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# IMPROVING THE TECHNOLOGY OF PART MACHINING BY SURFACE PLASTIC DEFORMATION

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***Метою роботи є дослідження технологічного процесу зміцнення пустотілих циліндричних деталей автотракторних двигунів з використанням поверхневого пластичного деформування.***

***Попередньо проведені експериментальні дослідження на моделях у широкому діапазоні зміни різних факторів. Одержані дані перераховувались з моделі на конкретні деталі – поршневі пальці та втулки верхніх головок шатунів автотракторних двигунів. Дослідження використовували при визначенні: зусиль, напружень, формозміни, властивостей та структури матеріалу деталей. При проведенні досліджень дотримувався закон подібності, відповідно до якого моделі-зразки та деталі були геометрично подібними та фізично однакові. Експериментально встановлені раціональна форма обробного інструменту – конусна, а також його оптимальні розміри: кут нахилу 10°30′, величина калібруючого пояска 6–7 мм, що забезпечують величину зміцнення та якість поверхні оброблюваного матеріалу. Експериментально встановлено вплив кута нахилу обробного інструменту на величину налипання металу на його робочу поверхню. Встановлена залежність кількості налипання металу від його твердості та модуля пружності. Визначено вплив висоти калібруючої частини обробного інструменту на шорсткість оброблюваної поверхні деталі.***

***На основі одержаних лабораторних даних отримана емпірична залежність припуску на обробку із залишковою деформацією по зовнішньому діаметру поршневого пальця. Виявлено, що найбільш небезпечними є тангенційні напруження по зовнішній поверхні поршневих пальців, визначення яких проводили в процесі деформування методом тензометрування. Експериментально встановлено значення припуску за один прохід робочого інструменту при вібраційному деформуванні поршневих пальців, що забезпечує зменшення розтягуючих залишкових напружень. Проведеними дослідженнями статичної міцності поршневих пальців встановлено, що величина зносу залежить від наступних основних факторів: методу обробки, матеріалу та часу роботи.***

***Дослідженням вагового зносу поршневих пальців та втулок верхніх головок шатунів встановлено, що при вібраційному деформуванні величина зносу менша у порівнянні зі звичайною роздачею. Величина зносу поршневих пальців, що відновлені вібраційним методом, в 1,13 рази менше в порівнянні з відновленими звичайною роздачею***

***Ключові слова: пластичне деформування, моделювання процесу, вібраційна обробка, залишкові напруження, шорсткість поверхні, зміцнення***

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## 1. Introduction

Modern repair production faces an issue related to the loss of performance by parts and assemblies of machines associated with the destruction of their surface layer. In this regard, the technological processes of restoration (manufacturing) require that more attention should be paid to operations aimed at surface hardening in order to provide for the required operational properties.

A series of studies have been conducted recently to devise requirements to a hardened surface layer of restored parts. It has been established that in some cases it is necessary, in order to increase the durability of parts, to form a surface layer with a heterogeneous hardened structure [1].

Existing hardening techniques do not always make it possible to meet the requirements to the quality of the hardening material of parts. Research is therefore needed to enhance the technological capabilities of hardening techniques.

One of the effective hardening techniques for treating the parts are the techniques of surface plastic deformation (SPD), which ensure the formation of a strengthened layer with enhanced indicators of a material's quality: the depth of hardening, its firmness, an increase in compressive residual stresses [2].

However, a possibility to obtain a surface layer with the required hardening indicators has remained insufficiently implemented, which is often an obstacle to the effective use of a series of machine parts.

The application of dynamic load at machining is more beneficial than static, as the dynamic force action can be obtained at lower energy costs.

Thus, it is a relevant task to obtain a hardened surface layer with a greater depth and degree of hardening. Such surface characteristics are most appropriate to obtain when using SPD techniques based on vibration oscillations of the machining tool. However, this requires additional research.

## 2. Literature review and problem statement

One can manage the quality indicators of a surface layer of machine parts machined by SPD by changing the parameters that characterize the conditions of contact between the machining tool and the treated surface. Different combinations of parameters form the types of SPD techniques that make it possible to create microrelief at the surface with the shape of micro-irregularities that improve durability [3].

Using a dynamic load at SPD makes it possible to increase performance, improve the properties of a surface layer's material. Such a technological process is the shock saddling [4]. However, it is very difficult to ensure that the surface is strengthened evenly in this case.

Restoration of hollow cylindrical parts by plastic deformation without heating is usually used at high plasticity of the material [5].

Expansion of parts with a cemented, tempered outer surface in a cold state is possible only at small allowances. This makes it possible to obtain the necessary magnitude of deformation to compensate for the wear of restored parts [3]. The deformation of such parts at large allowances leads to cracks and other defects on their surface.

Cold machining should increase the outer diameter of the restored parts by the magnitude that compensates for their wear and provide the allowance for subsequent mechanical treatment.

Restoring the piston fingers of automotive engines over one or two runs of the machining tool results in up to seventy percent of defects [6].

The patterns in the deformation parameters, the structure and properties of a machined material, which are necessary to develop cold treatment modes at parts restoration, are described in the scientific literature for a limited number of materials [7].

There are no specific recommendations for the restoration of cylindrical hollow parts at their machining [8]. The physical nature of hardening when deformed in a cold state is not revealed.

When restoring parts, the literature describes a technique in which ultrasonic oscillations are used in the process of deformation [9]. It should be noted that the effect of ultrasonic oscillations on deformation causes a complex process: the imposition of static and dynamic stresses and the absorption of ultrasonic energy.

Therefore, the restoration of worn-out parts using ultrasound has not become common in the repair industry due to the complex technological process and the equipment used.

In some cases, electrohydraulic treatment of parts is used, which implies creating a shock wave of up to 1,500 MPa, causing a change in the shape and size of the machined part [10]. Given the complexity of technological operations, this process has not yet been properly applied in repair production.

The above techniques for cold pressure treatment of metals are mainly used in industrial production to obtain parts such as cups, bushings, gears made of structural carbon and doped steels.

These techniques have not been widely used now in repair production due to the complexity of the technological process and the lack of expensive equipment.

Recently, a new method of metal treatment has been used, based on applying mechanical oscillations – vibrations. The increased intensity of processes in the presence of vibrations is predetermined by the character of their impact on the treated objects.

The basis of vibrational strengthening is the dynamic character of the process, accompanied by many micro-shocks of the working tool or particles of the working environment against the surface of machined parts. This ensures the plastic deformation of a surface layer, which leads to an increase in micro-hardness, the formation of favorable compressive residual stresses and a reduction in the surface roughness [6].

Thus, it is important to ensure that the equipment is more durable and reliable. This requires undertaking a research into the use of vibration oscillations in order to obtain optimal technological parameters when restoring hollow cylindrical parts. The most common parts are the piston fingers and bushings of the top heads of connecting rods of automotive and tractor engines.

## 3. The aim and objectives of the study

The aim of this work is to improve the technological process of strengthening the hollow cylindrical parts of automotive and tractor engines using surface plastic deformation.

To accomplish the aim, the following tasks have been set:

– to determine the optimal parameters for the working tool;

– to identify the effect of the treatment regime on the amount of deformation and the character of distribution of residual stresses;

– to investigate the strength of piston fingers and assess the durability of piston fingers and bushings of the top heads of connecting rods.

## 4. Procedure to define quality indicators

The theoretical study of the piston finger expansion process was carried out based on calculating it as a thick-walled pipe exposed to internal pressure.

We employed formulae adopted in the theory of elasticity and plasticity as estimated dependences.

In order to define an effective technological process of parts restoration, it is important to choose the parameters of treatment that depend on many factors, the main of which is the amount of wear of mated parts.

A fabricated set-up was used to experimentally study the samples of bushings, as well as the restoration of worn piston fingers and bushings of the top heads of connecting rods by the method of vibrational deformation.

The vibrational set-up ensures the execution of technological processes (expansion, reduction, surface hardening) with the required working parameters: disturbing force, amplitude, frequency, deformation rate.

The intervals and varying levels of the experiment's factors were as follows. The samples' deformation rate varied from 0.015 to 0.055 m/s at intervals of 0.020 m/s. The oscillation amplitude of the machining tool was: 0.5 mm, 1.25 and 2.0 mm, and the oscillation frequency was 1,200 $min^{-1}$, 1,900 $min^{-1}$ and 2,600 $min^{-1}$.

The rate of deformation was regulated by a wedge-belt two-pass hydraulic drive variator.

To determine the impact of the type of load on the strength characteristics of the treated material, experimental studies were preliminary conducted on samples, and then on worn-out parts. The sample bushings were made from piston fingers, steel 45, bronze CuSn5Zn5Pb5.

Laboratory studies have made it possible to exclude the influence exerted on process of expansion by such technological and experimental factors as inaccuracy and quality of machining of piston finger holes, different depth and hardness of the tempered layer, different amount and the character of their wear.

The machining tools (punches) were made from steel U10 steel, hardened in oil, tempered, and cooled. Hardening temperature was 760–780 °C, tempering temperature was 390–420 °C. Hardness of a punch's working part reached 62–65 HRC, that of a shank – 50–52 HRC.

We measured the diameter of the samples and punches by the vertical optimeter IKV and an indicator bracket with a count accuracy of 0.001 mm, as well as by the small instrumental microscope mmI-2 with a count accuracy of 0.003 mm.

Samples were produced under the same mode at the same technological equipment.

The samples were marked for measurements in the same cross sections and planes.

Fluctuations of a punch contribute to a change in the physical and mechanical properties, which exert a significant impact on the strength characteristics of parts: hardness, microhardness. We determined hardness at the hardness tester TK-2M, and the microhardness was measured by the device PMT-3.

Structural study was carried out using the MIM-8M microscope.

We measured the roughness of parts' surface using the profiler, mod. 252, and the profilometer, mod. 253.

Residual stresses: radial, tangential, and axial, were determined in the samples exposed to expansion by the sequential removal of concentric layers and measuring a sample's deformations resulting from the removal of part of the stresses.

Residual stresses are in most cases undesirable because they impair the properties of a metal [11].

Our study has established that at the surface of piston fingers there emerge the compressive residual stresses, which amount to: at standard expansion of annealed fingers – 112–120 MPa; at standard expansion of hardened fingers – 375–430 MPa; at vibration deformation – 140–165 MPa.

At a depth of 0.2–1.7 mm, they are converted into stretching ones, equal, respectively, to 65–70, 220–245 and 80–95 MPa. At a depth of 1.8–2.1 mm, the stresses are converted into compressive ones, equal, respectively, to 50–60, 170–215 and 75–85 MPa, and are reduced to zero at the inner surface of the fingers.

One of the causes for the emergence of residual stresses is the uneven deformation. The effect of vibration on the material of the restored piston fingers causes a more fine-grained structure [11] across the section compared to standard expansion, which creates the prerequisites for a more even deformation.

When the samples are deformed, the most dangerous are the tangential stresses at the outer surface, which were determined at deformation by a strain gauge method.

The oscillograph Hitachi V-1565 (USA), an amplifier, the strain gauge installation TUP-12 (Ukraine), wire strain gauges with a base of 5 mm and resistance $R$=100 Ohm were used in the course of strain gauge measurements.

We studied durability of the restored parts at the friction machine MI-1M, which implied determining the wear of their surfaces, restored by conventional and vibration deformation. The tests were conducted under the same load modes following the scheme «roller – pad».

The number of revolutions of the roller – a friction path – was recorded by a counter mounted on the friction machine. The assessment of wear implied determining the loss of sample mass during trial using the analytical scale VLA-200M with an accuracy of 0.1 mg.

Efforts, stresses, and deformations under pressure treatment in some cases can be determined experimentally under industrial conditions in the manufacture of parts. However, setting these experiments involves high costs of materials and equipment downtime.

It is also impossible to set the experiment under production conditions when developing new technological treatment processes.

Therefore, the issues raised were previously experimentally examined under laboratory conditions using samples (models) in a wide range of changes in various factors. The data obtained in the laboratory on the model were recalculated to specific parts (natural).

Such a technique of experimental investigation was applied both in determining efforts, stresses, and changes in shape, and when studying the effect of deformation conditions on the change in properties and structure of a metal, which ensure its hardened state. The latter is particularly important in the development of technological processes for the restoration of parts.

In order for the patterns and quantitative data obtained in the laboratory to apply to specific parts, the law of similarity (the Kirpichev-Kick law) was maintained. According to this law, deformed bodies (model samples and parts) must be geometrically similar and physically identical.

Geometric similarity was enabled by the equality of ratios of similar linear sizes, that is:

$$\frac{l_\partial}{l_M}=\frac{R_\partial}{R_M}=\frac{r_\partial}{r_M}=n, \qquad (1)$$

where $n$ is the scale of modeling; $\partial$ and $M$ are the part' and model's indices, respectively.

In order to provide for geometric similarity, we maintained during deformation, the equality of the degree of deformation of the model and the part, that is $\varepsilon_M=\varepsilon_\partial$. The tool for deforming the model and the part was geometrically similar.

To provide for the similar friction conditions, we, in addition to the same material, the quality of its surface, and a lubricant, maintained respective indicators of the speed of metal sliding along the tool. This was ensured by the same speed of deformation of the model and the part:

$$\upsilon_M=\upsilon_\partial. \qquad (2)$$

In order to provide for the same conditions of hardening at equal degrees of deformation, the speed and duration of the deformation were adjusted:

$$\omega_M=\omega_\partial; \;\; t_M=t_\partial. \qquad (3)$$

We maintained the requirement for the same physical properties of the model and the part in a multifactorial study, including the effect of deformation conditions on properties.

The data obtained during the experiments were processed using a V. V. Smirnov criterion [13].

At the sample size $n<50$, the average indicator value was determined from:

$$\bar{t} = \frac{\sum_{i=1}^{n} t_i}{n}, \tag{4}$$

where $t_i$ is the parameter value.

The average quadratic deviation at $n<50$ was determined from:

$$S = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(t_i - \bar{t}\right)^2}. \tag{5}$$

The error of experiments was determined from:

$$\delta = \sqrt{\frac{t_\alpha S}{\bar{t}}}, \tag{6}$$

where $t_\alpha$ is the Student criterion.

## 5. Results from studying the hardening of a material of piston fingers and bushings of top heads of connecting rods

### 5. 1. Determining optimal geometric parameters for a working tool

We have experimentally established the rational shape and optimal parameters for the machining tool-punch. It was revealed that cone-shaped punches under normal deformation conditions changed after 5–7 working runs the shape of the working surface due to sticking the metal from the machined parts. Thus, the thickness of sticking at 20 working runs at standard deformation by cone-shaped punches was 0.014 mm, and by ball-shaped ones – 0.038 mm. At vibration deformation – 0.005 mm and 0.032 mm, respectively.

The amount of the sticking metal at the surface of the punch after the restoration of 30 parts was:

a) at standard deformation by a ball-shaped punch – 0.48 g, by a cone-shaped punch – 0.15 g;

b) under conditions of vibration deformation, these magnitudes are equal to 0.28 g and 0.08 g, respectively.

It was experimentally established that the cone shape of a punch provides for a reduction of metal sticking at the surface by 3.2 times at standard deformation and by 3.5 times at vibration deformation.

The sticking of a metal on the surface of a punch has a negative impact on the process of deformation: the quality of the machined surface is reduced; the deformation non-uniformity is increasing, both in the radial direction and lengthwise the sample; the machining force increases.

Our laboratory study has established that the above-specified magnitudes are directly dependent on the angle of inclination α of the punch.

The study has shown that an increase in the angle of inclination of a punch increases the amount of sticking metal on its surface under conditions of conventional and vibration deformation. Thus, at machining allowance Π=0.5 mm and the punch angle of inclination α=12° at standard deformation of samples made from steel 45 the amount of the sticking metal was 0.020 g, and for samples made from hardened steel 45 – 0.014 g. At vibration deformation of the samples, the magnitude of the sticking metal was 0.005 g and 0.001 g, respectively.

It was experimentally established that the minimum sticking of a metal occurs at the punch angle of inclination α=10°30′, both under conditions of conventional and vibration deformation of samples with an outer diameter of 25–40 mm.

A decrease in the punch angle of inclination increases its surface of contact with a deformed sample, which in turn leads to an increase in the sticking of the metal. As the angle increases, the contact surface decreases. This causes an increase in specific pressure, which leads to the greater sticking of a metal at the surface of a punch. At angle of inclination 10°30°, there is probably an optimal ratio between the contact surface and the magnitude of specific pressure [12].

Our study has found that the amount of a sticking metal depends on the material of restored parts. The higher the hardness and the larger a material's elasticity module, the smaller the amount of metal sticking to the surface of the working tool-punch.

To determine the impact of height of the calibrating part of a working tool on the quality of the machined surface of parts, the punches were made in the following sizes: the height of a calibration belt was 2, 3, 4, 5, 6, 7, 8 mm. The punch angle of inclination was α=10°30′.

The study involved samples of 80 mm long made from hardened steel 45 with a machining allowance of 0.6 mm under conditions of conventional and vibration deformation.

Our study has found that the lowest value of roughness at standard $R_Z$=13.2 μm and vibration $R_Z$=6.3 μm deformation is characteristic of the height of the calibrating part of a punch of 6–7 mm.

### 5. 2. Effect of machining mode on the amount of deformation and the character of distribution of residual stresses

For practical purposes, it is advisable to have a dependence that links the level of the required residual deformation to the amount of machining allowance $Z$ [12].

Based on laboratory data, we have derived an empirical dependence of allowance $Z$ on residual deformation $\Delta D$, which resembles a parabola of the following form:

$$Z = a\left(\Delta D\right)^b, \tag{7}$$

where $a$ and $b$ are the unknown coefficients.

In logarithmic form, this equation, if one assumes $\lg Z = y$, and $\lg \Delta D = x$, can be represented in the form of a straight line:

$$y = \lg a + bx. \tag{8}$$

To determine the unknown quantities $a$ and $b$, we applied a least square method, whereby it is necessary that the sum:

$$S = \sum_{i=0}^{n}\left(y - \lg a - bx\right)^2$$

should have the least value in comparison with other functions, from which the desired approximated one is selected.

Values for coefficients $a$ and $b$ were derived from solving a system of equations:

$$\frac{\partial S}{\partial a} = 0; \ \frac{\partial S}{\partial b} = 0. \tag{9}$$

Values for particular derivatives from expression $S$ were determined from equations:

$$\frac{\partial S}{\partial a}=\sum_{i=0}^{n}2\left(y-\lg a-bx\right)\left(-\frac{0.4343}{a}\right)=0; \quad (10)$$

$$\frac{\partial S}{\partial b}=\sum_{i=0}^{n}2\left(y-\lg a-bx\right)\left(-x\right)=0. \quad (11)$$

After multiplying and reducing by constant magnitudes, we obtain:

$$\sum_{i=0}^{n}\left(y-\lg a-bx\right)=0; \quad (12)$$

$$\sum_{i=0}^{n}\left(x\cdot\lg a-xy+bx^{2}\right)=0. \quad (13)$$

After replacing $y=\lg Z$ and $x=\lg\Delta D$, we obtain a system of equations:

$$\sum_{i=0}^{n}\lg Z-n\lg a-b\sum_{i=0}^{n}\lg\Delta D=0. \quad (14)$$

$$\lg a\sum_{i=0}^{n}\lg\Delta D-\sum_{i=0}^{n}\lg\Delta D\cdot\lg Z+b\sum_{i=0}^{n}\left(\lg\Delta D\right)^{2}=0. \quad (15)$$

Values for $a$ and $b$ were found from solving a system of the derived equations based on the data obtained experimentally (Table 1).

Substituting the derived values in equations (14) and (15), we obtain:

$$-4.3566-10\lg a+10.4299b=0; \quad (16)$$

$$-10.4299\lg a-5.04886+11.9036b=0. \quad (17)$$

By solving equations (17) and (18), we obtain:

$\lg a=-0.1422;\ \ a=0.72;\ \ b=0.554.$

Thus, the parabola equation takes the following form:

$$Z=0.72\Delta D^{0.554}. \quad (18)$$

Experimental data have shown that at the wear of piston fingers from 0.02 to 0.06 mm, the required residual deformation along the outer diameter can be achieved by a single-run machining at allowances of 0.18 and 0.27 mm.

Table 1

Parameter values for finding magnitudes *a* and *b*

| $\Delta D$ | $Z$ | $\lg\Delta D$ | $\lg Z$ | $\lg\Delta D\cdot\lg Z$ | $(\lg\Delta D)^2$ |
|---|---|---|---|---|---|
| 0.02 | 0.161 | –1.6990 | –0.7932 | 1.347647 | 2.886601 |
| 0.04 | 0.233 | –1.3979 | –0.6326 | 0.884311 | 1.954124 |
| 0.06 | 0.290 | –1.2218 | –0.5376 | 0.656840 | 1.492795 |
| 0.08 | 0.348 | –1.0969 | –0.4584 | 0.502819 | 1.203189 |
| 0.10 | 0.372 | –1.000 | –0.4295 | 0.429500 | 1.000000 |
| 0.12 | 0.425 | –0.9208 | –0.3716 | 0.342169 | 0.847872 |
| 0.14 | 0.466 | –0.8539 | –0.3316 | 0.283153 | 0.729145 |
| 0.16 | 0.498 | –0.7959 | –0.3028 | 0.240998 | 0.633456 |
| 0.18 | 0.535 | –0.7447 | –0.2716 | 0.202280 | 0.554578 |
| 0.20 | 0.592 | –0.6990 | –0.2277 | 0.159162 | 0.488601 |
| | | $\Sigma\lg\Delta D=-10.4299$ | $\Sigma\lg Z=-4.3566$ | $\Sigma\lg\Delta D\cdot\lg Z=5.04886$ | $\Sigma(\lg\Delta D)^2=11.79036$ |

Values for tangential $\Sigma_t$, axial $\Sigma_l$ and radial $\Sigma_r$ stresses, calculated from dependences (1) to (3), are given in Table 2.

Table 2

Values for residual stresses

| Number of recess | Inner diameter of the sample after each recess, mm | Stress, MPa | | |
|---|---|---|---|---|
| | | $\Sigma_t$ | $\Sigma_l$ | $\Sigma_r$ |
| 0 | 16.00 | –201.1 | 0 | 0 |
| 1 | 16.70 | –12.0 | 71.5 | –5.4 |
| 2 | 17.35 | +88.2 | 138.0 | –2.1 |
| 3 | 18.05 | +175.1 | 173.5 | +5.6 |
| 4 | 18.65 | +244.6 | 209.4 | +10.8 |
| 5 | 19.30 | +144.1 | 172.5 | +15.2 |

It has been established that the magnitude and character of axial residual stresses before and after deformation differ slightly from each other.

Radial residual stresses before and after the deformation of piston fingers are at the level of 10–25 MPa.

It is shown that a change in the depth of the tempered layer from 0.5 to 1.2 mm does not have a significant impact on the character and magnitude of residual stresses after deformation.

This can be explained by the fact that with an increase in the depth of the tempered layer the stretching residual stresses at the outer surface of piston fingers, caused by a heterogeneous deformation in the recovery process, slightly increase. However, at the same time there is an increase in the magnitude of compressive residual stresses caused by surface hardening in the manufacture of piston fingers.

Given this, the amount of total residual stresses is almost constant and does not depend on the depth of the tempered layer.

At vibration deformation with allowances exceeding 0.3 mm, due to a significant plastic deformation of the core of a part, at its outer surface there are the residual deformations exceeding 120–150 MPa.

The emergence of large stretching residual stresses at the outer surface of a piston finger helps reduce its strength. When restoring piston fingers, one should choose a machining allowance depending on the amount of their wear.

It was experimentally established that vibration deformation should be performed over a single run at allowances $Z=0.15$–$0.25$ mm, in order to reduce the stretching residual stresses.

**5. 3. Studying the static strength of piston fingers**

We studied static strength of the specified parts during their testing for crushing at a 30-ton machine (Fig. 1).

The magnitude of static strength was assessed from the value of the effort that led to destruction.

Our study has found that the magnitude of a machining allowance and the number of runs at expansion, as well as the depth of a tempered layer of 0.5–0.8 mm, do not have a significant impact on the amount of static strength.

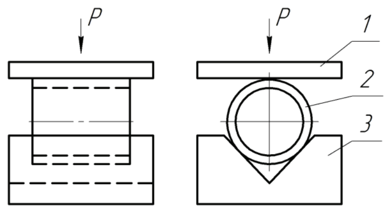


Fig. 1. Schematic of testing piston fingers for strength:
1 — loading plate; 2 — piston finger; 3 — prism

It was experimentally established that the magnitude of average load at which the piston fingers, restored by conventional deformation, as well as new ones, were destroyed, was 82 and 92 kN. The average value of a destructive load for the fingers restored by vibration deformation was 101 kN.

**5. 4. Assessment of durability of piston fingers and bushings of top heads of connecting rods**

Experimental study into the durability of a material of parts restored by different methods was conducted at a bench (MI-1M friction machine).

The bench tests have made it possible to evaluate variants for restoring parts over a relatively short time, as well as to determine the most effective method.

The results of our study (Table 3) show that the amount of wear depends on the following basic factors: the method of machining a parts' material and the time of operation.

Table 3

Data on weight wear of the roller and pad, g

| Pair number | Standard deformation | | Vibration deformation | | Samples of new parts | |
|---|---|---|---|---|---|---|
| | Pad wear | Roller wear | Pad wear | Roller wear | Pad wear | Roller wear |
| 1 | 0.2611 | 0.1702 | 0.2122 | 0.1512 | 0.1986 | 0.1498 |
| 2 | 0.2554 | 0.1664 | 0.2088 | 0.1480 | 0.2022 | 0.1506 |
| 3 | 0.2496 | 0.1694 | 0.2005 | 0.1522 | 0.2009 | 0.1449 |
| 4 | 0.2560 | 0.1750 | 0.1994 | 0.1500 | 0.2019 | 0.1324 |
| 5 | 0.2486 | 0.1722 | 0.1880 | 0.1497 | 0.1994 | 0.1536 |
| $\Delta G_{cp.}$ | 0.2541 | 0.1706 | 0.2018 | 0.1502 | 0.2005 | 0.1461 |

The study has found that the average wear of rollers was: after standard deformation – 0.1706 g, after vibration deformation – 0.1502 g, of those made from new parts – 0.1461 g. The average wear of pads was 0.2541 g, 0.2018 g; 0.2005 g, respectively.

The wear of a pad at vibration deformation is 1.25 times, that of a roller is 1.13 times, less compared to standard expansion.

The data obtained in our study show a decrease in the amount of wear at the vibration deformation of samples through the hardening of the machined surface.

Errors in the performed study are in the range of 2.85–8.92 % with a confidence probability of 0.95.

## 6. Discussion of results of improving the durability of piston fingers and bushings of top heads of connecting rods using vibration deformation

The increased durability of the specified parts, by 1.13 times, when they are machined by surface plastic deformation occurs due to the emergence of compressive residual stresses in surface layers. This phenomenon leads to the greater hardening of a material of the machined parts.

It should also be noted that the treatment by surface plastic deformation using the vibration oscillations of the machining tool provides for an improvement in the physical-mechanical properties of the machined surface. This is due to the cyclical effect of vibrations on the machined part through a working tool.

Thus, the use of oscillations in the restoration of piston fingers and bushings of top heads of connecting rods could improve the technological process.

Increasing the durability of working surfaces of machined parts solves the task on improving the reliability of work of the assembly unit that contains the parts.

The disadvantage of using vibrations at plastic deformation is the additional use of electrical energy to power the vibrator. However, this shortcoming is offset by an increase in the lifespan of the machined parts.

Further advancements in this field could be aimed at studying the behavior of working surfaces that are machined by vibrations and work in pairs.

## 7. Conclusions

1. We have determined the optimal parameters for a working tool-punch: the angle of inclination $\alpha=10°30'$; the calibration belt height is 6–7 mm.

2. The effect of a machining regime on the magnitude of deformation and the character of distribution of residual stresses has been revealed. The optimal machining parameters are: the amplitude of oscillations $A=1.25$ mm; the rate of deformation $\nu=0.03$ m/s; the frequency of punch oscillations is 1,900 $\text{min}^{-1}$.

3. The strength of the piston fingers, restored by the method of vibration deformation, complies with the technical conditions for their restoration. The average value of destructive load on the piston fingers, restored by vibration and conventional deformation, as well as new ones, was 101; 85; and 95 kN, respectively. The amount of wear of the piston fingers, restored by a vibration method, is 1.13 times less than that of those restored by a conventional expansion.

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