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IMPROVING THE PROCESSING QUALITY OF CYLINDER LINERS USING COMBINED TECHNOLOGY

Abstract. *Due to the use of surface engineering methods, a combined technology for processing the working surface of internal combustion engines cylinder liners has been developed. The advantages and disadvantages of traditional liners processing technologies are analyzed, which allowed identifying ways to improve them. A new technological process of cylinder liners processing is proposed, which includes operations of deforming broaching and finishing antifriction non-abrasive treatment. The technological equipment and tools for the chosen technological process realization are chosen. Experimental studies of the proposed technical solutions feasibility are carried out. The microrelief of the treated surface, roughness parameters, hardness distribution according to the wall thickness were determined for the studied liners, and the amount of wear was determined for the liners after running-in. Parameters analysis of geometric, mechanical and tribological characteristics of the liners working surface, processed by the existing and proposed technology showed significant advantages of the latter. There is an increase in the productivity of processing part up to 4 times, reducing the cost of the tool up to 3 times, and in general – reducing the cost of restoring the liner. It is proved that the use of the proposed technology allows improving the physical-mechanical characteristics of the working surface: strengthening the surface layer to a depth of 0.3 mm, as well as obtaining a roughness close to the operational.*

Keywords: *deforming broaching; finishing antifriction non-abrasive treatment; cylinder liner; roughness; hardness; durability.*

1. INTRODUCTION

Improving the quality of products in many cases depends on the surface layer properties of the parts working surfaces that are part of the product. Therefore, when choosing a material, processing technology should distinguish between the functions of the core and the surface layer of the part. This design and technological concept of product creation is not only strategic but also universal, as it dominates throughout the life cycle of the product, in particular, in its manufacture, operation and repair, as well as in the restoration of individual components and parts.

To date, many methods have been developed that affect the surface layer properties of the machine parts working surfaces [1-2]. Each of these methods affects the operational properties of working surfaces through a complex of geometric and physical-mechanical characteristics of the surface layer. First of all it is accuracy, roughness, bearing surface area, a microrelief, strengthening, residual stresses, microstructure, texture, adhesive properties of the coating and the base, a resource of plasticity used.

The complex of a surface layer physical-mechanical and geometrical characteristics of friction surfaces received in the course of processing allows increasing wear resistance, fatigue strength, antifriction properties, durability of landings with tension and other properties.

The above determines that the priority of modern mechanical engineering is the engineering of machine parts surfaces, which is to develop new combined technologies that can effectively affect the working surface layer of the part to control its composition, structure and properties.

2. LITERATURE REVIEW

The most effective processes of engineering the machine parts surface, both in the main and in the secondary (repair and restoration) production are combined (hybrid) technologies.

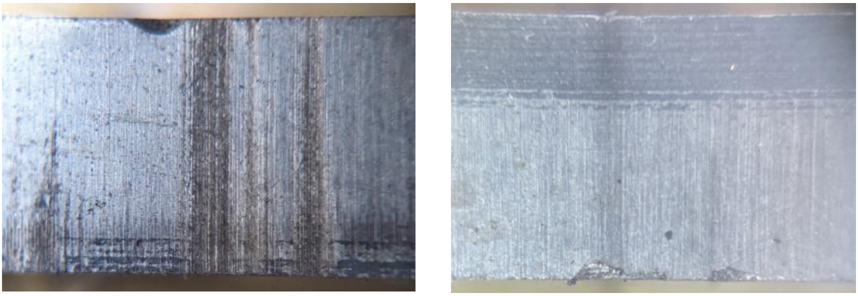
As an example, consider the existing technological process of the cylinder liner working surface processing made of modified gray cast iron SCH20.

According to [3], the condition of the liners surface layer is one of the main factors determining the resource and reliability of the engine. The existing technological process, which includes boring operations with subsequent honing, does not provide the optimal combination of mechanical and geometric characteristics of the working surface. Therefore, engines equipped with such liners are subjected to many hours of running-in on the stand for running-on friction surfaces. This provides the transformation of the initial roughness to equilibrium, the redistribution of residual stresses, etc.

In work [4] the researches of the existing technological process, and also data on influence of deforming broaching on a working surface condition of the processed liner are given and the new technological process of liners processing using cold plastic deformation with the subsequent final honing is offered. The proposed technological process has advantages over the existing one due to the treated surface with improved mechanical characteristics and roughness close to equilibrium that is technological microrelief is almost no different from the microrelief formed during the liners operation process.

However, this technological process has a significant drawback. After the clean honing operation, abrasive microparticles inevitably remain on the working surface of the liner, which leads to accelerated wear of the piston rings. Fig. 1 (a, b) shows fragments of the car piston rings, which can be seen longitudinal traces due to the action of abrasive particles placed on the working surface of the liner.

The aim of this study is to develop a new technological process that combines deforming broaching operation and antifriction coatings application operation by finishing antifriction non-abrasive treatment (FANT), which will allow to provide on a working surface of a liner the complex of geometrical and mechanical characteristics of the processed surface favorable in relation to wear resistance with simultaneous improvement of antifriction properties.



a) b)

Figure 1 – Piston ring fragments with traces of abrasive wear (liner after treatment according to the existing technological process, including honing)

3. RESEARCH METHODOLOGY

The experiments were performed on a batch of 24 liners of boosted diesels made of modified cast iron (type SCH20) when restoring them to the first repair size. In the process of processing it is necessary to remove the allowance of 0.5 mm. 8 liners were processed according to the existing technological process: boring, honing and polishing. The remaining liners were processed by deforming broaching on a vertical broaching machine mod. MA7U-750 in conditions of ISM named after V.M. Bakul NAS Ukraine (Fig. 2).

The tool for broaching is made on the researches basis carried out by authors [5] and consists of a cutting ring on both sides of which groups from hard-alloy deforming elements are placed.

The tool provides the necessary allowance removal for 1 pass that allows reducing hole processing complexity in 4 times. After broaching, the working surface of 8 liners was polished with fine-grained diamond bars ASM20/14 M1. The remaining 8 liners were processed using FANT technology on a vertical honing machine mod. 3M83 in the following modes: pressure of the brass tool P = 6 MPa, rotation speed of the tool V = 0.996 m/s, reciprocating motion speed V_1 = 0.24 m/s.

Repaired engines, in each of which were installed 4 liners, processed according to the existing technological process, and two liners, processed according to the following technological processes: deforming broaching – polishing; deforming broaching – FANT, was subjected to 2-hour run-in. Then the engines came into operation. The study of the liners working surfaces characteristics, treated using the considered technological processes, was carried out after running-in the engine.

Figure 2 – The process of the ICE liner processing
by deforming – cutting – deforming broach

The microrelief of the treated surface, roughness parameters and hardness distribution according to the wall thickness were determined for the studied liners, and the amount of wear was determined for the liners after running-in. Measurement of the liner working surface wear was performed on a profilograph – profilometer "Talysurf-5". Wear resistance was assessed by linear wear recorded by profilograms taken at a base length of 120 mm. Also on the profilograms taken from the liner surface after processing and running-in, determined the roughness parameters.

The profile of the profilograph was discretized and processed on a PC. In addition to the roughness parameters, histograms were constructed that reflect the empirical law of roughness ordinates distribution. The experimental distribution law was approximated by a number of theoretical distribution laws. The conformity of the experimental distribution law with the theoretical one was assessed by criterion χ^2 [6], with 95% probability.

According to the profilograms taken from the working surfaces of the liners after processing and running-in, the mutual correlation functions of the roughness profiles were additionally calculated.

The Vickers hardness of the liners surface layer, treated in accordance with the considered technological processes, as well as its distribution by wall thickness were measured on the device HPO – 250 at a load of 50 N.

4. RESULTS

Table 1 shows the parameters of geometric, mechanical and tribological characteristics of the ICE liner working surface, treated by the existing process, developed by the authors [4] and according to the proposed process.

Table 1 – Parameters of microrelief roughness and ICE liners working surfaces frictional indicators (above the line – data after processing, below the line – after running-in)

Type of processing	Ra, µm	Rmax, µm	Rz, µm	Rp, µm	t_r, %	t_p=10%, %	S_m, µm	HV, GPa	Wear after two hours of running-in, µm
Deforming broaching	1,08	12	7,8	2,35	59	52	146	2,92	-
Boring + double honing	$\frac{1,45}{0,20}$	$\frac{13,8}{2,4}$	$\frac{10,7}{1,66}$	$\frac{2,45}{0,46}$	$\frac{43}{49}$	$\frac{24}{38}$	$\frac{90}{125}$	$\frac{2,35}{2,35}$	7,2
Deforming broaching + honing	$\frac{0,85}{0,18}$	$\frac{7,5}{1,8}$	$\frac{5,99}{1,05}$	$\frac{1,51}{0,22}$	$\frac{66}{63}$	$\frac{60}{58}$	$\frac{155}{153}$	$\frac{2,8}{2,7}$	5,5
Deforming broaching + FANT	$\frac{0,81}{0,16}$	$\frac{7,21}{1,6}$	$\frac{5,2}{1,02}$	$\frac{0,6}{0,28}$	$\frac{68}{65}$	$\frac{62}{59}$	$\frac{164}{162}$	$\frac{2,86}{2,85}$	4,2

Analysis of the data in Table 1 shows that the operation of deforming broaching significantly improves the surface layer microrelief, which in this case (Fig. 3) has support sites alternating with cavities and playing the role of lubrication tanks during operation.

It should be noted that the operation of deforming broaching significantly increases the parameter S_m in comparison with boring, which, according to the data presented in works [7, 8], increases the fatigue strength of the treated surface. Moreover, the use of finishing operations after broaching also leads to an increase in this parameter, especially when using FANT.

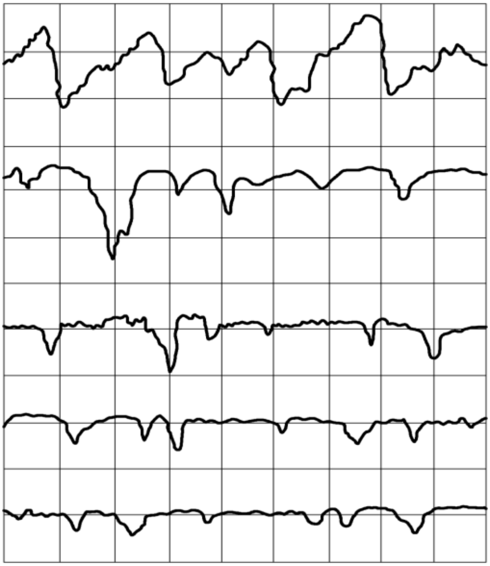


Figure 3 – Microroughnesses profilograms of the ICE liner working cavity after processing: a) boring; b) boring + honing; c) deforming broaching; d) deforming broaching + polishing; e) deforming broaching + FANT

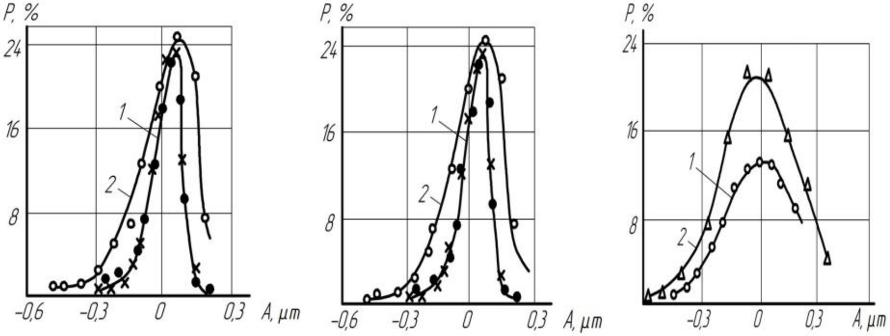
After running-in, the height parameters of roughness decreased slightly, and the supporting lenght of the profile and the step along the midline did not change. The microrelief of the surface treated by the existing technological process differs from the microrelief obtained after treatment, in accordance with the technological processes based on broaching. Particularly noticeable differences in the values of the profile supporting length.

In the process of running-in, the values of the roughness height parameters also decrease, but in contrast to the microrelief obtained after broaching, the average step of the profile microroughnesses along the midline and the profile supporting length increased markedly. Therefore, the change in the roughness parameters obtained by the existing technological process during operation is more significant than when using technological processes based on broaching. This indicates the difference in the restructuring of the roughness technological parameters obtained after the compared technological processes during their operation.

Comparison of two technological processes based on broaching showed that the technological roughness and microrelief of the treated surface are very close. Although when using FANT the parameters of technological roughness R_p and S_m

are slightly better, this is explained by the process of rubbing the antifriction material on the liner working surface.

Roughness reconstruction was evaluated according to the method described in work [9], comparing the laws of roughness ordinates distribution after processing and operation. The distribution of the surface roughness ordinates treated by technological processes based on broaching corresponds to Weibull law (Fig. 4 a, b).



a) b) c)

Figure 4 – Laws of roughness ordinates distribution:
1 – after processing; 2 – after operation.
Treating by technological process on the basis of broaching:
a) broaching and honing; b) broaching and FANT; c) the existing technological process

It should be noted that after operation the law of roughness ordinates distribution for the considered technological processes practically does not change (Fig. 4 a, b, curves 2). This indicates a slight restructuring of the rough layer during operation, which is confirmed by the analysis of mutual correlation functions of the roughness profiles recorded before and after operation. The value of the coefficient of their mutual correlation is greater than zero that is in the process of the engine running-out on the liner working surface reproduces the roughness, which is close to technological. The given data testify to insignificant transformations of the liner surface layer treated by technological process on the basis of broaching.

However, two technological processes are considered, which include the broaching operation with subsequent finishing operations: honing and FANT are somewhat different. Thus, after the clean honing operation, abrasive microparticles remain on the treated surface, which impairs the wear resistance of the surface, interaction with the piston ring surface and leaving traces on it in the form of longitudinal lines (Fig. 1). These shortcomings are reflected in the amount of wear.

The minimum wear of the liner surface is observed when processing using FANT and after two hours of running-in is 4.2 μm. At the same time, the wear of the liner surface when processing it after broaching by honing is slightly higher and is 5.6 μm.

Another picture is observed in the analysis of data obtained on the liners, processed by the existing process, which includes the operations of boring and honing. In this case, the roughness ordinates distribution, determined by the method [9], obeys the law of normal distribution (Fig. 4, c). During operation, the type of distribution law changed became logarithmically normal and approached Weibull distribution law. This means that after the restructuring that took place during operation, the difference in the nature of the profiles ordinates distribution treated by technological processes based on boring and broaching has decreased significantly. Some difference in the roughness ordinates distribution of the running-in surfaces is due to the influence of the treated surface initial state, namely – technological inheritance. Analysis of profiles mutual correlation functions confidence intervals before and after operation shows that the value of the cross-correlation coefficient is 0 that is during engine operation process on the liner working surface occurs a rough layer restructuring and a new microrelief is formed, completely different from the technological one.

Thus, the given material testifies that the most effective of the considered technological processes is the process consisting of operations of broaching and FANT. It provides minimal transformation of the rough layer during operation process, improved typological characteristics and the absence of abrasive particles on the treated surface and minimal wear of the liner working surface during operation.

Comparison of physical-mechanical characteristics of the surface layer treated by two different technological processes (boring, honing and broaching, FANT) showed a large difference between them (Fig. 5). The operation of deforming broaching significantly (up to 25%) strengthens the surface layer of the liner material. Depth of hardening thus reaches about 0.3 mm that guarantees existence of the strengthened material in friction pair even at long operation. Thus, the combination of cold plastic deformation and FANT allowed developing a successful version of the technological process for the diesel liner inner surface treating made from gray modified cast iron.

As shown by the results of technical-economic calculations, the use of the developed technological process can increase the productivity of the hole processing up to 4 times, reduce tool costs by 3 times, which reduces the cost of restoring the liner by about 4 times. Moreover, the use of the proposed technological process provides a liner working surface with improved physical-mechanical and tribological characteristics and roughness close to equilibrium.

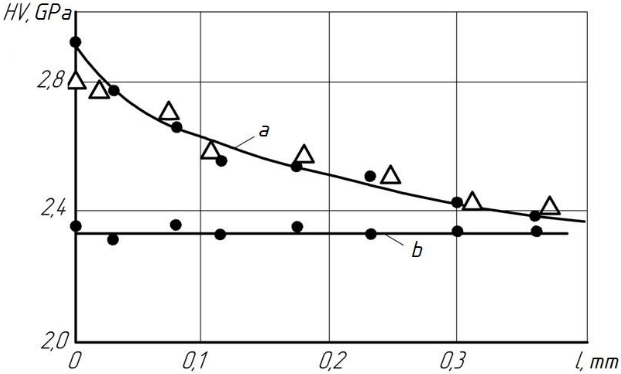


Figure 5 – Hardness distribution according to the wall thickness
of the diesel liner during processing: a – according to the new technological
process (• – after broaching; Δ – after broaching and FANT);
b – according to the existing technological process (boring and honing)

5. CONCLUSIONS

1. The expediency of combining the cold plastic deformation operation and FANT, which allows offering the technology for processing the cylinder liners of internal combustion engines.

2. A new technological process of ICE liners processing has been developed, which includes deformation broaching operations and FANT, which provides receiving a working surface of the part with improved physical-mechanical and tribological characteristics and roughness close to equilibrium.

3. The effectiveness of the proposed technology is confirmed by improving the operational characteristics of the cylinder liners working surface.

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ПІДВИЩЕННЯ ЯКОСТІ ОБРОБКИ ГІЛЬЗ ЦИЛІНДРІВ ЗАСТОСУВАННЯМ КОМБІНОВАНОЇ ТЕХНОЛОГІЇ

Анотація. *За рахунок використання методів інженерії поверхні розроблено комбінована технологія обробки робочої поверхні гільз циліндрів двигунів внутрішнього згорання. Проаналізовані переваги та недоліки традиційних технологій обробки гільз. Показано, що після використання фінішної операції хонінгування на робочій поверхні гільзи залишаються абразивні мікрочастки, що призводить до прискореного зносу поршневих кілець. Запропоновано новий технологічний процес обробки гільз циліндрів, що вміщує операції комбінованого протягування та нанесення покриттів фінішною антифрикційною безабразивною обробкою. Вибрано технологічне оснащення та інструмент для реалізації технологічного процесу. Проведені експериментальні дослідження доцільності запропонованих технічних рішень. Вивчення характеристик робочих поверхонь гільз, оброблених з використанням розглянутих технологічних процесів, здійснювалося після обкатки двигуна. Для досліджуваних гільз визначено мікрорельєф обробленої поверхні, параметри шорсткості, розподіл твердості за товщиною стінки, а для гільз після обкатки – величину зносу. Аналіз параметрів геометричних, механічних та трибологічних характеристик робочої поверхні гільз, оброблених за існуючою та пропонованою технологією, показав суттєві переваги останньої. Встановлено, що використання комбінованого протягування дозволяє сформувати мікрорельєф поверхневого шару, який являє собою опорні площадки із впадинами, які грають роль змащувальних резервуарів при експлуатації. Нанесення покриття фінішною антифрикційною безабразивною обробкою, суттєво не змінюючи мікрорельєф, підвищує антифрикційні властивості поверхні. Доведено, що застосування розробленої технології обробки гільз циліндрів забезпечує отримання шорсткості, близькою до експлуатаційної, зміцнення поверхневого шару на глибину до 0,3 мм, поліпшені трибологічні характеристики, відсутність частинок абразиву на обробленій поверхні і мінімальний знос робочої поверхні гільзи при її експлуатації.*

Ключові слова: *деформуюче протягування; фінішна антифрикційна безабразивна обробка; гільза циліндрів; шорсткість; твердість; зносостійкість.*