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*face milling, cutting forces,*

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# MODELLING OF COMPONENTS OF RESULTANT FORCE DURING FACE MILLING

Cutting forces during face milling are investigated intensively analytically and experimentally. Some of previous approaches to cutting forces determination consider only main (tangential) cutting force component, and according to this define cutting power. The experimental investigations were performed during face milling with a goal to determine models of cutting force versus cutter revolution. Different models were determined according to the cutter approach to the workpiece during cutting angle of revolution.

## 1. INTRODUCTION

Face milling process is one of the most often used and the most efficient process among high productive machining processes. It is logically that the most of the papers and investigations are connected with this machining process. Cutting forces during face machining are investigated intensively analytically and experimentally. Some of previous approaches to cutting forces determination consider only the cutting force and according to this define cutting power. Later attempt consider other cutting force components also.

Face milling processes particularly multi tooth milling, that are simultaneously cutting with difference in chip cross section so that one tooth cut influences development of a variety of models for cutting force calculation. Variation in chip cross section gives difference in intensity of cutting forces and thermal load of single tooth.

For easier cutting force model definition, usually is considered case of one tooth milling cutter cutting where cutting width is equal to cutter diameter D. In this case chip cross section is as shown in Fig. 1.

During experimental investigations in milling process by dynamometer it is possible to measure only in three orthogonal directions x, y, z (Fig. 1). For determination of function $F_i = f(F_x, F_y, F_z)$, i = (v, p, s) it must be expond measured values of cutting forces components in this directions. In this way cutting force components $F_v$, $F_p$ i $F_s$ are calculated according to the following equations:

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$$F_v = -F_x \cdot \sin\varphi - F_y \cdot \cos\varphi \tag{1}$$

$$F_p = F_x \cdot \cos\varphi - F_y \cdot \sin\varphi \tag{2}$$

$$F_s = -F_v \cdot \cos\varphi - F_p \cdot \sin\varphi = F_y \tag{3}$$

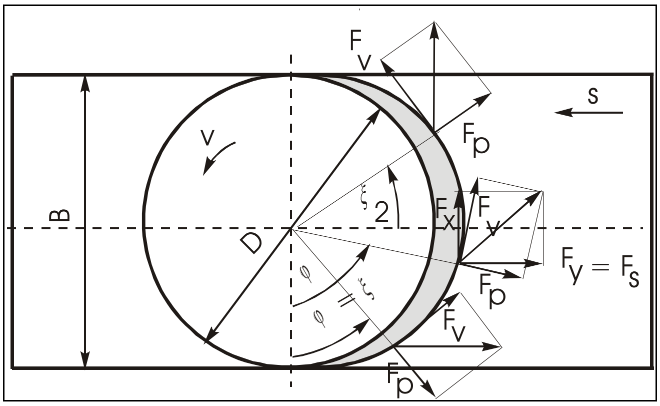


Fig. 1. Scheme of cutting forces [2]

Using the equations (1), (2) and (3) is possible to determine diagrams of the cutting force $F_i$ flow versus cutting time or position angle of a tooth during cutting (Fig. 2).

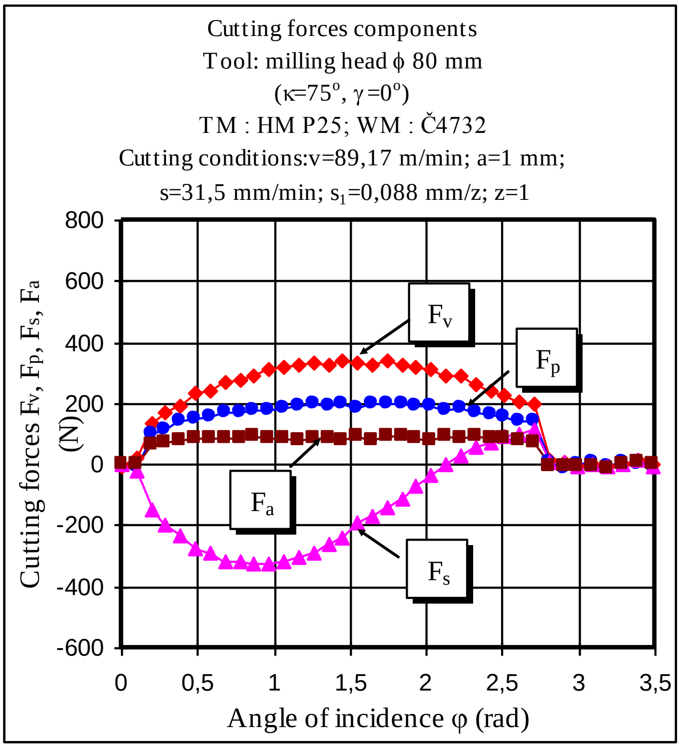


Fig. 2. Cutting forces Fi versus angle φ [2]

## 2. EXPERIMENTAL INVESTIGATIONS

Presented experimental investigations were conducted in the Department for Production Engineering in Novi Sad. Cutting forces were measured in three orthogonal directions x, y, z according to the model in informational system presented in Fig. 3. In Fig. 3. is shown the model of information system for cutting force measuring in face milling with one insert in face milling cutter. Signal acquisition is supported with software Labtech Notebook ver 5.0, which provide acquisition of the data in normal and high-speed mode, control of the process, necessary calculations and real time graphical output. For more complex analysis of the data Microsoft Excel and MicroCal Origin are used.

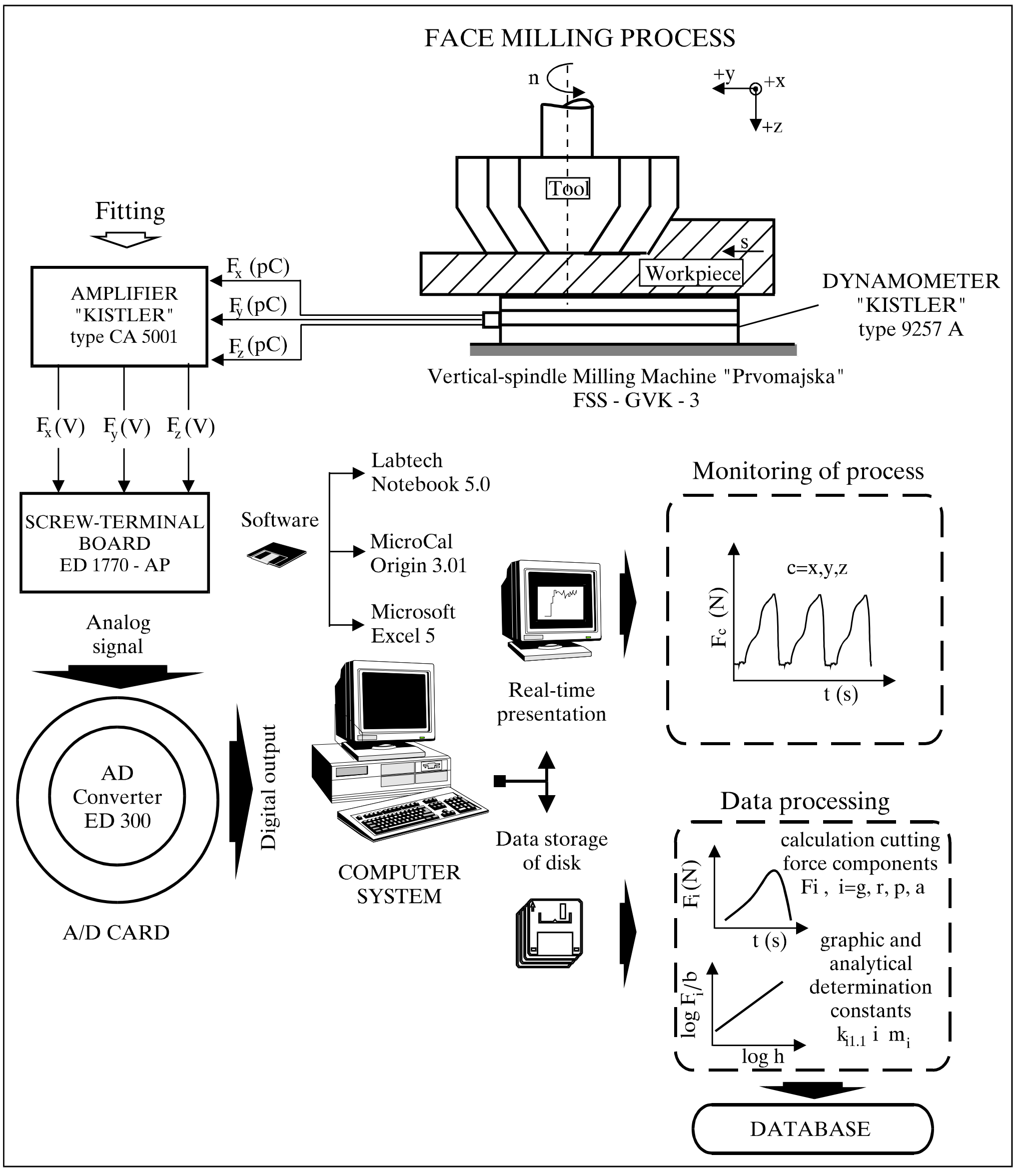


Fig. 3. Model of information system for cutting force measuring [3]

Results of experimental investigation shown in the paper are part of investigations provided for determination of unit cutting forces. The experimental investigation results from numerous of prepared investigations for solving of many problems that could appear during planned investigations. At first it was planned to provide experiment during up milling, with width of cutting B=40 mm and cutting depth a=5mm (Fig. 4. - experiment A).

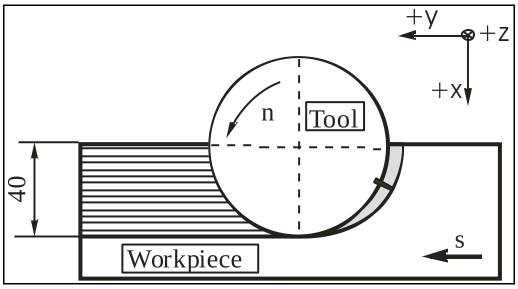


Fig. 4. Experiment A [2]

Experimental investigations were provided during machining steel C1730 with one tooth face milling cutter. During cutting highest values of the strike force during cutting acting in the x direction (nearly 2200 N). This strike value influenced the values of force components $F_v$ and $F_p$ (according to equations 1. and 2.). According to this the component $F_v$ was smaller than component $F_p$ in disagreement with results in many literature sources (Fig. 5).

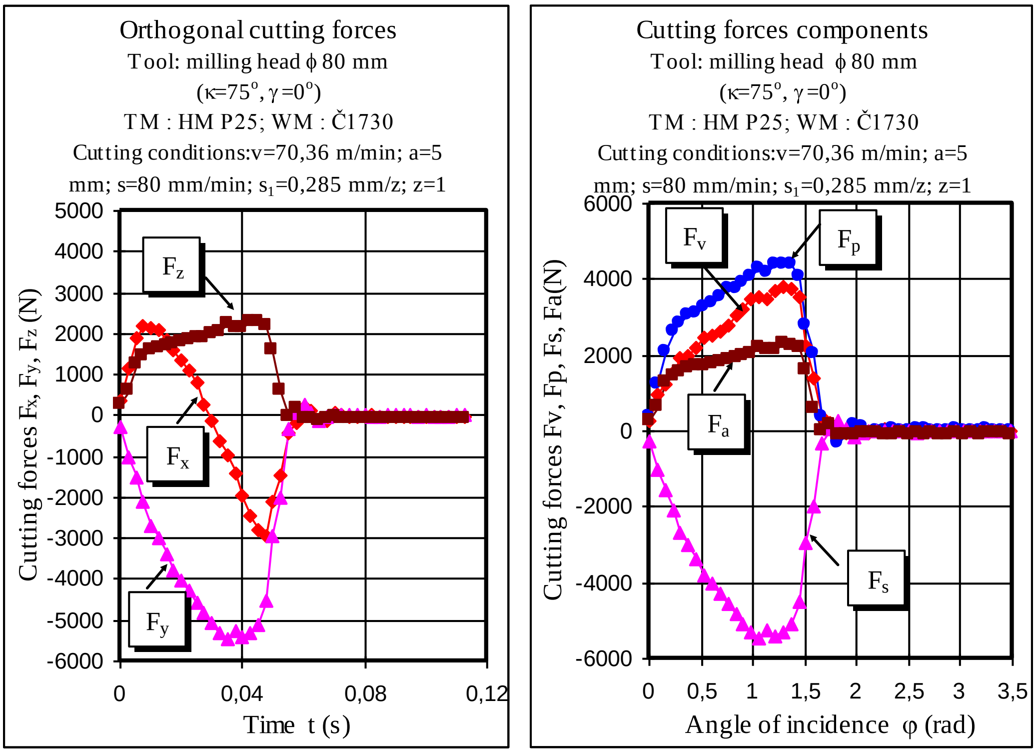


Fig. 5. Cutting forces components during up milling- experiment A [2]

New experimental investigations were provided with depth of cut a = 1 mm (experiment B). In this case strike force in x direction was smaller and was approximately 1500 N (Fig. 6). Decreasing of strike forces did not influence the relationship between main cutting force and radial force. In this case $F_v$ was much smaller than $F_p$.

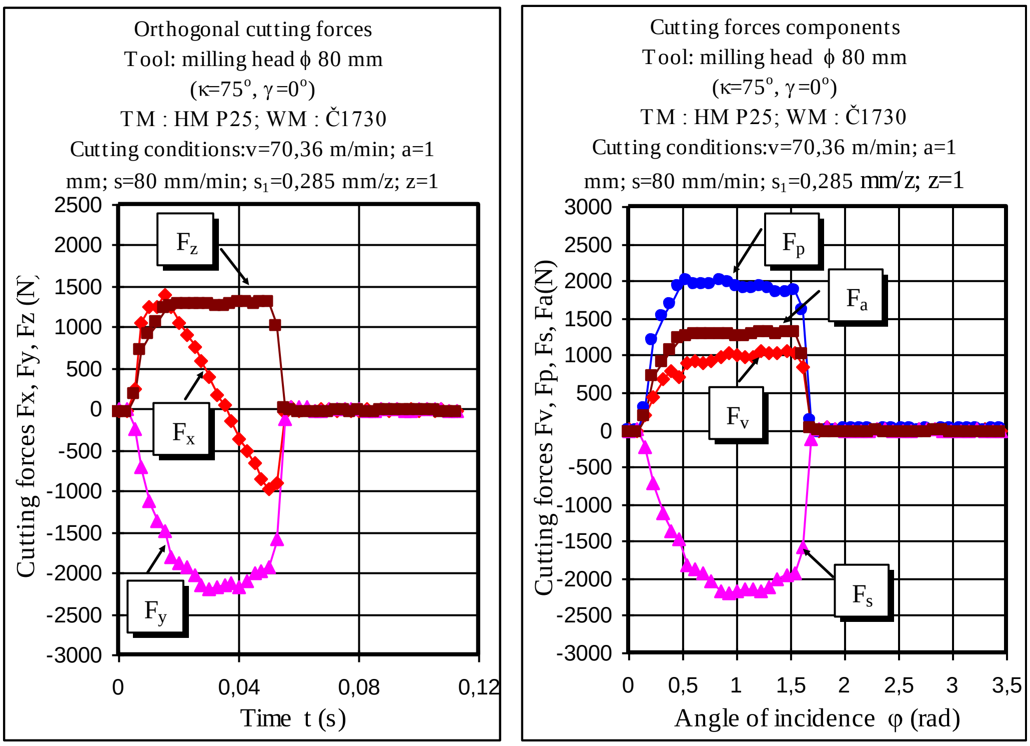


Fig. 6. Cutting forces components during up milling- experiment B [2]

Repeated investigations on the same material of workpiece and with same tool with symmetrically located three inserts ( 120º), (Fig. 7-experiment C). This way, there was decreased influence of radial and axial throw of tooth. Because maximal angle of contact was less than 120º, only one tooth was always in cut in workpiece. This way was ensured that cutting force results only from one tooth. Measured cutting forces have similar changes as shown in Fig. 5 and 6, and provided identical relationship between force components $F_v$ and $F_p$.

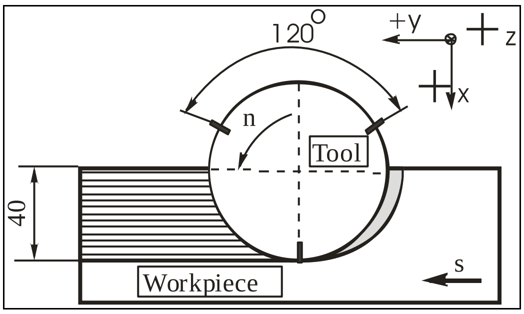


Fig. 7. Experiment C [2]

New investigations were provided on workpiece with the groove for relief, with width 4mm and depth 3 mm (Fig. 8, experiment D).

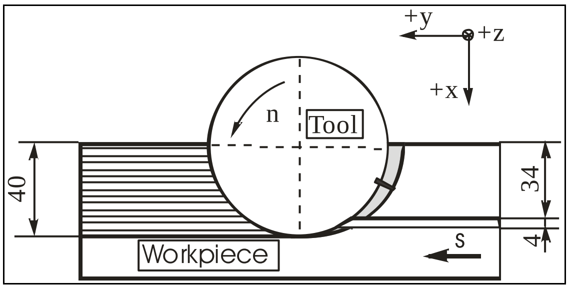


Fig. 8. Eksperiment D [2]

Presence of groove provide only for short time relief. The dynamometer, registered zerou values and after that strike force value, was 1000 N, which caused similar relationship between calculated cutting forces components (Fig. 9).

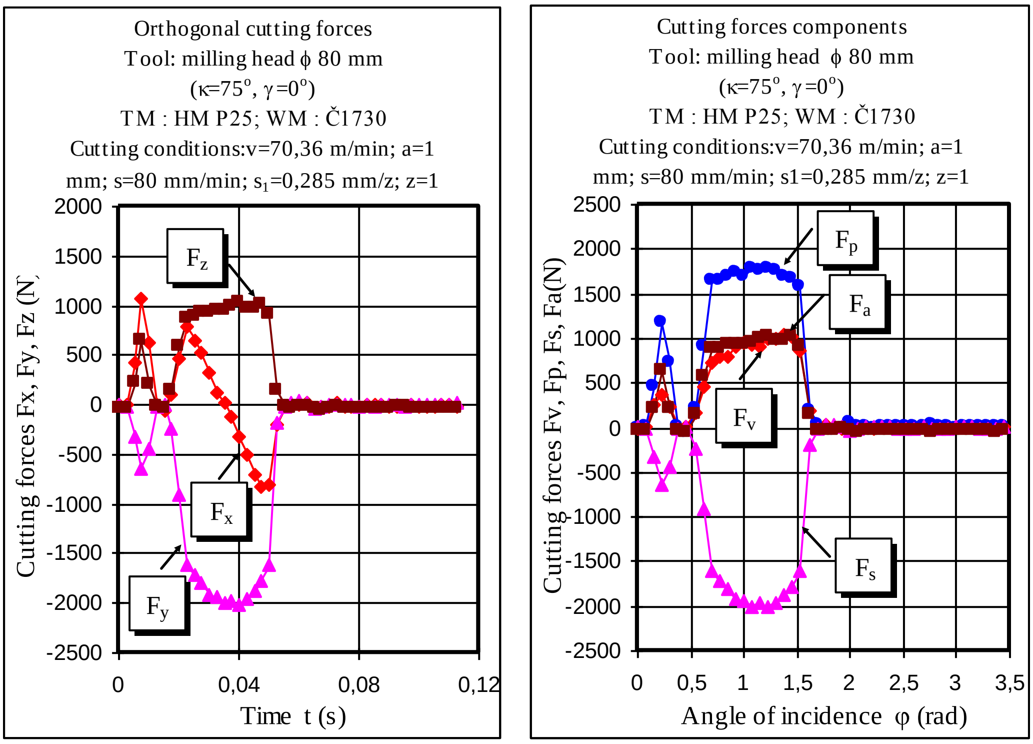


Fig. 9. Cutting forces components during up milling- experiment D [2]

Pilot investigations were provided during down face milling (Fig. 10 – experiment E). Results show extremely high strike forces in y direction. The most part of components section $F_y$ is negative (with maximal value about 1000 N, Fig. 11), and only on small section has positive value. This caused the force component $F_p$ to have negative values, contrary to every early hypothesis.

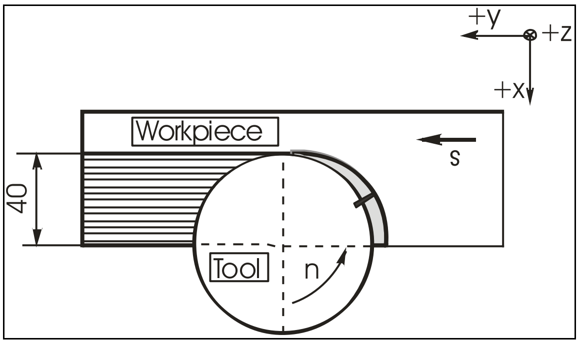


Fig. 10. Experiment E [2]

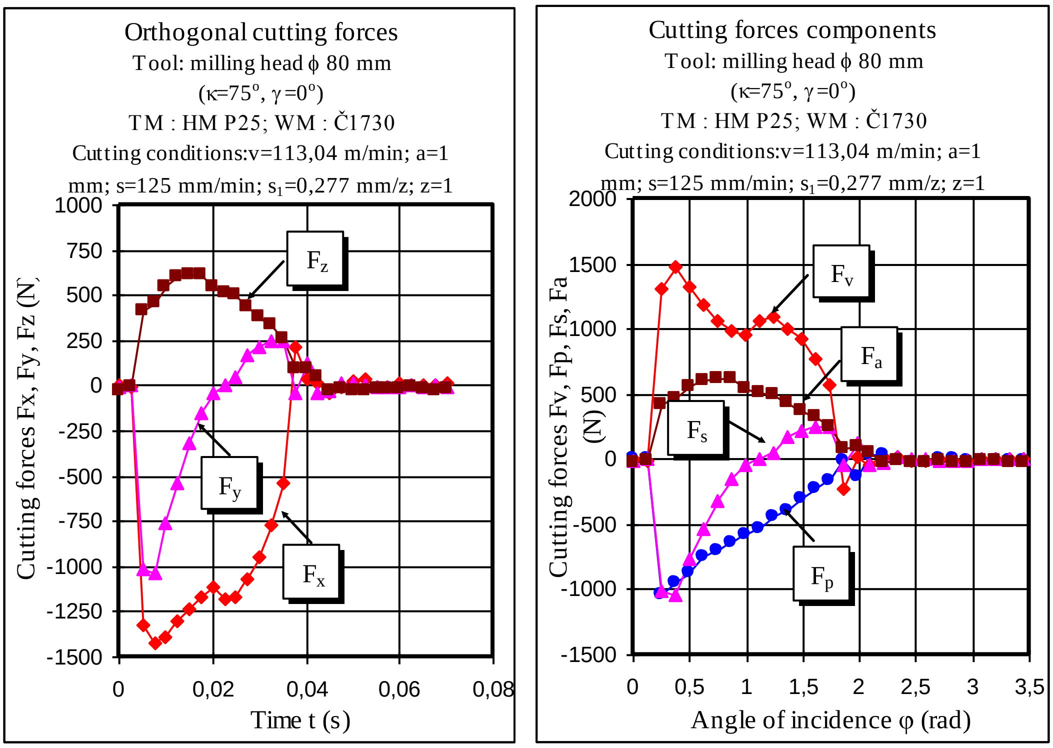


Fig. 11. Cutting forces components during down milling- experiment E [2]

Experiment F was combination of up and down milling with milling width equal to milling cutter diameter, and depth of cut 1 mm. In this case cutter tooth evenly come in workpiece (Fig. 12) and cutting depth of material with changeable chip thickness form maximal to zero or from zero to maximal value.

This way eliminated the strike load and peaks in measured values of cutting force components x and y directions. During machining this way (B=D) a burr appeared around periphery of the workpiece. To avoid the burr influence on cutting force values experiments were provided with milling width 2-3 mm less than milling cutter diameter.

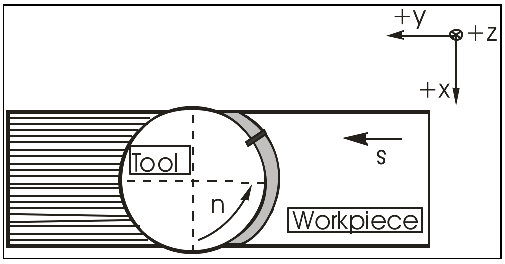


Fig. 12. Experiment F [2]

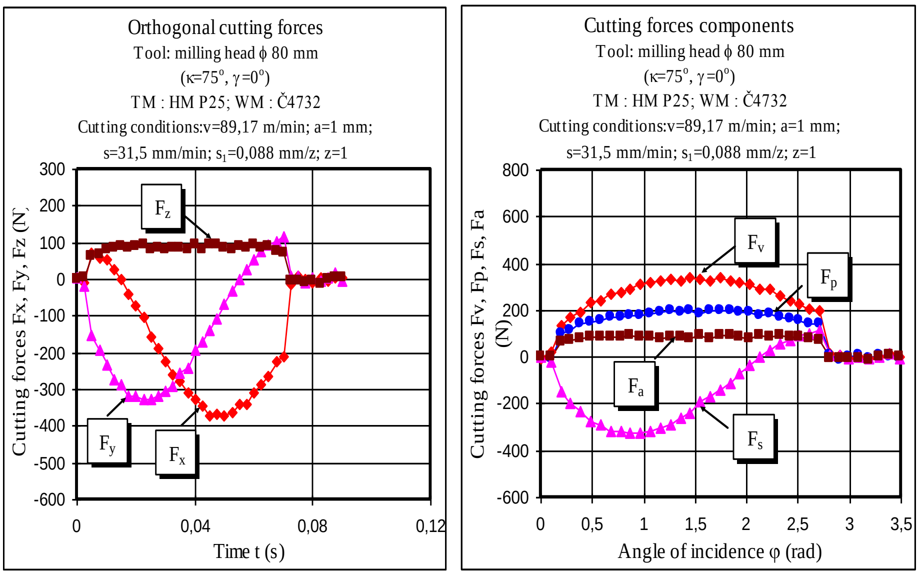


Fig. 13. Cutting forces components during combined milling - experiment F [2]

## 3. CONCLUSION

Results of experimental investigations during face milling showed that it is extremely complex to follow and predict cutting forces during cutting process. It was proved that the most realistic measured and calculated cutting force components were obtained during combined face milling cutting with one tooth when the width of milling was equal to cutter diameter and when depth of cut was a=1 mm (Fig. 12-experiment F). In this case of milling cutter tooth come steady into to workpiece strike load was avoided and also peaks during cutting force measurement.

REFERENCES

[1] ARMAREGO E. J., WANG J., DESHPANDE N. P., *Computer-Aided predictive Cutting Model for Forces in Face Milling Allowing for Tooth Run-Out*, Annals of the CIRP, Vol. 44, 1995, 43-48.
[2] SEKULIĆ M., *Development of bases for cutting forces calculation*, Master thesis, University of Novi Sad, 1998.
[3] SEKULIĆ M., KOVAČ P., *The influence of machining conditions change on cutting forces in milling*, PSU-UNS International Conference of Engineering and Environment ICEE-2007, Phuket-Thailand, 655-658.