On-line diagnostics of the physical and mechanical properties of the surface at the production stage

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Abstract. The article deals with the issues of increasing the efficiency of the formation of the performance of the surface layer of machine parts. The results of computer modeling of thermophysical processes in the cutting zone are presented. The possibility of controlling the process of formation of the surface layer structure on the basis of the measurement of the thermal EMF, which make up the cutting forces, as well as the vibro-acoustic signal is considered.

The state of the surface layer substantially affects the performance characteristics of a workpiece, which is illustrated by a large number of researches and can be explained by the change in the incubation time of developing and propagating rate of a fatigue crack in the surface layer. Though the parameters (surface roughness, hardening and residual strains) act on the surface layer together, each of them has its own independent effect on the change in fatigue characteristics. Therefore, in order to create highly efficient technologies and technological processes that ensure a considerable increase in the performance characteristics of the workpiece surfaces, it is necessary to know the regularities of the integrated and separate types of the influence of the surface layer parameters and form the optimal level of each of the basic parameters of the surface layer during production work [1].

A large number of scientists, including Dalsky A.M., Bazrov B.M., Vasiliev A.S., Drachev O.I., Blumenshtein V.Yu., Yashchericyn P.I. etc. studied the formation of quality characteristics of the surface layer in the process of mechanical processing and the problem of technological heredity. A considerable amount of knowledge has been accumulated in this field. However, there has been no effective instrument for introducing of the required surface quality parameters applicable in production conditions and monitoring of their formation so far.

It should be noted that the machining of a workpiece is not a one-stage process, but may involve various technological operations and passes. The complexity and multifactority of the machining processes and considerable variation in characteristics of the tool material and material being processed are also necessary to be taken into account. All these substantially reduce the reliability and effectiveness of technological preparation, as well as

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the consistency of processing results. So, the challenge to develop a theory of technological evolution of the surface layer characteristics becomes more complicated [2].

In conditions of actual production, the assignment and maintenance of optimal processing rates are difficult to perform and lead to a deviation from the specified performance characteristics of the workpiece surfaces, which means that the productivity and processing efficiency decrease.

Thus, the problem lies in the influence of the surface layer state on the quality of the cutting process not to be taken into account in creating highly efficient technologies and technological processes that provide a considerable increase in the performance characteristics of the workpiece surfaces.

The purpose of the research is to study the influence of the surface layer characteristics of a workpiece on the processing regularities and machining results.

To achieve this goal one need

- to consider the physics of the processes and formation regularities of quality parameters of the surface machined; and

- identify the surface layer parameters that affect the formation of the quality of the surface machined.

From the point of view of classical concepts, the cutting process consists in the interaction of two mutually counteractive processes, i.e., strain hardening and thermal softening. Under the action of the cutting tool, the volume of the workpiece material undergoes plastic hardening to the values of the limit strain providing a shear of the layer to be removed. Hardening of the cutter-contacting layers of the processed material is accompanied by the release of heat that is distributed into the workpiece itself, chips, cutting tools and the environment. The heat release intensity that depends on a whole set of the parameters, including the characteristics of the material being processed, tool, etc. has a considerable effect on the nature of the cutting process, its consistency, tool wear, quality of the surface machined, etc. [3].

To determine the influence of the characteristics of the workpiece surface layer on the process regularities and processing results, there has been performed research studies on lathe turning the workpiece from stainless steel 12X18H10T (steel 321), with the initial surface of the workpiece to be subjected to plastic deformation (rolling) with various forces.

Measurements of the thermal conductivity of the workpiece surface layer on the KITS-02TS device made it possible to establish that such an influence led to a change in the thermal conductivity of the layers deformed. So, one can talk about a different redistribution of temperature fields in the cutting process in comparison with the initial conditions.

Table 1. Results of X-ray diffraction analysis of the surface layer samples of austenitic steel grade 12X18H10Tsubjected to plastic deformation.

Sample	Intrinsic broadening of the x-ray lines β 10-3, rad		Size of mosaic D block, A	Relative lattice deformation $<\varepsilon>$ 10-3	Microstrain level $\sigma 2$, MPa
I (section)	4.9	12.3	400	0.0028	560
II (section)	5.26	13.9	358	0.0031	620
III (section)	9.9	15.4	248	0.0035	694

In addition, the X-ray diffraction studies have made it possible to establish changes in the structure of the substance, texture and magnitude of internal strains (Table 1).

In [2 and 3], it was found, that the deformation and thermal fields were localized by the hardened surface layer, and the cutting forces and heat release intensity were reduced. All this contributed to the consistency, facilitating the cutting process, reducing the cutting tool

wear and improving the microgeometry of the surface machined. The hypothesis was confirmed by the experimental data. The processing of all sections was carried out at constant cutting conditions. It was noticeable that the greatest depth of deformation provided the best Ra-values (Table 2).

Table 2. Influence of the surface layer deformation on the height of the microroughness Ra of the surface machined when turning the steel of austenitic class 12X18H10T (steel 321).

Feed (mm/rev)	V=120 m/min		
	I (section): initial layer	II (section): deformation depth of 0.51 mm	III (section): deformation depth of 0.92 mm
0.256	Arithmetic average of the roughness profile (Ra, μm)		
	0.653	0.336	0.298

The conclusions were confirmed by the results of the computer simulation. To study the work of the cutting process and determine the optimal rates, a solid model (Fig. 1) in the SolidWorks CAD imported into the finite element modeling system DEFORM-3D was created. When creating the model, the following parameters were set:
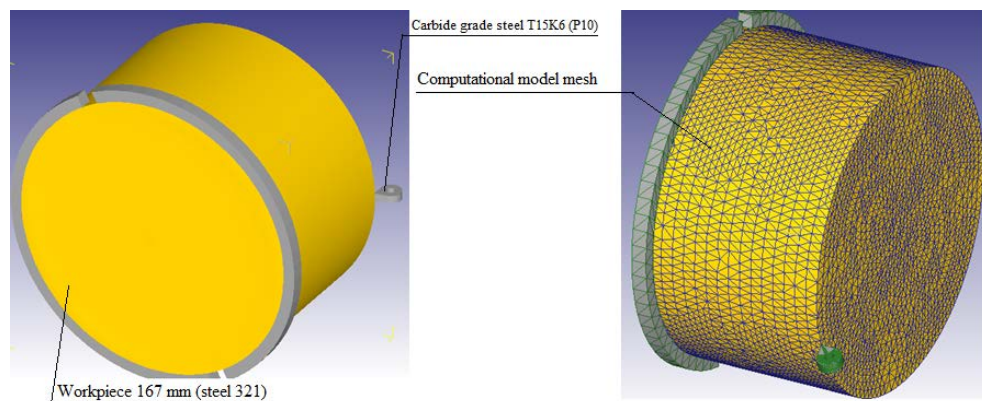

Fig. 1. Creation of a solid computer model for studying thermophysical processes in the cutting zone Set-up parameters: *V = 2 m/s; S = 0.256 mm/rev;* depth of deformation - *0,92 mm*

Fig. 2 shows the diagrams of the distribution of temperature fields and internal strain in the cutting process. The level of temperatures and strains during processing of the reinforced layer is noted to be much lower.

Thus, the analysis of technical literature, reference and regulatory sources and experimental studies conducted has established that the reason for the considerable discrepancy between the calculated and actual basic parameters of the edge cutting machining during the technological process design lies in the influence of the surface layer state on the cutting process not to be taken into account; and the absence of the actual, not reference thermophysical properties of the material processed and tool material in the simulation models.

This problem cannot be completely solved by the systems of cutting process adaptive control due to the high simplification degree of the machined surface parameters in quality control. It is necessary to modernize and refine existing mathematical models for calculating the cutting force components, cutting speed and model for calculating the height of microroughness, and introduce the diagnostic parameters obtained on the basis of information from the cutting zone into their structure. As the channels for the on-line evaluation of the processing, it has been proposed to use measurements of the thermoelectric power, the components of the cutting forces and the vibro-acoustic signal.
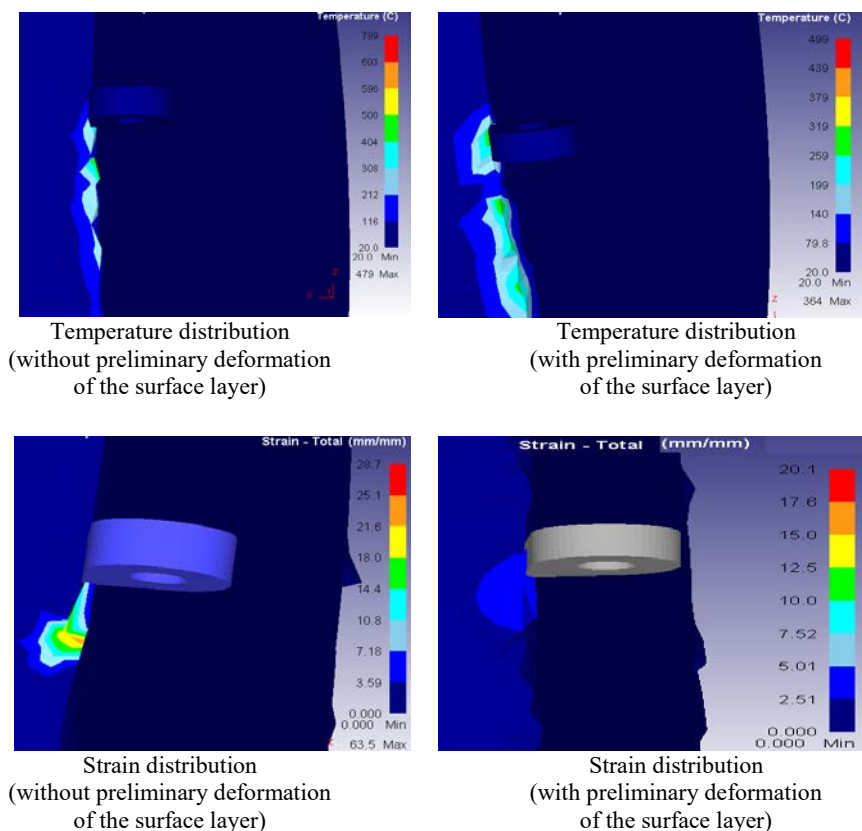
Temperature distribution
(without preliminary deformation
of the surface layer)

Temperature distribution
(with preliminary deformation
of the surface layer)

Strain distribution
(without preliminary deformation
of the surface layer)

Strain distribution
(with preliminary deformation
of the surface layer)

Fig. 2. Diagrams for the temperatures and strains distributions in the cutting zone during edge cutting machining

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