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THREE-PARAMETER SYSTEM FOR MONITORING THE WEAR OF CUTTING TOOLS ON CNC MACHINES IN AUTOMATED PRODUCTION CONDITIONS

Annotation. This paper presents a method for controlling the gradual wear of cutting tools during turning operations using ultrasound diagnostics, measuring the tangential cutting force using strain gage sensor and acoustic emission of the process, measured by a vibrometer for CNC machines directly during the cutting process. A measurement scheme and an analytical model are presented.

Keywords: instrument wear, ultrasound, echo signal, strain gage sensor, acoustic emission, automated production.

INTRODUCTION

Knowledge of the condition and expected service life of the tool is an important input for determining the optimal processing parameters, so cutting process control systems based on measuring the wear of the cutting tool are introduced into production [1]. Such systems make it possible to ensure the accuracy of processing and surface quality, and increase the productivity of automated equipment.

Since the working surfaces of the cutting tool are exposed to mechanical stresses, high temperatures, and coolant, the efficiency of the tool is reduced due to plastic deformations and wear.

The aim of the work is to develop a three-parameter control system for processing parts on CNC machines in terms of "unmanned technology" based on the measurement of three signals: ultrasonic signal, tangential cutting force and acoustic emission level.

METHODS OF MEASURING SIGNALS

The ultrasonic method provides real-time monitoring of the cutting tool condition. This method is based on measuring the length of the cutting edge by determining the time of passage of an ultrasonic wave through the tool body.

Ultrasonic vibrations into the medium are emitted by a piezoelectric source in the form of short-term pulses. Accordingly, when ultrasonic waves collide with an obstacle, part of the emitted energy is reflected and returned back in the form of an echo pulse, which is read by a piezoelectric element.

The time between emitting and reading an echo pulse is the time it takes for the pulse to travel the "transmitter-reflector-receiver" distance, which can be measured with an accuracy of 1 ns. It was found that the ultrasound control method can be measured with an accuracy of ±2 microns [2].

On the cutting tool, a mark is created by electrical discharge machining, which has constant dimensions (1.2 mm in depth and 1.2 mm in thickness). The ultrasonic wave transmitted to the tool body passes along the entire length of the tool and is reflected from the mark, as well as from the front and back surfaces of the cutter.

This system also measures the acoustic emission signal (high-frequency oscillations over 80… 100 kHz) using vibrometers, the signal to which is supplied from the vibration transducer – accelerometer, and the cutting force using a strain gauge. These parameters determine the amount of wear of the cutter and do not allow breakage or defect.

It is known that with increasing tool wear, the values of forces and power required for cutting increase [2]. Therefore, both the cutting forces and their derivatives can be used as a source of diagnostic signal. Sources of acoustic emission in the cutting process include: microcracks in the workpiece, areas of friction, plastic deformation and fractures, areas of chip breakage and its contact with the surfaces of the tool and parts.

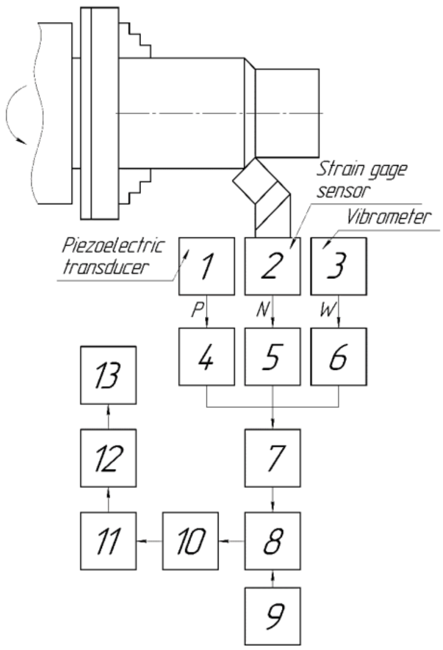

Fig. 1. Block diagram of the control system of the turning process

The block diagram of the wear control system of the cutting tool is shown in Fig. 1. In this diagram, Block 1 is a piezoelectric transducer that generate and receives ultrasonic waves. Block 2 measures the tangential component of the cutting force using strain gage sensor. The acoustic emission signal is measured using a vibrometer, that installed in the tool holder (Block 3). Accordingly, the received signals are amplified and filtered in blocks 4, 5 and 6, from where they enter the analog-to-digital converter (Block 7). In Block 8, the received signals are processed and compared with those stored in the database 9. Based on this comparison, Block 10 evaluates the wear of the cutting tool and sends a signal to the control unit (Block 11), which generates corrected control signals that are entered in the CNC machine program (Block 12). The program processes the signals and transmits them to the machine's actuators (Block 13).

This change in the geometry of the tool is directly proportional to the total amount of reflected ultrasonic energy. Thus, this energy increases during the cutting process.

DEVELOPMENT OF A MATHEMATICAL MODEL

The measurement process is influenced by the following factors: the area of the wear site (S), the angle of incidence of the ultrasonic wave beam on the wear site in the horizontal and vertical planes (α_1, α_2), and the temperature of the cutting tool ($f(T)$).

The approximate total area of the wear site can be written as [3]:

$$S = W \cdot H \cdot \left(1 - k_2 + \frac{\pi}{2} k_1 k_2\right), \qquad (1)$$

where W – width of the wear area,
H – height of the wear area,
k_1 and k_2 – constants that are set from the database.

The energy reflected from the wear site is proportional to the area of this site, so the energy model that depends on the area of the reflective surface can be expressed as follows:

$$\frac{P_{rec}}{P_{rad}} \sim S^2 \text{ or } P_{rec}^{tool} = k_3 S^2 P_{rad}, \tag{2}$$

where P_{rec}^{tool} – received part of the reflected energy from the worn area,
P_{rad} – amount of radiated energy,
S – reflective surface area,
k_3 – constant.

The energy reflected from the wear site is proportional to the angle of incidence α_1 in the horizontal plane and α_2 in the vertical plane, then the mathematical model looks like this [3]:

$$\frac{P_{rec}}{P_{rad}} \sim \frac{1}{\cos(\alpha_1)} \text{ or } P_{rec}^{tool} = k_4 \frac{1}{\cos(\alpha_1)} P_{rad}, \tag{3}$$

$$\frac{P_{rec}}{P_{rad}} \sim \cos(\alpha_2) \text{ or } P_{rec}^{tool} = k_5 \cos(\alpha_2) P_{rad}, \tag{4}$$

where k_4 – constant,
k_5 – constant.

The amount of reflected energy is also affected by the temperature of the cutting tool, so the dependence can be expressed by a mathematical function $f_1(T)$:

$$\frac{P_{rec}}{P_{rad}} \sim T \text{ or } P_{rec}^{tool} = f_1(T) P_{rad}, \tag{5}$$

where T – tool temperature,
$f_1(T)$ – a function that represents the effect of temperature on the amount of received energy.

The value of the acoustic emission signal is expressed by the formula of the combinational parameter of the acoustic emission [4]:

$$W = \frac{A^2 \cdot N_\Sigma}{N}, \tag{6}$$

where $A^2 \cdot N_\Sigma$ – acoustic emission power,
A – amplitude of the acoustic emission signal,
N_Σ – acoustic emission signal activity,
N – cutting power.

Since the value of the cutting force is measured by means of a strain gauge, the cutting power must be expressed through it [2]:

$$N = \frac{P_Z \cdot V}{60 \cdot 102}, \tag{7}$$

where V – cutting speed.

Then the mathematical model of the energy reflected from the cutting edge of the tool can be represented as follows:

$$P_{rec}^{tool} = \left(k_3 S^2 \cdot k_4 \frac{1}{\cos(\alpha_1)} \cdot k_5 \cos(\alpha_2) \cdot f_1(T) \right) \cdot P_{rad}. \tag{8}$$

Since the calibration mark is a flat surface with an angle of incidence of the ultrasonic beam equal to 90° and a temperature equal to the temperature of the cutter, its mathematical model has the form:

$$P_{rec}^{mark} = f_1(T) \cdot P_{rad}. \tag{9}$$

Then the analytical mathematical model of cutting tool wear by estimating the echo signals received from the cutting edge and label will look like this:

$$\frac{P_{rec}^{tool}}{P_{rec}^{mark}} = k_3 S^2 \cdot k_4 \frac{1}{\cos(\alpha_1)} \cdot k_5 \cos(\alpha_2). \tag{10}$$

The mathematical model of wear of the cutting tool is as follows:

$$h = \Delta h + k \cdot j \cdot \frac{60 \cdot 102 \cdot A^2 \cdot N_\Sigma}{P_Z \cdot V} \cdot k_3 S^2 \cdot k_4 \frac{1}{\cos(\alpha_1)} \cdot k_5 \cos(\alpha_2) \tag{11}$$

where Δh – the available wear of the tool, mm;
j – wear intensity;
k – correction factor, which is laid in the database and depends on the material of the tool and the workpiece.

CONCLUSION

The developed mathematical model can be used in turning in CNC machines in flexible production systems to find the optimal processing mode, reduce the number of defective parts and increase production productivity.

The cutting process monitoring system based on ultrasonic measurements will allow to monitor the level of cutter wear in real time during processing in automated production conditions, assess the wear rate under specified cutting modes, and increase the reliability and accuracy of the cutting workpart procedure.

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