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Increasing warning resistance of engine valves by gas nitrogenization method

D.D. Marchenko*, K.S. Matvyeyeva

Mykolayiv National Agrarian University, Mykolayiv, Ukraine
**E-mail: marchenkodd@mnau.edu.ua*

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Abstract

The article presents the results of tribological research on the most promising way to restore and increase the wear resistance of engine valves by developing a method of gas nitriding. It is established that with increasing operating time the guide bushings of the outlet connections wear out with the displacement of the axis of the forming surfaces of the hole. Characteristic significant displacement of the axes of the inlet connections is not detected, ie. their wear on the diameter of the hole is 1.5 ... 3 times less than the wear of the exhaust bushings, the values of the displacement of the axes are within the error of the measuring instrument. The average value of ovality is greater in the exhaust seats - the maximum beating values of the intake seats are 0.34 mm, exhaust - 0.22 mm. It is proved that the non-uniformity of the wear of the sleeve hole is determined by the balance of acting forces, which, in turn, are determined by deviations from the optimal ratios μ and e. the side of the rocker arm axis. Distortions of the valve in the longitudinal axis of the engine contribute to an earlier reduction in the tightness of the valve pairs. Redistribution of the valve end material with the formation of a wavy concentric surface, the shape of the contact spot on the rocker arm and the corresponding direction of wear of the saddle chamfer was observed in 43% of the studied connections. Technological means and methods for improving the quality of repair, measuring instruments for accurate study of the parameters of parts and connections of the valve group are given. The results of laboratory and operational tests are presented. A method of gas nitriding with an installation for its implementation has been developed, which provides an environmentally friendly method of low-temperature and high-temperature hardening, obtaining deeper and well-developed layers of the diffusion near-surface zone and reduces training, technological time in the process of strengthening and reducing energy consumption.

Key words: gas nitriding, wear resistance, friction steam, engine valves, recovery technology, wear intensity.

Introduction

The urgent need to reduce engine oil consumption during engine operation has led to many changes in the design of engine parts, including the design and choice of valve stem material. Which is once again confirmed by the expression: "For every action there is opposition."

As the amount of oil entering the orifice of the valve guide sleeve has decreased, there is an urgent need for such treatment of the valve stem, which will withstand abrasion resistance or other types of wear at high temperature fluctuations and loads.

Nitriding is widely used to strengthen a variety of steels and alloys, machine parts, tools operating in different conditions and environments, as well as to increase hardness, wear resistance, abrasion resistance, fatigue and corrosion resistance. Deformation of products during nitriding is minimal, nitrided layer is well polished and polished [1].

This process is the most modern metal nitriding technology in the world. This method is based on the strengthening treatment of heavily loaded parts of machines, tools, stamping equipment by diffusion saturation of the surface layer with nitrogen nitrogen-hydrogen plasma pulsating current. In this process, the phenomenon of ionic deposition in a dilute gaseous medium is used to saturate the surface layer of metals with nitrogen. Pulsed ion-plasma nitriding is a modern type of gas nitriding, in which ammonia is replaced by nitrogen and hydrogen, which do not pose a threat to the environment.

The process is carried out at low temperatures (starting from 400 °C, which is also one of the many advantages of ion-plasma nitriding) and under reduced pressure. The main result of this process is to obtain nitrided layers of high hardness. Control of process temperature in the working range from 400 °C to 600 °C allows to receive various indicators of hardness of a surface layer. The highest hardness of the nitrided surface is formed when using operating temperatures in the range of 400 °C - 500 °C. The nitriding process itself takes place in a chamber with a vacuum of 1-10 hPa. The workpiece is the negative electrode (cathode) and the chamber walls are the positive electrode (anode). When a constant voltage (400-700 V) is applied between the cathode (negative potential) and the anode (positive potential), a heterogeneous electric field arises and a glow discharge is excited. Due to the collision of electrons and gas atoms, the latter accelerate and bombard the cathode surface, knocking out atoms of iron, its compounds, carbon, nitrogen and electrons required for ion deposition. Iron atoms combine with active nitrogen atoms and are deposited on the surface of the part as nitrides and saturate the surface layers with nitrogen during diffusion. As a result of pulsed ion-plasma nitriding, a diffusion layer with a developed nitride zone is obtained, which provides high corrosion resistance and workability of friction surfaces. Optimization of the properties of the reinforced surface is ensured by the necessary combination of nitride and diffusion layers, ensuring a significant increase in wear resistance, burr resistance and fatigue [2].

The range of steel grades is constantly expanding, which develops individual technological parameters of the process of pulsed ion-plasma nitriding.

As a result of surface hardening by the above method we obtain a diffusion layer, which provides a 5-fold increase in service life, wear resistance and increase the anti-emergency properties of parts. The use of this technology can significantly improve the performance of the pair "valve rod - guide", reduce the adhesion of soot in the area of the valve plate and increase the corrosion resistance of the valve and its overall service life. The results of tests of valve steels before and after nitriding by the method of linear wear measurement show more than 5-fold reduction in wear of nitrided steel.

Literature review

Nitriding as a method of strengthening machine parts and tools has come a long way of development and improvement. Currently, in terms of ensuring the functional properties of numerous parts and tools, it is one of the most effective and common methods of strengthening in various fields of mechanical engineering (automotive, aerospace, engine, machine tool, chemical industry, etc.).

Among the advantages of the nitriding process should be noted:

1. High hardness (up to HV 1300), which is achieved without hardening;
2. Insignificant in comparison with other methods of strengthening deformation of details;
3. Heat resistance of the surface saturated layer up to 500… 600 °C;
4. High wear resistance;
5. Corrosion resistance (especially in the air);
6. High fatigue resistance;
7. High resistance to alternating loads.

The disadvantages of this method of strengthening are as follows:

1. Long duration of the saturation process (up to 100 hours);
2. Low in comparison with cement details contact strength;
3. High fragility of the surface layer;
4. Reduced viscosity of nitrided parts;
5. Instability of nitriding results in its implementation in industry [3].

Although many varieties and methods have been developed and implemented since the industrial development of the nitriding process (laser and plasma nitriding, vibration in the vibrating fluidized bed, in salt melts, etc.), however, practical experience shows that the most common process in industrial conditions is the vast majority. machine-building industries are gas nitriding using as saturating the atmosphere products of partial dissociation of ammonia NH_3.

In particular, the so-called classical process of gas nitriding, which was developed by Lakhtin Y.M., Kosolapov G.F., Minkevich A.N., Beloruchev A.V., Jurgenson A.A., Arzamasi B.N., Kogan I.D., is actively used to strengthen parts of machines and tools in the current production. This is due to the relative simplicity of the technological implementation of the gas nitriding process using ammonia as a saturated medium, the relatively low cost of equipment and equipment required for this process (compared, for example, with equipment for ionic nitriding), as well as fairly well-established chemical regimes - heat treatment of various steels and alloys using this type of saturation. However, based on empirical observations and practical experience of gas nitriding of some of the above companies, it was observed that this type of nitriding leads to significant embrittlement of products, some time after their saturation in ammonia.

In high-speed engines, the end working surfaces of the pushers are also welded with high-strength alloys. Phosphating of pusher working surfaces and molybdenum dioxide treatment (to prevent burrs during operation) are also used. Improving the wear resistance of pushers is achieved by using the most advantageous forms of their working surfaces. The surface of the collision of the pusher with the cam is made, for example, spherical, which significantly reduces the compression stress due to the inability to maintain parallelism in the plane of the cam of the cam of the camshaft. For the same purpose, the barrel-shaped shape of the pusher guide surface is used in combination with a flat end surface. To increase the wear resistance of the valves and use a device that ensures their rotation during engine operation. At the same time the term between grinding of valves doubles.

Serviceable valves must quickly and reliably seal the combustion chamber, withstand large temperature fluctuations and have good wear resistance to ensure the longevity of the engine. Failure of the valves (or even one valve) disables the engine. And in the most severe case - to the destruction of the piston, cylinder or cylinder head. Therefore, thorough defecting of valves and bushings is very important when repairing the motor [4].

At pushers surfaces of a core and a plate wear out. Pusher rods are restored by vibro-arc surfacing, using high-carbon steel wire, or baking metal powders. After surfacing or baking, the pusher rod is ground on a grinder. It is not recommended to restore the push rods by chrome plating, as this leads to rapid wear of the guides in the unit. The pusher plates of modern engines are welded with a thin layer of bleached cast iron, so when grinding they remove a very thin layer (up to 0.3 mm), necessary only to remove traces of wear.

The valve in the sleeve makes not only reciprocating movements, but also rotational-angular. If you take into account the speed of such movements, you can understand what the load will be on the sleeve. Naturally, wear occurs over time. Due to the radial beating the load increases, the rotational movement of the valve becomes more difficult and production increases.

This leads to one-sided wear not only of the bushing, but also the valve with the seat. Increased clearance in the pair of "valve-sleeve rod" leads to increased oil consumption, as the oil cap is not able to hold oil, which again is caused by increased side beats of the valve. With the untimely intervention of the master, this can lead to irreversible consequences - the replacement of seats, valves, bushings, and sometimes the replacement of the entire head of the unit.

The shape and material of the guide sleeve of the valve are selected taking into account the high speed of movement of the valve in the sleeve, the high temperature load and the limitation of the lubrication of the friction pair "sleeve-valve". If the head of the cylinder block is made of cast iron, then often the seats and guide bushings of the valves are integral with the head of the block. This design ensures alignment and, consequently, a more accurate fit of the valve on the seat, which reduces the temperature of the inlet and outlet valves. Cast iron cylinder heads were used on some engines from Opel, Ford and other manufacturers. But the technology of production of cast iron heads is complex and requires expensive equipment, so most of the heads of modern car units are made of aluminum alloys. In their production, the guide bushings and valve seats are made separately, and then pressed into their seats in the cylinder head [5].

Guide bushings are made of wear-resistant materials with good thermal conductivity. These are special cast iron, cermets, bronze and brass. Higher thermal conductivity in bronze and brass, so they are used on most boosted engines, such as BMW, Audi, Volvo. To fix the sleeve in height in the cylinder head on its outer surface there is usually a support flange. Sometimes a split support ring is used instead. If the sleeve is smooth on the outside, you will need a special border or a remote sleeve to install it in the head.

The intake manifold guide bushings should not protrude too much into the intake manifold so as not to increase its aerodynamic drag. But the exhaust valve bushes, on the other hand, should close the valve stem to the maximum length for protection against hot exhaust gases and for better heat dissipation from the exhaust valve rod. If the guide bushings are made of bronze or brass, they usually have the same length, as these alloys have high thermal conductivity.

To ensure the alignment of the seat and the plate of the valve requires high precision manufacturing of the sleeve. In addition, the outer surface of the sleeve, pressed into the head of the unit, should be treated with a high degree of surface cleanliness and should not have scratches and scratches. This is done to improve heat dissipation from the bushing to the cylinder head.

The main defect of the guide bushings is the increased wear of the inner surface caused by prolonged (at least 60-100 thousand km for domestic and 150 - 200 thousand km for foreign cars) operation of the engine. However, the use of poor quality oils dramatically reduces the life of the bushings, not to mention the engine as a whole. Prolonged operation of the engine with incorrectly set thermal gaps of the valves is also the cause of uneven wear of the guide sleeve. This is due to the increase in lateral loads on the rod and the deterioration of the rotation of the valve.

In the presence of repair valves, the sleeve is first deployed under the repair diameter of the valve stem, and then under the required clearance between the sleeve and the valve. The clearance is the same as for standard valves. When deploying the sleeve to obtain the correct geometry, the deployment holes must start from the oil cap side, as this part of the sleeve is subject to less wear.

The method of knurling the inner surface of the sleeve with subsequent scanning to the desired inner diameter. This method requires a special tool. When using it, the seat under the guide in the head of the unit is not damaged. However, its inner surface, erased by the valve stem, will have a greater hardness than the body of the sleeve, which occurs due to plastic deformation.

This method is especially suitable for engines that have a cast iron block head, and the valve guides are made directly in the block head. At wear to 0.3 mm it is easier and cheaper to restore them by unrolling, than by boring and pressing of new directing plugs.

In addition, before pressing the sleeve, be sure to check the diameter of the seat under the oil cap. If this diameter is smaller than on the old bushings, the caps may simply fly off while the engine is running. Many companies, such as Volvo, BMW, Volkswagen, produce repair guide bushings with increased outer diameter for pressing. The seat under such a sleeve in the head of the unit must be expanded to a size that provides a landing with a tension of 0.02 to 0.1 mm [6].

Before pressing the new bushings, the block head is heated again to 90 °C - 100 °C, and the bushings are cooled, which is most desirable to do in liquid nitrogen.

To increase the wear resistance of the valves and bushings crystallize on nickel-phosphorus-copper coatings. Immediately after precipitation, all coatings containing more than 4% P were amorphous. The only composition that was obtained with a crystalline structure was a coating containing 4% R. Its structure consisted of supersaturated phosphorus - Ni from a strongly distorted crystal lattice.

Ni-P-Cu coatings are also used. The processes of joint chemical reduction of metals, as well as the processes of their electrochemical reduction, are subject to the same thermodynamic laws. Therefore, the equilibrium potentials of metals and their change as a result of complexation in solution and formation of alloys play a special role in these processes. Assuming that the chemical reduction of metals proceeds by electrochemical mechanism, we can assume that the processes of chemical and electrochemical deposition of metals are similar. However, it should be borne in mind that the rate of entry into the metal of active agents of the reduction reaction - electrons, is determined by the rate of anodic oxidation of the reducing agent, sensitive to nature and the state of the reaction surface. This leads to the lack of a complete analogy between chemical and electrochemical deposition of alloys, which is primarily expressed in the effect on the rate of chemical deposition of alloy components of the catalytic properties of metals.

The composition of solutions is empirically substantiated in most works on chemical deposition of alloys and the simplest regularities of deposition processes are revealed, and only in some the structure of sludge, influence of deposition conditions on its composition, kinetics and process mechanism are considered [7].

Purpose

The purpose of scientific research is to increase the wear resistance of engine valves by developing a method of gas nitriding and a technology for its implementation.

Research methodology

The main characteristic of wear of a detail is linear wear which is measured in the direction perpendicular to a friction surface. Due to a number of reasons, wear can be uneven. Therefore, to fully characterize the amount of wear of the part, it is necessary to know the distribution on the friction surface the shape of the worn surface [8].

To obtain the dependences of the size of the contact site *a* on the friction path *S*, wear tests of two friction pairs were performed. The tests were performed on a lathe equipped with a special device. The scheme of the device is shown in Fig. 1.

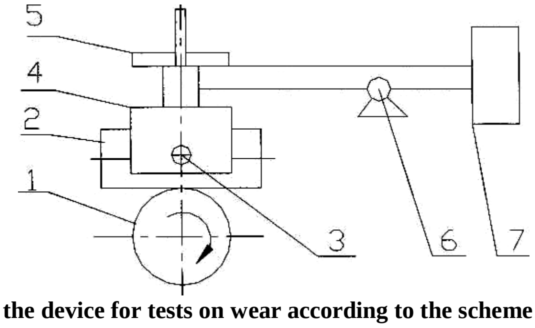

Fig. 1. Scheme of the device for tests on wear according to the scheme of cross cylinders: 1 - shaft; 2 - sample; 3 - screw; 4 - mandrel; 5 - cargo; 6 - support; 7 - counterweight

A shaft 1 made of steel 45 (HRC 48 ... 55, counter body) is mounted in the machine spindle, on which a cylindrical specimen 2 is mounted and pressed by a force *Q* (load 5 with known mass). The sample is fixed to the mandrel 4 with screw 3. To compensate for the mass of the device at the other end of the holder is screwed counterweight 7.

A lubricating cup is installed on the machine for lubrication testing, then both cylinders are immersed in the oil [9, 10].

The tests are performed in the following sequence:
- install the sample in the clamp 4;
- press the sample 2 with screw 3;
- counterweight 7 compensate for the mass of the sample and other elements of the device;
- on the axis of the clamp set the load with a known mass;
- turn on the machine and record the time;
- after a certain period of time we take out the sample in the reverse sequence and measure the size of the contact area;
- install the sample in the clamp so that the contact spot rises to its previous place.

Research results

Friction pair 1: 40X hardened steel - cast iron SC 20.

The test results of the samples are entered in the table (Table 1), having previously determined the equivalent radius of the circle by the formula:

$$a = (a^* b^*)^{1/2}.$$

According to these results, we construct a graph of the dependence of the contact spot on the friction path ($S = \pi d n T$) - Fig. 2.

$$S_1 = 3.14 \text{ x } 20 \text{ x } 100 \text{ x } 1 = 6280 \text{ mm} = 6,280\ 10^3 \text{ mm}$$
$$S_5 = 3.14 \text{ x } 20 \text{ x } 100 \text{ x } 5 = 31.4\ 10^3 \text{ mm}$$
$$S_{10} = 3.14 \text{ x } 20 \text{ x } 100 \text{ x } 10 = 62.80\ 10^3 \text{ mm}$$
$$S_{15} = 3.14 \text{ x } 20 \text{ x } 100 \text{ x } 15 = 94.2\ 10^3 \text{ mm}$$

Table 1

The results of the test of cast iron midrange 20 (Friction pair 1: Cast iron SC 20 - steel 40X hardened)

T, min	*S* 10^3, mm	2*a**, mm	2*b**, mm	*a*, mm
1	6,280	0,554	1,167	0,211
5	31,40	0,634	1,428	0,234
10	62,80	0,75	1,598	0,267
15	94,2	0,943	1,761	0,315

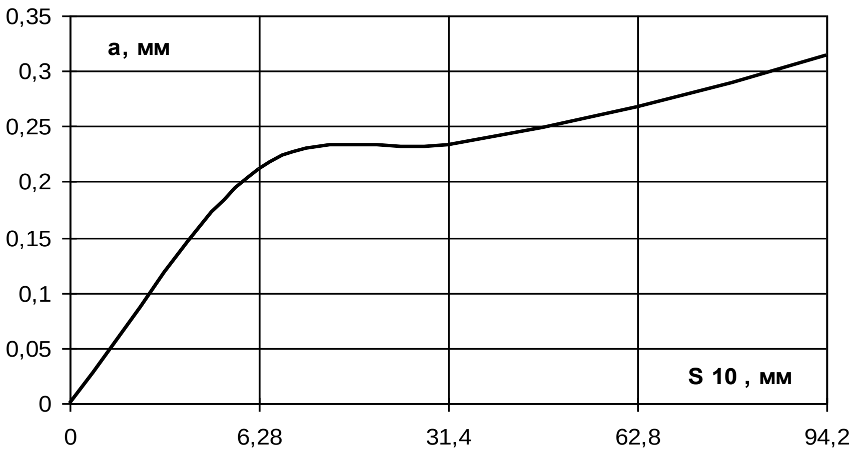

Fig. 2. The plot of the equivalent radius is spotted cast iron SC 20 from the friction path

Friction pair 2: Cast iron SC 20 - steel 40X nitrided.

Table 2

The results of the test of cast iron midrange 20 (Friction pair 1: Cast iron SC 20 - steel 40X nitrided)

T, min	*S* 10^3, mm	2*a**, mm	2*b**, mm	*a*, mm
1	6,280	0,554	1,167	0,203
5	31,40	0,634	1,428	0,227
10	62,80	0,75	1,598	0,243
15	94,2	0,943	1,761	0,277

According to these results, we plot the dependence of the contact spot on the friction path (Fig. 3.)

It is established that with increasing operating time the guide bushings of the outlet connections wear out with the displacement of the axis of the forming surfaces of the hole. Characteristic significant displacement of the axes of the inlet connections is not detected, their wear on the diameter of the holes is 1.5 ... 3 times less than the wear of the exhaust bushings, the values of the displacement of the axes are within the error of the measuring instrument [11, 12].

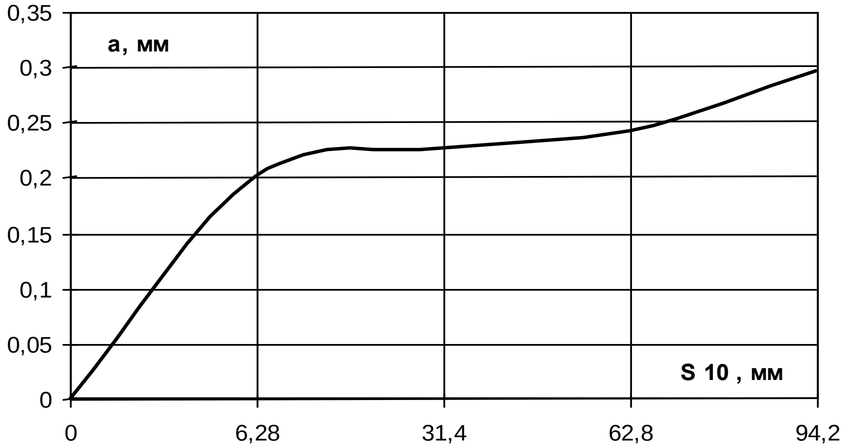

Fig. 3. Graph of the dependence of the sizes of the equivalent radius the spot of contact of cast iron SC 20 from the friction path

In Fig. 4 combined Fig. 2 and 3.

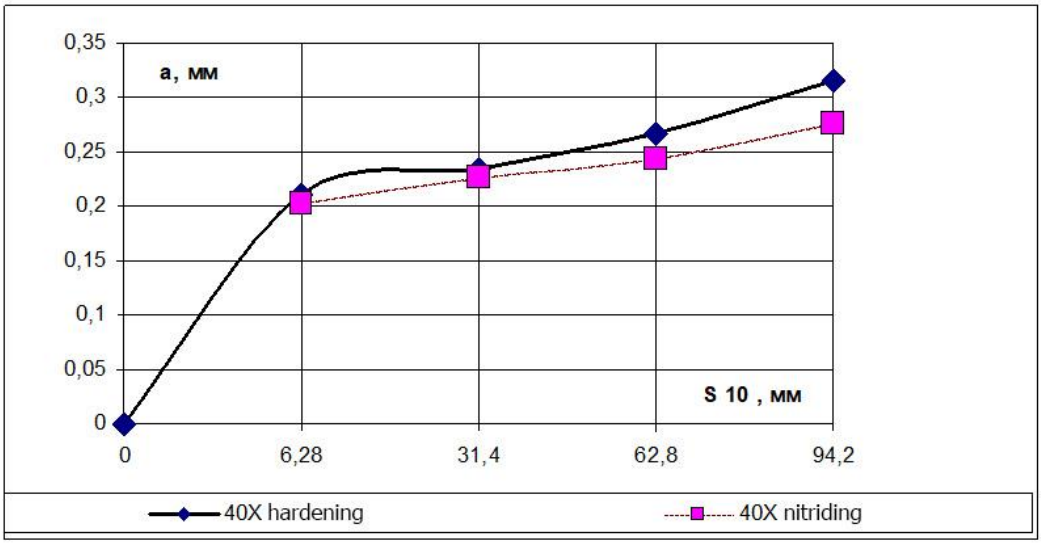

Fig. 4. Graphs of the dependence of the dimensions of the equivalent radius of the contact spot on the friction path of cast iron SC 20 (counterbody - nitrided and hardened steel 40X)

The nature of the distortion of the shape of the saddle chamfer inherits the main direction of displacement of the axis and the shape of the distortion of the guide sleeve during wear. The most frequent deviations of relative displacement occur not in the plane of rocking of the rocker arm, but at an angle to it and directed to the center of the combustion chamber. In contrast to the bushings, the relative displacement of the axes of the inlet seats is the same pattern [13]. Moreover, the average value of the ovality is greater than that of the exhaust seats - the maximum beating values of the intake seats are 0.34 mm, exhaust - 0.22 mm.

Conclusions

The analysis of materials to increase the wear resistance of the friction pair "valve - bushing" and identified the main faults, causes of wear and existing repair technologies. It was found that severe wear of the guide bushings leads to a violation of the geometry of the seats and even to their destruction. The surface of the collision of the pusher with the cam is made, for example, spherical, which significantly reduces the compression stress, which occurs due to the inability to maintain parallelism in the plane of the cam of the cam of the camshaft. The purpose of repair of valve seats - to provide the correct geometry of connections "valve-seat" and their tightness which are defined in turn mainly by vacuum pressure and "beating" of a facet of the valve and a seat. Existing technologies for repairing valves and bushings are determined by the high cost of processing equipment and consumables. Therefore, we have proposed a method of gas nitriding, which has significant advantages over existing methods. Researches of technology of repair of conjugation of valve group of engines are carried out. It is established that the non-uniformity of wear of the sleeve hole is determined by the balance of acting forces, which, in turn, are determined by deviations from the optimal ratios μ and e. the side of the rocker arm axis.

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Марченко Д.Д., Матвєєва К.С. Підвищення зносостійкості клапанів двигунів методом газового азотування

В статті приведено результати трибологічних досліджень з найбільш перспективного способу відновлення і підвищення зносостійкості клапанів двигунів шляхом розробки методу газового азотування. Встановлено, що із збільшенням напрацювання напрямні втулки випускних сполучень зношуються зі зміщенням осі утворюючих поверхонь отвору. Характерного значного зміщення осей втулок впускних сполучень не виявлено, т. я. їх знос по діаметру отвору в 1,5 ... 3 рази менше зносу випускних втулок, значення зміщення осей знаходяться в межах похибки засобу вимірювання. Середня величина овальності більше у випускних сідел - максимальні значення биття впускних сідел складають 0,34 мм, випускних - 0,22 мм. Доведено, що нерівномірність зношування отвору втулки визначається балансом діючих сил, які, в свою чергу, задаються відхиленнями від оптимальних співвідношень μ і е. З урахуванням сил тертя, що виникають на поверхні втулки, зношування отвору втулки відбуватиметься з поворотом її осі в нижній частині в сторону осі коромисла. Перекоси клапана в поздовжній осі двигуна сприяють більш раннього зниження герметичності клапанних пар. Перерозподіл матеріалу торця клапана з утворенням хвилястої концентричної поверхні, форма плями контакту на бойку коромисла і відповідний напрям зносу фаски сідла спостерігалося у 43% досліджуваних сполучень. Приведені технологічні засоби і методи, що забезпечують підвищення якості ремонту, засобів вимірювань для точного дослідження параметрів деталей і сполучень клапанної групи. Представлені результати лабораторних та експлуатаційних випробувань. Розроблено метод газового азотування з установкою для його здійснення, який забезпечує екологічно чистий спосіб низькотемпературного і високотемпературного зміцнення, отримання глибших і добре розвиненіших шарів дифузійної приповерхневої зони і дозволяє скоротити підготовку, технологічний час при проведенні процесу зміцнення та скорочення витрати енергоносіїв.

Ключові слова: газове азотування, зносостійкість, пара тертя, клапани двигуна, технологія відновлення, інтенсивність зношування.