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Control of the Cutting Forces in Turning by Entry Angle and Cutting Inserts Geometry

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Machinability is assessed by a set of criteria or machinability functions, the knowledge of which is needed in optimising the machining process. New cutting tool materials and new concepts of the machine tools provide new possibilities and cause quantitative changes in machinability functions. This research has studied the cutting forces function, as one of the crucial machinability functions. The research was done at longitudinal turning of steel 16MnCr5. Coated carbide inserts for roughing and finishing with different inclination angles were used, and tool clamping system has enabled the changes of entry angle. Obtained results confirm that entry angle and geometry of cutting insert significantly influence cutting forces especially thrust cutting force.

Keywords: turning, cutting forces, cutting tool inserts, inserts geometry

0 INTRODUCTION

Main aims of modern machining processes are productivity, economy, accuracy and quality of machined surface, which are achieved by continuous analysis of machinability indicators. Machinability is a very complex term, and it is most often described as the basic technological characteristic of the material and evaluated by a set of criteria or functions of machinability. In metal cutting, the basic set of machinability functions include [1] and [2]:

- function of tool life,
- function of cutting forces,
- function surface roughness,
- function of the chip forms.

Apart from the basic functions, also a number of additional functions are applied such as temperature, material removal rate, built-up-cutting edge, power, etc.

The study of the machinability results also in obtaining the guidelines for the development of the cutting tools. It has contributed to very intensive development of the cutting tools, particularly in the area of high-speed machining, hard machining and dry machining. Improvement of existing and development of new cutting tool materials, same as the new concepts of machine tools, provide new possibilities and change quantitatively the machinability indicators. Therefore, the study of machinability represents a continuous process [3] to [6].

Force modelling in metal cutting is important for a multitude of purposes, including design of machine tools, thermal analysis, tool life estimation, chatter prediction, tool condition monitoring etc. Numerous approaches, in orthogonal and oblique cutting, have been proposed to model metal cutting forces with various degrees of success [7].

1 STUDY OF INFLUENCE OF TECHNOLOGICAL PARAMETERS ON THE CUTTING FORCES

1.1 Goal, methodology and condition of study

The goal of the research is to define the cutting forces as the functions of influencing parameters. Among a great number of influencing parameters, for this research the major entry angle (κ_r) (Fig. 1), machining depth (a_p), feedrate (f), and geometry of cutting insert are selected as independent factors.

The experiment was made in the Laboratory for machine tools of Faculty of Mechanical Engineering and Naval Architecture, University Zagreb, at universal turning machine. Longitudinal turning process has been used, cutting speed 120 m/min, without coolants. A steel for cementation (16MnCr5) was selected. Three different coated carbide inserts have been used:

1) positive cutting insert (λ = 0°) for finishing marked as DCMT11T304-FF1 TP2000,

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2) negative cutting insert (λ = -6°):
   a) cutting insert for finishing marked as DNMG150604-FF1 TP2000,
   b) cutting insert for roughing marked as DNMG150604-M5 TP2000.

Tool clamping system has enabled the changes of entry angle (Fig. 1). The measurement of cutting forces was made by three-component measuring device "Kistler 9257B".

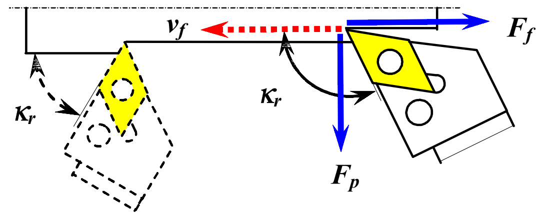

Fig. 1. *Scheme of longitudinal turning with exchangeable (adaptable) entry angle* κ_r

1.2 Research results obtained with positive cutting insert for finishing (λ = 0°)

Statistical analysis of experimental data (SW Statistica) resulted with mathematical models presented by:

Graphical interpretations of the obtained mathematical models are presented in Figures 2 to 4.

Figure 2 shows that the main cutting force slightly increases with the increase of the entry angle. More adequate explanation is obtained by single-factorial analysis, whose results are shown on Figure 5.

Figure 3 shows that feed cutting force also slightly increases by increasing the entry angle even when it's value exceeds 90°. Such result differs from Kienzle's formula and can be caused by the same reasons as the increase of the main cutting force.

Figure 4 shows that passive cutting force is considerably reduced by increasing the entry angle. Furthermore, for certain combination of cutting data, passive cutting force can take negative values.

Single-factorial analysis (Fig. 5) shows that significant increase of main cutting force happens when entry angle exceeds 90°. It is the situation in which contact length between the cutting edge and the workpiece is increased and the end cutting edge angle, κ_r', is reduced. As a result there is a significant amount of friction from three sides, as shown on Figure 1. That fact can be cause of formidable increase in roughness of the machined surface, as shown in Figure 6.

$$F_c = 1207.5 - 26.5\ \kappa_r + 0.14\ \kappa_r^2\ + 1.6\ \kappa_r\ a_p + 2196.5\ a_p\ f \tag{1}$$

$$F_f = -223.2 + 201.7\ a_p + 1.57\ \kappa_r\ a_p + 1025.6\ a_p\ f \tag{2}$$

$$F_p = -403.3 + 0.049\ \kappa_r^2 + 708\ a_p + 3206.5\ f\ - 7.45\ \kappa_r\ a_p - 28.26\ \kappa_r\ f \tag{3}$$

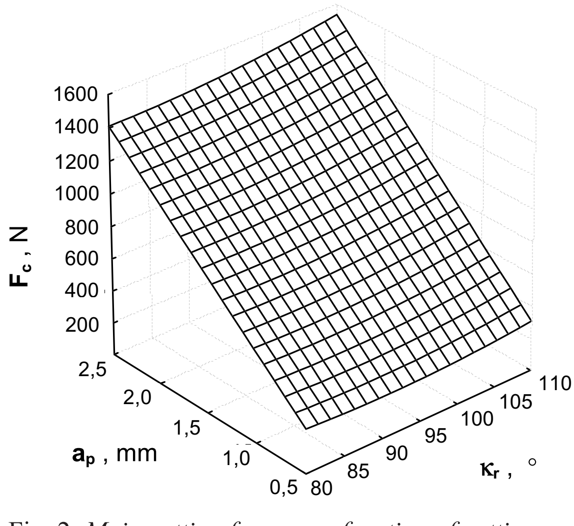

Fig. 2. *Main cutting force as a function of cutting depth and entry angle (cutting insert for finishing,* λ *= 0°, f = 0.2 mm)*

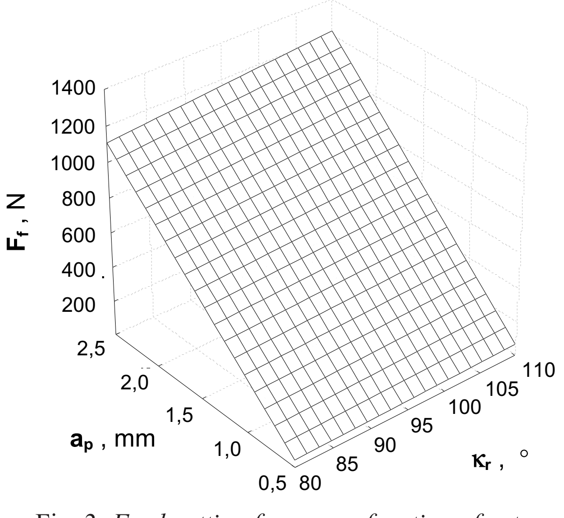

Fig. 3. *Feed cutting force as a function of entry angle and cutting depth (cutting insert for finishing,* λ *= 0°, f = 0.2 mm)*

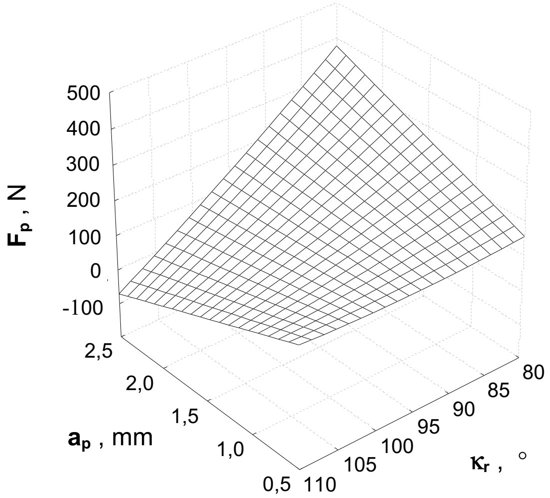

Fig. 4. *Passive cutting force as a function of entry angle and cutting depth (cutting insert for finishing, $\lambda = 0^o$, $f = 0.2$ mm)*

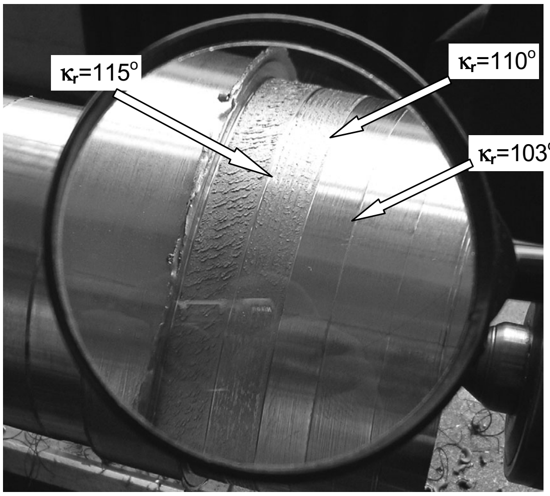

Fig. 6. *Roughness of the machined surface as a function of entry angle (v_c =120 mmin $^{-1}$, a_p =2.5 mm, $f = 0.16$ mm)*

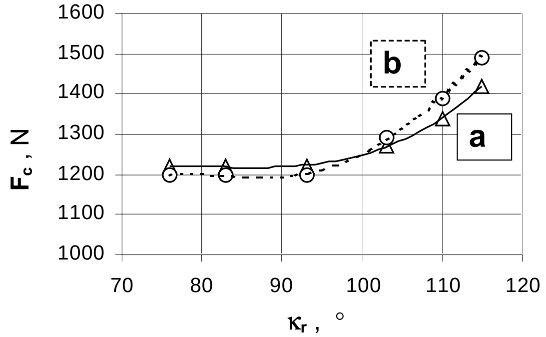

Fig. 5. *Main cutting force as a function of entry angle (a_p =2.5 mm, $f = 0.16$ mm)*
a – positive cutting insert for finishing,
b – negative cutting insert for finishing

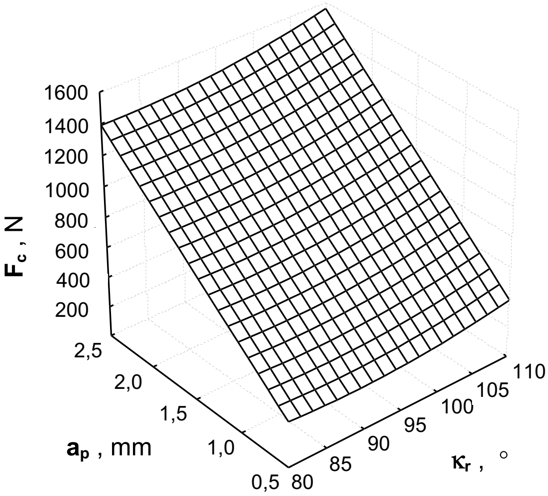

Fig. 7. *Main cutting force as a function of cutting depth and entry angle (cutting insert for finishing, $\lambda = -6^o$, $f = 0.2$ mm)*

1.3 Research results obtained with negative cutting insert ($\lambda = -6^o$)

1.3.1 Cutting insert for finishing

Statistical analysis of experimental data (SW Statistica) resulted with mathematical models presented by:

Figure 7 shows that by increasing the entry angle, the main cutting force is increased. Also, obtained results don't show significant difference compared to positive cutting insert, except in the area of greater values of entry angle. In that area

$$F_c = 1742.8 - 38.36\,\kappa_r + 0.21\,\kappa_r^2 + 1.52\,\kappa_r\,a_p + 2113.5\,a_p\,f \quad (4)$$

$$F_f = -158.12 + 188.43\,a_p + 1.54\,\kappa_r\,a_p + 982.36\,a_p\,f \quad (5)$$

$$F_p = -462.84 + 0.053\,\kappa_r^2 + 607.24\,a_p + 4234.6\,f - 6.3\,\kappa_r\,a_p - 37.9\,\kappa_r\,f \quad (6).$$

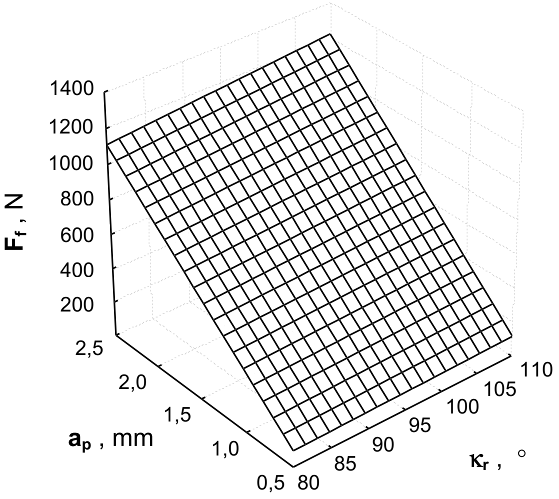

Fig. 8. *Feed cutting force as a function of cutting depth and entry angle (cutting insert for finishing, λ = -6°, f = 0.2 mm)*

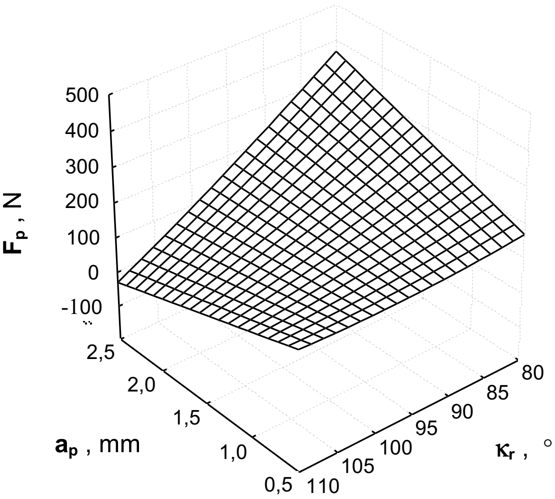

Fig. 9. *Passive cutting force as a function of entry angle and cutting depth (cutting insert for finishing, λ = -6°, f = 0.2 mm)*

(Fig. 5) was measured more significant increase of main cutting force, caused by the fact that tools with negative cutting insert (λ_s= -6°) have formidably reduced end clearance angle.

Figure 8 shows that by increasing the entry angle, the feed cutting force is increased even when its value exceeds 90°. Also, obtained results don't show significant difference compared to positive cutting insert.

Figure 9 shows that by increasing the entry angle, the passive cutting force is formidably reduced. Furthermore, passive cutting force can take negative values for certain cutting data combinations. However, negative values are harder to achieve than using positive cutting insert. This is mainly consequence of the fact that tools with negative cutting insert have formidably reduced end clearance angle.

1.3.2 Cutting insert for roughing

Statistical analysis of experimental data (SW Statistica) resulted with mathematical models presented by:

Graphical interpretations of the obtained mathematical models are presented in Figures 10, 12 and 13. Graphical presentation of single-factorial analysis of main cutting forces for negative cutting inserts (for roughing and finishing) as a function of entry angle is given in Figure 11.

Analysis of Figures 10 and 11 shows that shape of main cutting force, obtained with cutting insert for roughing, differ in some elements from shape of main cutting force, obtained with cutting insert for finishing. In the area with lesser values of entry angle and higher values of cutting depth, measured values of main cutting force obtained with cutting insert for roughing are smaller. However, in the area with higher values of entry angle measured values are formidably increased.

Analysis of Figure 12 shows that shape of feed cutting force, in the area of all values of entry angle, is similar as for main cutting force.

Analysis of Equation 9 and its graphical presentation, Figure 13, shows that the increase entry angle, at higher values of cutting depth formidably reduces the passive cutting force. However, passive cutting force can't take negative values.

$$F_c = 2948.76–62.28\kappa_r+0.34\kappa_r^2–196.3a_p+2.52\kappa_r a_p+2052.1a_p f \quad (7)$$

$$F_f = 1551.7–34.05\kappa_r+0.2\kappa_r^2+ 1.15\kappa_r a_p+883.43a_p f \quad (8)$$

$$F_p =1599.3–35.75\kappa_r+0.21\kappa_r^2+311.38a_p+1586.9 f -3.65\kappa_r a_p–13.95\kappa_r f+293.7a_p f \quad (9).$$

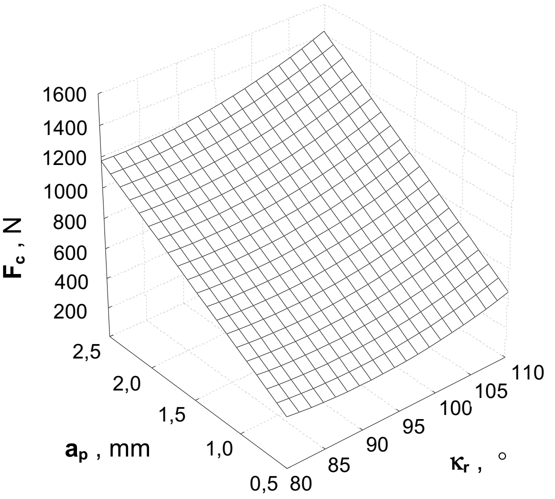

Fig. 10. *Main cutting force as a function of entry angle and cutting depth (cutting insert for roughing, λ = -6°, f = 0.2 mm)*

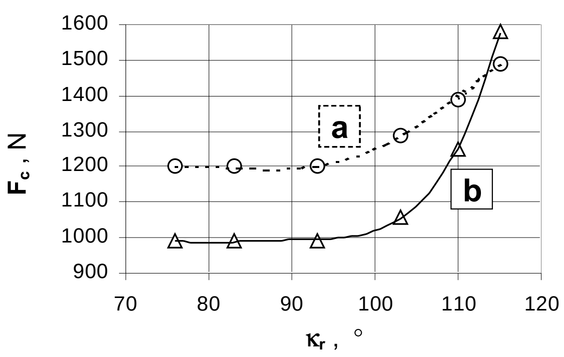

Fig. 11. *Main cutting force as a function of entry angle (a_p =2.5 mm, f = 0.16 mm)*
a – cutting insert for finishing,
b – cutting insert for roughing

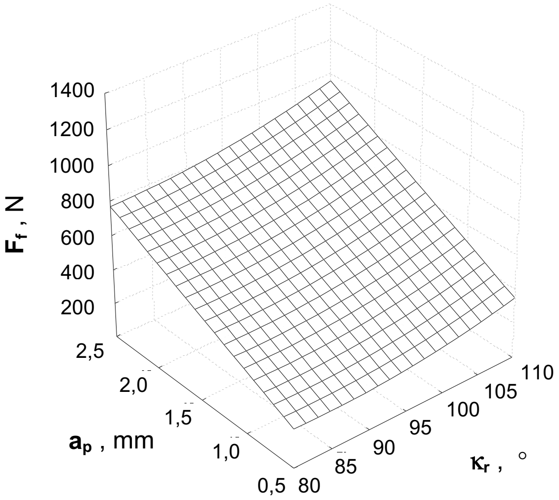

Fig. 12. *Feed cutting force as a function of entry angle and cutting depth (cutting insert for roughing, λ = -6°, f = 0.2 mm)*

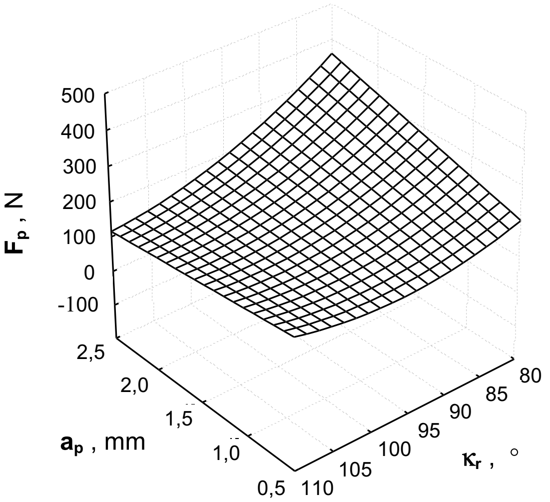

Fig. 13. *Passive cutting force as a function of entry angle and cutting depth (cutting insert for roughing, λ = -6°, f = 0.2 mm)*

2 CONCLUSION

Obtained results confirm the possibility to control the thrust cutting force with entry angle, what is particularly important when turning lean workpieces (high ratio length/diameter), and thin wall workpieces. Analysis of mathematical models and their graphical presentations, shows that the increase of the entry angle, at higher values of cutting depth, formidably reduces the passive cutting force. However, passive cutting force, by cutting insert for roughing, can't take negative values.

However, it should be noted that there is no research of cutting tool temperature, chattering or surface roughness. In situation when cutting tool has significant amount of friction from three sides, and generated heat is almost captured, the complete picture of influence of entry angle is still missing. The generated heat in conjunction with reduced cutting tool cross section (caused with increased entry angle) could significantly reduce tool life, what would, in great extent, neutralize the positive effect of reduced thrust cutting force. Potential field of application would be adaptive control of

B axis with carefully selected limits. That would open possibility to optimize the machining conditions by adjusting entry angle in contour turning operations.

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