Problems of Tribology, *V. 29, No 2/112-2024, 37-49*

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2024-112-2-37-49

Analysis of tribological aspects during operation and repair of internal combustion engine valve mechanism parts

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Received: 31 March 2024: Revised 15 April 2024: Accept 10 May 2024

Abstract

The problem of researching mechanisms of wear of valve mechanism parts remains very relevant due to the need for constant improvement of the design and increase in durability of internal combustion engines. The paper provides an overview of modern research on the following issues: analysis of operating conditions and malfunctions of the valve mechanism of the internal combustion engine, research on friction and wear of valve mechanism parts, repair and restoration technologies, increasing the wear resistance of engine valves, modeling, calculations of valve mechanism parts. It is shown that an important aspect for the analysis of the wear resistance of valve mechanism parts is the operating conditions and the nature of damage to the surfaces of the friction pair parts. The existing hypotheses about the mechanisms of friction, lubrication and wear of valve mechanism parts are considered, the designs of test stands are given, and the results of tribological tests are analyzed. It is substantiated that the technological methods of surface engineering are becoming an increasingly viable alternative to structural changes to improve the performance of valve mechanism parts. An overview of calculation methods for assessing the stress and thermal state of valve mechanism parts of internal combustion engines is provided.

Keywords:internal combustion engine, valve, guide, damage, restoration, wear resistance, modeling, finite element method

Introduction

The engine valve is a responsible part of every internal combustion engine and gas distribution mechanism. The valve mechanism is responsible for the harmonious operation of the engine, controlling the quality of the following processes: timely supply of fuel to the combustion chambers, removal of spent fuel - exhaust gases.

The main principle of operation of the engine valve is to create the necessary hermetic conditions in the chamber at the moment when the fuel mixture ignition procedure takes place. During operation of the power unit, such parts are subjected to special loads. The number of valves depends on the specific engine. Most often, engines with four valves are installed in modern vehicles: two intake and two exhaust.

Automotive engine valves must meet the following characteristics:

1. Ensure a hermetic connection in connection with the saddle.
2. Do not be negatively affected by corrosion even when moisture gets inside.
3. Provide high resistance to shock loads, mechanical damage during operation.
4. Provide effective heat transfer.
5. To have a small weight, without creating an additional load on the unit, to be a strong, rigid part.

The valve mechanism consists of a spring made of steel, a seat, a sleeve and a mechanism responsible for fixing the rotary device. During operation of power units, the base of the exhaust mechanism is exposed to high temperatures up to 500-700 degrees.

As a result of valve guide wear, the following valve damage and sealing problems may occur: burnt valve heads; cracks in the valve stem; cracks in the grooves for valve crackers; excessive wear of valve stem ends; worn on one side of the rocker arm; increased oil consumption due to wear of valve stem seals; worn or burnt valve seat rings.

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If there is too much clearance or uneven, conical or tubular wear, the valve guides must be replaced. Deformed valve guides strongly affect valves with a stem diameter of less than 8 mm. If the guide is deformed, the valve head is off-center on one side of the valve seat and is pulled into the seat by the force of the valve spring. After some time, this can lead to valve failure. Under the action of the variable load that occurs during bending, the valve breaks at the junction of the rod and the valve head. When using rocker arm or balancer actuated valves, deformed valve guides cause increased radial force to be applied to the valve stem. As a result, the valves break in the area of the groove for the valve wedges. The problem of researching mechanisms of wear of valve mechanism parts remains very relevant due to the need for constant improvement of the design and increase in durability of internal combustion engines. In this work, a review of the results of modern research on the wear resistance of the parts of the valve mechanism of various engines in operational and laboratory modes of operation is carried out. The review was carried out in the following directions: analysis of operating conditions and malfunctions of the valve mechanism of the internal combustion engine, research of friction and wear of valve mechanism parts, repair and restoration technologies, increasing the wear resistance of engine valves, modeling, calculations of valve mechanism parts.

Analysis of operating conditions and malfunctions of the valve mechanism of the internal combustion engine

An important aspect for analyzing the wear resistance of valve mechanism parts is the operating conditions and the nature of damage to the surfaces of the friction pair parts. Research [1] is focused on different failure modes of internal combustion engine valves. The closed valve is loaded by the force of the spring and the pressure inside the cylinder, which periodically changes during engine operation and reaches a peak value of the order of 15 MPa. This high pressure inside the cylinder causes the valve cone to bend, resulting in slippage and improper contact between the valve face and the seat insert, ultimately leading to wear.

Exhaust valves operate at very high temperatures and are subjected to cyclic loads. The failure of the conical valve surface is mainly caused by elastic and plastic deformation and fatigue. The exhaust valve stem usually fails due to overheating as the temperature of the exhaust valve is around 720 ºC.

At high loads, multiple cracks are initiated if the valves are exposed to high temperatures, and under these operating conditions it would be logical to expect failure to occur within several million cycles. The broken valve stem is shown in Fig. 1.

Fig. 1. The edge of the fracture surface of the valve stem

Considerable hardness is lost due to overheating and surface oxidation and galling of the valve stem occur. Fatigue properties of the alloy suffer from high temperature. This is the reason for the initiation of multiple fatigue cracks. Faulty exhaust valves are shown in fig. 2.

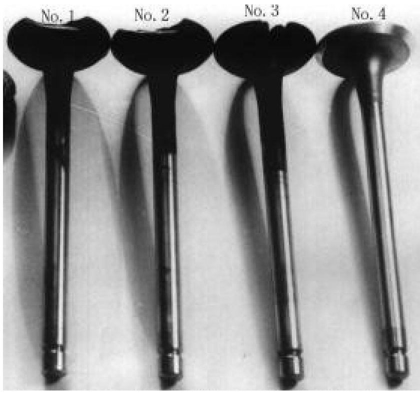

Fig. 2 General appearance of valve damage

It has also been found that wear usually occurs on the valve seat surface and on the stem due to sliding within the stem guide. The rate of wear increases with the number of cycles. Erosion-corrosion failure of exhaust valves is also a recognized failure mode of internal combustion engine valves.

An analysis of exhaust valve failures was carried out in [2].diesel engine. A visual inspection of the damaged engine parts showed that the fracture of the exhaust valve showed signs characteristic of fatigue failure. Additional observations of the crack initiation zones showed that the origin of the crack was not covered by material defects orcorrosion products. Nonlinear finite element analysis was used to explain the cause of premature valve failure. The results of the stress analysis performed on the soot valve showed that high bending stresses occur in the valve stem.

The car had a diesel engine failure with a mileage of 230,000 km. Damaged 4-cylinder turbocharged piston engine, fatigue failures of exhaust valves in this engine occurred at significantly higher mileage (600-900 thousand km).

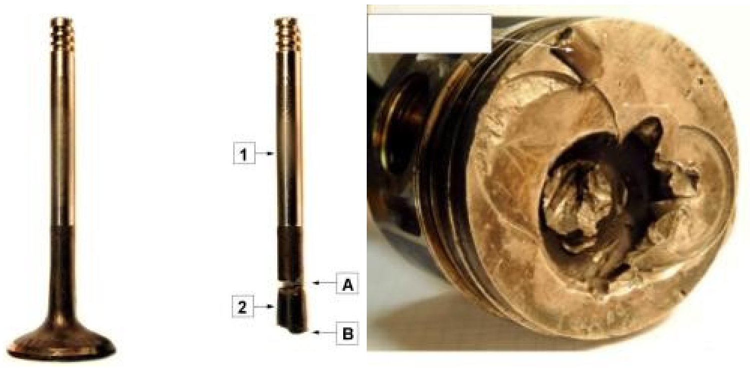

Fig. 3. View of the details of the damaged diesel engine valve

After the breakdown, the engine was disassembled. A piece of the exhaust valve was found in the engine head (part No. 1, Fig. 3). The second piece of the damaged valve (part #2, Fig. 2) was driven into the upper surface of the piston. In fig. 3 shows the depressions formed after the collision of the broken valve head with the piston. The third piece, the damaged valve (head), was lost during the engine repair, so it is not shown. Therefore, the problem of the destruction of the exhaust valve of the diesel engine was investigated. A visual inspection of the damaged valve revealed that fatigue cracks had formed in the valve during engine operation.

Gasoline direct injection (GDI) engines have a well-known tendency to develop intake valve deposits (IVDs), regardless of operator maintenance, engine architecture, or cylinder configuration [3]. The process of deposit formation is not sufficiently studied and there is no standardized engine test to study the effect of variable fuel composition or lubricants.

Since the fuel is injected directly into the combustion chamber and not into the intake valve like in PFI engines, there is no longer the washing action of the fuel and the cleaning additives contained in the fuel to keep the intake valves free of deposits. Possible intake valve deposits now build up steadily over time until they affect engine performance, often with disastrous results. In fig. 4 shows the direct fuel injection system with the position of the fuel injector relative to the intake valve.

Fig. 4. Direct fuel injection system

Due to the lack of a fuel flushing process, characteristic of engines with port fuel injection, deposits constantly accumulate over time and can lead to poor combustion, unstable operation, valve sticking or engine failure (Fig. 5). Vehicles using these engines often have to undergo expensive maintenance to mechanically remove the deposits that re-form over time. On a car equipped with a 2.0-liter GDI turbo engine, the mechanisms leading to the formation of deposits were studied and analyzed. It has been determined to be a combination of engine oil, engine wear, unburned fuel and exhaust pollutants. It was also found that the rate of accumulation is affected by the composition variables of the motor lubricant.

Fig. 5. Deposits on intake valves

The dynamic development of the design of internal combustion engines creates the need to introduce operation strategies based on information about their technical condition. The article [4] analyzed the problems associated with the vibration diagnosis of the valve gap of the internal combustion piston engine, which is significant from the point of view of efficiency and durability. Classification methods are proposed for evaluating valve clearance. Experiments aimed at providing information necessary for the development and verification of the proposed methods were performed and described. In the conducted studies, vibration signals were obtained from a triaxial accelerometer located in the head of the engine cylinder block.

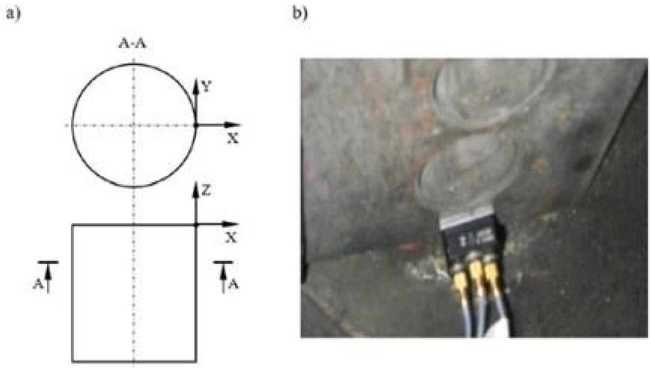

Fig. 6. a) Orientation of vibration measurement directions on the cylinder head, b) view of the vibration sensor installed on the cylinder head

The selection of the vibration measurement point (Fig. 6) was preceded by an analysis of the design of the cylinder head, studies related to the determination of the influence of the valve clearance of the diesel engine on the selected vibration parameters. The received vibration signal was parameterized for the engine operating under different engine loads, rotation frequency and valve clearance settings. The parameterization concerned the characteristics of vibration signals, the derivative of the vibration signal as a function of time, as well as the envelope of this derivative. Based on the conducted research and analysis, a methodology for assessing the valve gap is proposed.

In work [5] malfunctions of automobile valves were considered. Changes in valve microstructure were studied and analyzed using a scanning electron microscope (SEM). Samples were made from failed engine valves, while new valves were also analyzed for comparison. This was done by analyzing images of defective and new valve samples at sufficient magnification. A comparative analysis of the microstructures of defective valves and new valves showed that the grain size and distribution of carbide particles in the material matrix are affected by high temperature conditions. The microstructure of the valve material shows noticeable changes after working at high temperatures. The grain size of the material also changes at high temperature, which reduces the hardness of the valve material and causes more wear.

The article [6] presents an analysis of elements of internal combustion piston engines that interact with the combustion chamber. An assessment of the state of tribological nodes: valve stem - valve guide and valve head - valve seat in random operating conditions was carried out. The image of wear and damage of parts of tribological nodes was studied (Fig. 7).

Fig. 7. Pathological wear of the guide part of the intake valve stem from the head side

Analysis of digital images of real objects was carried out using an optical microscope and measurement of macro- and microgeometry. Identification of the main wear processes was carried out.

Study of friction and wear of valve mechanism parts

In the article [7], he proposed a multifunctional device for determining wear for the study of tribological characteristics of connections of the valve mechanism of the engine (Fig. 8). The device uses a mechanical load system, which consists of a special eccentric wheel and disk springs that simulate the load from the engine combustion chamber, as well as simulate the contact loads of the valve mechanism elements. The test bench has three functions for different studies using specially designed instruments. The first function aims to evaluate the interaction between the valve seat surface and the seat insert at high temperatures and loads. The second function is used to investigate the friction and wear properties of the valve stem and valve guide. The third function is designed to evaluate the performance of valve seals. Tests were conducted using the proposed experimental complex. It was established that the wear mechanisms occurring in the studied friction pairs are a combination of oxidative wear, adhesive wear, and fatigue delamination.

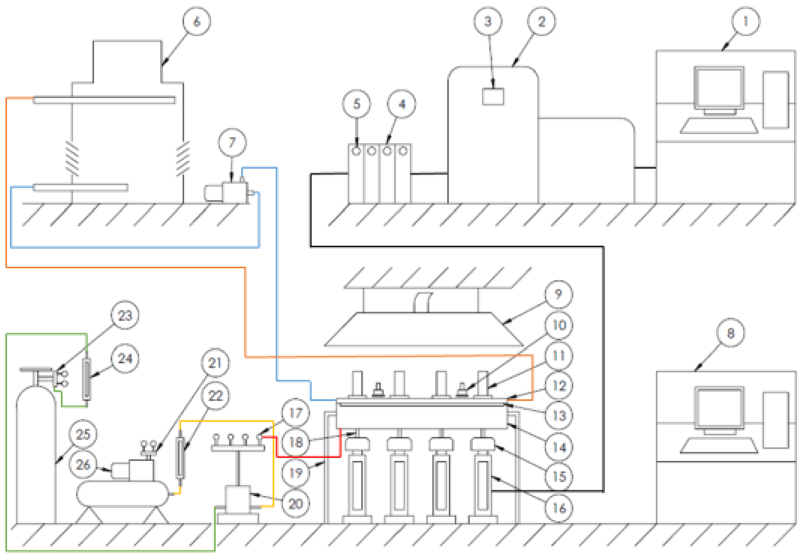

Fig. 8. Experimental complex of tests of friction pairs of the internal combustion engine valve mechanism: 1 - hydraulic control system, 2 - hydraulic pump, 3 - hydraulic control panel, 4 - oil pressure in the hydraulic accumulator system, 5 - pressure indicator, 7 - pump cooling system, 9 - exhaust system, 10-rotor valve, 15- strain gauges, 16- hydraulic drives, 19- stand for testing holders, 20- gas mixer, 25- cylinder, 26- compressor

In fig. 9 shows the results of SEM analysis on the valve surface. After the tests, no signs of cracks or corrosion pits were observed. Quantitative analysis using energy dispersive spectroscopy (EDS) was performed on different areas of the valve surface.

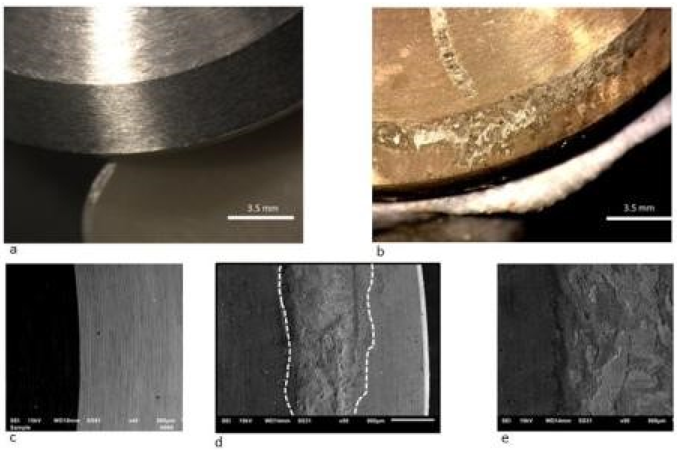

Fig. 9. Microscopic analysis of the valve surface before and after the tests

As a result of repeated loads and high temperature, the valve seat material became detached and adhered to the valve surface. This was confirmed by microscopy when additional material was observed attached to the valve surface (Figures 9a and 9b). A stellite coating was preserved on some parts of the valve surface (Figs. 9d and 9e).

A lightweight valve is often made of TiAl alloys, and its stem can be solid or hollow. Such valves can be connected to guides made of cast iron or phosphor bronze under different conditions in the contact zone. The purpose of the study [8] was to measure the frictional force in the sliding contact between a valve stem made of TiAl alloy and its guide made of phosphor bronze in the absence of oil. The load on the contact zone changed periodically during the series. During the tests, the displacement and acceleration of the valve were measured, as well as the force when it hit the saddle insert. In addition, the sound level was measured. Tests were conducted for different frequencies of the driving force. In addition, research was carried out on a pin-on-disc tribotester with a pin made of Ti6Al4V alloy and a disc made of phosphor bronze. A model of a research stand for modeling the dynamics of a rotating plate assembly of a material sample has been developed. The purpose of such studies was to obtain values of the coefficient of friction for such a tribological/ The article presents the obtained dependences of the coefficient of friction on the load, sliding speed, and duration of movement of the material sample.

Growing requirements of environmental legislation are changing the operating conditions of the valve mechanism in heavy-duty engines. Increased pressure, higher temperatures and a smaller amount of soot that can form a protective film are the main problems in these mechanisms. Three pairs of valves and valve seat inserts with the same material and structural properties, but with different operating conditions, were analyzed in [9] to investigate the wear process. The identified wear mechanisms were a combination of oxidation and adhesive wear, which was observed in the form of material transfer. Tribofilms with a thickness of 1 to 5 μm, consisting of Ca, O, P, S, and Zn, were found on the surfaces of the sample. The film in all cases protected the surface from wear, but in some cases it had a corrosive effect.

The efficiency of the valve mechanism of the engine largely depends on the valve guide. The choice of material is influenced by the extended life of the engines, which favors the use of casting and finishing materials such as cast iron. The purpose of the study [10] is to study the dry sliding characteristics of GG25 cast iron with copper additives. It has been established that changes in load and sliding speed affect the wear characteristics is of primary importance. The loads varied by 30 N, 40 N and 50 N, maintaining a constant speed of 1 m/s. Next, the sliding speeds of 0.5 m/s, 1 m/s, and 2 m/s were changed, maintaining a constant load of 30 N. In the course of the research, friction forces and the friction coefficient were also determined. The wear mechanisms of the samples were checked using a scanning electron microscope in combination with EDX analysis. The study highlights the significant influence of normal load and sliding speed on wear. In conditions of moderate load and speed, the influence of normal load is more significant. However, as sliding accelerates, it becomes the dominant factor. The analysis of friction forces and the coefficient of friction showed that under load conditions of 30 N–50 N, the coefficient of friction increased from 0.238 to 0.43.

In addition to the problems of valve guide wear, one of the most common problems is the study of valve seat wear, which researchers pay a lot of attention to. In [11], an experimental approach to solving valve and seat wear problems is described. The test bench contained sample valves and seat inserts simulating combustion loads and a cylinder head to study the impact effect on valve closing without applying combustion loads. Bench tests make it possible to evaluate the impact of changes in design and operating parameters with less time spent than when testing an engine.

Valve wear has been a problem for engine designers and manufacturers for many years. Although new valve materials and manufacturing techniques are constantly being developed, these advances are outpacing the demands for increased engine performance. The objective of [12] was to establish the effect of engine operating parameters on diesel engine intake valve wear and to test seat materials using test equipment designed to simulate load environments and contact conditions. Valve wear has been shown to increase with combustion load, valve closing speed, and valve displacement. Two of the tested materials have increased wear resistance. These are martensitic aging steels and ductile cast irons. Both showed significantly higher wear resistance than other tested materials.

In [13], the wear of the seating surfaces of the exhaust valve and the seat insert was investigated, which affects the engine performance depending on the mileage (number of cycles). All other parameters such as temperature (350 °C), fuel (LPG) and load (1960 N) were fixed. Exhaust valves and seat liners were used as test specimens. Tests with showed that the average maximum valve roughness increased at a rate of 7.76 μm/106 cycles. The products of the tribochemical reaction coated the metals of the valve and seat inserts, preventing wear, and included O, V, S, and Al. The wear mechanism of the valve and seat insert was investigated using a tribochemical reaction.

Engine valve seat wear affects engine performance. Improving valve quality and valve life is a common goal for both valve and engine manufacturers. By performing tests on a valve seat wear simulator, [14] investigated the effects of cycles, load, and temperature on intake valve seat wear. Test temperatures ranged from 180 to 650 °C, number of cycles varied from 150,000 to 3,420,000, and test loads were applied from 6,615 to 24,255 N. The relationship between valve seat and insert wear as a function of cycles, load, and temperature was determined experimentally. . A load-dependent wear transition was found to exist, implying different wear mechanisms operating in these different regions. Higher temperatures resulted in less saddle wear. Inlet valve seat/insert wear mechanisms were found to be a complex combination of adhesion, shear deformation, and abrasion. Oxide films formed during testing were found to play a significant role. They can prevent direct metal-to-metal contact and reduce friction and wear.

Ball reciprocating tests on a flat surface were performed on prepared sections cut from cast iron, silicon nitride, and composite graphite valve guides over a given range of temperatures, normal loads, speeds, and lubrication conditions [15]. The goal was to find out if the ceramic composite would create a lubricating film on the surface and serve as a self-lubricating material. Stainless steel type 440C was used as the counterbody material. Tests were also performed using graphite powder on a silicon nitride matrix material to determine what frictional behavior could be observed in the most favorable case. Friction and wear data combined with surface chemical analysis confirmed that the current composite, despite its wear resistance, does not provide any lubrication benefits over silicon nitride itself.

Lightweight valves are commonly used in modern internal combustion engines with cam and camless camshafts. They can be made of TiAl and Ti6Al4V alloys. The stems of such valves can be covered with a protective layer obtained by nitriding, chrome plating or others. Rods can be connected to guides made of cast iron, phosphor bronze or beryllium bronze. Coupling can occur under conditions of mixed friction with a different proportion of lubricant. Research of the valve mechanism was carried out in a tribotester [16].

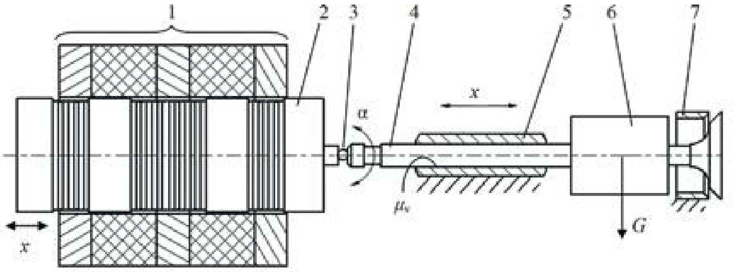

Fig. 10. Unit model: 1 – fixed part of the drive, 2 – moving coil, 3 – hinge, 4 – valve, 5 – guide, 6 – additional load, 7 – seat insert

A model of the unit was developed (Fig. 10), which consisted of valve 4 and a moving coil 2 of the actuator and is presented in Fig. 3. The displacement x of such a coil parallel to the axis of the stationary part 1 of the drive was assumed to be equal to the displacement of the valve obtained during its measurement in the tester. Such displacement is limited by the settlement of the seat insert 7. The valve is loaded with an additional weight 6, which causes a force G, perpendicular to the axis of the guide 5. The valve can also wobble by an angle α, within the limits limited by the gap between the valve stem 4 and its guide 5. Such wobble is allowed due to the presence of a spherical joint 3.The studied valve was set in electromagnetic motion for different strokes and frequencies of the valve. Contact took place in the absence of oil. The valve was loaded with additional mass to create a normal force between the valve stem and its guide. The acceleration and displacement of the valve, the impact force of the valve on the seat insert, the friction force between the valve stem and its guide and the sound level were measured. The purpose of the research is to obtain and compare the values of the coefficient of friction between the cast iron guide and the Ti6Al4V valve stem for a certain number of valve strokes and frequency. The leg under study can be bare or covered with a layer of Cr or nitriding. An analytical model was developed to calculate the contact pressure and friction force between the valve stem and its guide for the mixed friction conditions that occur for the selected engine oil and the movement of the valve relative to its guide.

In work [171], experiments were conducted using a high-temperature tribological test system (Fig. 11). For this experiment, an exhaust valve made of a nickel-based alloy called Pyromet was machined into a flat disc, and a sample pin was made of a Co-based alloy (Stellite). The pin had a spherical end with an initial radius of 9.53 mm and the test was carried out under a normal force of 1710 N at a sliding speed of 0.1 m/s. Sliding was performed for 60 seconds at each of the following temperatures: 450, 550, 650, 750, 800, 850 o C.

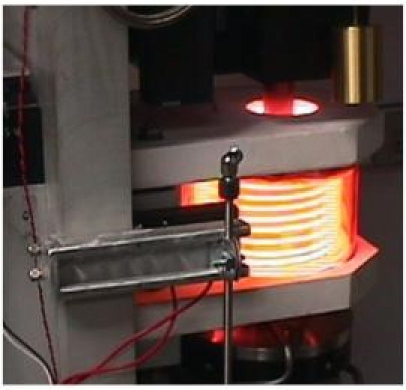

Fig. 11. High-temperature sliding friction and wear test system.

The growing demand for more powerful internal combustion engines has led to higher temperatures in the combustion chamber. As a result, TiAl valves have been investigated for use in a natural gas diesel internal combustion engine, taking advantage of their low density and high temperature resistance. In [18], comparative bench tests of traditional steel valves and TiAl valves were conducted using a specially designed apparatus for testing wear. Compared to traditional valves made of heat-resistant steel (X60, X85), TiAl valves have 50% less weight, which leads to a decrease in resistance during engine operation. By reducing the inertia of the engine valve movement, the dynamic characteristics of the engine valvetrain system can be optimized. Each contact pair of the valve and seat insert has been tested for 3 million impact cycles. Compared with the austenitic exhaust valves (X60) tested at 700℃, the TiAl valve had better wear resistance and the wear loss was reduced by 24.8%. The dominant wear mechanism is considered to be a combination of oxidative wear and adhesive wear. However, for the intake valves tested at 400℃, the wear loss of the TiAl valve was three times higher than the martensitic intake valves (X85). The predominant wear mechanism can be defined as abrasive wear and adhesive wear (Fig. 12).

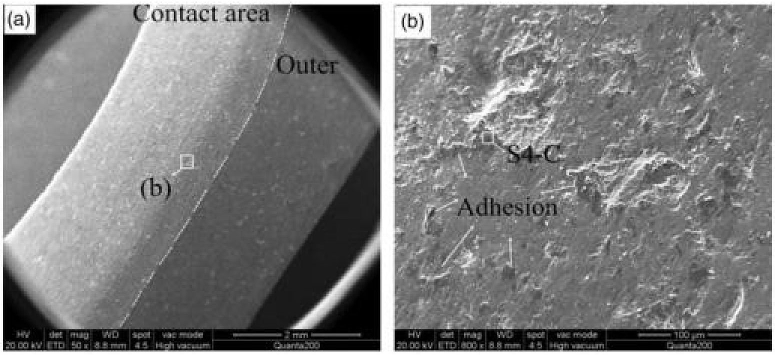

Fig. 12. (a) Worn surfaces of valve seat insert; (b) magnified image of worn surfaces and EDS S4-C test area.

Thus, it is concluded that the TiAl exhaust valve is a potential solution for a diesel engine running on natural gas.

Technologies of repair, restoration, increase of wear resistance of engine valves

The article [19] presents the results of tribological research on a promising method of restoring and increasing the wear resistance of engine valves by the method of gas nitriding. It was established that with increasing operating time, the guide bushings of the output connections wear out with the displacement of the axis of the form-forming surfaces of the hole. It has been proven that the uneven wear of the bushing hole is determined by the imbalance of the forces acting on the side of the rocker arm. Distortions of the valve in the longitudinal axis of the engine contribute to a decrease in the tightness of valve pairs. Technological means and methods of improving the quality of repair, measuring devices for accurate research of the parameters of parts and connections of the valve group are presented. A method of 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.

In an internal combustion engine, a system of valves controls the flow of gases into and out of the combustion chamber. The contacting surfaces are subjected to a severe tribological situation with high temperatures, high-velocity impacts, corrosive environments, and high clamping forces, causing micro-slip at the interface. Work surfaces must withstand hundreds of millions to billions of operating cycles, resulting in extreme requirements for low wear. Such low wear rates can be achieved due to the protective action of tribofilms formed from oil residues, avoiding pure metal-to-metal contact.

One way to combat random behavior may be to promote the reliable operation of protective tribofilms by texturing valve seal surfaces to improve grease capture and storage [20]. At the same time, depressions perpendicular to the slip are created (Fig. 13).

Fig. 13. Appearance of the textured surface of the valve after 100,000 cycles.

The number and localization of tribofilms became more stable than without texture, which led to a decrease in surface wear. For the same width, deeper depressions showed less delamination of the tribofilm.

Article [21] is devoted to the issues of friction, lubrication and wear of internal combustion engine parts, the improvements of which provide an important increase in energy efficiency, productivity and durability of internal combustion engine systems. The paper considers the process of reducing friction with surface textures or coatings. The paper also discusses surface engineering technologies such as diamond-like carbon coatings and surface texturing technology. Information is also provided on thermal spraying techniques that have led to improvements in engine parts. The wear of the piston unit, valve mechanism, cylinders, engine bearings is described. A detailed analysis of the wear mechanisms of the intake valve and seat of the internal combustion engine is given.

Since surface engineering is becoming an increasingly viable alternative to design changes made to increase the efficiency of internal combustion engines, various types of coatings for internal combustion engine parts have been proposed and tested in [22]. One of the vital organs is the engine valves, which during operation are subjected to combined thermal, mechanical, corrosion and wear, which lead to severe corrosion and complete failure. In this paper, the valve wear aspects were analyzed and the active surfaces were coated by atmospheric plasma sputtering (APS) with two commercial powders: Ni-Al and YSZ. A microstructural analysis of these layers was carried out, as well as observations regarding the possibility of their use as a thermal barrier and antioxidant coatings.

Modeling, calculations of valve mechanism details

The production of additive layers of metal components provides significant opportunities to reduce the weight of parts in order to increase the fuel efficiency or performance of the vehicle. In the article [23], filling materials are considered to reduce the weight of intake or exhaust valves of an internal combustion engine. Micro-computed tomography (μ-CT) was used to reverse engineer the original component and assess the internal geometry and material integrity of the valve (Fig. 14.).

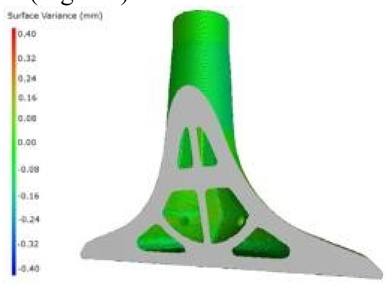

Fig. 14. Results of valve design analysis

The valve has been redesigned using Finite Element Analysis (FEA) to select a lightweight weighted design that provides a weight savings of 9.4g (20%) compared to the original equipment valve. The engine was tested for more than 175,000 cycles at 2,000 to 9,500 rpm, after which μ-computed tomography confirmed no signs of internal cracking, failure, or significant deformation.

The article [24] describes the concept of a non-invasive method for diagnosing the value of valve clearances in internal combustion engines, based on the analysis of engine surface vibration signals using artificial neural networks. The applicability of the method was tested on a single-cylinder compression-ignition engine with a low power rating, which had an indirect valve-acting valve timing mechanism and manually adjusted valve clearances. The method uses the readings of vibration sensors as diagnostic signals, which record the acceleration of the engine head depending on the angle of rotation of the crankshaft, with pre-set values of valve clearances measured in a cold state. Among the registered signals, the components corresponding to the impact of the rocker arms on the valve stems were identified, and low frequencies were filtered out in order to eliminate measurement interference. A classifier of selected features of the processed signals was built using artificial neural networks. This classifier recognizes signals generated by engines with the correct valve clearance, as well as engines with too much and too little valve clearance.

In the article [25], a study of the causes of engine intake valve damage was conducted, during which the intake valve heads were overheated and deformed as a result of material creep. On the example of a malfunction detected in the analyzed engine, it was established that traditionally known causes, such as a failure of the combustion process, cannot cause the described damage. In order to determine the real causes of damage to the intake valves, the authors simulated the thermal state of the intake valve under cooling conditions with the influence of gas in the cylinder and the influence of air in the intake pipeline, as well as contact heat exchange with the seat, taking into account the thermal conductivity along the stem. The calculations showed that with an increase in the rotation frequency, the failure of the control system leads to an increase in temperature higher than recommended for the materials used. Based on the conducted research, the authors have developed recommendations for increasing the reliability of intake valves with variable gas distribution phases.

In [26], a methodology for the analysis of valve wear of internal combustion engines is proposed, which is the result of the combined use of numerical and experimental methods. Numerical solutions are obtained using a specialized finite element method where a solution contact algorithm is used to model the flexible-flexible contact along with the adhesive wear law. Experimental results are obtained on a wear test rig specially designed to evaluate wear parameters under valve operating conditions. A good agreement was found between the experimental wear profiles and the numerical calculations of the wear on the contact surfaces.

In [27], engine reliability was improved using Al-Sic composites for engine guide valves. Aluminum matrix composites turned out to be the most suitable for the automotive industry. Finite element analysis of Al-Sic composite with titanium alloy (Ti-834), copper-nickel silicon alloys (CuNi3Si) and aluminum bronze alloy as alternative engine valve guide material was performed using Ansys 13.0 software. The finite element method is one of the most widely used methods for analyzing mechanical load characteristics in modern engineering components. The directional valve model was modeled as shown in Fig. 15. A finite element model was built to analyze the guide valve.

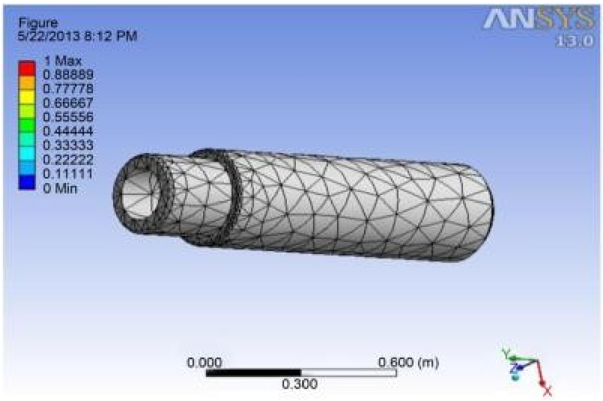

Fig. 15. Finite element model of the valve stem-guide bush connection

The stress analysis of the engine valve guide at different pressures and temperatures was carried out. The pressure is taken from 10 MPa to 100 MPa with different temperatures from 600ºC to 650ºC. It was found that the stresses were significantly lower than the allowable for all materials, but Al-Sic composites were found to be the most optimal.

In diesel engines, the valve seat contact is one of the few non-lubricated contacts subject to significant deterioration. This deterioration is confirmed by the removal of material on the intake valve. Wear and tear can lead to gas leaks and engine failure. The purpose of the work [28] was to determine the main parameters affecting this wear. The approach was based on the tribological triplet and material flows within the contact, using both numerical and experimental approaches. A dynamic model and valve train test bench showed that wear flows can be activated by the architecture of the valve opening system. Therefore, limiting these flows can be achieved by controlling the geometry of the system without changing the properties of the materials. In the same way, the finite element model of the local response of the seat-valve contact emphasized the influence of the "local" contact geometry. Tests carried out on the engine and on a specially adapted test bench completed the understanding of the degradation and wear mechanisms. The morphological interpretation of the worn surfaces from the point of view of material flows made it possible to understand the stages of the build-up of the protective layer.

As noted in [29], intake and exhaust valves are important engine components used to control intake and exhaust gas flow in internal combustion engines. They are used to seal the working space inside the cylinders and are opened and closed by means of a valve mechanism. These valves are loaded by spring forces and subjected to thermal stress due to high temperature and pressure inside the cylinder. The study is devoted to various types of failure of internal combustion engine valves: due to fatigue, exposure to high temperature, shock load.

Static and thermal analysis was performed on the valve (Fig. 16) by changing two materials at 5000 cycles.

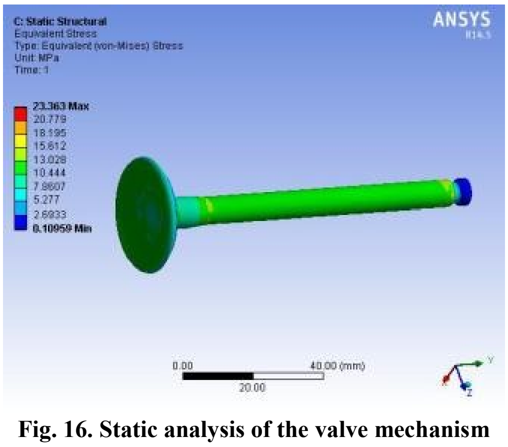

Fig. 16. Static analysis of the valve mechanism

The rapid aggravation of environmental legislation in recent decades has forced engine manufacturers to radically modify the design of parts of the gas distribution mechanism. In works [30-31] it was shown that sliding in the valve sealing area is one of the main causes of wear. Sliding wear is expected to play an even more important role in modern engines.

Experimental data obtained using a special technique on a test bench are presented. Experimental data are supplemented by FEM modeling. The simulation involves checking the sliding behavior of the valve seal area on a test bench and investigating how different parameters affect the sliding length. These parameters include combustion pressure, contact angle, contact length, valve head thickness, friction coefficient, run-in wear, and change in modulus due to temperature variations.

Conclusions

1. The valve mechanism is responsible for the coordinated operation of the engine, controlling the timely supply of fuel to the combustion chambers, the removal of spent fuel.

2. As a result of wear of the valve guide, the following valve damage and sealing problems may occur: burnt valve heads; cracks in the valve stem; cracks in the grooves for valve crackers; excessive wear of valve stem ends; worn on one side of the rocker arm; increased oil consumption due to wear of valve stem seals; worn or burnt valve seat rings.

3. The efficiency of the valve mechanism of the engine largely depends on the wear resistance of the valve guide. The problem of researching mechanisms of wear of valve mechanism parts remains very relevant due to the need for constant improvement of the design and increase in durability of internal combustion engines. In addition to the problems of valve guide wear, one of the most common problems is the study of valve seat wear, which researchers pay a lot of attention to.

4. Technological methods of surface engineering are becoming an increasingly viable alternative to structural changes made to increase the efficiency of internal combustion engines, including valve train components. To extend the service life of valves and guide bushings, a variety of modern technologies are used to increase wear resistance, restore the worn layer, and ensure reliable lubrication in various operating conditions.

5. To analyze and predict the durability of the friction nodes of the valve mechanism parts, calculated estimates of the structural characteristics of the mechanism, stress and thermal state are widely used. Numerical methods, in particular the method of finite elements, occupy a predominant place.

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Вичавка А.А. , Диха О.В. , Гетьман М.В. Аналіз трибологічних аспектів в процесі експлуатації і ремонті деталей клапанного механізму двигуна внутрішнього згорання

Проблема дослідження механізмів зношування деталей клапанного механізму залишається вельми актуальною внаслідок потреби невпинного вдосконалення конструкції і підвищення довговічності двигунів внутрішнього згорання. В роботі проведений огляд сучасних досліджень з наступних питань: аналіз умов експлуатації та несправностей клапанного механізму двигуна внутрішнього згорання, дослідження тертя та зношування деталей клапанного механізму, технології ремонту, відновлення, підвищення зносостійкості клапанів двигуна, моделювання, розрахунки деталей клапанного механізму. Показано, що важливим аспектом для аналізу зносотійкості деталей клапанного механізму є умови експлуатаціїї та характер пошкоджень поверхонь деталей пари тертя. Розглянуті існуючі гіпотези про механізми тертя, змащення та зношування деталей клапанного механізму, наведені конструкції випробувальних стендів, проаналізовані результати трибологічних випробувань. Обгрунтовано, що технологічні методи інженерії поверхні стають все більш життєздатною альтернативою конструктивним змінам для підвищення працездатності деталей клапанного механізму. Наведений огляд розрахункових методик оцінки напруженого і теплового стану деталей клапанного механізму двигунів внутрішнього згорання.

Kewwords: двигун внутрішнього згорання, клапан, напрямна, пошкодження, відновлення, зносостійкість, моделювання, метод скінчених елементів