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MEASUREMENT OF DYNAMIC CHARACTERISTICS OF TECHNOLOGICAL SYSTEM

Г.М. Голобородько, Л.М. Перпері, В.П. Гугнін, Ю.Г. Паленний. **Вимірювання динамічних характеристик технологічної системи**. Розглянуто способи вимірювання вільних коливань консольних інструментів і вимушених коливань в процесі різання. Для таких вимірювань зазвичай використовуються безконтактні ємнісні або індуктивні датчики. Найчастіше використовуються методи вимірювання за допомогою індуктивних та ємнісних датчиків. ***Мета:*** Метою роботи є апробація розробленого авторами стенда для безконтактного вимірювання вібрацій інструмента, що обертається, з подальшим порівнянням амплітудно-частотних характеристик на холостому ході і в процесі обробки широколезовою розгорткою для встановлення вібростійкості процесу різання. ***Матеріали і методи:*** Для вимірювання віброперeміщень інструмента відносно деталі при низькочастотних коливаннях запропоновано застосовувати безконтактний метод вимірювання з використанням датчиків, що працюють на основі ефекту Хола. ***Результати:*** Розроблено стенд для проведення безконтактних вимірювань вібрацій інструмента в реальному часі. Отримано осцилограми амплітуди коливань центра інструмента під час обертання, дані спектрального аналізу коливань інструмента відносно оброблюваної деталі і графіки переміщення центра інструмента на холостому ході і в процесі різання. Проведено аналіз даних вимірювань на різних етапах обробки отвору розгорткою. Показано, що інструмент здатен виправити початкову похибку попередньо обробленого отвору в діапазоні від 25 до 50 %. Висновки*:* Обробка отриманих віброграм дозволяє оцінити параметри динамічної системи як на холостому ході, так і в процесі обробки, оцінити дані відхилень ексцентриситета на основі осцилограм амплітуд по осях *Y* і *Z*, відхилення від круглості і зробити висновки про розмірну точність при обробці заготовок з різними режимами різання.
Ключові слова: безконтактні вимірювання, ефект Хола, вібрація, різання.

G.M. Goloborodko, L.M. Perperi, V.P. Guhnin, Yu.G. Palennyi. **Measurement of dynamic characteristics of technological system**. It is overview of the measurement methods of free oscillations of console tools and forced vibrations during cutting. Non-contact inductive and capacitive sensors are commonly used for such measurements. Often used measurement methods are using inductive and capacitive sensors. ***Aim:*** The aim is to probe the stand developed by the authors for non-contact measurement of vibration of the rotating tool and then comparing the amplitude and frequency characteristics at noncutting rotation and during processing using wide blade to establish the vibration resistance of cutting process. ***Materials and Methods:*** To measure the tool vibration displacement relatively to the part at low frequency vibrations, it is proposed to use non-contact measurement method, using sensors, that are operate on the basis of Hall effect. ***Results:*** the stand for non-contact vibration measurement instrument in real time has been developed. The oscillograms of tool center amplitude during rotation, spectral analysis data of tool vibrations relative to processed part and moving center tool graphics noncutting rotation and in the process cutting were obtained during the experiments. The analysis of measurement data at various stages of processing of the hole scan carried out. It is shown that the tool is able to correct the initial error of the pre-processed hole in the range of 25 to 50%. ***Conclusions:*** Processing of the data allows estimating the parameters of the dynamical system both at noncutting rotation speed and during processing to estimate data deviations of eccentricity at the base of oscillograms amplitude on axes *Y* and *Z*, deviation from roundness and make conclusions about the dimensional accuracy in the processing of workpieces with different modes of cutting.
Keywords: non-contact measurement, Hall effect, vibration, cutting.

Introduction. The sensors that operate on the principle of non-contact measurement are used to measure the free oscillations of console instruments and forced oscillations during the cutting process. Most frequently used measurement methods using the inductive and capacitive sensors are based on the frequency change of circuit oscillation at change of inductance or capacitance in the measuring system [1, 2]. The frequencies of circuit sensor and master oscillator are compared using scheme and technical solutions [1, 3]. This scheme complicates the design of instrumentation. Also the laser measurement system oscillations tool is known [4]. Despite the high accuracy of the system, high complexity and cost do not allow extensive use the system in research laboratories. The known system of non-contact measurement of vibration rotating parts, which working principle is that in 2...2.6 mm from the rotating parts is installed the permanent magnet which is mounted on an elastic diaphragm.

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During the rotation of the parts due to mismatch rotation axis and geometric axis, the force of gravity of magnet for parts is changing. The high accuracy primary converter based on fiber Bragg gratings principle [5] is attached to an elastic diaphragm. These systems are the high accuracy ones, with primary transducer protected from electromagnetic interference through the use of fiber optic sensors, but these systems are difficult for manufacturing and maintaining.

The aim is to probe the stand developed by the authors for non-contact measurement of vibration of the rotating tool and then comparing the amplitude and frequency characteristics at noncutting rotation and during processing using wide blade to establish the vibration resistance of cutting process.

Materials and Methods. To measure the tool vibration displacement relatively to the part at low frequency vibrations, it is proposed to use non-contact measurement method, detailed written in [6], using sensors which include primary converters that are operate on the basis of Hall effect. (Hall sensors are placed close to the one of the poles of the permanent magnet and installed in mutually perpendicular directions so that when ferromagnet is approaching to the magnet, the magnetic field fixed by sensors is changing).

Non-contact measurement using allows measuring in difficult machining conditions such as mechanical shock, vibration, high temperature and so on.

The block diagram of non-contact measurement stand for vibration measurement is presented in Fig. 1.

The stand for non-contact measurement of the tool displacement relatively to processed part during the cutting process has two displacement sensors 1 and 2; primary signal conversion unit 9 and the computer storage and processing output 10. The primary signal conversion unit 9 includes two modules of level control signal 3, 4 and matching amplifiers 5, 6, analog-to-digital converter 7 and microprocessor unit of data measurement units 8. The listed block of the primary signal conversion unit 9 constructively combined in one unit.

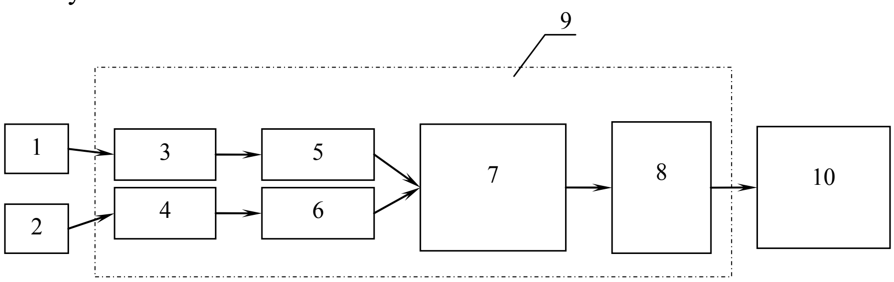

Fig. 1. Block diagram of the stand: 1, 2 — primary converters; 3, 4 — regulation signal modules; 5, 6 — matching amplifiers; 7 — analog-to-digital converter; 8 — microprocessor; 9 — previous signal conversion unit; 10 — computer

Measuring stand allows real-time displaying of the data coming from the microcontroller ADC system at a computer screen in the form of oscillograms and to start the process of recording information in time. The measuring information about signal amplitudes that characterize the geometrical tool axis deviation from the axis of rotation in two mutually perpendicular directions in the horizontal plane is stored during information recording. Also the time of these signals receipt is saved.

The measurement stand software consists of two parts:

— The first module performs the operations on process management setup, calibration of sensors, visual control of the measurement process and store measurement data for later analysis;

— The second module processes the stored measurement data. The information about the time and amplitude variations of the tool allows carrying out the spectral analysis of the tool vibrations relative to processed part. These records have been used to analyze the vibrations that occur during the cutting process, changing the shape of processed part during the machining process, the tool axis input and other factors that affect the accuracy of part processing by edge cutting tools.

Results and Discussion The oscillograms of the tool center amplitude during rotation, spectral analysis data of tool vibrations relative to processed part and moving center tool graphics at noncutting rotation and in the cutting process were obtained during the experiments.

Processing of the experimental data was carried out using the NI LabVIEW software tool.

Fig. 2 shows the tool data measurements at noncutting rotation speed of $n = 160$ min^{-1} for 6 sec. The left top window displays a graph of the amplitude of the tool center in time. The left bottom window displays the spectral analysis of vibrations of the tool relative to processed part. On the right side is the graph of moving of tool geometric center in the horizontal plane.

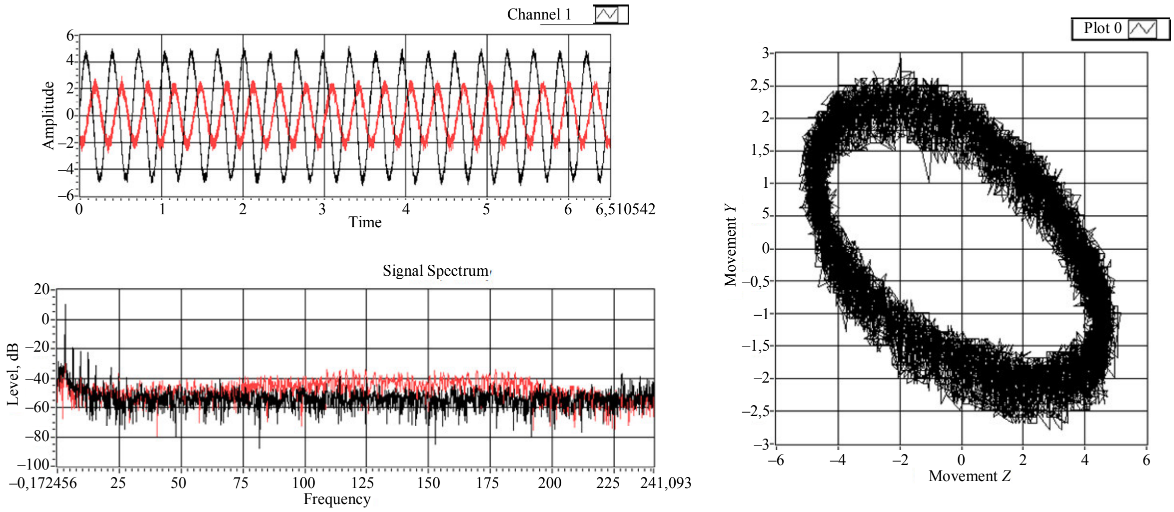

Fig. 2. The results of the measurement tool center vibrations at noncutting rotation

Fig. 3 shows the measurement data during processing with cutting modes: tool rotation frequency $n = 200$ min^{-1}; feed $s_o = 0.005$ mm/rev ($s = 1$ mm/min); hole diameter $D = 39.95$ mm; blade length $L = 15$ mm. To assess the changes in the value of instrument center moving at different times during processing, the measurement data were examined in a short period of time (5 sec) and then were exported to MS Excel.

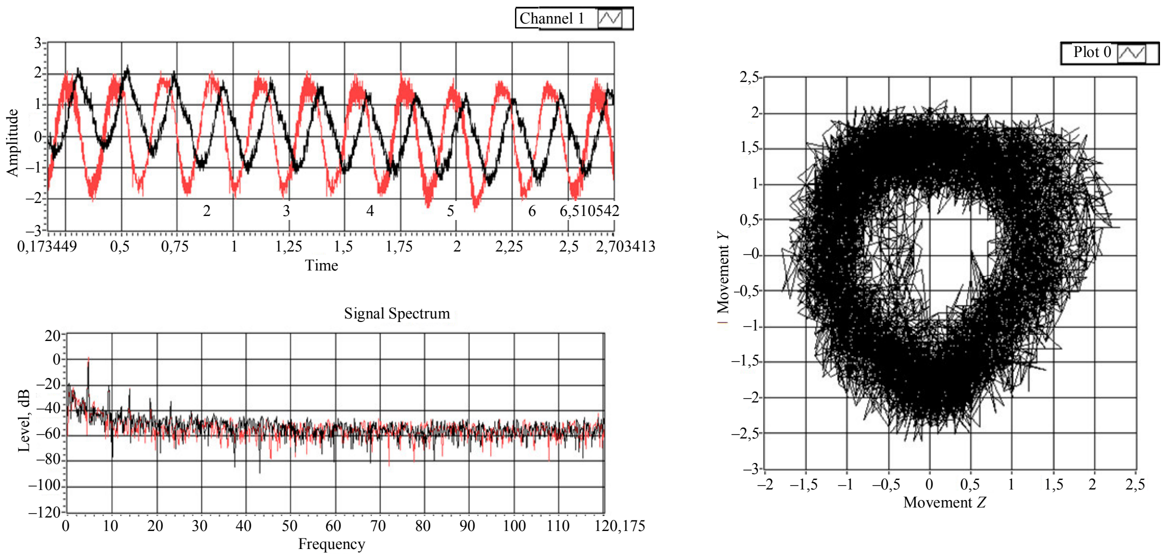

Fig. 3. Processing of measurement results during the cutting process in NI LabVIEW software environment

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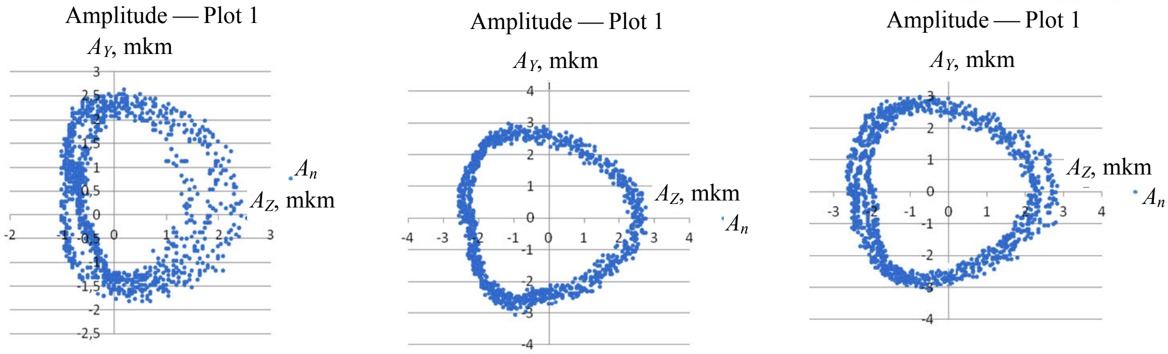
Processing results were calculated for points of cutting start, middle and end. Data processing results in the cutting process are shown in Fig. 4.



a *b* *c*

Fig. 4. The field of the center scan towards the center of rotation: a — at the beginning of processing; b — in the middle of processing; c — end of processing

The measuring system allows recording of the measurement data throughout the cutting process.

Mixed large number of measurements (Fig. 3, right window) makes it impossible to conduct a detailed analysis of changes in the characteristics of the cutting processes in time therefore among thousands of measurement results were selected data packets of 300 measurements at the beginning, middle and end of processing. The amount of data in the package caused by the fact that on the one hand, the data should be enough for statistical analysis of measurement results, and on the other hand, the data should reflect the state of the process at a certain time of processing.

Fig. 4 shows data packets received at different stages of scan processing of the hole. Each measurement included in the package of data is displayed on the graph as a separate point. All points of the provisions of geometrical axis of the tool are shown in the graph and form the field of the scanning center in relation to the center of rotation. Deviations are measured in cross-section scan at the level set of sensors.

After analysis, we can conclude that the tool is able to correct the initial error of the pre-processed hole in the range of 25 to 50 %.

The analysis of the fields geometric axes position of the tool is the source of the following information:

— average radius of geometrical axis deviation of the tool from axis of rotation;

— roundness deviation, that characterizes the heterogeneity of stiffness of the system in different directions, and error of centering tool axis and the axis of the hole during processing;

— spread of points relatively the midline of the position of the circle describes the processing instability and the presence of vibrations during cutting.

Several parameters were measured during the experiment: the eccentricity of deviation Δ_E based on oscillograms amplitude on axes Y and Z — A_Y and A_Z, deviations from roundness $\Delta_{FR\max}$ while hole processing with diameter of 39.95 mm and length of 12 mm in workpieces made of gray cast iron SCh18 and Steel 45 at various modes of processing. The modes are: speed v — 25, 32 and 44 m/min; supply s_0 — 0.01 mm/rev. Measurement results showed that A_Y is in range 1.9...3.2 m; A_Z — 2.0...2.8 mm; Δ_E — 2.9...4.3 m; $\Delta_{FR\max}$ — 3.9...5.8 mm.

Conclusions. The proposed measurement system allows estimating of geometric center moving for the tool, take measurements at an unlimited time. Processing of the obtained vibration graphs allows estimating the parameters of dynamical system as at noncutting state and during processing, evaluating data of eccentricity Δ_E deviation through oscillograms of amplitudes on axes Y and Z — A_Y and A_Z. The proposed system also allows evaluating the deviation from roundness $\Delta_{FR\max}$ and make conclusions about the dimensional accuracy while workpieces processing with different modes of cutting.

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