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Wear resistance and lubricity of the spiral oil distribution profile of the valve guide sleeves of an internal combustion engine

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Abstract

Valve guides are crucial for maintaining the correct alignment, positioning, and clearance of the valve stem as it moves in the cylinder head. When the guides are heavily worn, the engine begins to consume oil and the valve mechanism becomes noisy. Reliable lubrication of the inner surface of the guide bushing ensures the wear resistance of the valve-guide pair. This work proposes a special tool and technology for obtaining an oil-retaining profile on the inner surface of the valve guide, which increases the oil capacity of the surface, and therefore improves the lubrication conditions in the valve-guide friction pair. A gas labyrinth seal is created in the connection, which prevents oil from entering the combustion chamber. The surface of the bushing bore is strengthened due to the sealing of the surface. The results of wear tests of guide bushings with spiral oil-retaining grooves confirmed their effectiveness in terms of wear resistance. The wear rate of the bushings with grooves for the entire time range of the tests is on average 20% less than the wear rate of the bushings without grooves.

Keywords: internal combustion engine, valve guide, lubricity, wear resistance, oil-retaining spiral profile, tests

Introduction

One of the main reasons for repairing the cylinder head is the wear of the valve guide bushings. Bushings are constantly subjected to frictional loads. Lateral forces act on the valve stem, caused by a change in geometry in the valve mechanism, wear of the rocker cam or rocker arm. When the guides have a lot of wear, the engine begins to consume oil and there is an increased noise of the valve mechanism. This applies to both the intake tract (discharge in the cylinder) and the exhaust tract (Venturi effect). Oil in the catalytic converter exhaust system can cause it to overheat and fail. Oil in the intake system can "throw" spark plugs, contaminate exhaust gases, and also quickly accumulate as combustion products on the air surface of the valves and combustion chamber.

Guide bushings have the following defects: wear of the inner surface (58...96%), loosening of the fit (7...13%), cracks and fractures (3...10%). The amount of wear of the bushings has a pronounced uneven character. In the upper part of the bushing, the wear is small and has the shape of an oval, the major axis of which is perpendicular to the longitudinal axis of the engine. In the lower part, the bushings wear out more than in the upper part, while preserving the direction of wear. The greatest wear is observed at the point of impact of the valve stem on the sleeve with subsequent sliding at extreme friction. Greater wear of exhaust bushings compared to intake bushings is due to the additional heat load in combination with the valve.

Valve guides, which are critical to maintaining proper alignment, positioning, and clearance of the valve stem as it moves through the cylinder head, are typically made from materials that offer high wear resistance and improved thermal conductivity. The choice of material for guide valves largely depends on the operating conditions and requirements of the engine or mechanism. Manganese bronze is a group of high-strength, hard bronzes that are typically used in assemblies that require a combination of high strength, wear resistance, and corrosion resistance. Such alloys provide excellent durability and heat dissipation properties.

Review of literary sources

Research [1] was carried out 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. This pressure inside the cylinder causes the valve cone to bend, resulting in slippage and improper contact between the valve face and seat insert, ultimately leading to wear. 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. Direct injection engines have a well-known propensity for intake valve deposits, 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. 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 the information necessary for the development and verification of the proposed methods were conducted and described. In work [5] malfunctions of automobile valves were considered. Changes in the microstructure of the valves were studied and analyzed using a scanning electron microscope. The samples were made from failed engine valves, while new valves were also analyzed for comparison. The article [6] presents an analysis of elements of piston internal combustion engines that interact with the combustion chamber. An assessment of the condition of the tribological nodes: valve stem – valve guide and valve head – valve seat in random operating conditions was carried out. In the article [7], he proposed a device for determining wear for studying the tribological characteristics of the connections of the valve mechanism of the engine. 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. Pairs of valves and valve seat inserts with the same material and structural properties, but with different operating conditions, were analyzed in [9] to study the wear process. The identified wear mechanisms were a combination of oxidation and adhesive wear, which was observed in the form of material transfer. The purpose of the research [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. Loads were changed step by step, maintaining a constant speed.

Thus, increasing the wear resistance and lubricity of the parts of the valve mechanism of the internal combustion engine is an urgent task.

Causes of failure and defection of guide bushings

Valve guide bushings are made of wear-resistant materials with fairly good thermal conductivity. These are special cast iron, metal ceramics, bronze and brass. Bronze and brass have a higher thermal conductivity, which is why they are used on most forced engines, for example, BMW, Audi, Volvo. To fix the sleeve in height, there is usually a support shoulder on the outer surface of the head of the cylinder block. Sometimes a split support ring is used instead. If the sleeve is smooth on the outside, then a special mandrel or remote sleeve will be needed to install it in the head.

The guide bushings of the intake valves should not protrude too much in the intake channel so as not to increase its aerodynamic resistance. But exhaust valve sleeves, on the contrary, should cover the valve stem for the maximum length to protect against heated exhaust gases and for better heat removal from the exhaust valve stem. If the guide bushings are made of bronze or brass, then they usually have the same length, since these alloys have high thermal conductivity.

The geometric dimensions and general appearance of the guide sleeve are shown in fig. 1.

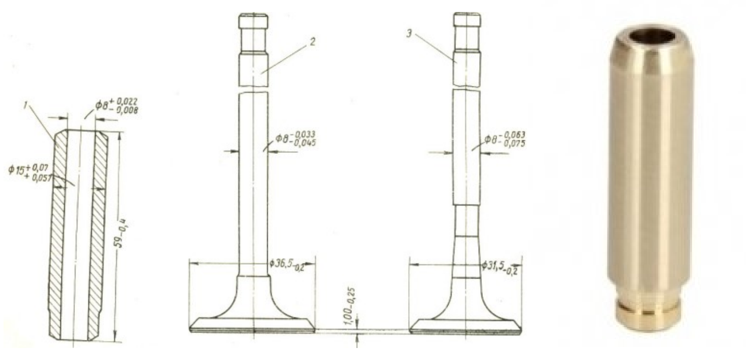

Fig. 1. The geometric dimensions and general appearance of the guide sleeve

Guide bushings have the following defects: wear of the inner surface (58...96%), loosening of the fit (7...13%), cracks and fractures (3...10%). The amount of wear of the bushings has a pronounced uneven character.

In the upper part of the bushing, the wear is small and has the shape of an oval, the major axis of which is perpendicular to the longitudinal axis of the engine. In the lower part, the bushings wear out more than in the upper part, while preserving the direction of wear. The greatest wear is observed at the point of impact of the valve stem on the sleeve with subsequent sliding at extreme friction. More wear of exhaust bushings compared to intake bushings is due to the additional heat load in combination with the valve. At the time of overhaul, wear of the valve bushings in the upper part is usually 0.06...0.08 mm, and in the middle part 0.04...0.07 mm. In the lower part, the wear of the bushings above reaches 0.24 mm or more. The coefficient of unevenness of wear along the length of the product is equal to: for intake valve bushings 3...4, for exhaust valve bushings 8...13. But in addition to natural wear, there are other reasons for the guide sleeve to fail. For example, if the timing belt breaks, the bushing can crack due to the bend of the valve. Improper installation or removal of oil caps can lead to deformation or breakage of the seat under the cap.

In engines receiving major repairs, clearances in the valve-sleeve combination are usually 1.5...3.5 times higher than the nominal ones. This leads to an increase in the consumption of oil for smoke through the valve-sleeve steam by 18...20%, and an increase in the smokiness of the processed gases - by 10...15%.

Operations for processing valve chamfers and seats are considered the most important in the technological process of repairing block heads. But there is an equally responsible operation – replacement (or restoration) of guide bushings, which are the technological basis for further processing of the saddle. Often, when repressing the bushings, the axis of the hole is shifted, which, with a large "skew", does not allow processing the working chamfer of the saddle of the same width all around. As a result, the heat dissipation is disturbed, and subsequently the seat or valve plate may burn out. In addition, the "skew" of the axis leads to accelerated wear of the valve stem and face.

Defecting guide bushings is a necessary condition for high-quality repair of the cylinder head. Due to the small hole, there are certain difficulties in controlling the dimensions of worn bushings. Defection of the bushings is carried out with the help of calipers or gauges (Fig. 2).

Fig. 2. Tool for measuring valve bushings.

The feeler gauge and cylindrical calipers allow for defecting of guide bushings with an accuracy of 0.01 mm. A micrometer is used to measure the valve stem. Measurements of the valve are necessary to determine the "sleeve-valve" gap.

In practice, most heads that come in for repair have bushings with wear that exceeds the allowable (usually 0.15 mm or more). As a rule, "exhaust" bushings are worn out more than "intake" bushings, which is explained by their increased thermal load. Traditionally, sleeve wear in a horizontal section has a pronounced ellipse with a larger axis in the plane of the rocker arm swing (rotation of the camshaft cam), and in a vertical section it resembles a "corset".

Technological methods of repairing valve guide bushings

The technology of replacing bushings by repressing is traditional. Aluminum heads are usually heated to a temperature of 1100C. They work with cast iron heads without their heating. Bushings must be pressed out using special mandrels and a pneumatic hammer or hydraulic press. This provides additional load along the axis of the bushing and minimizes damage to the hole (seat) of the bushing. When pressing the bushings, they are first cooled in liquid nitrogen, and then the block head is installed using special mandrels. After pressing, the opening of the sleeve must be processed to a size that provides the necessary thermal gap for the "sleeve-valve" connection.

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

The bushing opening can be restored without pressing by using the method of plastic deformation of the metal. Using the tool set for the restoration of guide bushings from the company Neway (USA), it is possible to restore bushings with hole diameters from 6 to 12 mm. The degree of restoration of the worn hole in the sleeve is determined by its material. For example, bushings made of non-ferrous materials with wear up to 0.5 mm can still be restored, and bushings made of strong cast iron or metal ceramics only with wear up to 0.15 mm.

The technology of restoring guide bushings by installing thin-walled sleeves made of special copper alloys is used. For the reliable application of this technology, it is not enough to have only a set of tools, and it is also necessary to observe the modes and sequence of operations. As a finishing operation, the hole is drawn with a ball.

Thus, the main advantage of bushing restoration technologies is maintaining maintainability due to the elimination of bushing repressing operations.

Restoring and increasing the wear resistance of guide bushings by knurling the oil-retaining profile

In this work, the use of a special knurling tool is proposed to restore and increase the wear resistance of guide bushings (Fig. 3).

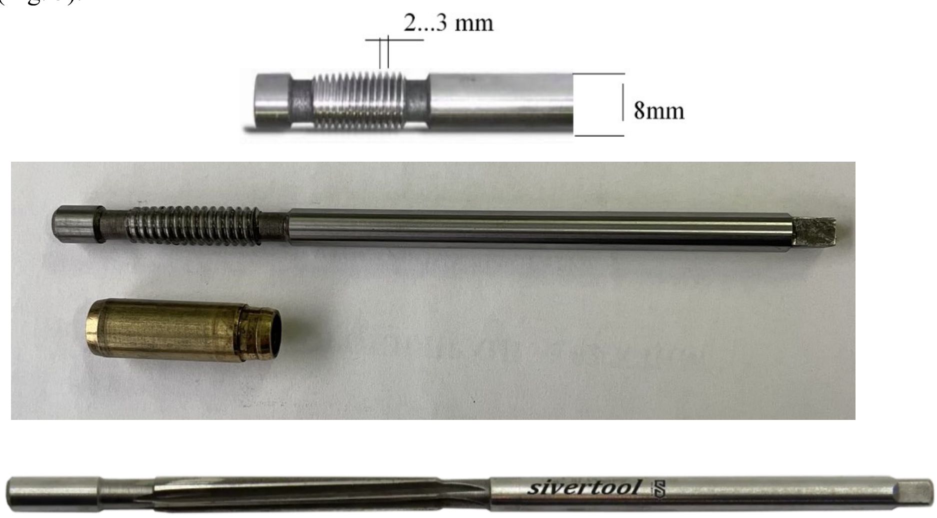

Fig. 3. A special tool for restoring valve bushings.

The TOKAR (8.1) Knurling & Resizing arbors HSS tool is designed for restoring guide valves by rolling a spiral groove on the inner surface of the sleeve. This allows to reduce the internal diameter of the valve guide by deformation of the material. The material of the tool is HSS (High Speed Steel) – HRC 62±1. Restoration (knurling) of the valve guide must be carried out from a tool of smaller diameter with further increase to the stop of the valve guide rod, the entrance to the sleeve. The cone of the working part prevents the parts from cracking. Knurling reduces the size of the hole with an allowance of 0.04-0.06 mm, depending on the material. Example: The output size of a ø8.02 valve guide after rolling a ø8.1 bore will be ø7.95-7.98, depending on the material. After restoration (rolling), the inner hole is calibrated with a reamer of the required size.

The guides were processed on a lathe (Fig. 4). The sleeve was centered and fixed in the cam cartridge and rotated. The tool carried out a progressive axial feed movement.

Fig. 4. Treatment of the oil-retaining profile of the valve guide sleeve

After applying this technology, a spiral oil retaining profile remains on the surface of the sleeve opening, which:

• increases the oil capacity of the surface, and therefore improves the lubrication conditions in the "valve-guide" friction pair;

• a gas-labyrinth seal is created in the connection, which prevents oil from entering the combustion chamber;

• the surface of the sleeve opening is strengthened due to surface compaction (slander effect).

Since due to the spiral groove, the surface of the hole in the sleeve is reduced by only 10... 15%, its presence has almost no effect on the service life of the cylinder block, since the valve in the sleeve oscillates within the thermal gap and the valve stem never contacts the sleeve over the entire surface of the hole .

In fig. 5 shows the profile of the spiral oil retention grooves formed on the inner surface of the valve guide sleeve. The profile of the grooves, in accordance with the design of the tool, had a rounded shape.

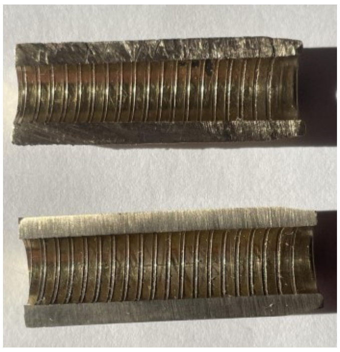

Fig. 5. Spiral oil retaining grooves of the valve guide sleeve

In the process of plastic processing of the oil-retaining grooves in the opening of the guide bushing, the surface layer of the working surfaces is defamed, which also contributes to increasing the wear resistance of the bushings with grooves.

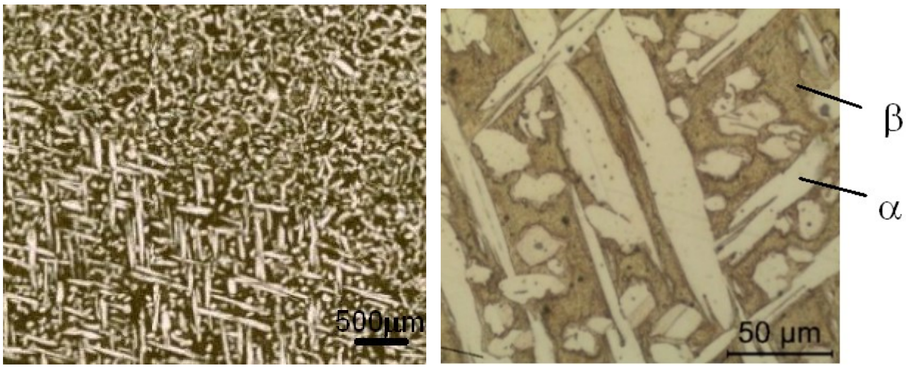

Fig. 6. Photomicrographs of the surface layer of bronze after plastic processing of the grooves

Optical microphotographs of the materials shown in fig. 6 show that the alloy consists of an α-phase and a β-phase, and that the α-phase has a long island shape typical of deformed bronze. In the microstructure, the light regions correspond to the α-phase, which has a face-centered cubic (fcc) lattice, while the dark regions correspond to the β-phase, which has a body-centered cubic (bcc) lattice. As a result of plastic deformation, the granular structure of the copper alloy is crushed.

Study of the wear resistance of the valve guide with oil retaining grooves

Tests for the wear of guide bushings were carried out on a special stand (Fig. 7).

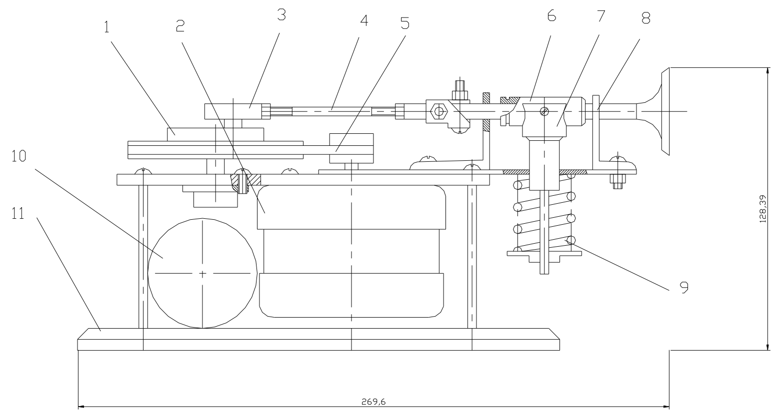

Fig. 7. Experimental stand for testing valve mechanism wear

The stand is mounted on the platform 11. The valve movement is driven by the DC motor 2, the shaft of which is located vertically and flanged to the intermediate plate. The engine shaft is equipped with a belt transmission pulley 5 to reduce the number of engine revolutions. On the driven pulley 1 there is a crank-sliding mechanism for converting rotary motion into translational motion. The valve moves in the guide sleeve 6 from the crank mechanism. The load on the coupling is carried out using a spring 9. A capacitor 10 is used to start the engine.

The tests were carried out under the following conditions. The load on the sleeve is 150 N. The number of double strokes of the valve is 100 strokes/min. Lubrication was carried out with engine oil M-8B.

The amount of wear of the guide bushing was periodically measured by an indirect method of measuring the chord L of the trace of wear on the ends of the bushing according to the diagram in Fig. 8 as the average value of two indicators.

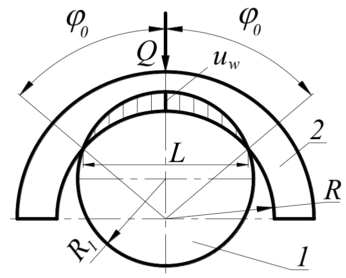

Fig. 8. Scheme for measuring the wear of the guide sleeve of the valve mechanism

The amount of linear wear was determined by the formula:

$$u_W(\varphi_0) = \Delta(\sec\varphi_0 - 1),$$

where Δ –the nominal gap between the valve and the sleeve;

φ_0 – the contact angle between the sleeve and the valve:

$$\phi_0 = \arcsin(L/2R).$$

The tests were carried out for two versions of guide bushings: with a spiral groove and with a smooth hole. The results of tests and calculations are given in the table. 1.

Table 1

The results of determining the wear of the guide bushings of the valve mechanism

Number of cycles x103	2	4	6	8	10	12	14	16	18
Wear (K), µm	50	100	140	160	170	175	178	180	182
Wear (G), µm	70	120	160	185	200	210	220	230	235

In fig. 9 shows a graphical interpretation of the results of tests on the wear of guide bushings of the valve mechanism.

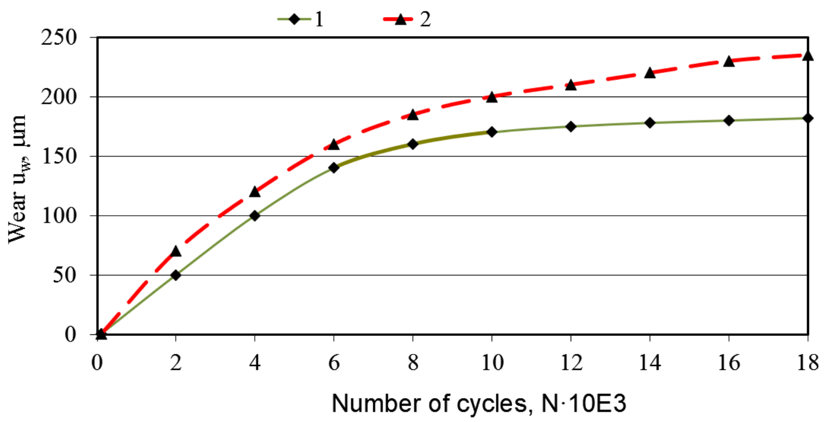

Fig. 9. The results of tests on the wear of valve mechanism bushings: 1- guide with grooves, 2- guide smooth.

Therefore, the results of the wear tests of guide bushings with spiral oil retention grooves confirmed their effectiveness according to the criterion of wear resistance. The value of wear of bushings with grooves for the entire time range of tests is on average 20% less than the value of wear of bushings without grooves.

Conclusions

1. A special tool and technology for obtaining an oil-retaining profile on the inner surface of the valve guide is proposed, which increases the oil capacity of the surface, and therefore improves the lubrication conditions in the "valve-guide" friction pair. A gas labyrinth seal is created in the connection, which prevents oil from entering the combustion chamber. The surface of the sleeve opening is strengthened due to surface sealing (slander effect).
2. The results of the wear tests of guide bushings with spiral oil retention grooves confirmed their effectiveness according to the criterion of wear resistance. The value of wear of bushings with grooves for the entire time range of tests is on average 20% less than the value of wear of bushings without grooves.

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Диха О.В., Вичавка А.А., Диха М.О. Зносостійкість і мастильна здатність спірального маслорозподільного профілю напрямних втулок клапанів двигуна внутрішнього згоряння

Направляючі клапанів мають вирішальне значення для підтримки правильного вирівнювання, позиціонування та зазору штока клапана під час його руху в головці блоку циліндрів. Коли напрямні мають велике зношування, то двигун починає витрачати масло і з'являється підвищений шум клапанного механізму. Надійне змащування внутрішньої поверхні напрямної втулки забезпечує зносостійкість пари «клапан-напрямна». В даній роботі запропонований спеціальний інструмент і технологія отримання маслоутримувального профілю на внутрішній поверхні напрямної клапана, який збільшує маслоємність поверхні, а отже, покращуються умови змащення в парі тертя «клапан-напрямна». Створюється газолабіринтне ущільнення у сполученні, що запобігає потраплянню масла у камеру згоряння. Зміцнюється поверхня отвору втулки за рахунок ущільнення поверхні. Результати випробувань на знос напрямних втулок із спіральними маслоутримувальними канавками підтвердили їх ефективність за критерієм зносостійкості. Величина зносу втулок із канавками для всього часового діапазону випробувань в середньому на 20% менша ніж величина зносу втулок без канавок.

Ключьові слова: двигун внутрішнього згорання, напрямна клапана, мастильна здатність, зносостійкість, маслоутримувальний спіральний профіль, випробування