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Characterization of microrelief forming on the hardened steel surface with ultrasonic reinforcing burnishing processing

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Abstract. The numerical surface characterization makes it possible to compare two different machining technologies. Ultrasonic is one of the actual additional physical effects imposed during the processing. The article presents a comparison of surface topography after burnishing processing with and without ultrasonic. Workpieces made of hardened steel, ultrasonic frequency 22 kHz. It was discovered that the surface has a plastically deformed ordered structure after processing with ultrasonic vibrations.

1. Introduction
The performance characteristics of engineering products are largely determined by the quality of the surface and the surface layer of formed machine parts at the stages of the technological process of their manufacture [1, 2, 3]. One of the important technological tasks, along with ensuring the accuracy of manufacturing machine parts and the stability of the physical and mechanical properties of the surface layer, is the task of forming a specified surface microgeometry [4, 5]. The finishing combined burnishing technology with application of mechanical vibrations of ultrasonic frequency (UF) to the instrument is effective technological method for quality maintenance of engineering products [6, 7]. The additional energy of ultrasonic leads to intensification of processing and a significant improvement in the quality of the surface layer (SL) in comparison with standard burnishing [8, 9].

2. Experimental technique
Experimental studies were carried out on a lathe with a CNC model 16B16T1S1 equipped with a device for ultrasonic burnishing and ultrasonic generator UZG-0.4/22 with a power of 0.4 kW and a frequency of oscillations of 22 kHz (figure 1). The ultrasonic vibrating system based on a magnetostrictor with a cross section of 20×20 mm matched with an ultrasonic waveguide of conical shape with input and output ends of diameters Ø 26 and 18 mm respectively, was connected to the generator. The burnishing instrument was attached to the output end of the waveguide through an adapter. The tool’s tips were made of natural diamond according to TU 2-037-631-88, version II with a spherical working surface with a radius of 2.5 mm [10]. The placement of the ultrasonic vibrating system is carried out in the device with the possibility of creating a static force of pressing the tool to the part by hydraulic system. Force monitoring was carried out using a manometer installed in the device.
The billets of hardened steel HVG (HRC 60...63) in the form of rings with an outer diameter of Ø56±0.2 mm and a height of 20±0.5 mm were used as samples. During the research, the hardening processing with standard and ultrasonic burnishing were performed on the end surfaces of the samples according to the scheme shown on Figure 1 c. Preliminarily, the ends of the samples were processed by grinding and hard turning. The initial roughness of the surfaces was Ra=0.4...0.6 μm after grinding and 1.6...2 μm after hard turning.

The burnishing was carried out in the following modes: pressure in the hydraulic system of the device - 0.1...0.3 MPa; tool’s feed s=0.1 mm/rev; rotation speed n=400 rpm. During ultrasonic burnishing the oscillation amplitude of the instrument was 9 μm, the frequency was 22 kHz.

The topography of the processed surfaces was studied using the Axiovert 40MAT optical microscope and a LEXT laser scanning microscope. The Mitutoyo Surftest SJ-210 device was used for measuring the roughness and surface profiling.

3. Results and discussion

Fig. 3 presents photographs of sample surfaces obtained with the Axiovert 40MAT optical microscope at a 400X magnification and corresponding profilograms of surfaces. There is an obvious qualitative difference in the formation of microgeometry of the treated surfaces: the presence of grinding scratches on the surface of the sample after grinding (figure 2 a); rectilinear tracks formed during standard burnishing (Figure 2 b, d) and a structured surface due to the vibrational action of the instrument during ultrasonic treatment (Figure 2 c, d).

The microprofile of the polished surface has chaotically alternating pointed protrusions and cavities, typical for abrasive processing methods [11, 12]. The profilogram of the polished surface contains low-frequency and high-frequency components of the microrelief. The highest values of microroughness form the low-frequency component of the relief. This can be explained by the action of the dressing process of the grinding wheel, when the ruling diamond forms on its working surface the elements of the threaded profile which "copied" during grinding the treated surface. The high-frequency component depends on the characteristics of the grinding wheel and grinding mode [13, 14].

The standard burnishing with less processing force (pressure is 0.1 MPa) contributes to the partial burnishing of the grinding scratches (figure 2 b), while the profile protrusions have a more rounded smoothed shape, which is typical for the finishing-hardening methods [15]. More substantial smoothing
of the grinding scratches is observed at a pressure of 0.3 MPa (Figure 2d). Also, there are alternating traces on the surface in the direction of feed which are the trace of the spherical shape of the tool.

Samples after ultrasonic burnishing with the corresponding values of the treatment force have a fundamentally different structure of the profile (Figure 2c, d). In this case, the burnishing tool makes additional oscillations with an ultrasonic frequency, which intensifies the process of plastic deformation and leads to corresponding distinctive changes in the formation of the surface micro-profile. Thus, grinding risks and marks from the burnishing tool are completely absent on the surface treated with a tool pressure of 0.1 MPa (figure 2).

![Figures a to e showing profilograms and photographs of the samples' surfaces after grinding (a), standard burnishing (SB) and ultrasonic burnishing (UB): b) SB with a force of 0.1 MPa; c) UB with a force of 0.1 MPa; d) SB with a force of 0.3 MPa; e) UB with a force of 0.3 MPa.](image)

Figure 2. Profilograms and photographs of the samples’ surfaces after grinding (a), standard burnishing (SB) and ultrasonic burnishing (UB): b) SB with a force of 0.1 MPa; c) UB with a force of 0.1 MPa; d) SB with a force of 0.3 MPa; e) UB with a force of 0.3 MPa.

Obviously, with a small processing force, the tool penetrates into the surface at a small depth, deforming the protrusions of the original roughness, and complete smoothing of the original surface profile is provided due to the high-frequency vibration of the tool. However, the tool marks appear alternately on the surface, alternating in the direction of feed at a higher pressure (0.3 MPa). At the same time, chaotic grinding risks are absent, and the topography of the surface is characterized by a relatively ordered highly deformed structure. Apparently, this is due to the fact that at high values of the treatment force the tool penetrates into the surface practically to the full depth of the initial profile, redistributing
the material volumes from the profile tops to the cavities [16, 17]. Vibrational action of the instrument with a determined amplitude of oscillations causes further multiple plastic deformation of the surface.

4. Conclusion
The topography of the sample surface after ultrasonic processing is characterized by the presence of an ordered plastically deformed structure.

The estimation of topography was carried out in two directions:
1. There is a deformed structure of the surface profile in the direction of the velocity vector (the direction of rotation of the workpiece) subjected to repeated impact from the tool;
2. There are highly deformed material rollers in the direction of the tool’s feed, which is displaced to the side due to multi-cycle deformation and tool movement.

Multiple vibrational action of the tool with a determined amplitude causes multiple plastic deformation of the surface. Also, traces of the tool appear along with increase in the static pressure on the surface. With a rational choice of treatment modes that take into account the features of the formation of topography in ultrasonic treatment, burnishing processing allows to obtain a given roughness with less static force and, consequently, less tool wear.

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