coating applied by FPH method is determined based on knowledge of the wear mechanisms experienced by different products, as well as the analysis of available experience of using various compounds as coatings.

If we consider fundamentally any tribosystem operating under the adhesive, fatigue, oxidation and abrasive wear, the most prospective thin-film coatings would be non-metallic solids - carbides, nitrides, borides, silicides, oxides, composite and nanocomposite materials based on them, as well as cermets and diamond [2]. In this case, the coating must have the maximum adhesion and thermal expansion coefficient close to the hardened work piece, and its surface properties should comply with the characteristics that increase the product durability, i.e. they must have high hardness, chemical inertness, thermal stability, low thermal conductivity, minimal friction coefficient, etc.

In recent decades, the processes of coating with chemical precipitation widely employ the element-organic (organometallic) compounds; their use in coatings determines the improved level of safety (considering they are non-toxic) and zero explosion risk (considering they are used in the liquid state). It is significant that the element-organic compounds can contain all the necessary elements for producing the coatings in a single substance, which improves the effectiveness of the monitoring over the process and reproducibility of the coatings properties.

The X-ray diffraction analysis confirms that after the FPH, the coating is formed in the amorphous state, with no dislocation activity, and the coating exhibits high values of resistance to plastic deformation and elastic recovery. The Si-O-C-N system coating applied with the FPH technology is characterized by high hardness at low elasticity modulus and close values of the coating elasticity modulus and the base coat material, which should objectively result in the improved wear resistance of the surface layer.

2. Findings and discussions

The object of the tribological characteristics study were the journal ball bearings ШС30 (GOST 3635-78, ISO 6125-82). The hardening was performed on the exterior ball surfaces of the inner rings of ШС30 journal ball bearings which are shown in Figure 1.

![Figure 1](image)

**Figure 1.** The ball surfaces of the inner rings of ШС30 journal ball bearings treated by FPH (left) and the bearings manufactured by the factory technology (right).

The factory technology (baseline option) provides the bulk hardening of the inner ring of journal ball bearing made of ШX15 alloy steel with the following abrasion (grinding) of the ball surface. The FPH technology for the bearings ball surfaces was implemented in NPF Plazmacentr OJSC (St. Petersburg).
The wear-resisting properties of the modified ball journal bearings and those manufactured by the factory technology were tested on a specially designed and produced installation; using the automated research system, the installation allowed determining the tribological performance of the ball journal bearings friction surfaces.

The bearings test plan is presented in Table 1, which shows the numbers of the tested bearings, the method of finishing applied to friction ball surfaces of the inner ring of the bearing, the lubricant used for the test surface preconditioning and the main lubricant.

| Bearing No. | Finishing method | For preconditioning | Main |
|------------|------------------|--------------------|------|
| 1          | Baseline option  | –                  | Molykote BR 2 Plus |
| 2          | Baseline option  | –                  | Gazpromneft Grease L |
| 3          | FPH              | Molykote D-321R    | Molykote Longterm 2 Plus |
| 4          | FPH              | Molykote G-Rapid Plus | Molykote Longterm 2 Plus |

The bearings were tested in the following conditions: relative sliding velocity of the ball surfaces is \( \nu = 0.84 \, \text{m/s} \) (with ball surfaces diameter \( d = 40 \, \text{mm} \) and rotating velocity \( n = 400 \, \text{min}^{-1} \)); normal force loading \( N = 2000 \, \text{Н} \) (corresponds to the pressures calculated by Hertz, about 11 MPa); type of lubrication - boundary; a predominant wear mode - fatigue; lubricant - in accordance with the test plan (see Table 1); total time of every bearing test is 6 hours.

During the tests, the sensor system continuously and synchronously recorded the test time, load, friction coefficient and linear wear. Their numerical values were displayed on the PC monitor. The strain gauges were used to measure the friction torque and the load. To ensure the continuous measurement of wear in the course of the test, we developed a special scheme using an inductive sensor, which allowed having the measurement results free from the radial motion variation and thermal deformation of the tested specimen.

The analysis of recorded parameters established the following indicators of tribological properties:

- running-in time \( t_0 \) (hrs), which is defined as the time from the start of the test until the time when the wear curve reaches the area of normal wear;
- running-in wear \( h_0 \) (micrometers) which is defined as the value of binding at the end of running-in time \( t_0 \);
- friction coefficient value at the end of the test, \( f \);
- \( f_0 / f \) - the ratio of the friction coefficient maximum value during running-in \( f_0 \) to its value at the end of the test \( f \);
- the average value of the wear rate during normal wear is \( I_h = (h - h_0) / (L - L_0) \), where \( h \) (micrometers) is the total value of the sample wear during the test; \( L \) (micrometers) is the friction path covered by the sample surface during the test; \( L_0 = 3,6\cdot10^9 \cdot t_0 \cdot \nu \) (micrometers) is the friction path covered by the sample surface during the running-in;
- the value of the wear rate during the total test time is \( I_h \Sigma = h / L \).

The results of the tribology tests of the bearings are presented in Table 2.
Table 2. The results of the journal ball bearings test

| Tribotechnical property | Indicator | Indicator value for the bearing |
|------------------------|-----------|--------------------------------|
|                        |           | 1     | 2     | 3     | 4     |
| Running-in             | $t_0$, hrs| 2.73  | 2.23  | 2.23  | 2.53  |
|                        | $h_0$, micrometers | 15.0  | 14.5  | 2.0   | 2.2   |
| Antifrictionality      | $f / f_0$ | 1.71  | 1.53  | 2.31  | 1.62  |
|                        | $h$, micrometers | 0.045 | 0.059 | 0.013 | 0.021 |
| Wear resistance        | $I_h \cdot 10^{-10}$ | 7.69  | 11.40 | 0.79  | 1.52  |
|                        | $I_{h,2} \cdot 10^{-10}$ | 12.46 | 15.16 | 1.60  | 2.09  |

Note. The bearings numbers correspond to those in Table 1.

It should be noted that the applied lubricant never leaves the friction area on the working surfaces of the journal ball bearings for the duration of the test, which is ensured by its properties.

Despite the significant wear of the hardened layer during the test of the journal ball bearings (initial running-in and normal wear), one should bear in mind that the period of running-in and the initial period of normal wear is the time of establishing the basic provisions and patterns of further friction and wear of the workpiece in the continuous service, which primarily affects its wear resistance and durability, along with the other relevant factors.

Also, the FPH coating wear products never leave the friction area and keep being an additional solid lubricant and a means of healing of micro-defects (microcracks, microchips, microcutting effects (abrasive scratches), etc.) at the friction surface.

Having determined that the products of wear of the coating of the Si-O-C-N affect the tribological characteristics of friction pairs and can help to prevent direct transfer of coating material to the indenter, and fill microwave and to gain a foothold in microvascular roughness of the contacting surfaces, which reduces specific pressures and increase the wear resistance of the friction pair.

The micrograph of the wear track in tests on a tribometer Tribometer (CSM, Switzerland) in conditions of dry friction coatings of the Si-O-C-N confirmed the formation of products that are not brought up, but remain at the bottom of the track, providing ‘healing’ of wear areas (Figure 2).

Figure 3 shows parameters of a strip of the wear coating of Si-O-C-N, with measurements of its width. The antiwear and antifriction action of the wear coating of Si-O-C-N is stored for a long time for the entire test period (the curve of coefficient of friction decreases) of friction pairs and are not associated with the running process.

When compared to the journal ball bearings manufactured by the factory technology, the wear resistance of the FPH-treated journal ball bearings increased by 5...14 times (in the values of wear rate during normal wear), by 6...9 times (in the values of wear rate for total test time).

Figure 2. Micrograph of the wear track, obtained under the optical SA25 AXIOVERT microscope (Karl Zeiss, Germany), 100×
Figure 3. Appearance of the stripe wear coating of Si-O-C-N

The friction coefficient on the working surfaces of the FPH-treated journal ball bearings compared with the journal ball bearings manufactured by the base technology is 2...4 times lower.

3. Conclusion
The analysis of the comparative tests results of durability shows that the best tribological parameters are exhibited by the friction surfaces of the journal ball bearings formed by the technology of their modification with the finishing plasma hardening. The FPH technology can be applied at engineering plants as a highly efficient method of ensuring and improving the operational performance of machine parts at the stage of their manufacturing, in particular, in the manufacture of journal ball bearings.

References
[1] Grigoriev N and Tarasova T 2015 Met Sci Heat Treat. 10(724) 5-10
[2] Stanski D et al 2015 Met Sci Heat Treat. 7(721) 77-83