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[1.] Dalibor JUROK, [2.] Josef BRYCHTA, [3.] Jana PETRŮ

EXPERIMENTAL MEASUREMENTS OF THE CUTTING FORCES AT MILLING OF STAINLESS STEELS

[1-3.] Department of Machining and Assembly, 17. listopadu 2172/15, Ostrava Poruba 70800, CZECH REPUBLIC

Abstract: The contribution deals with stainless steel machining. The theoretical part describes the general characteristics of the steel, their classification, milling operations and measure individual components of cutting forces during machining. In the main part of the experimental tests have been measured values of the cutting forces at milling experimental samples of steel 1.4301 (X5CrNi18-10). Cutting forces were measured on the piezoelectric dynamometer KISTLER 9255B. The measured results were evaluated in terms of surface finish, depending on the size of the measured components of the cutting forces at the proposed cutting conditions.
Keywords: stainless steel, cutting force, surface

1. INTRODUCTION
This paper is focused on field of stainless steels machining after face milling. Due to the growing trend of the development of science and technology there is a higher and higher demand on the issue of quality of machine parts. The efficiency of chip machining in manufacturing technology is based on material savings, a high quality of products and a high productivity. The aim of this paper is to propose appropriate cutting parameters for machining of steel 1.4301 and determine appropriate components sizes of cutting forces.

2. NOBLE STAINLESS STEELS – Measurement of cutting forces when machining
Noble stainless steel is a collective term for stainless steel containing at least 10.5 % of chromium. In comparison to non-alloy steel the noble stainless steel has a significantly better corrosion resistance. When there is higher content of chromium and alloying elements of nickel and molybdenum the corrosion resistance is higher. Stainless steel is alloy steel forming a steel group, which has higher corrosion resistance. Stainless steels are produced as rolled and forged steels or as steel casts. Stainless steels and alloys are classified according to their chemical composition and structure into several groups - ferritic, martensitic (hardenable); Austenitic, austenitic – ferritic (duplex) [1, 3, 9].

Cutting forces allow to specify a theory of cutting process. Determination of cutting forces is of great importance to the design of tools, a choice of cutting parameters and a machine construction. The cutting forces are measured by a dynamometer of various principles and constructions [12].

- ✓ **Static:** an average value between the highest and the lowest peaks of a record at the moment when the tool is in the cutting process;
- ✓ **Dynamic:** this is a real model of the size of cutting forces recorded in a flux, which is characteristic for a cutting force during the entire cutting process.

We must distinguish the overall cutting force and cutting resistance. The total cutting force can be decomposed into components in a connection with several influences of the cutting process, which has a general and unknown direction. Then we determine the magnitude and the direction of the resultant action of forces. Dynamometers, which are based on certain principles can determine the size of cutting components F_c , F_p and F_{fn}. The resultant force F is calculated from equation (1) [10].

$$F = \sqrt{F_c^2 + F_{fn}^2 + F_p^2} \tag{1}$$

Force F_c – cutting force. It acts in the direction of the main cutting movement, in the direction of a vector of cutting speed v_c [2; 5].
Force F_f – feed (axial) component of the cutting force [2; 5]. Force F_p – a passive component of a cutting force [2; 5].
The magnitude of a cutting force depends on cutting parameters (v_c, a_p, f_z), a tool geometry, machined material, cutting environment and cutting material. In case the cutting speed v_c , increases, the components of the cutting forces shrink.

Measurement of individual components of cutting forces is based on sensing pressures, which are acting on the cutting wedges into experimental samples of steels. Measuring device for measuring components of cutting forces must be highly sensitive and accurate. To express the total cutting forces or components an empirical relationships are used in machining [2; 5].

$$F_{fn} = C_{F_{fn}} \cdot v_c^{x_{Ffn}} \cdot f_z^{y_{Ffn}} \quad [N] \tag{2}$$

$$F_f = C_{F_f} \cdot v_c^{x_{Ff}} \cdot f_z^{y_{Ff}} \quad [N] \tag{3}$$

$$F_p = C_{F_p} \cdot v_c^{x_{Fp}} \cdot f_z^{y_{Fp}} \quad [N] \tag{4}$$

3. EXPERIMENTAL ACTIVITY

The experiment was carried out on a universal 3-axis CNC milling machine, which is a milling centre HURCO VMX 30 tons, using milling tools from ISCAR company. The steel 1.4301 was selected for the experiment. The steel 1.4301 was selected for the experiment (X5CrNi18-10) ČSN 17 240 [8].

During the experiment, some component were measured depending on the proposed cutting parameters and cutting tools used. The universal 3 – axis CNC milling centre HURCO VMX 30t was used for the experiment. The milling tools from ISCARE Company labelled FF FWXD050-06-22-05 and cutting inserts FF WOCT 060212T IC928 were used [7].

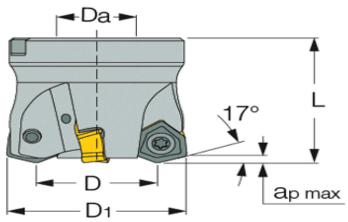


Figure 2: Cutter FF FWXD050-06-22-05 [6]

Table 1: Parameter of the milling cutter FF FWXD050-06-22-05 [6]

D_1 [mm]	D [mm]	$A_{P\,max}$ [mm]	Da [mm]	L [mm]	ZU [number of flutes]
50	40	1,0	22	40	5

The insert belongs is used for milling of stainless steel and other alloy steels. Replaceable insert FF WOCT 060212T IC92 is shown in figure 3 and the table 2 shows the dimensions of the insert [9].

Table 2: Parameters VBD FF WOCT 060212T IC92 [8]

D_i [mm]	l [mm]	ap [mm]	S [mm]	P [mm]	d_2 [mm]	r [mm]
9,86	7,0	1,0	2,7	4,7	5,6	2,0

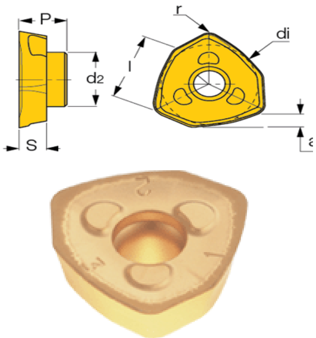


Figure 3: VBD FF WOCT 060212T IC92 [8]

During the experiment any process fluid was not used. The manufacturer does not recommend to use any process fluid during the machining process. The cutting forces in a face milling were measured by a piezoelectric dynamometer KISTLER type 9255B. The mentioned dynamometer is used for sensing a deformation of a piezoelectric phenomenon.

3.1. Sample of material

In the experimental part a steel 1.4301 (X5CrNi18 -10) DIN 17 240 was used. This type of steel belongs to the category of austenitic chromium-nickel stainless steel X5CrNi18-10. It has excellent resistance to corrosion and oxidation that can withstand temperatures to 350 ° C. It is designated in accordance to AISI 340, or according to ČSN 17 240 and DIN 1 [4].

3.2. Cutting conditions for the experiment

Conditions for face climb milling were set on the machine HURCO VMX 30t. These set cutting parameters for the selected proposed samples of material are given in the following table 3.

Table 3: Cutting parameters used in the experiment

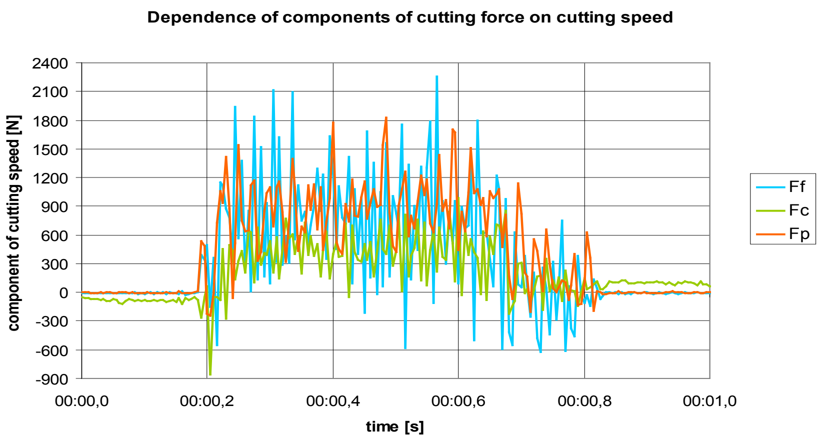
Material labeling	The depth of the cup a_p [mm]	Feed per tooth f_z [mm]	Diameter of the milling machine D_1 [mm]	Number a flute on the milling machine z	Catalogue labeling of the milling machine [-]
Ocel 1.4301	0,5	1,0	50	5	FF FWXD050-06-22-05

4. REALIZATION OF THE EXPERIMENTAL WORK – The measured data evaluation of components of cutting force

Terms and experimental work were carried out according to the design of the experiment in cooperation with the University of Žilina in Žilina, Department of machining and manufacturing techniques in the Engineering Faculty. The material used in the experimental work was steel 1.4301 (X5CrNi18-10) DIN 17 240. The experiment was carried out on the machine HURCO VMX 30t using a tool and replaceable inserts from ISCARE company. Before testing of the surface and measuring the forces the milled material was aligned by milling on the milling machine HURCO VMX 30t [5; 8].

Measuring of components of cutting forces in milling was ensured by the three - component dynamometer Kistler 9255 and by a charge amplifier Kistler 5006. The output was millivolts voltage that is processed by the analog-digital converter Adventech PCL 818-HG. The outputs from the converter were processed using a software Dasy Lab version 3.5 [8].

The data from the Dasy Lab version 3.5, which were measured during the experiments are processed into clear graphs. The graphs show the dependence of components of the cutting force on the cutting speed. Ø Max. component of a cutting force and Ø Min. component of a cutting force, which are shown in the table 4, were substracted. Subsequently, forces F_{fn}, F_f and F_p were calculated according to mentioned formulas. F_{fn} is a normal force , F_f is a force of feed and F_p is a passive fore [8]. Cutting speed $v_c = 450$ [m.min^{-1}], feed per tooth $f_z = 1,0$ [mm] a $v_f = 14,32$ [m.min^{-1}]



Graph 1: The course of the cutting forces when machining material 1.4301 ČSN 17 240

Table 4: The subtracted values of components of the cutting forces from graphs – steel 1.4301 DIN 17 240

Area no.	Feed per tooth f_z [mm]	Cutting speed v_c [m.min^{-1}]	Revolutions n [min^{-1}]	Feed rate v_f [m.min^{-1}]	Ø Max. Component of cutting force F_{fn} [N]	F_f [N]	F_p [N]	Ø Min. Component of cutting force F_{fn} [N]	F_f [N]	F_p [N]
1	0,5	250	1 592	7,96	1809	825	778	369	149	178
2		350	2 228	11,14	1362	974	714	686	239	212
3		450	2 865	14,32	1357	722	1115	105	168	321
4		550	3 501	17,51	2414	1010	1668	689	146	706

The shown example of calculating the cutting force components for material 1.4301 (X5CrNi18-10) DIN 17 240 for an area no. 1 see Table 4.

$$dynamics = Ø\ Max - Ø\ Min \quad [N]$$

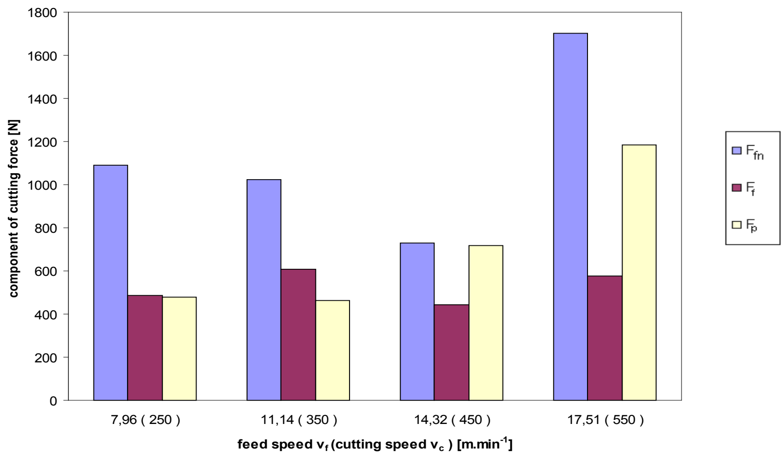
$$dyn = 1809 - 369$$

$$\underline{\underline{dyn = 1440\ \ N}}$$

$$Ff_n = \frac{dyn}{2} + Ø\ Min \quad [N]$$

$$Ff_n = \frac{1440}{2} + 369 \qquad (5)$$

$$\underline{\underline{Ff_n = 1089\ \ N}}$$



Graph 2: The course of components of the total cutting force Ffn, Ff a Fp at cutting speed vc=250÷550 [m.min-1] feed per tooth fz =1,0 [mm] a feed rate vf = 7,96 ÷ 17,52 [m.min-1].

Cutting speed: v_c=250÷550 [m.min^{-1}], feed per tooth: f_z=1,0 [mm], feed rate: v_f = 7,96 ÷ 17,51 [m.min^{-1}]. The chart at the feed per tooth $f_z = 1,0$ [mm] are the most favourable conditions for F_{fn}, F_f, F_p at a speed $v_c = 450$ [m.min^{-1}], F_p forces increase with increasing cutting speed.

5. STRUCTURAL EQUATION BY FUNCTIONAL DEPENDENCIES FOR THE TWO VARIABLES

Constants $v_c = 450$ [m.min^{-1}], $f_z = 1,0$ [mm] and variables $v_c = 250, 450, 550$ [m.min^{-1}] and $f_z = 0,5; 1,0; 1,5$ [mm] were chosen. A graph in a logarithmic system was created out of these values for a variable cutting speed f (log v_c, log F_{fn}) and a variable of feed per tooth f (log f_z, log F_{fn}). A regression equation and of reliability R are shown in figure 3 [8].

From the regression equation values „x" and „y" were. The calculated values were substituted into the structural equation and F_{fn}; F_f ;F_p was calculated.

$$F_{fn} = C_{F_{fn}} \cdot v_c^{x_{Ffn}} \cdot f_z^{y_{Ffn}} \quad [N] \qquad F_f = C_{F_f} \cdot v_c^{x_{Ff}} \cdot f_z^{y_{Ff}} \quad [N] \qquad F_p = C_{F_p} \cdot v_c^{x_{Fp}} \cdot f_z^{y_{Fp}} \quad [N]$$

$$\underline{\underline{F_{fn} = 1234,79 \cdot v_c^{-0,09} \cdot f_z^{0,59}\ [N]}} \qquad \underline{\underline{F_f = 422,64 \cdot v_c^{-0,07} \cdot f_z^{0,55}\ [N]}} \qquad \underline{\underline{F_p = 81,50 \cdot v_c^{0,28} \cdot f_z^{0,34}\ [N]}} \qquad (6)\text{-}(7)$$

6. FINAL EVALUATION OF RESULTS

The paper summarizes the measurement of cutting forces when machining stainless steels. In an experimental measurement of cutting forces in face milling a piezoelectric dynamometer KISTLER type 9255B was used. Measurement data were processed into tables and graphs. Graphs show the dependence of components of cutting forces on the cutting speed. Values of components of cutting forces were subtracted from the graph, where F_{fn} is a normal force, F_f is a feed force a F_p is a passive force. Graphs were created from the calculated cutting components of cutting forces and the dependence of cutting forces on speed. The following graphs show that the best selected condition is cutting speed $v_c = 450$ [m.min^{-1}] at feed rate $v_f = 14{,}32$ [m.min^{-1}] at feed per tooth $f_z = 1{,}0$ [mm]. After substituting structural equations for the components of the cutting forces were created. Any errors may have arisen due to an inaccurate measurement, inaccuracies in clamping the sample steels and because o fanny other factors that accompany the whole process of milling.

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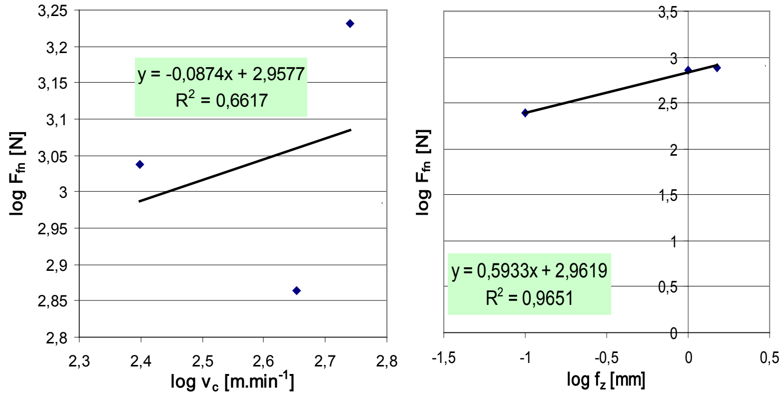
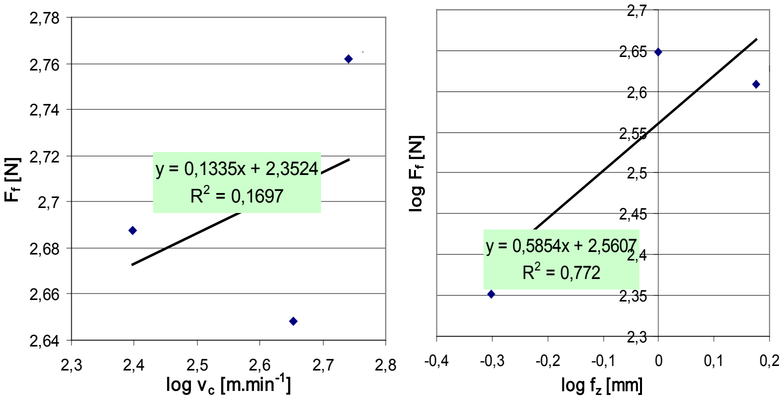
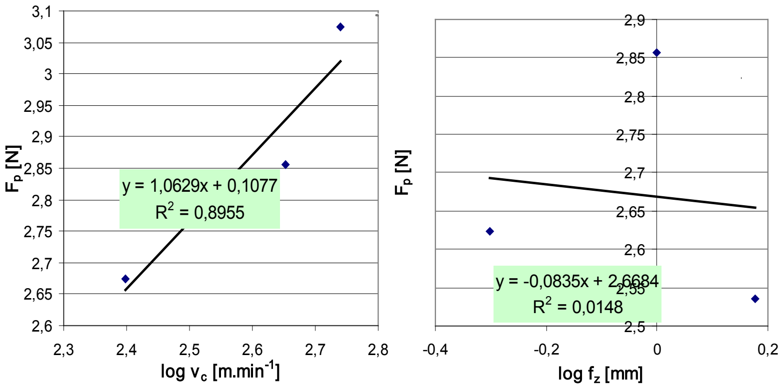


Graph 3: Total cutting forcea Ffn [N] in the logarithmic system for a variable cutting speed vc [m.min-1] f (log vc, log Ffn) a feed per tooth fz [mm] f (log fz, log Ffn) .



Graph 4: Total cutting forcea Ff [N] in the logarithmic system for a variable cutting speed vc [m.min-1] f (log vc, log Ffn) a feed per tooth fz [mm] f (log fz, log Ffn) .



Graph 5: Total cutting forces Fp [N] in the logarithmic system for variable cutting speed vc [m.min-1] and feed per tooth f_z [mm].

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