The study of the quality of the surface layer of the pump plunger

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Abstract. The paper presents data on the parameters that determine the quality of the surface layer of the pump plunger, such as roughness and hardness. The results of the study of the quality of the surface layer of the pump plunger, after turning with a blade tool and after ultrasonic hardening and finishing processing, are presented. Analysis of the obtained results of the state of the surface layer shows a significant decrease in roughness and an increase in the surface hardness of the plunger as a result of ultrasonic hardening and finishing processing, which contributes to an increase in the service life of the part.

1. Introduction
In the manufacture and during the operation of machine parts their mating surfaces wear out and the surface layer of the metal changes its structure, physical and mechanical properties; unwanted residual stresses arise.

In the process of work, the surface layer of the parts experiences the strongest loads: thermal, magnetic, mechanical, electrical, chemical, etc. Therefore, higher demands are placed on the state of the surface layer than on the basis of the part.

Processing the surface with plastic deformation (Surface Plastic Deformation Processing – further on – SPDP) is one of the most simple and effective ways to obtain the surface details of small roughness with the hardening of the surface layer [1,2].

The imposition of ultrasonic vibrations on the smoother contributes to reducing the resistance to plastic deformation, which leads to a significant reduction in static deformation efforts and helps to obtain a lower roughness, greater magnitude and depth of the hardening. These features of the process led to the emergence of a new direction in surface plastic deformation – ultrasonic hardening and finishing treatment deformation (Ultrasonic Hardening Finishing Treatment Deformation – further on -USHFTD) [3,5].
Figure 1. An image of the surface layers of the part by zones: 1 – zone of molecules and atom absorbed from the environment; 2 – zone of chemical interaction of metal with the environment; 3 – boundary zone with a thickness of several interatomic distances; 4 – zone with modified parameters compared with the base metal; 5 – zone with the structure, phase and chemical composition.

The properties of the surface layer may vary depending on the type of material, processing methods, operating conditions, etc. Monitoring the condition of the parts is carried out by various methods: chemical, physical and mechanical. Often, the state of the surface layer is assessed by a set of single or complex properties that characterize the quality of the surface layer [2,4]. The surface roughness is a set of irregularities forming the microrelief of the surface of the part.

A regular microrelief is obtained by cutting or surface plastic deformation with rollers, balls, diamonds.

2. Investigation of the quality of the surface layer of the plunger

The study was conducted using the part of the plunger made of steel 12X18H9T with a diameter 28 mm, length $L = 250$ mm.

The part was made on a lathe of normal accuracy with a turning blade tool and ultrasonic hardening and finishing processing.

Figure 2. Pump plunger.

The roughness was estimated using the Ra criterion. The roughness parameters of the treated surface were measured in the longitudinal direction using a profiler-profilometer, model 252, SI error, $\mu m \sim 5\%$. At present, profiler-profilometers are used to convert an analog signal to a digital one with subsequent processing according to the program set. The measurement method is a contact one with serial conversion of a profile into a digital signal and its further processing. Presentation of the measurement results in the table on the monitor screen and as a printout on the printer. To calculate the height of asperities, we recommend the formula:

$$R_z = R - \sqrt{R^2 - \frac{S^2}{4}}$$  \hspace{1cm} (1)
Figure 3. Plunger surface roughness profilogram: (a) roughness after cutting - Ra 3.2 (b) roughness after USHFTD - Ra 0.05

Roughness measurement results:
1. After cutting-turning (before USHFTD), the roughness was - Ra 3.2, (Figure 3a).
2. After (USHFTD), the roughness was - Ra 0.05, (Figure 3b).

3. Evaluation of the surface microhardness was carried out on a PMT-3 microhardometer
Measurement of microhardness is performed by determining the size of the imprint area of the indenter being introduced at a given and constant load.
As an indenter, when measuring microhardness, the Vickers diamond pyramid is most often used – a regular tetragonal diamond pyramid with an apex angle of 136 ° (Figure 4).
Figure 4. Scheme for determining Vickers hardness.

The value of the measured hardness does not depend on the applied load, which allows the use of the Vickers method for low loads on the indenter, i.e. when measuring the microhardness of materials. When indented into the surface, the diamond pyramid forms a pyramidal imprint image in the material. The projection of this print is a square (Fig. 1). The number of microhardness according to Vickers scheme is determined by the ratio of the magnitude of the load $P$ to the side surface area of the imprint $S$:

$$HV = \frac{P}{S}, \quad \text{kgf/mm}^2. \quad (2)$$

The surface area of the print can be calculated by the formula:

$$S = \frac{4ah}{2}, \quad (3)$$

where $h$ is the depth of the print, and $a$ is the length of the side of the square of the print.

Figure 5. Graph increase in hardness from the core to the surface.
The relationship between the side of the square and the depth of the imprint is determined from the geometric relationships for the correct pyramid:

\[ h = \frac{a}{2 \sin \frac{136^\circ}{2}} = \frac{a}{2 \cos 22^\circ} = \frac{a}{1,8544}. \]  

(4)

Table 1. The results of measuring the hardness of Hμ200 on the oblique microgrinder on the cylindrical surface of the part (sharpening length on slanting cut is 28 mm. Sharpening depth is 1.0 mm)

| Distance from the surface on grinding, mm | Depth indicated, mm | Hardness, Hμ200 |
|-----------------------------------------|---------------------|-----------------|
| 0.1                                     | 0.004               | 340             |
| 0.25                                    | 0.009               | 330             |
| 0.5                                     | 0.018               | 323             |
| 0.75                                    | 0.024               | 319             |
| 1                                       | 0.029               | 315             |
| 1.25                                    | 0.032               | 312             |
| 1.5                                     | 0.037               | 309             |
| 1.75                                    | 0.045               | 305             |
| 2                                       | 0.056               | 300             |
| 2.5                                     | 0.07                | 296             |
| 3                                       | 0.08                | 293             |
| 3.5                                     | 0.1                 | 288             |
| 4                                       | 0.14                | 280             |
| 5                                       | 0.18                | 275             |
| 6                                       | 0.21                | 272             |
| 7                                       | 0.25                | 269             |
| 8                                       | 0.29                | 267             |
| 9                                       | 0.32                | 266             |
| 10                                      | 0.36                | 264             |
| 11                                      | 0.39                | 263             |
| 12                                      | 0.42                | 262             |
| 13                                      | 0.46                | 261             |
| 14                                      | 0.52                | 260             |
| 16                                      | 0.57                | 260             |
| 18                                      | 0.64                | 260             |
| 20                                      | 0.71                | 260             |

The degree of work hardening (CH) is the degree of increase in the surface hardness after the SPDP, calculated by the formula:

\[ CH = \frac{HV_2 - HV_1}{HV_1} \times 100\% \]  

(5)

where HV_2 is the hardness after the treatment of SPDP; HV_1 - the initial hardness of the processed material.
4. Conclusion
As a result of this work, the surface layer of the pump plunger part was investigated after ultrasonic strengthening-finishing processing; roughness obtained was $\text{Ra} \ 0.05$ compared with the initial ($\text{Ra} \ 3.2$), and surface microhardness was $\text{HV} \ 340$ compared with the initial ($\text{HV} \ 260$). Using only one turn of the indenter, we received excellent characteristics of the surface layer of the plunger.

An important advantage of the USHFTD is the possibility of not only increasing the durability and reliability of machine parts, but also creating energy-saving technologies.

The use of ultrasound energy to produce new processing technologies of the materials is of great scientific and practical interest.

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