Technological Restrictions on Mode Parameters of Ultrasonic Plastic Deforming

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Abstract. The paper considers technological restrictions that appear under real conditions of machining during ultrasonic plastic deforming. Possible defects of machining which are formed at the regimes, not suitable for the conditions described, are presented. The reasons for their appearance because of the possibilities of the technological equipment are found out. The ways of preventing the appearance of defects in developing the finishing and hardening operations as well as in preliminary machining of surfaces are suggested.

Introduction

Nowadays the interest in the technology of ultrasonic plastic deforming as an effective way of modifying the surface layer of machine parts is growing. The advantages of ultrasonic plastic deforming in comparison with the competing methods of finish machining are shown in papers [1-7]. The authors present different schemes of using ultra sound in the hardening and finishing machining. The main characteristics of quality provided at the finish stage of parts machining are the depth and degree of hardening the surface layer material, the value, sign and character of distributing residual stress as well as surface micro-geometry. Besides, ultrasonic plastic deforming of metals and alloys of low hardness under certain conditions can be accompanied by forming roughness on the surface that can be classified as waviness according to the ISO 4287:1997 standard.

The main mode parameters of ultrasonic plastic deforming are the amplitude and frequency of oscillations of the ultrasonic tool, geometrical dimensions of its working part, i.e. the deforming element, the static pressure force of the tool applied to the machined surface. Such parameters of ultrasonic plastic deforming define the deformation conditions in the machined zone but the rotating speed and feeding - kinematic parameters of the process. A certain combination of deformation and kinematic parameters of ultrasonic plastic deforming provides the hardening and finishing effects during machining.

The regularities that allow us to predict the state of the surface layer after ultrasonic plastic deforming and suggest the optimal modes to provide the required quality of machining are described in papers [8-12]. However, these regularities do not allow us to determine the restrictions existing in practice for setting the mode parameters of ultrasonic deforming which can appear in reality. So, the paper is devoted to theoretical reasons and experimental confirmation of actions to determine the technological restrictions in setting the mode parameters of ultrasonic plastic deforming.
Results and Discussion

Frequency of ultrasonic oscillations. In conducting the experiments it was found out that even a slight change (up to 5%) in the frequency of ultrasonic oscillations induced by the generator leads to the change in forming the waviness. Fig. 1 shows changes in the geometrical parameters of waves under ultrasonic plastic deforming caused by changing the frequency of ultrasonic oscillations as a result of self-adjustment of the generator for the resonance frequency at the initial stage of its operation. Paper [9] presents the mathematical model of forming the waves of the plastic deformation after ultrasonic plastic deforming. According to the model the inclination angle of waves depends on the combination of the ultrasonic oscillation frequency, the number of spindle revolutions and the number of strokes which form a single wave crest. Instability of the frequency characteristic of ultrasonic oscillations under other consistent modes defines the topography of the formed waviness.

Amplitude of ultrasonic oscillations. The parameter under consideration is one of the components in controlling the deformation process during machining. The depth and the degree of the material deformation in the surface layer as well as the change in the dimension of a single imprint of the deforming element on the machined surface can be regulated by changing the amplitude. However, the excessive intensification of the deformation process can cause the destruction of the deforming element. Paper [9] presents the results of the investigations dealing with the influence of the ultrasonic tool shape on the coefficient of intensifying the amplitude. Thus, the use of the cone tool made from the titanium alloy resulted in increasing the amplitude in the deformer zone up to 100 micrometers. At such a value of the amplitude and even at a minimal value of the static force ultrasonic machining caused the destruction of the deforming element made of synthetic diamond. Such a fact confirms the existence of restrictions on the maximum value of the oscillation amplitude of the ultrasonic tool. So, in reality the values of the amplitude used during ultrasonic plastic deformation are limited by the range of 5-30 micrometers.

Static force. The static force of the deforming element applied to the machined surface is also a mode parameter that defines the deformation processes during machining. The minimum value of static force is determined by the design features of the technological equipment that provides the stability of the
force closure of the ultrasonic tool and the machined part under the elastic contact. The presence of certain friction losses in the connection joints of the equipment at an insufficient value of the static force can lead to the irregularity of the force closure. As a result, there appear zones on the machined surface that are not subject to the deformation impact (Fig. 2).

Fig. 2. Zone of the non-machined surface after ultrasonic static deforming as a result of insufficient static force

The maximum value of static force is limited by the necessity of obeying certain conditions to accomplish a discrete impact of the ultrasonic tool on the machined surface. The quantitative estimation of such a restriction is described in detail in investigating the deformation model of ultrasonic plastic deforming in paper [8]. The discrete impact with changing periods of intensive plastic deformation and pauses for the relaxation of stresses in the material creates favorable conditions to implement the hardening effect in machining. At the same time due to the fractional impact of the deforming element on the machined surface, a regular micro-relief is formed on it as single plastic imprints located on the surface with a coefficient of overlapping 0<k<1. Under real conditions the values of static force used varies from 50 N to 300 N during ultrasonic plastic deforming of metals and alloys. The specified value of the parameter is chosen depending on the properties of the machined material and the required characteristics of the hardening and finishing effects during machining.

**Initial roughness of the machined surface.** The role of ultrasonic plastic deforming in creating the finishing effect is in providing a new, fully regular micro-relief on the machined surface without traces of the previous machining. Because of this fact, there are certain restrictions in the value of the initial roughness before ultrasonic plastic deforming. Otherwise, a part of traces of the preceding machining will remain on the formed micro-geometry. Fig. 3 shows a scanned three-dimensional image of the surface after ultrasonic plastic deforming. The traces of the preceding lathe machining are seen on the surface as grooves from the cutting tool located at a distance of feeding (S) used during lathe turning. To form a fully new and regular micro-relief without traces of the preceding machining, the height of the initial roughness must not exceed a certain value. Experiments showed that during machining of unhardened steel by ultrasonic plastic deforming, it was possible to form a new micro-geometry when $R_{max}<2$ micrometers. This statement corresponds to the conditions when the oscillation frequency is 22
kH... kHz, the amplitude is 25 micrometers, the static force is 250 N, the speed of the part rotation is 110 m/min., the feeding is 0.1 mm per rotation, the diameter of the deforming element is 8 mm.

Fig. 3 Formation of the surface micro-geometry after ultrasonic plastic deforming with traces of the previous machining

Conclusion.
As a result of the investigations conducted, the recommendations concerning the mode parameters of ultrasonic plastic deforming were formulated by taking into consideration the restrictions described.

The restriction on the amplitude of ultrasonic oscillations by a value of 30 micrometers was suggested to exclude the destruction of the deforming element made of synthetic diamond.

When setting a minimum value of the static force, it is necessary to take into account the friction losses in the machining attachment that provides the force closure of the tool and the machined surface according to the elastic contact. The maximum value of the static force is determined by the necessity of preserving the discrete loading because of the pauses of intensive deforming and unloading.

The stability of the frequency characteristic of the ultrasonic process is provided by enduring the ultrasonic generator after its turning on during ten minutes, which allows us to exclude the instability of the geometrical parameters of plastic flow waves.

The necessity of forming a new, fully regular micro-geometry of the surface after ultrasonic plastic deforming limits the maximum value of the initial roughness of the surface.

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