ENGINEERING SCIENCES

TOOL FOR RESEARCHING THE DYNAMIC SYSTEM OF METAL-CUTTING MACHINE

[1]**Walid Ibrahim Alnusirat,** *assistant professor*
[2]**Litvin Oleksandr,** *assistant professor*
[3]**Ibrahim Farhan Alrefo,** *assistant professor*
[4]**Kravez Oleksandr,** *assistant professor*

[1]*Jordan, Salt 19117, Al-Balqa Applied University*
[2]*Ukraine, Kyiv, Department of Design of Machine Tools and Machines National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute»*
[3]*Jordan, Salt 19117, Al-Balqa Applied University*
[4]*Ukraine, Kyiv, Department of Design of Machine Tools and Machines National Technical University of «Igor Sikorsky Kyiv Polytechnic Institute»*

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ABSTRACT

Dynamic characteristics of the system flexibility of the machine affect the accuracy of machining, so the study of this problem is very important. Fluctuations of the machine elements significantly affect the error of the shape of the workpiece. The quality of the processing is determined not so much by the static displacements between the tool and the workpiece but the stability of the machine system as a whole. There are many solutions of vibroacoustic diagnostics devices for machines and machine-tools in the related publications. Defects in the spectrum of vibroacustic signals are found in the process of manufacturing and assembling machines in the form of discrete components, parameters of which are used in vibroacoustic diagnostics as informative diagnostic features. Along with that there is, but not so common, another type of dynamic system analysis of the machine, which can be carried out by experimental methods, or, in particular, by simulating the perturbation of a dynamic system by cutting forces of special type. Imitated disturbance is carried out by using a tool of a special form. During the processing cutting edges of the tool create a pseudorandom process with certain statistical characteristics, in particular, the correlation function. The proposed design of the tool makes it possible to perform the research of frequency parameters of the dynamic system of the machine without complex loading devices.

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Problem statement. In mechanical engineering, the efficiency improvement of machining process can be reached by different ways. Among these the study and proper use of dynamic processes occurring in technological systems is one of the least investigated ways which can open up large production opportunities. It can be primarily applied to the oscillations of technological systems. The development of special measures to reduce the level of oscillations in the technological system is an important task, the solution of which will allow to use more productive modes of cutting while providing the required quality of treated surfaces. To ensure the high technical characteristics of the machine, it is necessary to have quality indicators, such as geometric precision, rigidity, vibration resistance, and others within the specified limits for the whole time of operational activity and provide output of products with the specified accuracy. The solution of this problem is presented in this work.

Analysis of previous researches. Analyses of previous publications related to this problem shows that many different schematic and design solutions of devices and techniques for the study of the dynamic system of metal cutting machine tools are presented in the studies [1-6]. The oscillations of the machine elements significantly affect the error of the workpiece shape. That is, the quality of the processing is determined not so by the static offset between the tool and the work piece, but the stability of the machine system as a whole. Relative oscillations between the workpiece and the instrument occur simultaneously with several frequencies that correspond to different perturbation sources and the system's own oscillation frequencies.

Selection of previously unsettled parts of the general problem. Along with all mentioned above there is another type of analysis of the dynamic system of the machine which is not quite widespread until now. It can be carried out by experimental methods, in particular by simulating the perturbation of the dynamic system by special cutting forces.

The purpose of the study is to develop a method of simulated loading of the dynamic system of the metal-cutting machine by cutting forces while processing with a special kind tool.

Verification of vibroacoustic characteristics of the machine is one of the methods for assessing the quality of its manufacturing. Defects in the manufacture and assembly of machine tools are found in the spectrum of vibroacoustic signals in the form of discrete components, parameters of which (amplitude, frequency, phase) are used for vibroacoustic diagnosis as informative diagnostic features [4]. The most complete picture of the technical condition of the machine-tool is provided by its monitoring. Moreover, the following tasks can be solved: continuous monitoring of the vibroacoustic environment to assess operability of the machine; failure diagnostics of separate units and parts; comparison of the oscillation spectra for analysis of trends of the parameters of the machine at work.

The research objective. To achieve this goal, the following tasks need to be solved: to create a special tool in the form of interlocking side mill for stochastic stationary ergodic process of changing the cutting force and to develop a mathematical model for reproduction of the theoretical process. The conditions of the ergodicity of the process impose additional requirements on the probabilistic characteristics of the stationary process.

The first task of this study is the creation of a cutting tool design to study frequency parameters of the dynamic system of the machine without complicated loading devices that generate disturbing loading with different frequencies and disturb the whole range of operating frequencies of the machine during several cycles of processing. The peculiarity of the milling process is its non-stationary nature due to the periodic inputs and outputs of the teeth from contact with the work piece. During the cutting process the load impacts on the spindle. These impacts cause intense torsion oscillations of the drive and the maximum torque, acting on the spindle of the milling machine, can significantly exceed its average value due to pulse loading.

The analysis of the dynamical system of the machine can be carried out by experimental methods, in particular by simulating the perturbation of the dynamic system by the forces of cutting of a special character.

The statement of basic materials. Imitation of disturbance is carried out using a tool of a special form (Fig. 1). Cutting edges of the tool are created by processing a pseudorandom process, which has certain statistical characteristics, in particular correlation function. The proposed design of the tool consists of a mandrel on which a set of six disc cutters is fixed. On each of the cutters, a random profile was created due to the reshaping on the back surface.

The cutting tool of a special form contains a housing 7, which is located in the spindle of the machine, a mandrel 6, on which a set of several, for example, five disk cutters 1, 2, 3, 4, 5 with the same number of cutting edges is installed (Fig. 1, 2). Each milling cutter is a separate functional module, the number of which can be different. On the mandrel 7, a set of milling cutters is fixed with a nut 8. Milling cutters 1-5 are shifted to each other from a triangle and are determined from the condition of obtaining a random sequence of angles φ1, φ2, φ3, φ4, φ5, φ6, φ7 and φ8, the placement of the plates along the cutter periphery (Fig. 3).

The vertices of the teeth of each of the milling cutters are refiled to different heights, which is determined by the radii R1,1; R2.1; R3.1; R4.1; R5,1 within one module (Fig. 3). Due to this form of the tool each of the teeth during processing interacts with the machining surface in unevenly distributed moments of time and removes various allowances. As a result, the dynamic loading of the machine system is formed with a wide spectrum of disturbing frequencies. The location of the cutting edges of the tool is executed in such way that the processing generates a pseudorandom stationary process.

Depending on the technological parameters of the processing (rotation frequency of milling cutters, cutting depth and feed), a pseudo-random process of dynamic loading is formed that interrupts the dynamic system of the machine in the whole range of operating frequencies.

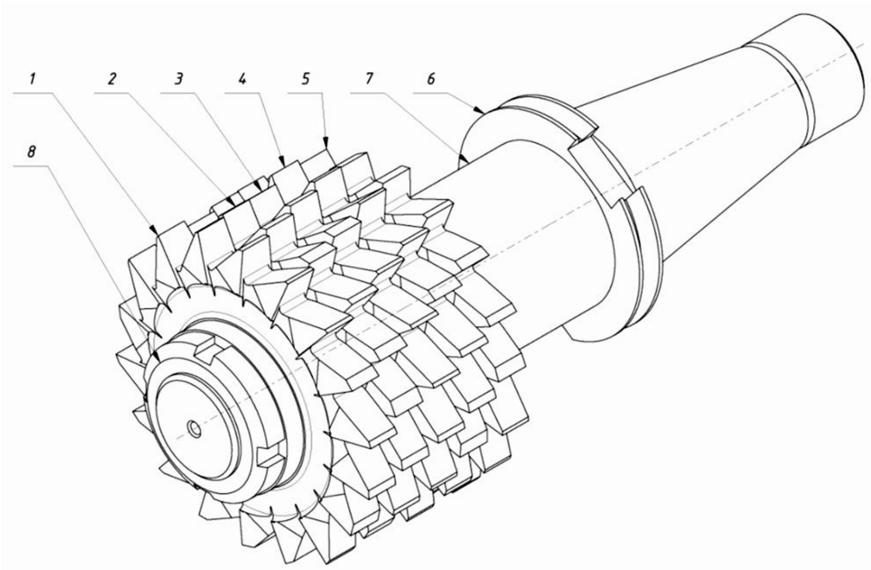

Fig. 1 interlocking side mill for simulated loading of the dynamic system of the machine by cutting forces

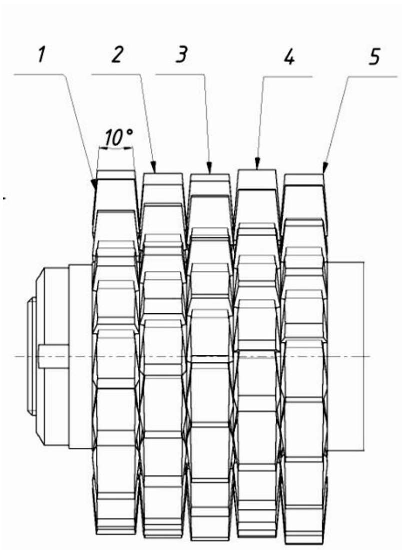

Fig. 2 Placement of modules of the interlocking side mill

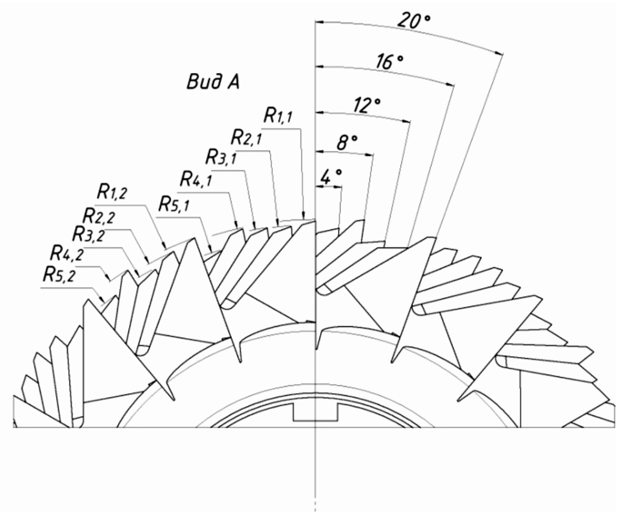

Fig. 3 Profile of a special milling cutter to form the loading

For each of the milling cutters 1-5, a pseudo-random sequence of values of the depth of re-sharpening is calculated according to Poisson's law of the distribution of a random variable. In addition to the fact that during the processing by a milling cutter a random process of changing the cutting force is modulated in amplitude by changing the depth of cut on each tooth of the milling cutter, the angle at which the next tooth of the milling cutter begins to contact the surface of the same row treated by the previous tooth (Fig. 3) is also randomly being changed, that is, the frequency modulation of the signal occurs.

This solution develops this field of technology in comparison with the prior art constructions.

The scheme of the formation of a random process during processing is shown in Figure 4.

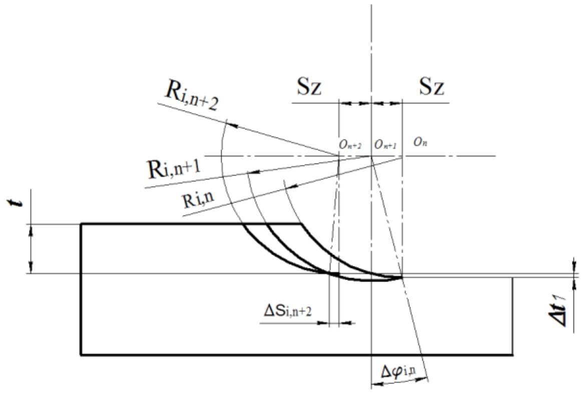

Fig. 4. The scheme of the formation of a random loading in the successive processing by teeth of milling cutters

To determine the characteristics of the random process of the imitating loading, we consider the scheme of the layer formation that is cut away by each tooth of milling cutter (Figure 5)

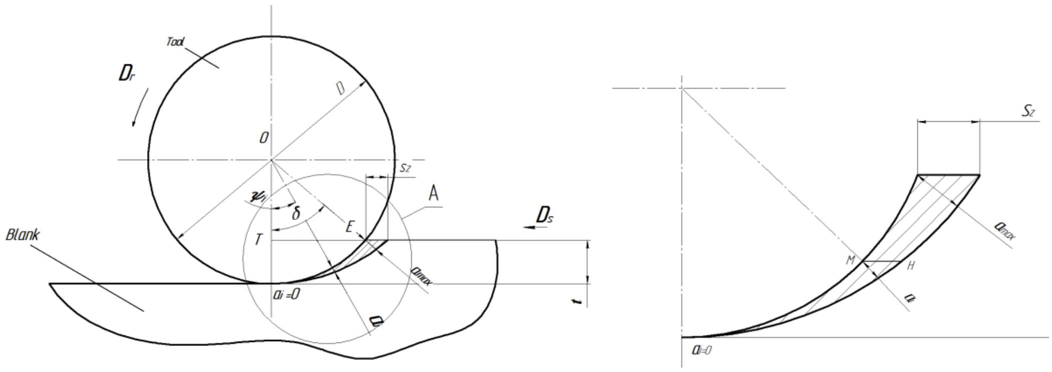

Fig.5. Elements of cutting mode and cutting layer geometry for machining with cylindrical milling cutter

As it is shown in the scheme the angle of contact δ_i (the central angle corresponding to the arc of the contact of the milling cutter with the work piece) is possible to determine. It can be found in Δ OTE

$$\cos\delta_i = \frac{\frac{D_i}{2} - t}{D_i/2} = 1 - \frac{2t}{D_i};\ \delta_i = \arccos\left(1 - \frac{2t}{D_i}\right)$$

The thickness of the cut away layer a_i is the variable distance between two consecutive positions of the cutting surface (formed by the cutting edges of two adjacent teeth) measured in the radial direction. For a straight-flute milling cutter, the value of a_i is constant over the entire length of the tooth and can be determined using Δ МКН:

$$a_i = S_z \sin\psi_i,$$

Where ψ_i is the instantaneous contact angle corresponds to the given position of the milling cutter tooth. When the tooth enters the work piece, the thickness of the cut layer is zero. When the tooth drops out of the contact with the work piece, the thickness of the cutting away layer corresponds to the angle of full contact and has the maximum value of a_{max}:

$$a_{max} = S_z \sin\delta = 2S_z\sqrt{t/D};\ \sin\delta = \sqrt{1-\cos^2\delta} = 2\sqrt{t/D}\,.$$

The area of the cut away layer of a tooth of the milling cutter

$$f_i = a_i b_i = B\cdot S_z \sin\psi_i;$$

On the basis of the given dependences, it is possible to calculate the characteristics of a random process of imitation loading, namely the level and nature of vibrations that are generalized indicators of the dynamic quality of the machine, and sometimes - the uniform criteria for its normal functioning. The sequence of pulses of each cutter generates a pseudo-random process in the sum φ_Σ.

The empirical formula for determining the strength P_z, which generates random vibration.

$$P_z(a_s) = \frac{C_{P_z} t^{X_{P_z}} \left(\frac{a_i}{sin\psi_i}\right)^{Y_{P_z}} B^{q_{P_z}} z}{D^{U_{P_z}} n^{w_{P_z}}} k_{P_z}\,.$$

Conclusions. The suggested design of the tool allows to perform the research of the frequency parameters of the dynamic system of the machine without complex loading devices generating disturbing loading of various frequencies and performing perturbations in the entire frequency range of the machine for several processing cycles.

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