# OPERATIONAL MONITORING OF METAL CUTTING

**Anton Panda - Volodymyr Nahornyi**

**Abstract:**
Today the tool wear cannot be measured directly during the cutting process. Therefore, indirect methods of estimating wear are used, using for this purpose information signals that are various physical natures, which accompany the machine work. However, in this case, the control problem is complicated by the absence of similar criteria (norms). To solve this problem, it is proposed to use dimensionless degree indicators of criticality technical state of the instrument. The quality control of the cutting process is automated.
**Key words:**
Processing system, tool wear, part quality

## Introduction – the operative assessment problem of the metal cutting quality

The key elements of the technological system are the cutting tool and the workpiece – the future part, for which, in fact, the metalworking technological system is created. Changes in her dynamic behaviour occur due to wear and subsequent destruction of the tool. Today the cutting tool wear cannot be measured directly, during the technological system operation. Therefore, indirect methods are used to assess tool wear. For this purpose, various information signals, which generate during the cutting process, are measured. Among these signals, there is a sound.
Carrying out such control, it is necessary to compare the current processing system dynamic behaviour with some of its normative (criterion) values. However, in this case, the control problem is complicated by the absence of similar criteria (norms), in contrast to, for example, rotary machines for which the "Vibration severity" [1] have been developed.
To solve this problem, it is proposed to use a number of dimensionless indicators that characterize the tool state and the workpiece quality. The value of this indicator varies from 0 to 1, which greatly simplifies the procedure for controlling the cutting and compensates for the lack of the necessary "Norms…".
The article considers the cutting quality control methodology based on calculation of one of the similar indicators $a_Q$.

## Methodology of cutting control

The method of operative quality control of cutting operations should provide prompt information on the criticality degree of the tool's technical state with the aim of timely adjusting the cutting mode or changing the tool to prevent its unforeseen failure (breakage) and the appearance of the workpiece defective.
When developing the cutting control methodology, the main provisions of the "fuzzy sets" theory were used [2]. According to this theory, the criticality degree of the tool's state, is estimated by the state dimensionless indicators $a_Q$. The functions of calculating the state indicators according to the theory of "fuzzy sets" are called "membership functions" [2].
The "membership function" transforms the initial values of the input variables (the monitored parameter E, the current cutting time $\tau$ and the tool life forecast TLF) into the linguistic variables "terms" values – diagnoses of the tool current state. An important property of the "membership function" is that it is a dimensionless function that varies from zero to one. Within the same limits, during the material processing, the state indicators also change,

passing successively a series of linguistic variable values.
A linguistic variable, called in this case "an instrument state indicator", has a number of "terms" meanings. "Terms" are a set of verbal quantities describing a gradually deteriorating diagnosis of the instrument state. In table 1 shows the intervals of changing the numerical "terms" values. The interval boundaries represent the normalized series of preferred numbers R5. Preferred numbers are a geometric progression with a root $q = \sqrt[5]{10} \approx 1,56$ [3].

**Table 1. The basic scale of the linguistic variable – "instrument state indicator"**

| The verbal meaning of "terms" | | | | |
|---|---|---|---|---|
| «good state» | «acceptable state» | «allowable state » | «requires adjustment » | «invalid state» |
| 0 – 0,41 | 0,41 – 0,63 | 0,63 – 0,9 | 0,9 – 1,0 | > 1,0 |

The diagnosis procedure consists in comparing the actual value of linguistic variables with their standard interval values, given in Table. 1. Depending on the standard interval, where the current actual value of the linguistic variable falls, the diagnostic object current state refers to one or another "term" and thus one or another diagnosis of its technical condition is put.
Below are the analytical expressions for the "membership function" describing the machined part state (the quality of machining of parts) using, for example, the lathe processing system. The workpiece condition (the workpiece quality), is characterized by the accuracy of its manufacture and the treated surface roughness (the degree to which these parameters meet the drawing requirements). In accordance with this, the workpiece quality is described by a linguistic variable called the "*cutting process quality index*". This variable is determined by the following "membership function" [4]:

$$a_Q = \varphi \cdot a_{ACC} + (1-\varphi) \cdot a_R , \tag{1}$$

where $a_{ACC}$ – the linguistic variable is the " *cutting process precision index*"; $a_R$ – linguistic variable - "*surface roughness index*"; $\varphi$ – weighting factor (φ = 0,1- 0,9).
The value of the weighting factor is chosen depending on the priorities (geometrical accuracy or surface purity is more important), which are used to evaluate the processing system quality. With equal requirements, both to the accuracy and to the surface cleanliness, the value of the weighting coefficient, is taken, to be 0.5.

The terms $a_{ACC}$ and $a_R$ are determined from the following expressions [4]:

$$a_{ACC} = \frac{E_{AC}(\tau)}{E_{AC}(\tau_0)} \frac{\tau}{T_{TFL}}, \tag{2}$$

$$a_R = \frac{E_{AC}(\tau)}{E_{AC}(\tau_0)}, \tag{3}$$

where $E_{AC}(\tau)$ – the current (actual) level of the monitored parameter; $E_{AC}(\tau_0)$ – the actual level of the controlled parameter at the cutting process beginning $\tau_0$; $\tau$ – current value of the cutting time, min; $T_{FTL}$ – forecast tool life, min.
Expressions (2) and (3) represent the desired "membership function", varying in accordance with the theory of "fuzzy sets" from 0 to 1 [2]. The forecast tool life FTL is determined by the results of predictive model identification (4), the number of it parameters includes the coefficient P, which is numerically equal to the instrument life (FTL = P) [4]. Identification is

carried out, based on the online monitoring results of sound cutting mode ($E_{AC}(\tau)$).

$$E_C(\tau) = E_{AC}(\tau_0) \cdot \left( \frac{P - \tau_0}{P - \tau} \right)^{\gamma}, \tag{4}$$

where $E_C(\tau)$ – calculated sound level; $\gamma$ – the exponent that is determined when the model is identified.

In Fig. 1 is a quality index graph $a_Q$, describing the workpiece machining quality from St 40x steels under normal and catastrophic wear of cutting blades made of T15K6 material.

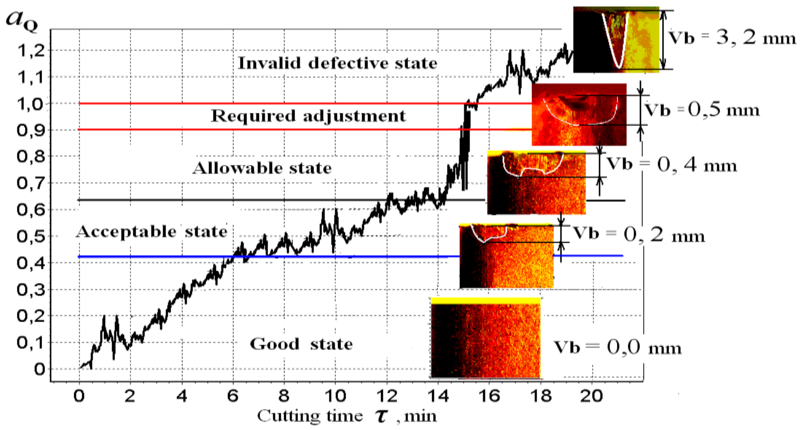
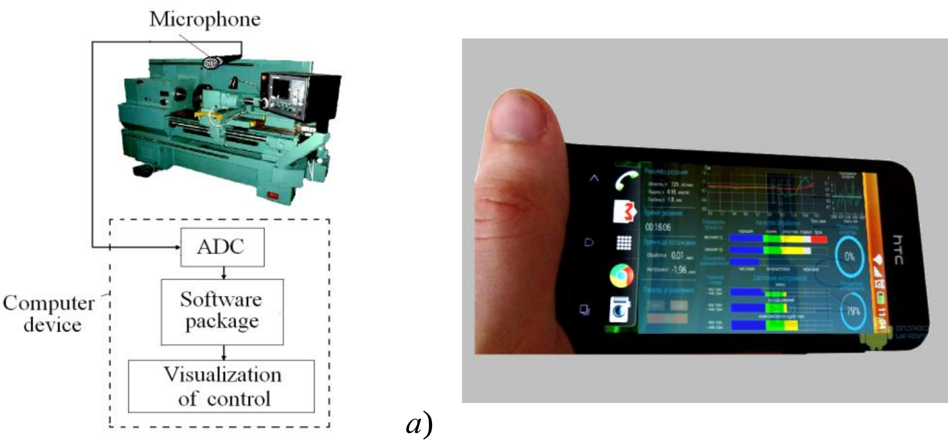



**Fig.1 Change the quality index $a_Q$ and tool wear at cutting of steel parts St 40X**

It follows from the figure that the change of the cutting quality index and the cutting blades state are consistent.

## Automation of machining quality control

The cutting control, was automated to measure on-line sound in the cutting zone (Fig. 2 *a*) [1].




*a*) *b*)

**Fig. 2 Automated control system:**

***a - basic circuit; b - display the monitoring process on the smart phone screen***

The automated system allows:

- determine the sound trend;
- predict the cutting tool resource and calculate the state index value $a_Q$;

- calculate (choose with their step change) directly in the cutting process the optimal cutting mode, allowing to complete the current technological transition, thus eliminating the tool breakage and the part defect;
- display the monitoring results in a visual form on the microprocessor device screen (Fig. 2 b);
- document the control results in the form of the "Cutting Protocol ...", stored in a text file.

On the screen, colors show the indicators change in the cutting process, characterizing the cutting quality $a_Q$, surface roughness $a_R$ and tool technical condition $a_{ACC}$.

## Conclusion

A methodology for quality control of material processing by cutting has been developed, which is based on the calculation of the state dimensionless index $a_Q$. The state index is developed according to the theory of "fuzzy sets" and is a linguistic variable that allows to give a verbal characteristic of the instrument critical state degree, evaluating simultaneously the quality of part processing.

The state indicators, calculated using "membership functions", allow us quantitatively describe various technological working conditions of the instrument from a single methodological position and to compare them with a number of standard (similar) working conditions. This makes it possible to compensate for the lack of normative documentation, which regulates the criticality degree of the cutting machine tool technical condition.

The quality control of the cutting process is automated.

***Acknowledgments:*** *The authors would like to thank the KEGA grant agency for supporting research work the project KEGA: 004TUKE-4/2017*

## References

[1] ISO2372 -Vibration severity. http://www.impact engineering.com/Vibration%20Severity%20-%20ISO%202372%20Chart.pdf
[2] Zade LA The concept of a linguistic variable and its application to making approximate decisions .- M.: The World, 1976. - 165 p.
[3] Handbook of the technologist - machine builder: in 2 t. / ed. A.G. Kosilova and R.K. Meshcheryakova. - 4 th ed. - M.: Mechanical Engineering, 1985. - T. 2. - 496 p.
[4] Nagorny V.V. Monitoring the dynamic state of the metalworking technological system and forecasting its resource. - Sumy: Sumy State University, 2016. - 242 p. http://essuir.sumdu.edu.ua/handle/123456789/44431.

## Contact address

(1.) prof. Ing. Anton Panda, PhD.
Technical university in Košice, Faculty of manufacturing technologies with the seat in Prešov, Štúrova 31, 080 01 Prešov, Slovakia, e-mail: anton.panda@tuke.sk
(2.) Senior Lecturer, Volodymyr Nahornyi, PhD.
Sumy State University, Faculty of Electronics and Information Technology, Section of Information Technology of Design, 2, Rymskogo-Korsakova st., 40007 Sumy, Ukraine
e-mail: v.nahornyi@cs.sumdu.edu.ua