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CHIP REMOVAL CHARACTERISTICS WITH CONSTANT CHIP CROSS-SECTIONAL AREA AND DIFFERENT a_p/f_z RATIOS IN FACE MILLING

A main development direction in production engineering is the of the enhancement productivity of machining procedures among the increasing of the accuracy and the improvement of surface quality. Since the sizes of blanks are getting closer to the final prescribed dimensions of the parts, the depth of cut and/or the number of passes decreases. Therefore, the improved productivity in face milling can be achieved by the increase of the cutting speed and/or the feed rate values. Due to the spread use of high speed milling procedures the possibilities in the cutting speed increase are more or less applied, so the study of feed rate intensification came into view. Thus, the previously applied $a_p/f_z>1$ rate turns into $a_p/f_z<1$ as the feed rate becomes higher. We describe our research results in face milling in this paper, which were carried out to analyse the chip removal during the alteration of scale rate (shape) of the chip.

1. INTRODUCTION

In the field of manufacturing technology, it is important to develop that machining procedures besides the novel procedures, which are already applied in the industrial practice [1,2]. In cutting three main development areas can be distinguished:

- increase of productivity [3,4,5],
- develop the achievable accuracy [6,7],
- improvement of the machined surface quality [8,9].

Face milling is one of the most spread cost-efficient machining procedure of planar surfaces [10]. Researches are also being carried out on this procedure on all three areas. The topic of our present paper was to increase productivity. One characteristic parameter of that attribute is the material removal rate, where the highest possible value should be achieved. This is the function of the depth of cut, the feed per tooth and the cutting speed according to the known equation [11]. Since the geometrical dimensions of the blanks are getting closer to the designed final dimensions of the parts, the number of passes and/or the depth of cut are typically decreased. The depth of cut is given or its change is limited, therefore its effect on productivity is also limited [12].

The possibilities in the cutting speed increase are more or less utilized by the application of high speed machining. These procedures are increasingly used in the industry [13,14].

Because of the above, the possibility of increasing the feed rate has come into view [15, 16]. This has been put into the focus of our research too. The shape of the chip cross-sectional area can be affected by the adjustment of the feed. One characteristic of this shape is the ratio of the depth of cut and the feed per tooth, which is known as a_p/f_z ratio. Traditionally this ratio is typically greater than 1 in face milling, which means that the depth of cut is greater than the feed per tooth. In high-feed milling our aim is to decrease this ratio ($a_p/f_z < 1$). Consequently, the machined surface roughness and the cutting forces needed for the chip removal are modified. If we would like to analyse the effect of chip shape, it is expedient to make the sectional area constant during our investigation ($A_c = a_p$ x f_z = constant).

In this paper, we study the effect of the chip shape on some characteristics of the chip removal with cutting experiments and finite element analysis.

2. EXPERIMENTAL CONDITIONS

The milling experiments were carried out on a Deckel Maho DMU 60 E type machining centre which meets our experiment requirements due to its high performance (P_{max} = 15 kW, n_{max} = 12,000 1/min) and rigidity. A C45 steel was chosen for the machined workpiece material, which was heat threated to 300 HV10 hardness. The machined surface dimensions were 250 mm X 70 mm.

A custom made cutting tool were applied during the experiments, which had one insert to analyse the nature of the cutting force during contact. An OCKX 0606 AD-TR octagon shaped cutting insert was used in the experiments, where the major cutting edge angle was 45°, however it also features an edge section for the finish, which is parallel with the machined surface. The other geometric attributes are: rake angle: 25°, flank angle: 7°, nose radius: 0.5 mm, insert width: 16 mm. The edge of the tool describes a115 mm diameter during machining. The material of the working part was P40 coated ceramic.

A three-axial Kistler Typ 9255B Dynamometer was applied for the cutting force measurement during the machining. The explanation of the force components acting on the workpiece can be seen on Fig. 1. The parameters on the figure: F_x, F_y, F_z: the x,y,z directional cutting force components acting on the workpiece, $v_{f,w}$: feed rate of the workpiece, ns: number of revolutions of the tool, α: half of the contact angle. The typical sections of the tool revolution are interpreted from Fig.1.

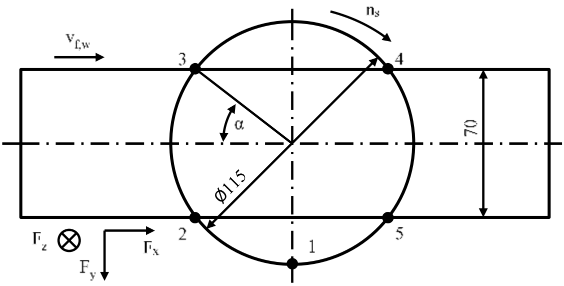


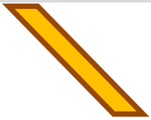
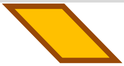
Figure 1 – Explanation of the cutting force components

Starting from Point 1 there is no contact between the tool and workpiece until Point 2. In this latter point a dynamic effect generated on the insert. The chip removal from the workpiece occurs between Point 2 and 3. During this section the absolute value of F_y force component increases continuously until the symmetry plane, from where it slowly decreases until the end of the section. The F_x force component will be negative in the first half and positive in the second half of the section. After the insert passes Point 3 there will be no contact between the tool and the workpiece until Point 4. The edge touches the machined surface between Point 4 and 5, however this contact occurs only in the zone of the roughness peaks. After leaving Point 5 the cutting edge returns to the starting point of our interpretation without interaction. In this paper, we examined the section between Point 2-3.

The adjusted cutting parameters for the experiments were chosen in a way that we can analyse the effect of the chip shape alteration. As the cross-sectional area remained a constant 0.08 mm^2 value, we varied the a_p/f_z rate in four steps: 0.25, 0.5, 1, 4 (Table 1). The cutting speed were chosen to 200 m/min value, which resulted in 554 1/min revolutions of the tool. On the chip shapes can be seen in the table that the side parallel to the machined surface increases and the perpendicular side decreases as the feed increases with constant cross-sectional area. The insert was in cut for 0.02249 sec and the rotational angle belonging to this was 74.99°.

The finite element simulations were done with the ThirdWave Advantedge software.

Table 1 – Applied parameters during the experiments

Case	**1**	**2**	**3**	**4**
A_c	0.08	0.08	0.08	0.08
f_z	0.1414	0.2828	0.4	0.5656
a_p	0.5656	0.2828	0.2	0.1414
a_p/f_z	4	1	0.5	0.25
v_f	78.288	156.576	221.433	313.153
shape				

3. EXPERIMENTAL RESULTS AND DISCUSSION

The measuring system collected the force affecting the workpiece in three (mutually perpendicular to each other) force components during our experiments. These can be seen on Fig. 1 as well:

- F_x – force component affecting in the feed direction

- F_y – perpendicular to the feed direction in the plane of the machined surface, which points to the direction of the revolution of the tool
- F_z – perpendicular to the machined surface, which points into that

The registered cutting force diagrams for Case 1-4 can be seen in Fig. 2.

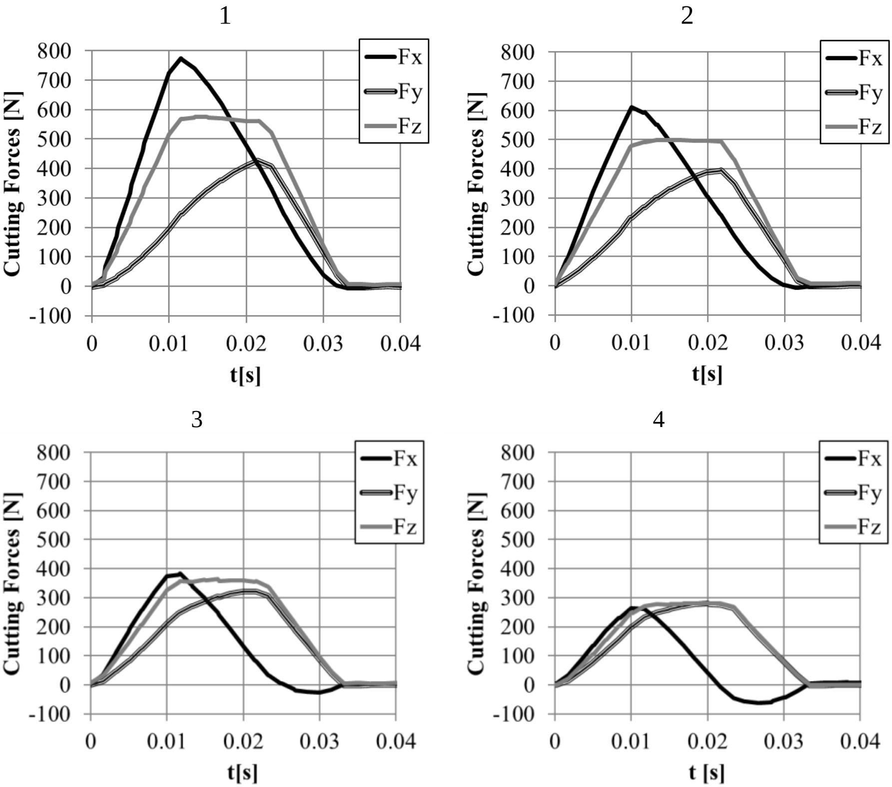


Figure 2 – Cutting force components as a function of time in Case 1-4

During the evaluation of the force components, these were transformed to the positive plane and we calculated the average of the ten percent range of the maximum values. In addition, the required cutting power is also calculated from the maximum values of the Y directional force (which is the same as the maximum cutting force in the symmetry plane). In Table 2 these values can be seen.

Table 2 – The force components and the calculated power consumption

Case	F_x [N]	F_y [N]	F_z [N]	P_c [W]
1	749.85	396.82	558.21	1421
2	584.15	365.64	485.90	1318
3	378.84	300.43	352.48	1072
4	263.12	266.31	273.61	933

The values presented in the table can be seen in a diagram in Fig. 3. It can be seen in each case after examining the three force components that the greatest is the F_x force, which is pointing into the direction of the rotation in the symmetry plane, and the smallest is F_y force which is parallel to the feed direction. The force perpendicular to the machined surface (F_z) is between the former two in value. However, the ratio between the three force components is not constant. If the $a_p/f_z < 1$, the F_x component less dominant namely only a small difference (0-20%) can be observed compared to the others. If the chip ratio is greater than 1, the F_x force component becomes dominant and it shows a higher difference (20-40%) to the others.

It can be concluded that the decrease of the a_p/f_z ratio (and so the increase of the feed per tooth) leads to decreasing force components in case of constant cross-sectional area of the chip. The X directional force changes the most among the three component, in the eighth value of the chip ratio it is halved. In the same case, the F_y force decreases by 30% and the F_z decreases by 60%.

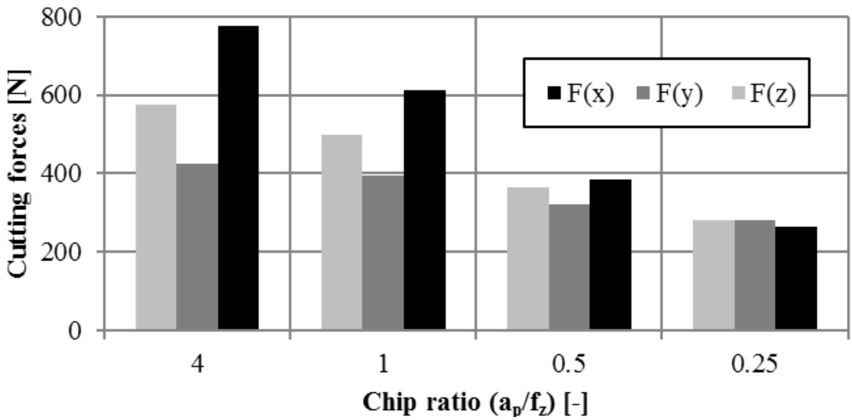


Figure 3 – The cutting force components as a function of the chip ratio in Case 1-4

In addition to the cutting experiments finite element simulations were carried out with the ThirdWave AdvantEdge 3D FEM software. In this paper, we show some partial results. Firstly, it can be said about the edge section which performs the chip deformation from Fig. 4, that in high a_p/f_z ratio it occurs on the 45° angle edge, in $a_p/f_z = 1$ it takes place near the tool tip, in $a_p/f_z < 1$ it appears on the parallel edge of the insert. Furthermore, from the simulation it can be deducted, that the chip height changes preferably as the a_p/f_z ratio decreases, because it becomes thinner.

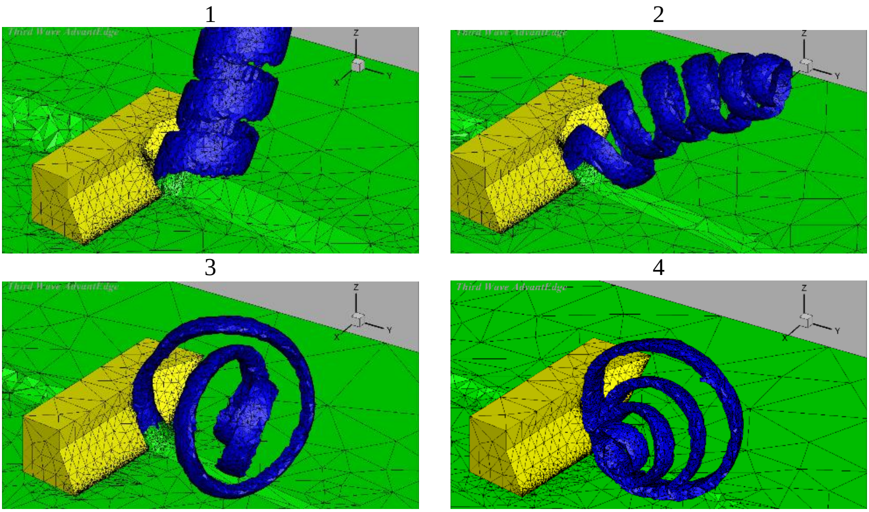


Figure 4 – Chip deformation in a_p/f_z = 4, 1, 0.5, 0.25

The resulted performance graphs from the FEM simulations were also shown in Fig. 5 to compare them to the values determined from the cutting experiments. It can be stated that in both cases the reduction of the a_p/f_z ratio results in the decrease of the consumed power, but the values of the FEM are smaller than those from the cutting experiments.

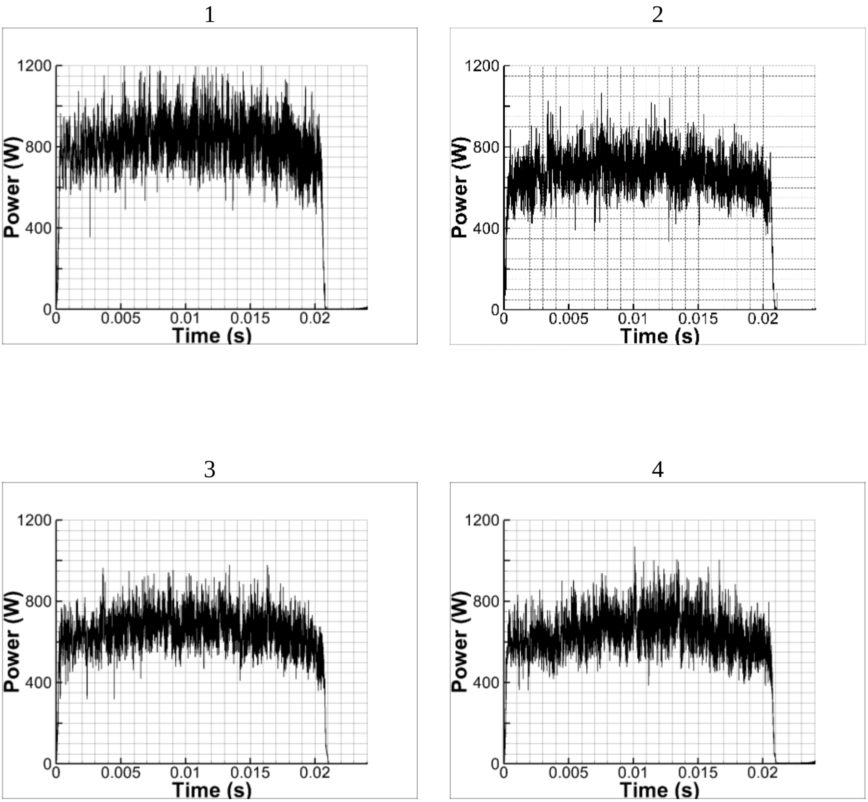


Figure 5 – Needed cutting power in a_p/f_z = 4, 1, 0.5, 0.25

This favourable change is well visible in the values and distribution of the temperature which characterizes the chip removal (Figure 6). In high a_p/f_z ratio the temperature is higher and it loads mostly the side edge. However, in lower chip ratio the temperature is lower and it loads primarily the parallel edge.

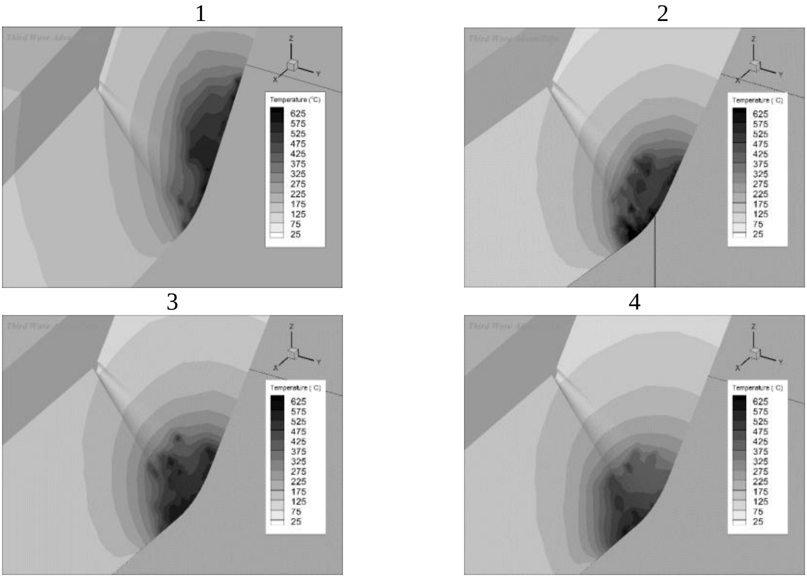


Figure 6 – Temperature of the tool rake in a_p/f_z = 4, 1, 0.5, 0.25

4. SUMMARY

The effect of the depth of cut and feed per tooth ratio on the values and rate of the force components was analysed with cutting experiments in face milling. We concluded that the chip removal process can be affected favourably with the increase of the feed rate and the decrease of the depth of cut in constant chip cross-sectional area. Thus each component of the cutting force and therefore the needed power can be significantly decreased. Lower temperature occurs on the cutting edge flank and the load distribution from the pressure change as well. Overall, it can be stated that the further investigation of the feed alteration effect is advisable to determine its as higher, still applicable value, because with its increase the machining time decreases proportionally.

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