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INCREASING THE WEAR RESISTANCE OF INTERNAL COMBUSTION ENGINE CYLINDER LINERS BY APPLYING ANTIFRICTION COATINGS

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Abstract: Since the service life of internal combustion engines depends on the durability of cylinder-piston group parts, the development of effective technologies for the restoration of cylinder liners that increase their wear resistance and durability is of particular importance. The effectiveness of the combination of finishing antifriction non-abrasive treatment and the method of cold plastic deformation – deforming broaching in the restoration of cylinder liners has been proposed and proven. The original design of a modeling device for testing the wear resistance of the cylinder liner working surface, including a counterbody that simulates a set of piston rings simultaneously interacting with the working surface of the liner, was developed. The use of the proposed accelerated testing methodology significantly reduces the time required to conduct wear tests. The technology for restoring cylinder liners using finishing antifriction non-abrasive treatment and deforming broaching reduces wear on the working surface compared to traditional processing. The technical solutions applied in this work increase the wear resistance of the machined parts.

Keywords: cylinder liner, wear resistance, antifriction coatings, plastic deformation, technological process of restoration.

1. INTRODUCTION

An extremely important and urgent task of modern mechanical engineering is the development and widespread implementation of new, environmentally friendly, technically and economically feasible processing technologies that improve the quality of machine parts working surfaces by achieving optimal performance properties [1]. Existing and developing technological processes of machining should provide increase of reliability and durability of both newly manufactured machines operating under conditions of high loads at increased speeds and force impacts, and during their operation and repair [2]. Thus, the improvement of existing and the creation of new technological processing methods should be aimed at improving the quality of working surfaces and achieving optimal operational indicators by increasing the wear resistance and durability of parts [3].

The problem of increasing wear resistance and durability is especially relevant for engine parts that limit their service life. Thus, according to data from [4], the service life of an internal combustion engine (ICE) depends on the durability of the cylinder-piston group (CPG) parts by 70-90%. It is for these parts that, earlier than for others, the limit wear occurs, mainly of an abrasive nature, requiring mandatory restoration during overhaul.

One of the most expensive and fast-wearing parts of the CPG is the cylinder liner. The intensity of cylinder liner wear after overhaul is 2...3 times higher than that of new cylinder liners. Therefore, the issues of developing and improving methods for restoring and increasing the service life of cylinder liners are important and relevant [5].

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Growing requirements for the performance properties of parts' working surfaces stimulate the development of surface modification methods and, above all, the application of protective coatings. A wide range of materials used to create coatings, as well as coating application technologies, make it possible to provide specified surface properties or a set of properties for any part of modern engineering. The correct choice of friction coating material and composition makes it possible to increase the wear resistance and durability of friction units during further operation [6].

Thus, it can be argued that the use of protective coatings is an important reserve for increasing the durability of cylinder liners and, consequently, the life of the entire ICE.

2. LITERATURE REVIEW

An analysis of existing technologies for improving the operational properties of parts has shown that no technological process has been developed so far that would allow the obtaining a layer on the working surface that increases the wear-resistant and antifriction properties of the part surface while ensuring a given service life [7].

Numerous studies [8, 9] have shown that achieving high quality machining, increased wear resistance and durability of cylinder liners is associated with the application of an antifriction coating to their working surfaces.

To reduce friction and wear of friction surfaces, the methods of finishing antifriction non-abrasive treatment (FANT), known from [10, 11], are becoming widespread. The essence of FANT is that the friction surfaces of parts are coated with a thin layer (1...5 µm) of copper, brass, bronze, or other antifriction solid lubricants, because of which they acquire high antifriction properties and contact stiffness [12]. The coating obtained in this way is in a stressed state, capable of selectively dissolving under the influence of an active lubricant and creating a servo film. The wide capabilities of FANT allow them to be used for dimensional restoration, reducing surface wear, and for applying hard lubricant coatings.

FANT can increase the wear resistance of parts, reduce their break-in time, improve the antifriction properties of the treated surface, and increase the life of the ICE. At the same time, the applied FANT methods are characterized by low productivity, uneven coating thickness, high tool loads and significant heat generation. The use of existing technologies and devices for the FANT of the cylinder liner working surface does not provide sufficient hardening of the parts surface, and therefore, wear resistance for a longer period. Therefore, various areas of FANT require further development and improvement in terms of restoring parts that limit the operation of machines and mechanisms, which should include cylinder liners of ICEs.

It should also be noted that, according to the authors of [8], the increase in the performance properties of cylinder liners is associated with the formation of a favorable stress-strain state in the surface layer of the coating. This requires additional operations to strengthen the antifriction coating obtained by FANT. For this purpose, in many branches of industry, methods of processing parts by cold plastic deformation have been widely used, which allow achieving a favorable microrelief of the treated surface, strengthening the surface layer and, as a result, high operational properties. In this case, special attention should be paid to the method of deforming broaching, the essence of which is a sequential stepwise plastic deformation of the inner surface of the part during the progressive movement of deforming elements through the machined hole [13]. The combination of low-height roughness with surface layer hardening and the ability to guarantee residual compressive stresses provides high operational properties when machining parts by deforming broaching [14].

Thus, it can be argued that the most promising in terms of increasing the wear resistance and adhesion strength of the coating to the base should be considered the direction of using combined processing methods for cylinder liners, which includes FANT and deforming broaching. The possibility of combining FANT with cold plastic deformation methods, in particular with deforming broaching, will increase the process productivity and the quality of cylinder liner processing.

The development of a new technological process for machining cylinder liners that combines FANT and deforming broaching will provide the working surface of the liner with a set of geometric and mechanical properties of the machined surface that is favorable in terms of wear resistance. Obtaining an antifriction coating will improve the tribological characteristics of the working surface, and the subsequent hardening treatment by deforming broaching will increase the strength of the coating, obtain the required dimensional accuracy, increase the fatigue strength of the treated surface and increase the wear resistance of ICE cylinder liners.

The aim of this work is to increase the wear resistance of ICE cylinder liners by developing a combined treatment of their working surface using FANT and deforming broaching technologies. To achieve this goal, the following tasks have been formulated:

- propose the design of a tool for applying antifriction coatings on the inner surface of cylinder liners;

- develop an accelerated test method for wear resistance of the coating applied to the working surface of the liner and prove its effectiveness;

- prove the feasibility of combining the FANT operation and deforming broaching in terms of increasing the wear resistance of ICE cylinder liners;

- determine the sequence of technological operations for the restoration of cylinder liners using FANT and deforming broaching.

3. RESEARCH METHODOLOGY

In terms of increasing the wear resistance and adhesion strength of the antifriction coating to the base, it is advisable to combine FANT with cold plastic deformation methods during hole processing – deforming broaching, which will increase the process productivity and the quality of the holes finishing treatment.

To increase the productivity and quality of cylinder liners FANT, a tool design was proposed (Figure 1), based on the principle of broaching.

Figure 1. Tool design for cylinder liners FANT

A composite tool consisting of 5 elastic bars made of antifriction material (brass) is brought into contact with the treated surface and moves in a reciprocating motion. The machining area is constantly wetted with a working fluid (glycerin), which helps to soften and dissolve the oxide films formed on the workpiece surface and the antifriction bars. As a result of friction, the material is transferred from the antifriction bars and a brass coating is formed, the width of which corresponds to the width of the bar. The discrete rotation of the tool ensures the application of a continuous antifriction coating on the entire inner surface of the part. The application of the proposed tool design for cylinder liners FANT will increase the productivity and quality of the antifriction coating application.

Deforming broaching was carried out using original broaching designs developed at the Bakul Institute of Superhard Materials (Kyiv, Ukraine).

Proving the effectiveness of technical solutions requires performing wear tests. Given that the existing methods of wear-resistant testing of the ICE liners working surfaces require large material and time costs, there is a need to develop new approaches to conducting such studies.

The following technical solution is proposed to reduce the time of wear resistance tests while maximizing the compliance of the working conditions of the counterbody (piston ring) with the liner.

To implement the accelerated process of studying the coating wear resistance, 1 mm wide grooves are created in the ring (Figure 2a). The width of the protrusions is 2 mm, which corresponds to the width of the piston ring. Then the developed design of the counterbody simulates the simultaneous operation of a large number of piston rings interacting with the liner surface. And the presence of grooves of the specified width creates endpoints in which areas of high stress concentration occur. Thus, each protrusion simulates the actual operating conditions of the piston ring in the contact area with the liner surface, including abrasion of the liner surface in combination with interaction with zones of high stress concentration.

These provisions formed the basis for the development of the counterbody design for testing the wear resistance of the liner working surface (Figure 2a).

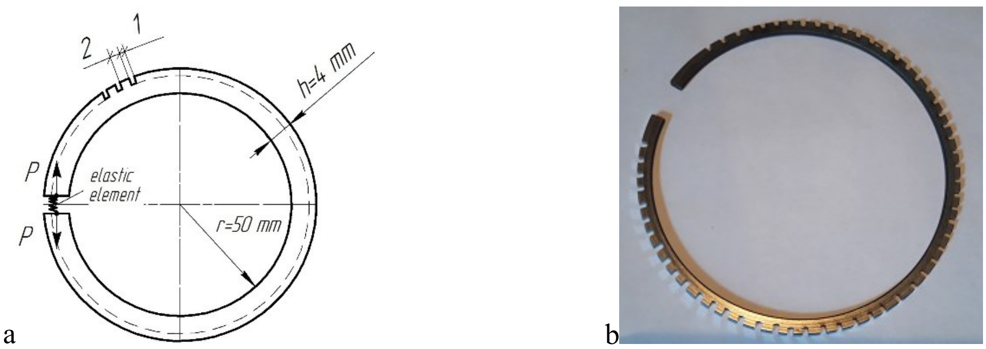

Figure 2. Design of the counterbody model interacting with the liner surface: a) model scheme; b) general view of the counterbody (split ring) during the wear study of the "liner – ring" friction pair

The counterbody (Figure 2a) is an elastic split ring with an inner radius r = 50 mm, a ring height – h = 4 mm, and a width of its outer surface – 2 mm. Thus, there can be about 100 protrusions on the ring circumference of 310 mm in length. This number corresponds to the number of piston rings operating in the simulation device and provides a significant reduction in the time of wear resistance tests with maximum compliance with the operating conditions of the piston ring in reality and in the model experiment (without considering the temperature). The rotation of the liner with a fixed counterbody simulated the operation of a friction pair.

4. RESEARCH RESULTS AND DISCUSSION

The study of the wear resistance of the cylinder liner surface layer machined using the developed technology, including FANT operation and deforming broaching, was performed according to the developed accelerated test methodology in an installation based on a lathe-cutting machine. In accordance with the developed methodology, a counterbody structure was made in advance (Figure 2b), which is an elastic split ring with grooves.

Wear tests using the developed methodology and the manufactured equipment made it possible to significantly reduce the time required for testing. For example, a 2-hour run-in was made possible on a lathe-cutting machine in 30 minutes.

Study results of the liner wear resistance processed by the proposed and known (honing) technologies are shown in Figure 3.

The results of wear tests have confirmed the effectiveness of the proposed technology for processing cylinder liners. The reduction of the liner surface wear compared to the existing technological process (honing) should be explained by the presence of an antifriction coating that reduces the friction coefficient and serves as a solid lubricant. Using deforming broaching allows to strengthen the surface layer of the treated surface. The developed methodology for accelerated tests for wear resistance of cylinder liners made it possible to reduce the time for wear tests by 4 times at low speeds – n_s = 80 rpm.

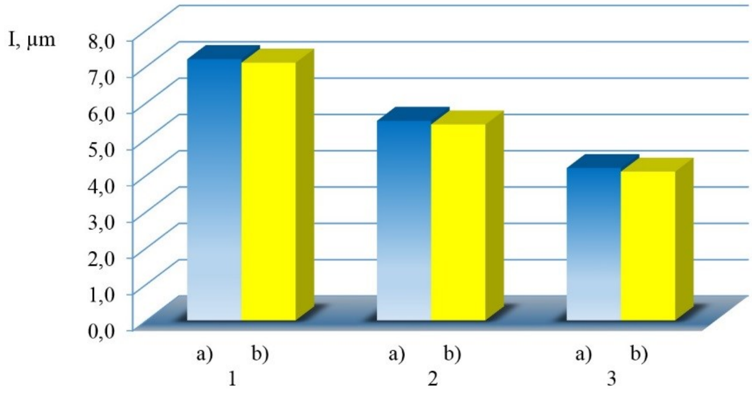

Figure3. Results of tests for wear resistance of cylinder liners treated: 1 – by boring and honing; 2 – by combined broaching and honing; 3 – by FANT and deforming broaching; a) – after bench tests; b) – according to the developed methodology

Obtained results made it possible to recommend the following technological process for the restoration of the ICE cylinder liners (Figure 4).

Figure 4. Structure diagram of the technological process for restoration of ICE cylinder liners

According to the presented scheme, after disassembling the engine, the liners are washed and cleaned of dirt and scale and inspected for defects. If the liners are found to be defective, they are subject to rejection if they have wear beyond the third repair dimension, as well as cracks and chips. It is proposed to compensate for wear by applying antifriction coatings using FANT, followed by their hardening by deforming broaching. The final step in the process is, as usual, dimensional control.

Wear tests have shown the effectiveness of the applied technical solutions. The average wear of the liner's working surface after processing using the proposed technology was 4.2 µm, which is 1.7 times less than the wear obtained on the liner processed using the existing technology (7.2 µm).

5. CONCLUSION

- A device for applying antifriction coatings by the friction-mechanical method has been developed. The use of the proposed design makes it possible to increase the productivity and quality of FANT cylinder liners.
- An original design of a simulation device for testing the wear resistance of the cylinder liner working surface has been developed, which includes a counterbody that simulates a set of piston rings simultaneously interacting with the liner surface. The use of the proposed methodology for accelerated wear resistance tests made it possible to reduce the time of implementation by 4 times compared to traditional test methods.
- The effectiveness of combining FANT and deforming broaching operations has been proven, which improves the operational properties of the treated surface. A technology for processing cylinder liners of internal combustion engines using combined processing has been developed. The application of an antifriction coating and its subsequent strengthening by the method of cold plastic deformation – deforming broaching provides obtaining a working surface of the liner with improved physical, mechanical and tribological characteristics, which increases the wear resistance of the treated surface.
- The established regularities made it possible to propose a technological process for restoration the cylinder liners of internal combustion engines using FANT and deforming broaching. The tests showed the effectiveness of applied technical solutions. Thus, the average wear of the liner's

working surface after running-in was 1.7 times less than the wear obtained on the liners processed using the existing technology.

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