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EFFECT OF CUTTING DATA SELECTION ON PRODUCTIVITY IN FACE MILLING

Face milling as a cutting procedure is used for high productivity manufacturing of prismatic components. In the automotive industry, characterized by mass production, the enhancement of productivity is a primary goal for manufacturing companies. There is a wide range of methods for increasing productivity. This paper analyses how productivity can be increased by the machining time, material removal rate and surface rate by choosing the appropriate cutting data. Cutting experiments were carried out for machining prismatic components and the change in machining time was analysed. It was proved that within the performance limits of the WGMT (Workpiece – Gadget – Machine – Tool) system a significant amount of manufacturing time and therefore cost can be saved while the geometric accuracy and surface quality of the component remain as specified in the blueprint.

1. INTRODUCTION

Increasing the machining efficiency of surfaces with different shape and quality became extremely important in recent decades in the automotive industry because the number of machined parts produced in great masses increased significantly. Moreover, in mass production an infinitesimal decrease in the machining time of one workpiece means a significant increase in total annual revenue and profit. The conditions for competitiveness of automotive industrial companies are the enhancement of production efficiency, innovation, and profitability. Considering the analysis of efficiency from a technical point of view, it can be approached from numerous directions: choosing the proper machining procedure or version of the procedure, optimization of cutting data, and performance enhancement of machine tools and equipment. Not only technological but also manufacturing process organization possibilities are available, and they become more and more important in cost-efficient manufacturing of the whole lot size [1]. In any of these improvement directions a company intends to offer its product to the customer at lower cost and higher profit. If the machining time of a component or a lot becomes lower as the result of a certain improvement, the production of more or other components can be undertaken in the extra free time. This results in higher profit as well as increased revenue and cost. If the goal is not volume increase, then the production cost of the fixed number components can be decreased, which also facilitates an increase in profit. Previous analyses introduced the effects of procedure choice on productivity [2, 3]. In [4] the material removal rate of hard turning, grinding and the combination of them was analysed in a detailed manner. When machining prismatic components not only the proper determination of the tool path or the material removal strategy but also the determination of the cutting data for decreasing machining time is of critical importance nowadays [5, 6]. In milling, as in other types of machining, a necessary condition that changes in the cutting data must not negatively affect the surface quality and accuracy specifications of the component [7, 8, 9]. When making technological decisions, economic factors also have to be considered. The effect of cutting data on the intensity of material removal is analysed in the paper in case of face milling.

2. PARAMETERS CHARACTERIZING MATERIAL REMOVAL EFFICIENCY

One alternative for analyzing the efficiency of cutting procedure is their comparison on the basis of the cutting parameters. These characterize a certain type of technology intensity. They are the following:

- material removal rate – Q_w [mm^3/s],
- surface rate – A_w [mm^2/s].

Q_w expresses how many units of material can be cut during one unit of time and A_w expresses how many units of surface area can be finished during one unit of time with a given procedure. The theoretical values of cutting parameters can be exactly calculated using the technological data of the given cutting procedure. The cutting parameters for face milling can be calculated as follows:

$$Q_w = a_p \cdot a_e \cdot v_f \ (\text{mm}^3/\text{s}) \tag{1}$$

$$A_w = a_e \cdot v_f \ (\text{mm}^2/\text{min}), \tag{2}$$

where a_p is depth of cut [mm]; a_e is width of cut [mm]; v_f is feed rate [mm/min].

From the equations for Q_w and A_w it can be seen that the calculation of the two parameters differs only in the depth of cut. In our case depth of cut can basically be considered as fixed (in the analyzed case it is the almost same volume of material that can be removed in one pass) and therefore it is enough to analyze the factors influencing the surface rate. Since the diameter of the milling tool always exceeds the variable width of the workpiece surfaces when machining prismatic components whose surfaces are machined by face milling, the length of the tool path has to be taken into account instead of the a_e value influencing the size of machined surface (Eq.(3)).

$$A_w = L \cdot v_f \ [\text{mm}^2/\text{min}], \tag{3}$$

where L is length of tool path [mm].

In machining plane surfaces of a concrete block-like part the length of tool path remains the same even if the cutting data are changed. Thus the surface rate (and the efficiency of machining) is influenced basically only by the v_f feed rate. The v_f feed rate in face milling can be calculated as follows:

$$v_f = f_z \cdot z_s \cdot n_s \text{ [mm/min]}, \quad (4)$$

where f_z is feed per edge [mm/pc]; z_s is the number of cutting edges [pcs]; n_s is revolutions per minute (*rpm*) [1/min].

From the formula of feed rate v_f it can be seen that the surface rate can be increased by:

1. increasing the feed per edge (f_z);
2. increasing the number of cutting edges (z_s);
3. increasing the *rpm* (or cutting speed).

Accordingly, to increase the efficiency two parameters are chosen. Feed was determined by recommendations in the literature and on the basis of experimental results. The increase of number of cutting edges z_s of a given tool construction can be ensured by the increase of the tool diameter, so this goal can be reached by choosing a higher diameter tool. In this paper, however, the number of cutting edges is considered as fixed. Increase in the *rpm* of the tool (n_s) is possible due to the aluminum-alloy specific cutting characteristics of a diamond tool, taking into consideration the performance limits of the machine tool.

3. CONDITIONS OF THE EXPERIMENT

The goal of the experiments was to measure the base time of face milling operation components when machining prismatic components. This served as the basis for calculating the main and additional machining time. A matrix is constructed to introduce the experiment plan for increasing f_z and v_c (or n_s). The values used in the current technology are considered as the basic parameters (d_s=63 mm [z_s=12], n_s=12500 1/min, f_z=0.12 mm). Four values of the feed per cutting edge were analyzed at three *rpm* values. The v_f/v_{f0} cells of the Table 1 show in percentage form how the feed rate (v_f) changes with the base feed rate (v_{f0}). The base value is considered as 100%; the change in main machining time is the reciprocal value of this. The experiment plan is summarized in Table 1.

Table 1 – Experiment plan experiment

d_s [mm] z_s [–]	n_s [1/min] v_c [m/min]	v_f [mm/min] v_f/v_{f0} [%]	f_z [mm/edge]			
			0.12	0.13	0.14	0.15
63 (12)	12500 (2474)	v_f	18000	19500	21000	22500
		v_f/v_{f0}	100	108	117	125
	13000 (2573)	v_f	18720	20280	21840	
		v_f/v_{f0}	104	113	121	
	13500 (2672)	v_f	19440	21060	22680	
		v_f/v_{f0}	108	117	126	

The experiment was carried out on workpieces in production. The base time of face milling was defined as the period between the end of milling tool manipulation and the end of positioning to tool change coordinates after machining the plane surfaces.

Main specifics of the experiment:
Machine tool: DMG MORI DMC 60 H linear type machining center
Tool: Lach Diamant MB-X3-063-08-Z12/P type soldered diamond insert face milling head; d_s=63 mm, z_s=12, κ_r=90°
Workpiece material: AlSi9Cu3(Fe)
Cutting data:

- cutting speed: v_c=2474–2672 m/min
- *rpm* of main spindle: n_s=12500–13500 1/min
- depth-of-cut: a_p=1.5 mm (average)
- feed per one cutting edge: f_z=0.12–0.15 mm/edge

4. EXPERIMENTAL RESULTS AND DISCUSSION

The analysis was carried out on the machining time data. In the currently applied technology, machining time is:

$$t_m = t_b - t_a = 19.35 - 13.9 = 5.45 \text{ s}, \quad (5)$$

where t_m is main machining time; t_b is base time; t_a us additional machining time.

For the component of the experiment the machining time, the change of it in percentage form, and the change of adjusted machining time (referring to one workpiece) were determined in each experimental setup. The data are given in Table 2. The change in machining times is plotted in Fig. 1.

Table 2 – Time data and cutting data of the components of the experiment

№	n_s [1/min]	f_z [mm/edge]	v_f [mm/min]	v_f/v_{f0} [%]	t_m		Δt_m [s/pcs]
					[s]	[%]	
1	12500	0.12	18000	100.00	5.45	100.00	0.00
2		0.13	19500	108.33	5.03	92.31	-0.42
3		0.14	21000	116.67	4.67	85.71	-0.78
4		0.15	22500	125.00	4.36	80.00	-1.09
5	13000	0.12	18720	104.00	5.24	96.15	-0.21
6		0.13	20280	112.67	4.84	88.76	-0.61
7		0.14	21840	121.33	4.49	82.42	-0.96
8	13500	0.12	19440	108.00	5.05	92.59	-0.40
9		0.13	21060	117.00	4.66	85.47	-0.79
10		0.14	22680	126.00	4.33	79.37	-1.12

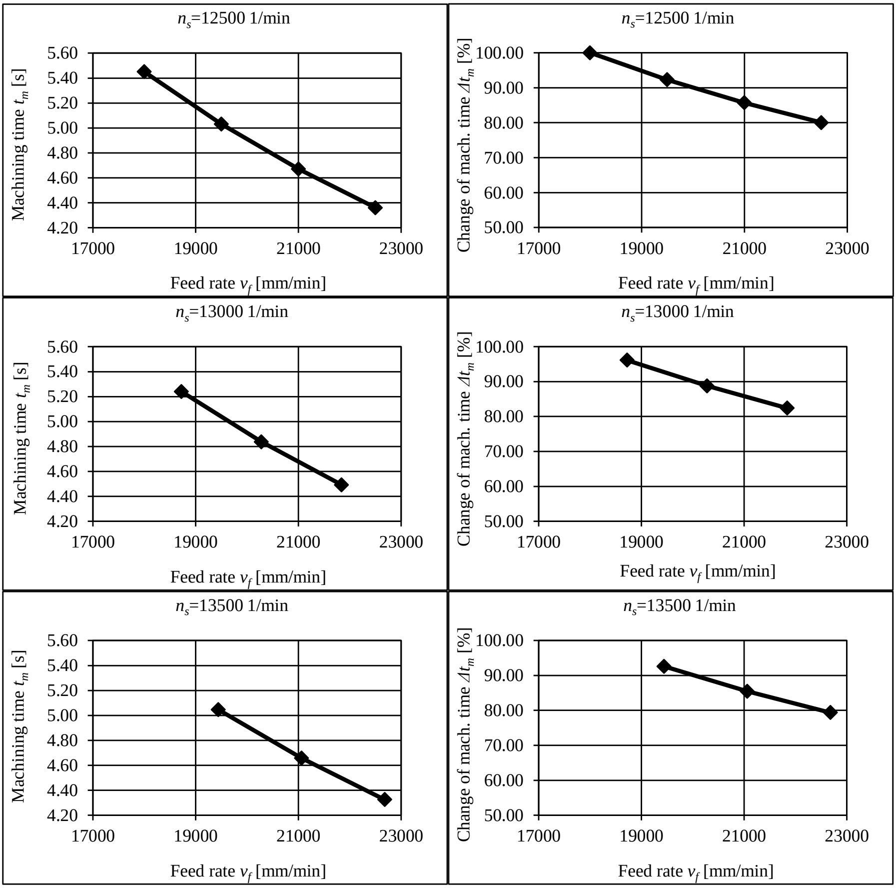

Figure 1 – Change in machining time with feed rate

From the results it can be stated that the strategy determined on the basis of the surface rate, the material removal rate and time analysis proved valid. The two alternatives, namely increasing of *rpm* and feed rate, allow reduction of machining time in the current machining system. In each experimental setup time was saved, i.e. increasing the *rpm* from 12500 to 13500 resulted in the reduction of machining time to 92.6%. Increasing the feed rate (in the case of f_z=0.14 mm/edge) at the three *rpm* values reduced the machining times to 86, 82 and 79%, respectively.

In serial manufacturing the reduction of machining time results in the reduction of operation time, too. This reduction allows extra free capacity while the direct and indirect costs of manufacturing can also decrease. It was shown that increasing the values of cutting data increases material removal rate and surface rate, which measure the intensity of the applied technology. The change in cutting data influences the WGMT system. When taking improvement measures the performance limits of the system have to be considered. If the increase in cutting values remains within the load bearing capacity of the machine tools, a significant amount of cost can be saved by the intervention.

5. SUMMARY

In machining aluminum components produced in large lot sizes the material removal rate and surface rate proved to be an efficient method to determine intensity. Using these rates, cutting data can be provided that will help in increasing the productivity and profitability compared to the current technology, if correctly chosen. Changing each of the two analyzed parameters (f_z and v_c) can save time, but a parallel change of both allows the reduction of machining time by 15–20%, which is significant in the case of large lot sizes.

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