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Use of sound for adaptive control of the materials cutting process

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***Abstract* – Adaptive control of cutting process using as initial data information signals of various physical natures, characterizing indirectly quality of part cutting. The article demonstrates that among a variety of information signals the cutting sound is the most informative. Firstly, it is registered in a contactless manner, making it noise-resistant to spurious signals generated by operating of a metal-cutting tool, and secondly, the cutting sound originating at the point of contact of the tool and the workpiece, has high sensitivity to tool wear and roughness of the machined surface. Further research should focus on the development of processing quality-forecasting methods to promptly change the cutting modes and therefore prolong the period of the defect-free part processing.**

***Keywords* – tool wear; surface roughness; information signal; sound of cutting.**

I. Introduction

The quality of product manufacturing must be monitored throughout the entire technological chain, including the process of material cutting operations. Thus, the processing quality is understood as compliance of the workpiece geometry and processed surface roughness with the requirements of technical documentation. The compliance is provided by the adaptive control of the processing system operation.

The decisive influence on the quality of controlled parameters is made by the cutting tool wear, which is simultaneously a cause of permanent change in the dynamics of processing equipment. This fact requires implementing of adaptive control with the purpose of varying cutting modes that allow in conditions of ever-changing equipment dynamics to prolong the period of defect-free performance of a predetermined operation of machining materials by cutting.

There are two ways of controlling tool wear-direct and indirect. In industrial practice, the indirect way became widespread. In this regard, the adaptive control of tool wear is indirectly evaluated by measuring information signals having various physical nature and accompanying the cutting process.

Effective performance management is dependent upon the noise resistance of the information signal and its sensitivity to the degree of tool wear and the workpiece surface roughness. These properties of the controlled signal are necessary for the effective management of defect-free workpiece manufacturing, because they eliminate the risk of giving erroneous order.

The article provides a rationale for the selection of suchlike information signal corresponding to the specified requirements.

II. Formulation of the Problem

The system of adaptive control of the cutting process is based on the measurement of different nature information signals. This signals representing a variety of external factors: mechanical stress, vibration, elastic deformations of the processing system, the electric current, chemical exposure, and the like, which have a decisive influence on the degree of tool wear and, consequently, on the quality of the manufactured product [1].

Therefore, in the process of tool wear such parameters as cutting force [2], the torque [3] and cutting power [4] undergo changes. These parameters are measured by dynamometers. Applying the vibration sensor being disposed, for example, when turning on the tool holder, the tool vibration accompanying inevitably the cutting process is measured [5]

In the course of the wearing tool interaction with a work piece, acoustic emission waves are generated. This signals are recorded by sensors of acoustic emission in the frequency band from 1 kHz to 1 MHz. Acoustic emission is more sensitive than the force factors and vibration to tool wear [6], but at the same time, it makes acoustic emission more sensitive to noise disturbance caused by the influence of the environment and the work of the structural units of the machine.

For this reason, the registration of "integrated settings" is referred to, as they are more resistant to noise disturbance. For example, thermocouples help to monitor the temperature in the cutting zone [7], in the same way thermo – EDS vapors are measured, couples "tool - part ", allowing, according to the authors [8] "to get information about the pace of change in the dynamic behavior of the processing system due to tool wear." The method for measuring the electrical conductivity of the contact "tool - part" enters the group of integral methods [9]. Drawback of "integral" methods lies in their considerable inertia and the need to embed a thermocouple and electrical connections to the instrument.

Adaptive control presupposes monitoring tool status as well as surface quality control that is evaluated by the results of the acoustic emission signals measurement and vibration.

The vibro-acoustic data signals turn out to be the simplest in the registration and subsequent processing [5]. However, in practice the use of these signals is related to a significant problem that is difficult to solve. These information signals are recorded by contact method. The implementation of the method requires a mechanical communication of the sensor with the source of the information signal (the surface of the object). To meet this requirement, it is necessary to solve two difficult tasks: to choose an informative point on the controlled objects where you want to install the sensor, and to avoid interference, always related to the method of measurement.

When monitoring the process of cutting an informative point, is considered, the point of the tool contact with the workpiece. At this point, the useful signal carrying information about the course of the cutting process arises. Placing the sensor at this point is impossible. Selection of other control points, the closest of which, for example, in turning the workpiece is on the cutting tool holder, makes it necessary to exclude the biggest interference from the measurement results

Noise disturbance in this case is the vibration generated by the machine constructive operating nodes. To select the useful signal without significant distortion on the background of the intensive level and complex in frequency parasitic vibration is almost impossible. The solution to this problem is achieved by eliminating the sensor contact with the vibrating surface of the machine tool that is implemented with non-contact measurement method.

The purpose of this article is grounding the rationale for the selection of a cutting sound as an information signal that is detected in a contactless manner.

III. Experimental Studies

A. Nature of the cutting sound

On the surface of the part resulting from machine tool processing irregularities are formed in the form of protrusions and depressions (Fig. 1), called roughness. The cause of the roughness is the trace left by a tool on the machined surface due to mutual oscillation of the tool and the workpiece. This phenomenon that is the tool interaction with the workpiece 135 years ago became the basis of recording, during which the cutter leaves a trail (a phonogram) on the lateral surface of the wax cylinder, and then on the surface of flat records.

Fig. 2 Represents a 1000 times magnified part of the sound track records, which is a part of the recorded track on a gramophone record. This soundtrack is just the surface of the part, which is formed while it is processed by a metalworking tool.

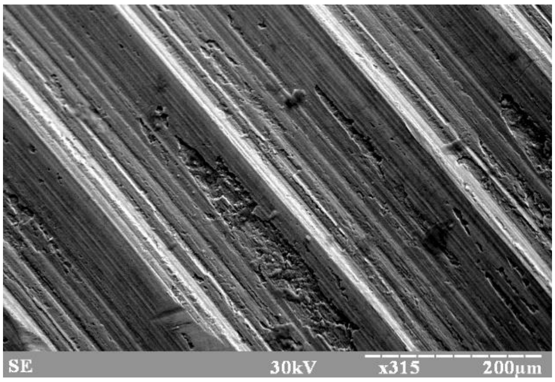

Figure 1. Increased by the microscope surface of the part after processing it by cutting

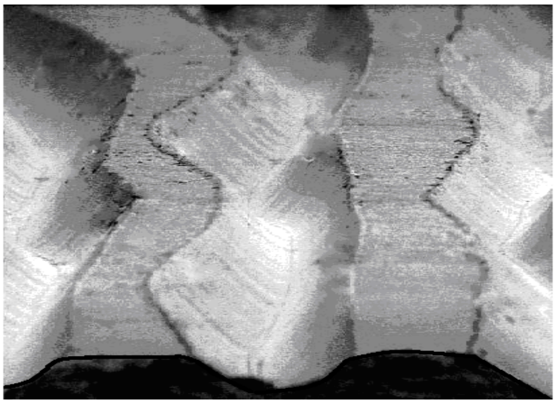

Figure 2. Increased by the microscope surface of the record

Roughness, similar to a phonogram contains information about the extent of tool wear and the quality of the processed surface of the workpiece, which is inextricably linked with tool wear.

A cutting sound is recorded by microphone typically of electret type (Fig. 3). The voltage of the electrical signal at the output of the microphone varies according to a change in the recorded sound.

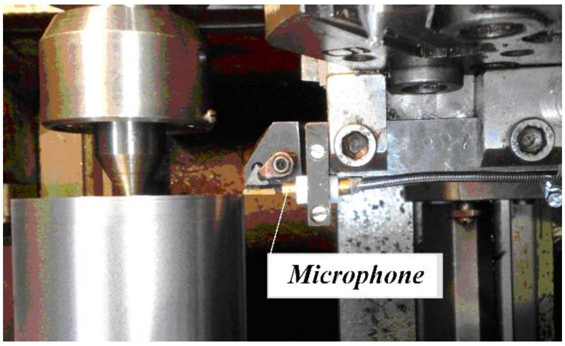

Figure 3. Installation example of microphone approximately the cutting area

Results of the studies revealed that the cutting sound has the properties of noise resistance, consequently it can be considered as the initial information signal used in the adaptive control process of cutting. In particular, for this purpose the measured signal E_S is reduced to the dimensionless form $\left(\bar{E}_S = \frac{E_S(\tau)}{E_S(\tau_0)}\right)$, where $E_S(\tau)$, $E_S(\tau_0)$ – is an value of the sound, defined respectively in the current time and in the beginning of cutting process.

At the same time, the cutting sound should ensure solving the basic problem of adaptive control - maintaining the required in the part manufacturing documents quality, characterizing the degree of compliance of the part geometry and the purity of its surface with the drawing requirements. Geometric accuracy is determined by the tool wear and surface finish by the size of its roughness. The degree of correlation between the sound and these parameters has been studied experimentally.

B. The ratio between the tool wear and cutting sound

The reason for deviation of the part geometry from the details of the drawing is sized tool wear of the cutting tool h_r, equal in magnitude and opposite in sign of radius change R_∂ of the processed workpiece surface (fig. 4). The purpose of the experiments was to determine the correlation between the sound and tool wear while workpiece being machined on a lathe.

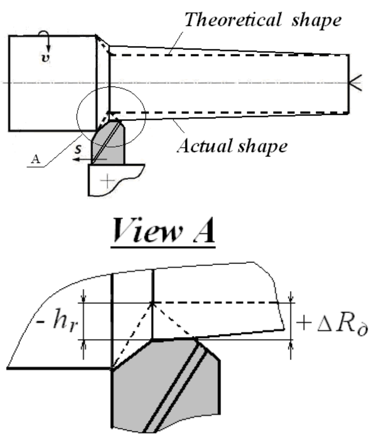

Figure 4. The deterioration of the geometric accuracy of the part because of the size wear of the tool blade

In the course of the experiments, the sound signal, was measured continuously. Measurements were carried out via a microphone installed near the cutting zone (Fig. 6) with the transmission of signal to the computer. Simultaneously, in steps (in two tool passes) using a measuring digital microscope, we recorded value of chamfer wear of major back surface *VB, мм* of the tool. The experiment was stopped, when the maximum allowable value of wear was reached.

The experimental results are shown in fig. 5, there is a graph of cutting sound change (parameter trend $\bar{E}_S$) and the curve of wear *VB*, as well as information about the correlation dependence between them, characterized by the correlation coefficient value *R*, equal to 0.926.

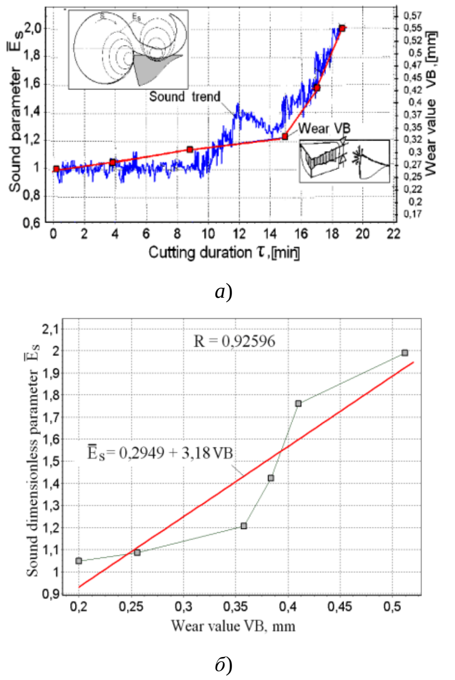

Figure 5. The relation between the curve of the tool wear and sound trend accompanying the treating by the cutting insert P25 of steel 12X18H10T for modes: *S* = 33 m/min, *f* = 0,15 mm/rev, *a* = 1,0 mm; a) the curve of wear *VB* and the trend of sound $\bar{E}_S$; b) the regression relationship between the dimensionless quantity of sound $\bar{E}_S$ and wear *VB*

As we see, the correlation of cutting sound and tool wear is big enough, that objectively indicates a high degree of coordination of change in the sound trend and wear curve.

C. The relationship between treated surface roughness and a cutting sound

The aim of the experiment was to determine the correlation dependence between the dimensionless sound parameter of $\bar{E}_S$ (1) and high-altitude R_a parameter characterizing the roughness. The roughness was measured at the longitudinal turning of steel billet St.40h on modes given in the caption to fig. 5. The roughness parameter *Ra* measurements were carried out periodically every five passes using a cutter-type profiler 283. The results of the measurements were recorded by the instrument dial indicator and additionally recorded on a laptop (fig. 6). The signal recorded on a laptop, subjected to further processing to determine the correlation between sound trends and roughness parameter.

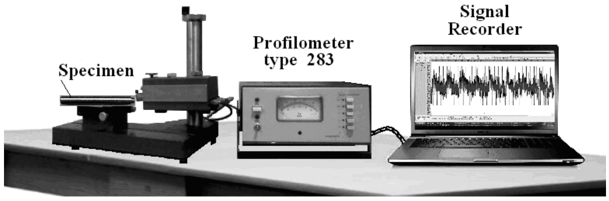

Figure 6. Registration roughness parameter *Ra* through profilometer type 283 and a laptop

The experimental results, are shown in fig. 7. In addition, for clarity and ease of comparison the roughness and sound roughness *Ra* , as well as the sound parameter $\overline{E}_S$, is given to the dimensionless form $\overline{R}a$ $\left(\overline{R}a = \dfrac{Ra(\tau)}{Ra(\tau_0)}\right)$, where $Ra(\tau_0), Ra(\tau)$ is an altitude roughness parameter defined respectively in the cutting process beginning and in the current time.Experiments have established that the correlation coefficient *R* between the sound trends and roughness parameter *Ra* equals to 0.944 (fig. 7).

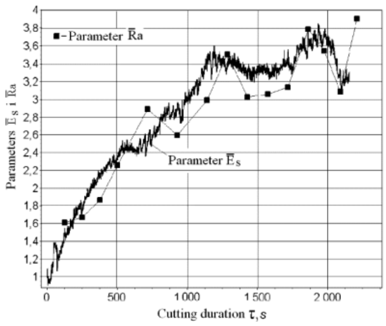

Figure 7. Comparison of sound trends (parameter $\overline{E}_S$) and roughness ($\overline{R}a$)

Conclusions

Thus, the results of studies presented in the article indicate the feasibility of using for the adaptive control of machining materials sound signal as initial information that is based on the following experimentally proven provisions:

– in contrast to the data signals, measured via contact method and subject, therefore, to noise disturbance generated by mechanical vibrations of the machine, a non-contact method of sound measurements via a microphone placed near the cutting area, and the transition in the processing of the measurement results to the dimensionless quantity of sound $\overline{E}_S$, provides noise resistant;

– sound trend and tool wear curve change during the cutting process with a high degree of coordination, as proven by a significant quantity of their mutual correlation coefficient *R* = 0,926;

– sound trends and altitude roughness parameter *Ra*, characterized by a correlation coefficient *R*, equal to 0.944.

Further research on the improvement of adaptive control of the cutting process should be directed at the development of quality forecasting methods of processing, allowing in the process of adaptive control to quickly determine the moment of the timely replacement of extremely worn-out tool. To solve this problem it is necessary throughout the entire workpiece treatment period monitor the cutting sound trend, quickly analyzing the nature of change and varies according to the analyses results cutting modes in order to extend the period of defect-free performance of a given technological operation.

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