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Development of a technological process for the restoration of piston pins using deforming broaching

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Abstract

The article discusses the technological process of restoring the geometric dimensional accuracy of piston pins of internal combustion engines (ICE) due to the expansion of the internal hole by a deforming element. As part of conducting research taking into account the resource of the used plasticity of the processed material, the processing modes are determined, the deformation scheme is selected and the geometry of the deforming element is calculated. The selection of the necessary deformation of the part during processing of the piston pin was carried out under the condition of compensating for wear and ensuring an allowance for subsequent mechanical processing. This made it possible to ensure the necessary processing quality of the pin hole surface layer according to the resource parameter of the used plasticity. The deformation scheme was chosen from the condition of ensuring the geometric accuracy of the pin outer surface, which determines the size and uniformity of the allowance for subsequent processing. For these reasons, a scheme was chosen in which the deformation is carried out by two elements with a change of the support end after the first pass. The optimal geometry of the deforming tool was determined from the standpoint of minimizing errors and preserving the initial length of the pin. The results of the conducted experiments showed that using selected expansion schemes, tensions and geometry of the deforming tool, made it possible to ensure the necessary allowance for the next mechanical processing, as well as the invariance of the part length after processing.

Key words: piston pin, expansion of the inner hole, expansion modes, expansion scheme, geometry of the deforming tool, geometric dimensional accuracy

Introduction

An important and urgent task of machine-building production is the repair and restoration of parts that limit the service life of the ICE. The economic feasibility of restoring parts is due to the possibility of repeated use of worn parts. At the same time, the cost of restoration, as a rule, does not exceed the cost of manufacturing new ones, and the material consumption is 15 … 20 times lower than in the manufacture of new ones [1].

To the number of parts to be restored including piston pins, the manufacture of which requires high-precision machine equipment, tooling, control and measuring tools. The resource of these parts is small [2], the wear of the pins working surface over 0.01 mm leads to a deterioration in the conjugation operation. Therefore, the search for new and intensification of existing technologies for processing piston pins is an important and urgent problem.

Literature review

The main defect of the piston pins is wear on the outer surface in the contact areas with the sleeve of the upper connecting rod head and the holes in the piston. Existing methods of restoring the outer diameter of worn piston pins can be divided into the following groups:

- mechanical processing to repair size;
- applying an additional layer of material followed by mechanical processing to the nominal size;
- increasing the geometric dimensions of the part by heat treatment with various methods of heating and cooling.

It should be noted that in repair production, when restoring the outer size of a pin, technologies associated with heat treatment are most widely used [3].

As studies [4, 5] have shown, hydrothermal expansion in connection with the harsh conditions of 12HN3A steel cooling (water) can lead to the appearance of cracks in the cemented layer (Fig. 1).

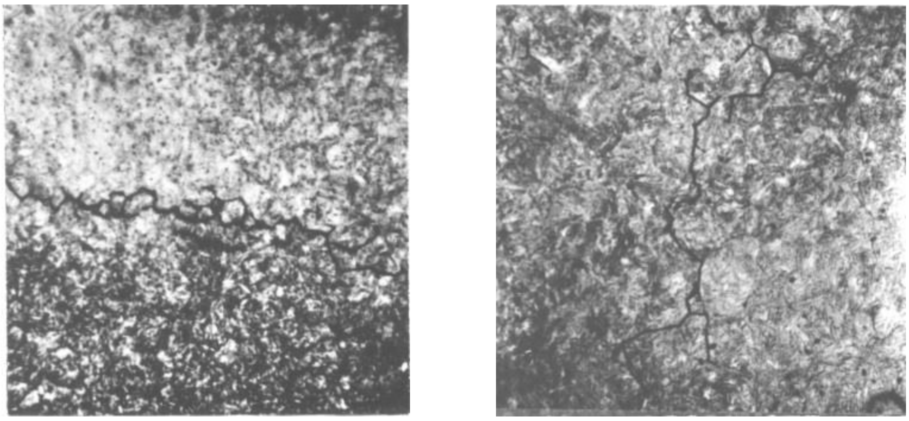

Fig. 1. Microstructure of a piston pin cemented layer made of 12HN3A steel, restored by thermoplastic expansion [5]

The cemented layer microstructure of the pin restored in this way consists of finely dispersed martensite, which is typical for the usual hardening of this steel in oil. After hydrothermal expansion, the core of the pin resembles pearlite in structure. Obviously, the heating for the core of the pin does not reach the point AC_3 (diagrams of iron – carbon) and hardening takes place in the interval AC_1 – AC_3. The AC_3 point for the carbon-saturated cemented zone is lower than for the low-carbon one. Therefore, heating is sufficient for complete hardening [5].

Despite the fact that the structure of the cemented layer of these pins is similar to the structure of pins processed by traditional technology, the thickness of the cemented layer is 0.5 mm, which does not meet the technical requirements for pins. In addition, the uncontrolled and uneven increase in the outer diameter along the length of the part leads to the need to remove significant allowances when grinding the outer surface of the pins. As a result, even within the same product, places with a small amount or complete absence of cemented layer can be observed.

The absence of a stabilizing release after hydrothermal expansion leads to the presence of thermal residual stresses in such pins. The latter can cause the appearance of cracks, or relax during the pin operation under the influence of alternating cyclic loads. This causes the loss of the pin working size.

More effective is the technology of piston pins restoration by the method of electric contact heating and combined spray cooling [6], which also has a number of disadvantages that are typical for methods of parts restoration based on the use of thermal deformations. The hardened cemented layer microstructure of restored pins represents martensite with the inclusion of cementite, residual austenite, and troostite. This indicates non-compliance with the basic requirements for the technological process of cemented steels heat treatment during heat treatment and leads to the appearance of defective signs in restored pins (presence of residual austenite).

At the V. Bakul Institute for Superhard Materials of the National Academy of Sciences of Ukraine developed a highly productive technology for restoring the outer surface of the piston pin using the deforming broaching operation [4]. The efficiency and, consequently, the feasibility of such a technology depends on a reasonable approach to choosing the modes of deforming broaching during expansion of ICE piston pins, taking into account the quality indicators of the treated surface layer. In this case, special attention should be paid to the choice of tool geometry for deforming broaching.

Purpose

The purpose of the work is to determine the modes, scheme, and geometry of the tool during the deforming broaching of ICE piston pins, taking into account the resource of the used plasticity of the processed material.

Research Methodology

Plastic deformation of a worn piston pin is practically impossible due to the presence of a brittle martensitic layer on its outer surface. Therefore, the worn pins are annealed, which restores the initial state of the material, and therefore creates the possibility of their plastic deformation [5].

The selection of the necessary pin deformation is carried out under the condition of pin wear compensation and provision of an allowance for the next mechanical processing. Experiments to determine the relationship between the pin hole deformation Σa and the required allowance of the pin outer surface made it possible to obtain the following dependence:

$$\frac{0.07AL}{d_0} = \frac{0.033}{d_0}\sum a \,, \tag{1}$$

where AL is the allowance of the processed part outer surface;

d_0 – the diameter of the processed part inner surface;

a – tension on the deforming element.

When choosing the amount of circumferential deformation of the pin hole (tension), the conditions affecting the quality of the pin material should be taken into account. One of these factors, according to the work [7], is the resource of used plasticity.

The technological process of restoring piston pins includes a heat treatment operation after a deforming broaching operation. As shown by studies [8], for parts exposed to the action of alternating loads during operation, the value of the resource degree of used plasticity in the operations preceding heat treatment should not exceed the following values:

$$\Psi = \left[\Psi\right] = 0.33 \,, \tag{2}$$

where ψ – the resource of the used plasticity of the material.

When re-restoring the piston pins after the expansion operation, it is necessary to provide for additional cementation of the pin working surface. According to the data of works [9], the value of the preliminary plastic deformation Ψ is optimal from the point of minimizing the time for the cementation process, as well as for obtaining a fine-grained uniform martensitic structure after heat treatment of the cemented surface without the presence of residual austenite, which is within the limits of:

$$\Psi_{\max} \le \left[\Psi\right] , \tag{3}$$

where $[\psi] = 0.2 \div 0.25$.

Therefore, the value of pin expansion, determined from the condition of ensuring the necessary technological allowance, must be checked based on condition (3).

As shown in works [10], on the outer surface of workpieces with a final wall thickness ($D/d_0 \le 2.5$), a rigid stress state scheme approaching the biaxial tension scheme is realized. Under such conditions, there is an intensive increase in the resource of the used plasticity even with small values of the accumulated circumferential deformation. For recoverable pins, the relation $D/d_0 = 1.7$, so it is necessary to check the quality of the recoverable pin according to the parameter Ψ for its outer surface.

The resource of used plasticity during two-cycle deformation of the pin on its outer surface, according to the data of work [7], is calculated by the formula:

$$\Psi = \frac{-1 + \sqrt{1 + 4\left[n\bar{z} + \left(1 + 2\Theta\right)\left(n\bar{z}\right)^2\right]}}{2} \,, \tag{4}$$

where $\bar{z} = \dfrac{\bar{e}_0^{\,n}}{e_{ult}(2)}$ – experimental parameter;

e_0^n – deformation brought to the outer surface.

The magnitude of the ultimate deformation in case of uniform biaxial stretching:

$$e_{ult}(+2) = 0.0065\delta_p \,, \tag{5}$$

where δ_p – relative elongation of the sample in standard tensile tests. For the pins material – steel 12HN3A $\delta_p = 36\%$.

The main accumulation of damage to the processed material during deforming broaching occurs at the value of the stress state indicator η = +2, which is realized on the outer surface of the workpiece. Therefore, when calculating the ultimate deformation, it is sufficient to know the deformation of the workpiece material under conditions of uniform biaxial tension η = +2.

Determination of deformation during biaxial stretching was carried out according to the following method. Plates with a diameter of 100 mm and a thickness of 5 mm were cut from the studied material. One of the plate surfaces was ground and polished, and then marked with equidistant marks along two mutually perpendicular axes. Marks were applied with a diamond pyramid using a hardness tester head mounted on a BMI-1 universal microscope under a load of 50 N. The base of measurements, i.e. the distance between two adjacent marks, was 1 mm.

The sample prepared in this way was installed in a special device and loaded with a spherical punch (Fig. 2).

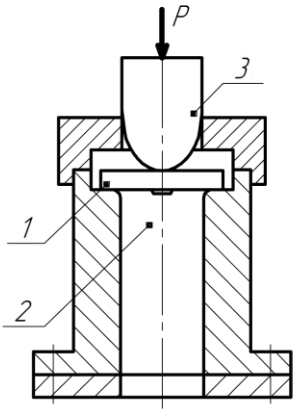

Fig. 2. Testing samples under biaxial uniform stretching: 1 – plastic sample; 2 – researched area; 3 – spherical punch

The punch polished surface and the sample were lubricated to reduce frictional forces. The load was applied until cracks appeared on the surface with marks. Destruction (the appearance of cracks) was observed in the immediate closeness of the punch top. At the same time, local thinning of the plate was not observed. According to the change in the distance between the marks, the deformation at the point of destruction e_x and e_y was determined.

The accumulated deformation was calculated according to dependence (5) given in work [10], based on the assumption that the deformation in the center of the plate is simple:

$$\bar{e}_0 = \sqrt{e_x{}^2 + e_y{}^2 + e_{x^i} + e_{y^i}} \; . \tag{6}$$

The value of the deformation at η = +2 made it possible to construct a plasticity diagram for the material of the piston pins – 12HN3A steel (Fig. 3).

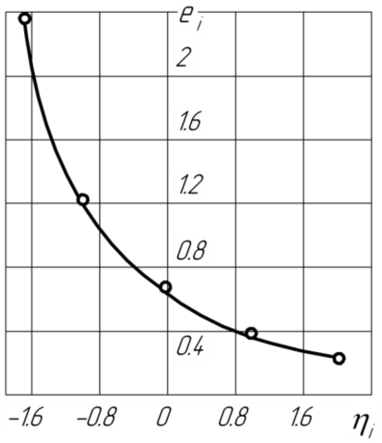

Fig. 3. Plasticity diagram of steel 12HN3A

The degree of the plasticity resource using on the inner surface of the pin, where intense local plastic deformation takes place, was performed according to the following dependence [8]:

$$\Psi = \frac{\Delta e_0^{\max}}{3e_{ult}\left(-1.73\right)}, \tag{7}$$

where $e_{ult}\left(-1.73\right)$ – plasticity under compression under conditions of plane deformation, i.e. at $\eta = -1.73$.

The dependence of the limit deformation during the processing cycle on the angle α was determined:

$$\Delta e_0^{\max} = 0.03\alpha + 0.1\,. \tag{8}$$

The deformation scheme was chosen from the condition of ensuring the geometric accuracy of the pin outer surface, which determines the size and uniformity of the allowance for subsequent processing.

The choice of the deforming tool geometry was carried out under the condition of preserving the pin initial length. At the same time, the case of part expansion in the absence of axial deformations is considered:

$$\alpha = \frac{0.35 + 34.8a / d_0}{t_0 / d_0}\,. \tag{9}$$

Results

The selection of the necessary part deformation during processing of the piston pin was carried out under the condition of compensating for wear and ensuring an allowance for subsequent mechanical processing.

Calculations performed according to expression (4) for real expansion conditions of pins A-01; D-37; 10D100, made of 12HN3A steel, showed that the resource of used plasticity on the pin outer surface during its expansion is within $\Psi = 0.2 \div 0.21$. This provides normal conditions for thermochemical treatment of deformed pins, which subsequently allows achieving the required quality of restored pins.

The degree of pin thickness D-37 is equal to: $t = 2.05$. Therefore, the stress-deformed state (SDS) of the pin hole surface layer approaches the SDS scheme of the workpiece with infinite wall thickness.

According to the recommendations of work [10], it is necessary to check the degree of the plasticity resource use on the pin inner surface, where intense local plastic deformation takes place.

According to the data of experiments on the samples compression, performed according to the method [11], e_{ult} (-1.73) for steel 12HN3A is equal to 2.34.

To calculate the plasticity resource according to dependence (7), it is necessary to know the value of the accumulated deformation $\Delta e_0^{\max}$ for 1 processing cycle in the considered inner surface of the pin.

In work [12] it was shown that when using a deforming element with an angle α = 5° for expansion, the value $\Delta e_0^{\max} = 0.25$, and with an angle α = 10° – $\Delta e_0^{\max} = 0.39$.

The conducted experiments showed that from the point of minimizing errors and ensuring the invariance of the pin length upon its expansion, the angle α = 2° is optimal. Using expression (8), we obtain the value of the accumulated deformation on the pin inner surface $\Delta e_0^{\max} = 0.16$.

This value was used to calculate the resource of used plasticity for one cycle of deformation, according to expression (7). Then in one cycle of deformation $\Delta\Psi = \frac{0.16}{3 \cdot 2.34} = 0.024$.

Since the pins expansion is carried out in two cycles of deformation, we obtain that the full resource of the used plasticity in the surface layer of the hole processed in 2 cycles is $\Psi = 2\Delta\Psi \approx 0.05$. This value does not exceed the limit value Ψ. Therefore, the processing quality of the pin hole surface layer according to the resource parameter of the used plasticity is ensured.

After determining the required deformation, the deformation scheme was selected. Taking into account the shape and design features of the pin, the presence of chamfers up to 3 mm long in the A-01 pin and 14 mm – 10D100 pin, a scheme was chosen according to which the deformation is carried out by two elements with a change of the support end after the first pass. A necessary condition when using this scheme is the constancy of the axial force *Q* at each pass. The general deformation ε is carried out by two deforming elements with tensions a_1 and a_2:

$$\varepsilon = a_1 + a_2\,, \tag{10}$$

where a_1 – tension on the first deforming element, $a_1 = \frac{\beta}{1+\beta}\varepsilon$;

a_2 – tension on the second deforming element, $a_2 = \dfrac{\varepsilon}{1+\beta}$.

The calculation of tensions values a_1 and a_2, their total value ε, as well as the values of the deforming tool angles α for different brands of pins, calculated according to dependence (9), are given in Table 1.

Table 1

Values of tension *a*, total deformation and angles of the tool α, necessary for the restoration of different brands of pins

No.	The brand of ICE restoring pin	a_1, mm	a_2, mm	ε, mm	α, degree
1	D37	0.42	0.40	0.82	$2^\circ 30'$
2	D240	0.44	0.42	0.86	$2^\circ 30'$
3	A01	0.47	0.43	0.9	$2^\circ 30'$
4	10D100	0.75	0.7	1.45	$2^\circ 30'$

The results of the experiments given in the Table 2 and Fig. 4 show that the use of the selected expansion schemes, tensions and geometry of the tools, made it possible to ensure the necessary allowance for the next mechanical processing, as well as the invariance of the part length after expansion.

Table 2

The value of allowances for the pin length for the next mechanical processing and the pin length after its expansion

No.	The brand of ICE restoring pin	Allowance Δ, mm			L, mm
		I end	middle	II end	
1	D37	0.19	0.2	0.19	$89_{-0.1}$
2	D240	0.2	0.21	0.2	$102_{-0.1}$
3	A01	0.21	0.22	0.21	$110_{-0.1}$
4	10D100	0.24	0.26	0.24	$182_{-0.1}$

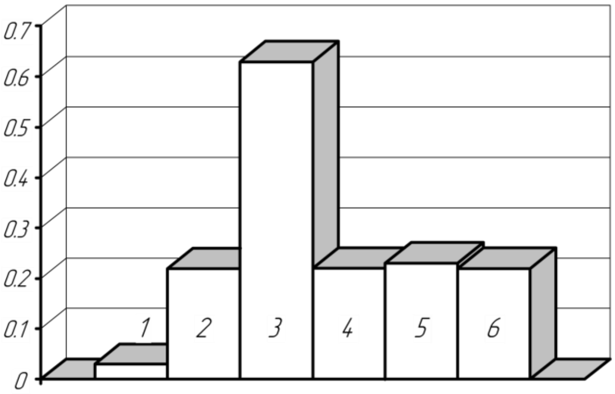

Fig. 4. Histogram of the allowance change for the pin A01 length when processing a batch of pins in production conditions in the amount of 100 pcs.: 1, 3, 4, 6 – allowance value on the edge areas of the processed pin; 2, 5 – allowance value in the middle of the processed pin; 1, 2, 3 – pin processing according to the compression scheme; 4, 5, 6 – pin processing according to the scheme with a change of the support end

The conducted research made it possible to determine the deforming broaching modes and the geometry of the tool during the expansion of ICE piston pin. Thus, the developed technological process of processing ICE piston pins, which includes their deformation and subsequent heat treatment, ensures the obtaining of piston pins, the quality of which meets the requirements for new pins.

Conclusions

1. Carrying out theoretical and experimental studies of ICE piston pins deforming broaching made it possible to make a choice:

- necessary deformation under the condition of wear compensation and provision of allowance for mechanical processing.
- scheme of the pin deformation from the conditions of ensuring the geometric accuracy of the part.
- geometry of the tool from the condition of ensuring the invariance of the part length.

2. The relationship between the total deformation of the hole and the amount of the required allowance on the pin outer surface has been established.
3. It has been proven that processing according to the scheme with a change of the support end ensures geometric accuracy of the pin outer surface.
4. It has been proven that the selected broaching modes and the geometry of the tool ensure a zero change in the pin length during its processing.

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Немировський Я.Б., Шепеленко І.В., Черновол М.І., Златопольський Ф.Й. Розробка технологічного процесу відновлення поршневих пальців з використанням деформуючого протягування

В статті розглянуто технологічний процес відновлення геометричної розмірної точності поршневих пальців двигунів внутрішнього згорання за рахунок роздачі внутрішнього отвору деформуючим елементом. З врахуванням ресурсу використаної пластичності оброблюваного матеріалу визначено режими обробки, обрано схему деформування та розраховано геометрію деформуючого елементу. Вибір необхідної деформації деталі при обробки поршневого пальця виконували з умов компенсації зношування та забезпечення припуску під наступну механічну обробку. З метою забезпечення геометричної точності зовнішньої поверхні пальця, що визначає величину й рівномірність припуску під наступну обробку, обрано схему деформування, при якій деформація здійснюється двома елементами зі зміною опорного торця після першого проходу. З позицій мінімізації похибок, збереження вихідної довжини пальця визначена отптимальна геометрія деформуючого інструменту. Результати проведених експериментів показали, що використання запропонованих схем роздачі, натягів та геометрії деформуючого інструменту дозволило забезпечити необхідний припуск під наступну механічну обробку, а також незмінність довжини деталі після обробки.

Ключові слова: поршневий палець, роздача внутрішнього отвору, режими роздачі, схема роздачі, геометрія деформуючого інструменту, геометрична розмірна точність.