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Dependence of the Passive Force Fp from the Revolutions, Back Engagement of Cutting Edge a_e, Working Engagement of the Cutting Edge a_p During Milling

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Abstract. In this contribution is analysed the force component of final force (passive force) by peripheral milling operation. Therefore, the main parameters that had influence to independent variable were revolutions, back engagement of a cutting edge ae, working engagement of the cutting edge a_p*. The article deals with the issue of milling in material AlMgSi0.5 (aluminium alloy). Specifically evaluates the force component with respect to change of revolutions (4000/min., 5000/min., 6000/min.), working engagement of the cutting edge* a_p *(1 mm, 2 mm, 3 mm) and back engagement of a cutting edge* a_e *(5 mm, 10 mm, 15 mm). The Alfaflex process fluid with 7% concentration was supplied in an amount of about cca 10 l/min.*

Introduction

The main aim of experiment described in this contribution was to study, analyse and realize the cutting force (via its components) at milling of box from aluminium alloy AlMgSi0.5 that is used in automotive industry. One of the main aim in every company is improve manufacturing process joins with reduce of tool costs, time etc. The new machined materials, cutting materials and higher and higher cutting parameters are reason for experimental testing of cutting forces, torque moments, power and other phenomena join with production process generally. One from way as to understand to cutting process is creation of various types of models, for turning or for milling and compare theoretical model with real situation, as for example (1), which results from milling of Titanium alloy by tool with 4 teeth and 30^{o} helix angle compared with linear milling force model. The prediction of cutting forces together with machining strategy, mainly of thin wall elements is very often in focus of researchers. (2) presents a comprehensive model of multi-axis ball-end milling operations with the associated mechanics and feed motions. The dependence of cutting force coefficients on milling process parameters including feed per tooth, spindle speed, and radial immersion was mentioned in research of (3). For determining the cutting force coefficients two methods were used: first with the average force, linear regression method; second with the instantaneous force, nonlinear optimization method. It was found that feed per tooth, spindle speed, and radial immersion exhibit a nonlinear relationship with the cutting force coefficients.

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The analytical force model obtained by (4) using the nonlinear model approximates the experimental force of the tools having helical flutes better than the linear model. The analytical force model obtained by using optimization method approximates the experimental forces better than the model that is obtained by using the average force method. The measurement of cutting force systems is one of the most frequently used techniques for the monitoring of machining processes. Its wide spread application ranges from tool condition identification, feedback control, cutting system design, to process optimization. Information about stablishing a closed form expression for the cutting force in end milling as an explicit function of cutting parameters and tool/workpiece geometry are mentioned in (5).

Based on the theoretical local cutting force model, the generation of total cutting forces is formulated as the angular convolution of three uncorrelated cutting process component functions, namely the elemental cutting force function, the chip width density function, and the tooth sequence function.

1. Methods

1.1. Machine

Cutting process was conducted on 3 axis vertical machine centre MAS MCV 500 Quick controlled by FANUC 21i-m numerical system.

Figure 1 Machine centrum

Parameter	Unit	Value
Feed in axe X, Y, Z	mm	500
Feed speed / rapid feed speed in X, Y, Z	mpm	10 / 25
Range of revolutions	min^{-1}	0 - 8000
Power	kW	7.5
Clamping system	--	conus SK 40
Tool magazine / number	--	Yes / 20
Control system	--	FANUC 21i-M
Dimensions of working table	mm	800 x 500
Working mass (max.)	kg	400

Table 1 Technical data of the machine

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1.2. Tool

In the experiments was used the solid router bit (made by Holex) with TiAlN layer. The router is suggested for machining of soft and hard aluminium alloys, Cu alloys and some kind of composite aluminium–plastic; for roughing and finishing operation; for free and non-free cutting.

Figure 2 Router bit (Holex)

Parameter	Unit	Value
Cutting diameter	mm	16 e8
Length of cutting part	mm	36
Diameter of clamping part	mm	16 h6
Clamping system	-	DIN 6535 – HA
Total length	mm	92
Number of teeth	-	4
Helical angle (λ)	°	42
Geometry	-	type W
Material	-	Universal TCT

Table 2 Parameters of cutter

1.3. Measuring Device

A measuring device from Kistler (Kistler Group, Winterthur, Switzerland) was used to measure force components consisted of a Quartz 3-Component Dynamometer Type 9257B, multiple channel amplifier 5070A, 16-bit A / D convertor 5697A. The computer software used was Kistler Dyno-Ware (type 2825D-02; version 2.5.1.2). The cutting force measuring equipment is shown in Fig. 3.

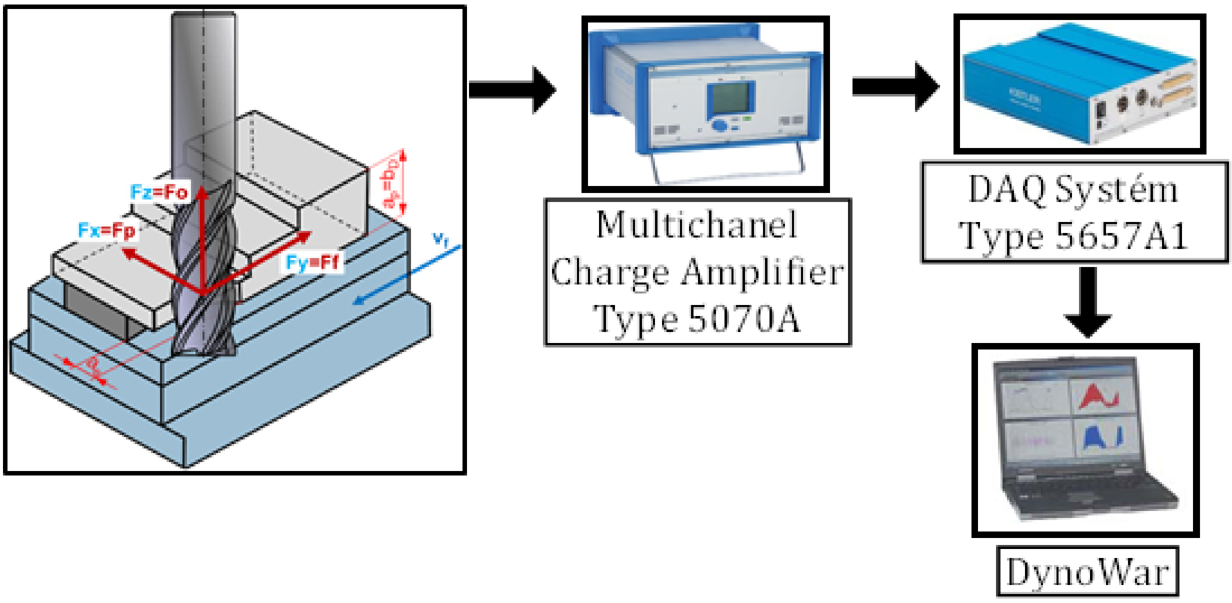

Figure 3 Measuring chain

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1.4. Materials and conditions of the experiment

Aluminium alloy AlMgSi0.5 (6060 – EN AW by EN 573-1-2; or AlMgSi0.5, 3.3206 by DIN) 6060 is a medium strength heat treatable alloy with a strength slightly lower than 6005A. It has very good corrosion resistance, very good weldability and good cold formability. It is commonly used for complex cross sections and has very good anodizing response.

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others	Al
0.3 – 0.6	0.1 – 0.3	0.10	0.10	0.35 – 0.60	0.05	0.15	0.10	0.05 – 0.15	rest

Table 3 Chemical composition according to EN 573-3

Metallic range (°C)	585 – 650	Specific heat (J/kg K)	898
Density (g/cm^3)	2.70	Young modulus (MPa)	69500
Electrical conductivity (MS/m)	34 – 38	Shear modulus (MPa)	26100
Thermal conductivity (W/m K)	200 – 220		

Table 4 Physical properties

The pieces were clamped to platform of Kistler 9257B. The experiment was designed as full factorial experiment based on a model of a classical experiments plan, with three independent factors:

- Revolutions n: 4000 /min; 5000 /min; 6000 /min.
- Back engagement of a cutting edge a_e: 5 mm; 10 mm; 15 mm.
- Working engagement of the cutting edge a_p: 1 mm; 2 mm; 3 mm.

The constant parameters were: up milling: feed speed v_f: 900 mm/min.; length of every machined part was 60 mm. Depended (measured) factor was force components Fx = Fp (passive force); where: x, y, z is coordinate system of measure platform. The Alfaflex process fluid with 7% concentration was supplied in an amount of about cca 10 l/min.

2. Results and analysis

The cumulative results are displayed in Fig.4. and they are divided to three main groups by working engagement of cutting edge a_p with three subgroups by back engagement of cutting edge a_e. The results can be processed by various requests, but always on the on the ground of one independent parameter like is demonstrated in paragraphs 2.1 and 2.2. There are presented results for a_p=1 mm. The general treatment of all values from experimental measuring, including of interaction 2.3 inclusive of final expression for formularization of Fp components. Additional force components can by computed by the same principle.

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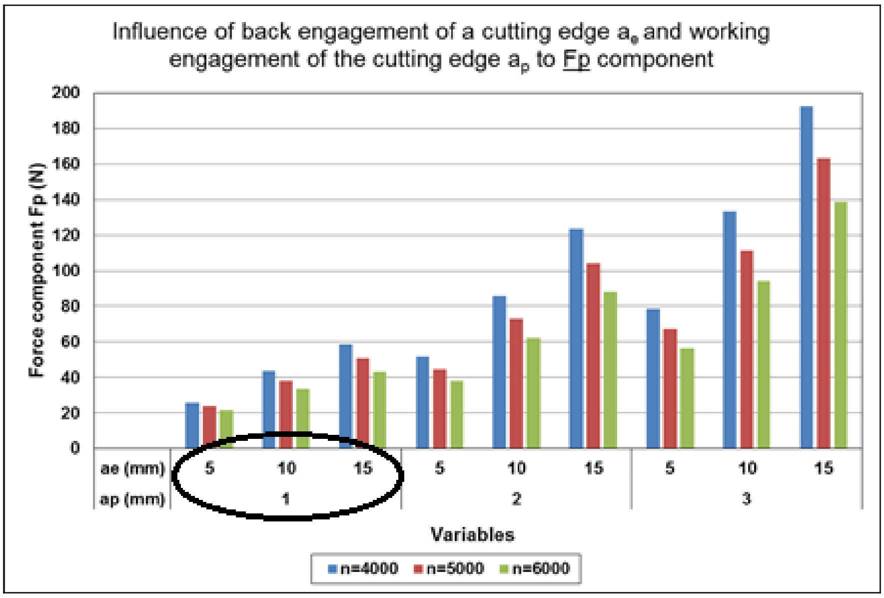

Figure 4 The influence of revolutions to force components

2.1. Influence of revolutions and back engagement of cutting edge a_e to force component Fp

On the graph (Fig. 5) is clearly visible that the change of revolutions from 4000 rpm to 6000 rpm., i.e. cca 1.37 times has significant influence to passive force, that goes down for back engagement of a cutting edge a_e = 5 mm cca 15.7%, for a_e = 10 mm cca 22.5%, for a_e = 15 mm cca 26.4 %, i.e. if it will be recalculated per 1 mm of work piece with, the passive force was 0.95 N ± 0.1 N.

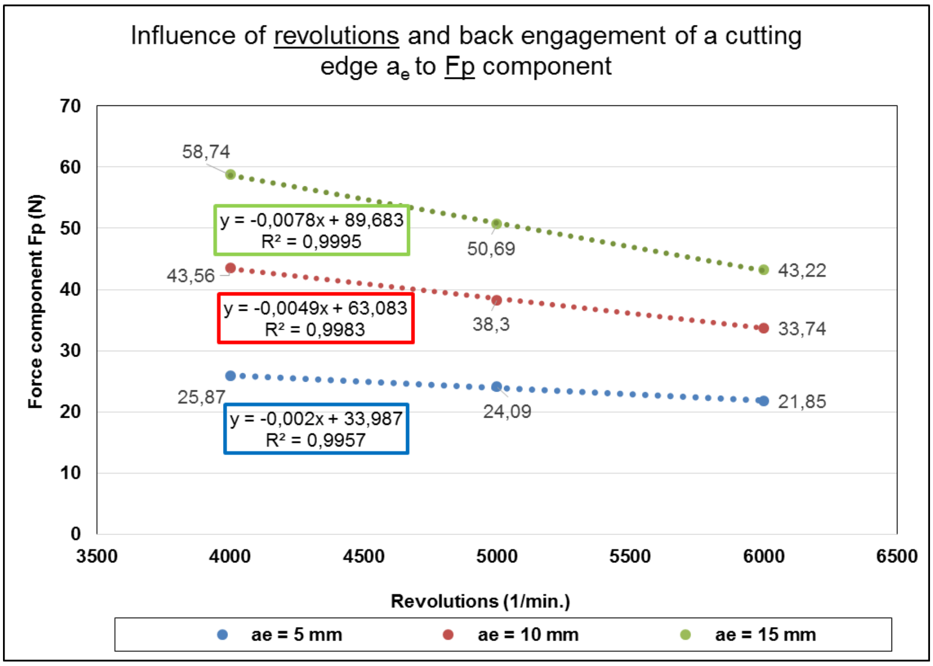

Figure 5 The influence of revolutions and back engagement of cutting edge a_e to Fp

2.2. Influence of back engagement of cutting edge a_e and revolutions to force component Fp

In the graph (Fig. 6) is pictured tendency of passive component Fp as function of revolutions and for three various widths of milled workpiece. From this graph is apparent a little more influence of cutting width to compare with revolutions. If the workpiece width will change from 5 mm to 15 mm, passive force will higher 2.27 times for 4000 rpm; 2.1 times for 5000 rpm and 1.97 times for 6000 rpm.

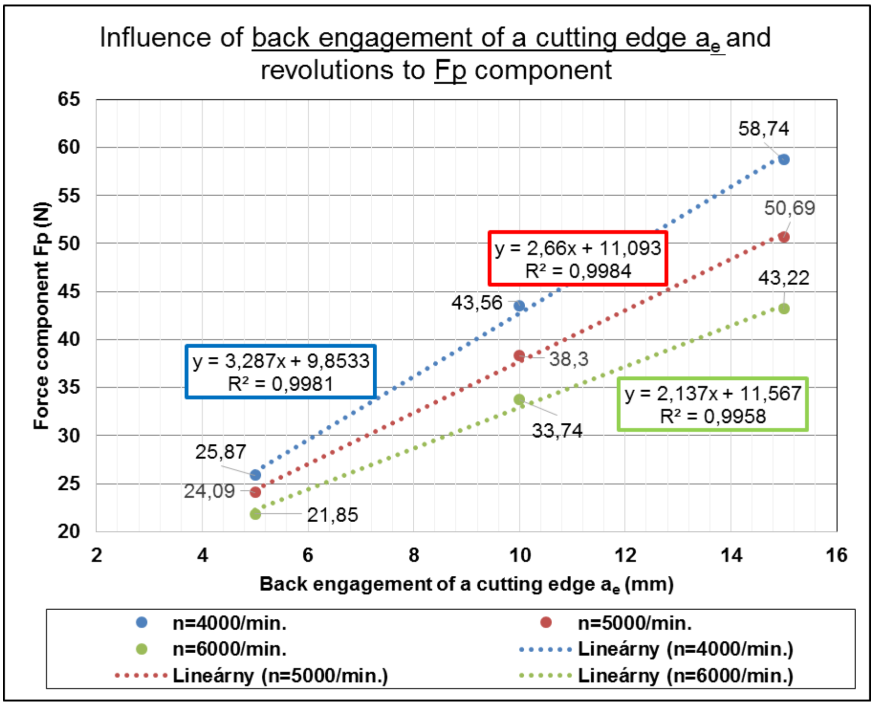

Figure 6 The influence of back engagement of cutting edge a_e and revolutions to Fp

2.3. Aggregate of all independent variables

In theory of metal cutting are mutual dependencies among depend and independent variables express by equation in exponential format.

Model: $Fp = K \cdot a_e^a \cdot n^b \cdot a_p^a$ Significant level: 95.0% (alfa =0.050)						
	Estimate	Standard deviation	t-value Sum square =77	p-value	Lower confidence limit	Upper confidence limit
K	3185.854	518.0976	6.1491	0.000000	2154.190	4217.518
a	1.051	0.0111	94.5693	0.000000	1.029	1.073
b	- 0.750	0.0203	- 36.9471	0.000000	- 0.791	- 0.710
c	0.840	0.0099	84.4021	0.000000	0.820	0.859

Table 5 Statistical results

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The results from whole experiment were computed by statistical software for α = 95% by three factors analyse with interactions. The basal results with model of force are in Table 5.

$$\boldsymbol{F_p = 3185 \cdot a_p^{1.05} \cdot n^{-0.75} \cdot a_e^{0.85}}$$

Notice: All results valid in the range of this experiment and it is impossible to apply its for another conditions.

3. Conclusions

The paper describes experiment of peripheral milling and process of the force component Fp (passive component) computing. The mathematical model for passive force was developed from the experimental values obtained during machining.

Generally may by conclude that:

1. The increasing of revolutions (i.e. cutting speed) has positive for bigness of all components; all went down; the maximum gradient was for Fx, than for Fp and Fo. During machining of thin wall elements force Fp has the biggest influence to walls deformation, so that it is required to monitor it.
2. The increasing of working engagement of the cutting edge a_e (i.e. with of cut) has the highest influence to force, to that during using of slim and long cutters it must be taken to account.
3. The increasing of back engagement of a cutting edge a_p, (i.e. depth of cut) has significant to all force components, but not so intense like with of cut.

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