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VARIATIONS OF TECHNOLOGICAL COSTS AND PRODUCTIVITY WHEN MACHINING USING MULTIPLE CUTTING TOOLS

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ABSTRACT: *Research has been conducted on the influence of the variation of durability of cutting tools on the technological costs and productivity when machining using multiple cutting tools and multiple-purpose machines. The examples are given assuming that the variation of durability follows the log-normal law.*
KEYWORDS: *durability, cost, productivity, cutting mode*

INTRODUCTION

The technical and economical results of manufacturing companies depend to a considerable extent on the reliability of the technological system elements. One of them appears to be the cutting tool. The experience from the technological systems investigation shows that cutting tools are most unreliable. Variation of cutting tools durability causes decrease of productivity, increase of costs and expenses on tools, production waste decrease and on the whole destabilizes the production process.

The defining of optimal cutting conditions when machining, using multiple cutting tools on multiple-purpose machines (MPM), is usually carried out by determined mathematical models [1, 4]. The experimental investigations and practical applications show that the variation of the metal cutting tools durability can be considerable. Therefore, if the instruments of the MPM work at optimal cutting conditions, defined by the determined mathematical model, in real conditions various technological costs and productivity will be obtained. The variation of the technological costs, caused by the variation of cutting tools durability, is investigated in [4, 5] but only for a single replacement of the tools and for a specific case of machining, using multiple cutting tools.

AIM OF THE RESEARCHING

The purpose of the present research is to investigate the variation of the technological costs and productivity when machining by means of multiple cutting tools on MPM, but also to determine quantitatively their relative average alteration for different variety levels of the cutting tools durability in a single and group replacement.

RESEARCH METHODOLOGY

This research was carried out, following a methodology, based on the statistical modeling of the replacement moments of worn-out cutting tools on MTM. It is assumed in such a modeling that the durability variation T of the cutting tools is described by a log-normal law with a density distribution [6]:

$$f(T)=\frac{1}{T\sqrt{2\pi}b}e^{-\frac{(\lg T-a)^2}{2b^2}},\ T>0;\ b>0. \qquad (1)$$

The law parameters a *and* b *are calculated, using the following formulas:*

$$a=\left\{\frac{(m_1[T])^2}{\sqrt{\sigma^2[T]+(m_1[T])^2}}\right\}, \qquad (2)$$

$$b=\sqrt{\ln\left\{\frac{\sigma^2[T]+(m_1[T])^2}{(m_1[T])^2}\right\}}, \qquad (3)$$

where: $m_1[T]$ *is the mathematical expectancy and* $\sigma^2[T]$ *is the dispersion.*

The technological cost A *needed for the production of a single MPM part, which depends on the elements of the cutting conditions, includes the cost of payment of the machine work time* A_1*, the cutting tools replacement and regulation costs* A_2 *and the expenditure costs* A_3 *for the production of a single part:*

$$A = A_1 + A_2 + A_3 \ . \qquad (4)$$

The productivity of the MPM, determined by the time $t_Д$, for the production of a single part is:

$$Q = 60 / t_Д, \text{ part/h.} \qquad (5)$$

The dependency of these costs on various factors is determined by parallel work of the force knots (FK) with instrumental appliances (IA) or instrumental compositions (IC), put on motion by a separate force head and either by an individual or a group cutting tools replacement.

Example: The force knots of an MPM are M in number, each of them puts on motion one IA or one IC. The IA of every j-FK has N_i number of instrumental blocks (IB). The instrumental block (IB) appears to be an aggregation of identical instruments, working under equal conditions. Each i-block of an j - IA (IC) has z_{ij} number of instruments.

The equations of the technological costs and productivity by a parallel work of the IA (IC) and an individual cutting tools replacement are [2]:

$$A = t_{рл}.E + \sum_{j=1}^{M} \sum_{i=1}^{N_j} z_{ij} \left[(E + E_н).t_{смij} + e_{ij} \right] . \ \frac{t_{pij}}{T_{ij}}, \text{ BGN/part.,} \qquad (6)$$

$$Q = 60 / \left(t_{рл} + \sum_{j=1}^{M} \sum_{i=1}^{N_j} z_{ij} . t_{смij} \frac{t_{pij}}{T_{ij}} \right), \text{ part/h.} \qquad (7)$$

By a group cutting tools replacement the equations are [2]:

$$A = t_{рл}.E + \sum_{k=1}^{R} \frac{t_{рк}}{T_{длк}} \sum_{e=1}^{N_k} z_{ek} \ . \left[(E + E_н).K_{смк}.t_{смek} + e_{ek} \right], \text{ BGN/part.,} \qquad (8)$$

$$Q = \frac{60}{t_Д} = 60 / \left(t_{рл} + \sum \frac{t_{pk}}{T_{длк}} . K_{смк} . \sum_{e=1}^{N_k} z_{ek} . t_{смek} \right), \text{ part/h.} \qquad (9)$$

Sufficiently great durability numbers are generated for each instrument and their distribution follows the log-normal law. The law parameters a and b are calculated by (2) and (3). The mathematical expectancy assessment is considered to be cutting tool durability, obtained through the optimal cutting condition, defined by a determined mathematical model [1], while the dispersion is calculated by the variation coefficient $V(T)$:

$$\sigma^2[T] = (V[T].m_1[T])^2 . \qquad (10)$$

By the individual cutting tools replacement for each instrument from the ij IB of the MPM, in the l replacement, the total durability in minutes machine work is determined by the formula:

$$T_{мijl} = T_{мij,l-1} + T_{ijl} + t_{смij}, \qquad (11)$$

where T_{ijl} is the generated cutting tool durability of the ij IB, by its 1 replacement in minutes work of the MPM.

The process of the statistical modeling is terminated when the following condition for any of the MPM instruments is achieved:

$$T_{мijl} \geq T_ф, \qquad (12)$$

where: $T_ф$ is the accepted stock of time, needed for the modeling of the cutting tools replacement. ($T_ф$ = 250000 min).

The statistical modeling of the group cutting tools replacement is realized under the condition that all cutting tools from the group are replaced at the same time, if only one of them had been worn out. The summarized group durability is determined in minutes work of MPM by each replacement of the instruments of a particular group through using their generated durability:

$$T_{мkl} = T_{мk,l-1} + T_{kлl} + t_{смk}, \qquad (13)$$

where $T_{мk,l-1}$ is the summarized durability of the k group during the l-1 replacement;

$t_{смk}$ is the replacement time of the instruments of the k group.

Modeling is applied to a cutting tools replacement from the group to which the instrument with the lowest summarized durability belongs. The statistical modeling is terminated when condition (12) is fulfilled for any of the MPM cutting tools.

If A_M and Q_M are correspondingly the technological cost and the productivity, obtained in optimal cutting conditions and determined by the mathematical model and A_i u Q_i are the corresponding values, obtained during the i statistical test, then the following is obtained for the relative alteration of the technological cost ΔA_i and for the productivity ΔQ_i:

$$\Delta A_i = A_i / A_M ; \quad \Delta Q_i = Q_i / Q_M . \tag{14}$$

The average value of the relative technological cost alteration $\Delta \bar{A}$ and the average value of the relative productivity alteration $\Delta \bar{Q}$ are calculated by the formulas:

$$\Delta \bar{A} = \frac{1}{m} \sum_{i=1}^{m} \Delta A_i ; \quad \Delta \bar{Q} = \frac{1}{m} \sum_{i=1}^{m} \Delta Q_i , \tag{15}$$

where: m is the number of the statistical tests.

The ΔA_i u ΔQ_i values are grouped in intervals with a number $k = 5 \lg m$ and the histograms of their distribution are determined.

In order to generate the random durability T_i, to determine the ΔA_i, ΔQ_i, $\Delta \bar{A}$, $\Delta \bar{Q}$, the intervals and the relative frequencies, a computer program is developed, facilitating the investigation of the influence of the durability statistical character on the technological cost and on the productivity by the statistical modeling of the cutting tools replacement.

Table 1.

MPM	A_M BGN./part	Q_M part/h	$V[x]=0,1$		$V[x]=0,3$		$V[x]=0,5$	
			$\Delta \bar{A}$	$\Delta \bar{Q}$	$\Delta \bar{A}$	$\Delta \bar{Q}$	$\Delta \bar{A}$	$\Delta \bar{Q}$
MPM-1	0,0582 0,0549	78,8 82,4	1,0002 1,0268	0,9999 0,9910	1,0022 1,1004	0,9990 0,9675	1,0063 1,2114	0,9972 0,9342
MPM-2	0,1190 0,1127	58,5 62,0	1,0001 1,0338	0,9999 0,9778	1,0007 1,1331	0,9995 0,9186	1,0018 1,2908	0,9986 0,8399
MPM-3	0,1439 0,1391	71,0 75,7	1,0003 1,0301	0,9999 0,9880	1,0023 1,1137	0,9987 0,9565	1,0062 1,2426	0,9964 0,9124
MPM-4	0,0460	90,4	1,0011	0,9996	1,0085	0,9968	1,0230	0,9914
MPM-5	0,2563	39,4	1,0058	0,9992	1,0199	0,9971	1,0514	0,9927
MPM-6	0,1187	82,5	1,0005	0,9997	1,0043	0,9976	1,0119	0,9935

The data in the numerator for the last three machines are related to the individual cutting tools replacement, while the data in the denominator are related to the group cutting tools replacement.

RESEARCH RESULTS

Research of five MPMs is carried out (table 1). The optimal cutting conditions are determined for all the five MPMs by an individual cutting tools replacement, while for MPM-1, MPM-2 and MPM-3 the optimal cutting conditions are determined for the group replacement too through the program complex ORAM [3]. Using the instruments durability values, obtained by these cutting conditions as a mathematical expectancy and by giving values of 0,1; 0,3 and 0,5 to the variation coefficient, a statistical modeling of the cutting tools replacement is carried out.

The histograms of the empirical distribution of the technological cost and productivity relative alteration, resulting from the durability dispersing, are of an asymmetrical character.

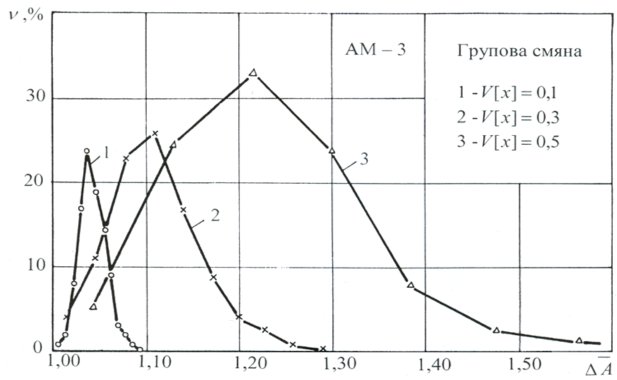

Fig. 1. Distribution of the technological cost relative alteration by a group change cutting tools

Figure 1 shows the empirical distribution histogram of the technological cost relative alteration for the group cutting tools replacement for MPM-3. Similar is the histogram character for *all the other MPMs. By decreasing the variation coefficient the asymmetric character of the histograms also decreases and at $V[T]=0{,}1$ it approximates the symmetric distribution.*

From the research carried out by an individual cutting tools replacement (fig. 1) it was determined that by changing the variation coefficient from 0,1 to 0,5 the average technological cost increase is in the ranges from 0,01% to 5,14%, while the average productivity decrease is from 0,01% to 0,86%. Generally, the admissible dispersing of the cutting tools durability when machining, using multiple cutting tools, is the one when the variation coefficient is not higher than 0,35. The cost and productivity alteration of the investigated MPMs is inconsiderable in such a durability dispersing.

The technological cost and productivity dispersing is considerable by group cutting tools replacement. The average technological cost increase for the investigated MPMs is from 2,68% to 29,08%, while the average productivity decrease is from 0,9% to 16%.

Recognizing the durability dispersing facilitates the determination of the most beneficial cutting tools replacement conditions. For example, for MPM-1 at the cutting conditions, defined by the determined mathematical model, for both aimed replacements the group one is the appropriate one (table 1). For the same MPM at $V[T]=0{,}3$ and an objective function the technological cost, more beneficial proves the individual replacement.

CONCLUSIONS

- *The proposed methodology for a statistical modeling of the cutting tools replacement and the developed computer programs expand the applications of PC ORAM.*
- *The cutting tools replacement conditions and the technological cost and productivity values can be determined more precisely by more particular dispersing values.*

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