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AN EXPERIMENTAL METHOD TO EVALUATE THE CUTTING FORCE IN FACE MILLING

BY

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Abstract. Precise assessment of cutting forces is important for both theoretical and experimental researches. Given that the milling process is intermittent and that some of its parameters change periodically, it follows that the evaluation of cutting forces is more difficult than in the case of continuous processes, such as turning.

The paper presents an experimental method for determining the cutting force (tangential) in the milling of the face, with the use of a stationary piezoelectric dynamometer and offline processing of the results.

Keywords: cutting force; single cutting milling face; stationary dynamometer; machining.

1. Introduction

As is known, one of the characteristics of the frontal milling process is the modification of the section of the undeformed chip along contact arc of the cutting tool with the workpiece (Fig. 1). Therefore, the cutting force changes at each point located on the contact arc, proportional to the surface of the undetached chip.

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The difficulty of measuring the (tangential) cutting force F_c increases when more teeth are found on the contact arc (usually a minimum of 2- teeth are needed) and if it is taken into account that the entrance and exit of each tooth in/out of contact with the workpiece is accompanied by dynamic phenomena.

The most accurate results of the measurement of cutting forces generated when processing with multi-teeth tools are obtained when using rotary dynamometers (Milfelner *et al.*, 2005). The use of stationary dynamometers for the same purpose is possible (Croitoru and Bocăneţ, 2019), but limitations arise in terms of the accuracy of the results.

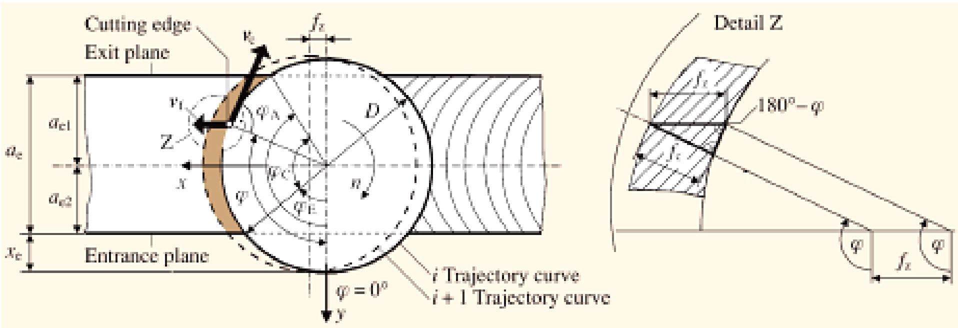

Fig. 1 – Tool-workpiece engagement variables in plain face milling (Grote and Antonsson, 2009).

To increase the accuracy of the experimental results, several researchers, that have used tools with a single tooth,are known (Pérez *et al.*, 2007; Grigorieva *et al.*, 2015).

This paper presents a method for determining the cutting force (tangential) F_c at the face milling, which involves the use of a stationary dynamometer type 9272, produced by Kistler, with which the components of the cutting force are measured along the axes of the dynamometer. Experimental data are then processed off-line.

2. Methodology

The basic idea of the study consists of the following:

• The decomposition of the active force F_a is considered in the two reference systems shown in Fig. 2, *i.e.* the fixed system (of the stationary M*xy* dynamometer) and the rotational system (formed from the direction of the V_c cutting speed and the radial direction);

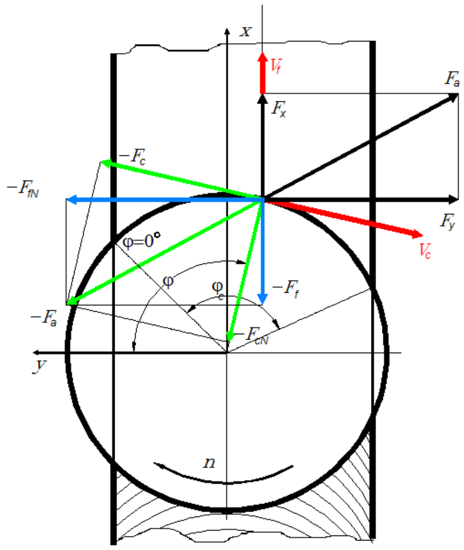

Fig. 2 – Decomposition of the cutting force in the two systems considered (fixed and mobile).

• Calculate the active force F_a using F_x and F_y components, measured using a stationary dynamometer;

• Tangential cutting force F_c is determined in the mobile reference system, depending on the active force F_a and the angle ψ that F_c makes with F_a, at each point on the contact arc of the tooth with the workpiece (Fig. 3 and Fig. 4).

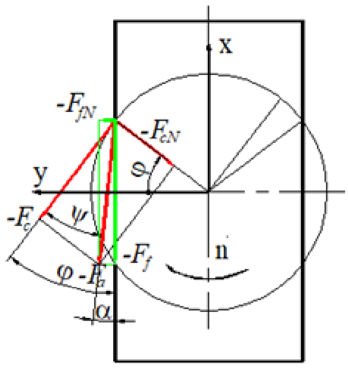

Fig. 3 – The case $0 < \varphi < \pi/2$.

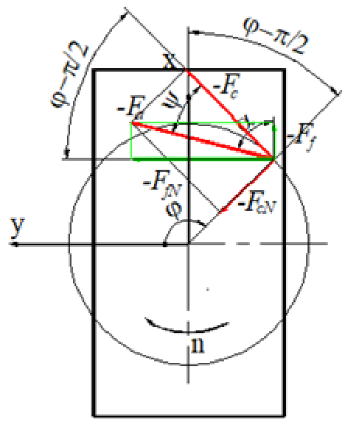

Fig. 4 – The case $\pi/2 < \varphi$.

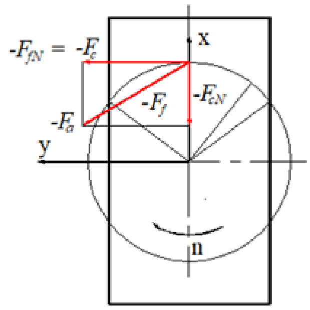

Fig. 5 – The case $\varphi = \pi/2$

Depending on the angular position of the tooth on the contact arc with the φ, three situations are possible, as follows:

• $0 < \varphi < \pi/2$ (see Fig. 3), when the cutting force F_c is computed with the relationship (1):

$$F_c = F_a \cdot cos\psi = F_a \cdot cos\left(\varphi - arccos\frac{F_f}{F_a}\right) \tag{1}$$

• $\pi/2 < \varphi$ (see Fig. 4), when the cutting force F_c is computed with the relationship (2):

$$F_c = F_a \cdot \cos\psi = F_a \cdot \cos\left(\varphi + \arccos\frac{F_f}{F_a} - \pi\right) \tag{2}$$

• $\varphi = \pi/2$ (see Fig. 5), when the force F_c is computed with the relationship (3):

$$F_c = F_{fN} = F_y \tag{3}$$

Experiments have been performed on blank steel 10503 DIN having 218 hardness (Brinell) and 730 (Mpa) yield strength.

The tests were performed on a FUS25 milling machine, in dry conditions, spindle speed 250 rev/min (corresponding to 50 m/min cutting speed), feedrate 54 mm/min (corresponding 0.026 mm/rev), axial engagement a_a (depth of cut a_p) 1 mm.

The feed direction was in the positive direction of x axis x (Fig. 6).

The cutting tool used in this research was a face milling cutter, 90° main cutting angle, 63 mm diameter, equipped with 1 (one) coated carbide insert with positive rank angle.

The two milling force components (F_x and F_y) were measured by a 9272 type Kistler dynamometer.

The sampling frequency was 1000 Hz, corresponding to 1.5° increments of the spindle rotation.

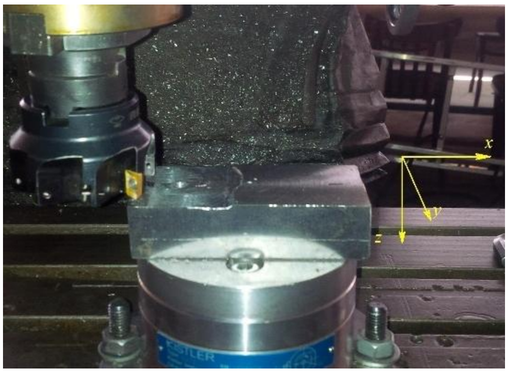

Fig. 6 – Feeding direction in dynamometer coordinates.

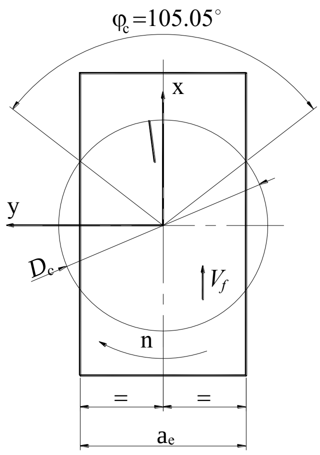

Fig. 7 – Position of the cutting tool and the workpiece during the tests.

According to Fig. 7, it follows that the contact angle of the cutting tool with the blank is approximately 105°, symmetrically positioned in relation to the width of the workpiece.

3. Analysis of Results and Discussion

In the first part of the experimental research, the active force generated when processing with a frontal mill with a single tooth was determined.

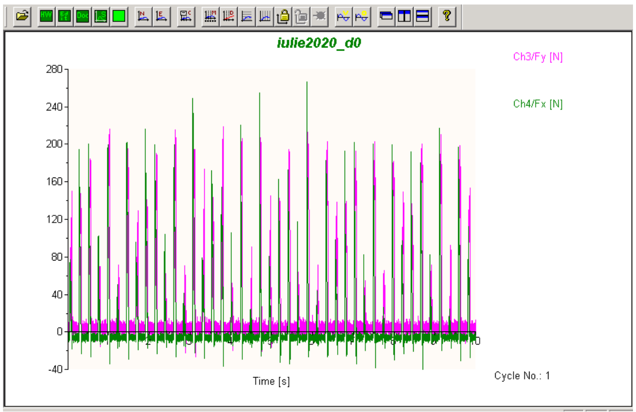

Fig. 8 – Cutting components F_x and F_y measured as a function of time.

According to the methodology presented in a previous paper (Croitoru and Bocăneţ, 2019), the following steps were accomplished:

• the evolution of the F_x (F_f) and F_y (F_{fN}) components of the cutting force was recorded in both graphic form (see Fig. 8), as well as numerical;

• the active force F_a was calculated using the geometric relation (4):

$$F_a = \sqrt{F_x^2 + F_y^2} = \sqrt{F_f^2 + F_{fN}^2} \quad (4)$$

• the graphs of the evolution of computed active force F_a over time were visualized by means of geometric relation (4), as shown in Fig. 9 and the areas of action of the tooth were identified on the contact arc of the cutting tool with the workpiece.

• some details of the active force F_a were highlighted along the contact arc of the cutting tool with the workpiece (see Fig. 10), such as the entry point for cutting the tooth (P) and the exit point for cutting (R), the 73 samples registered on the contact arc with an aperture of 105°;

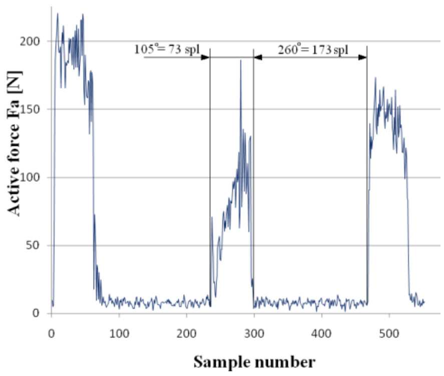

Fig. 9 – Computed active force component F_a.

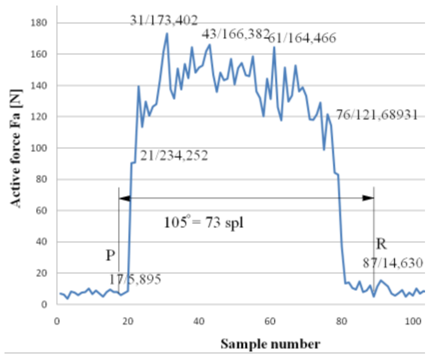

Fig. 10 – Computed active force component F_a corresponding one rotation of cutter.

Next, the cutting force F_c was calculated for each considered point. Therefore, the values of the active force F_a were used, previously calculated with the relations (1), (2) and (3), depending on the current position of the tooth on the contact spring with the workpiece.

Also, graphs of cutting force evolution F_c throughout the contact arc of the cutting tool with the workpiece were plotted (Fig. 11).

In this way, it was revealed:

• the values of the cutting force F_c in each point along the contact arc of the cutting tool tooth with the workpiece;

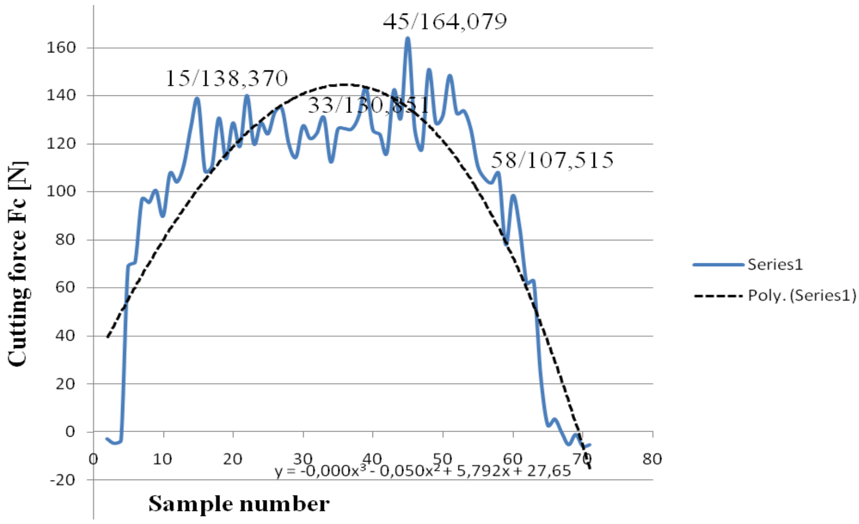

Fig. 11 – Chart of calculated cutting force component F_c.

• for the calculated values of the force F_c an approximate function was made by means of a polynomial function of the third order (Fig. 11);

• by this approximation it was highlighted that the value of the force F_c changes at each point of the contact arc, in accordance with the change of the thickness of the undeformed chip;

• in case of symmetrical arrangement of the tool in relation to the workpiece (the case studied in this paper), the maximum value of the force F_c is reached for the point corresponding to the maximum thickness of the detached chip, *i.e.* for the point located in the middle of the tool contact arc (corresponding to the direction of the x-axis in Fig. 7).

4. Conclusions

An experimental method has been established which may describe modification the tangential cutting force F_c throughout the contact arc of cutting tool with the workpiece according to the variation of the instant chip thickness.

In this way it has been shown that the method can be useful for the study of complex phenomena regarding the influence of relative position of the tooth tool on the cutting effort.

Also, the adopted methodology proves that it is possible to use a stationary dynamometer to study complex dynamic phenomena, such as the influence of microgeometry of cutting-edge on cutting efforts in case of milling operation.

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METODĂ EXPERIMENTALĂ PENTRU EVALUAREA FORŢEI DE AŞCHIERE LA FREZAREA FRONTALĂ

(Rezumat)

Evaluarea precisă a forțelor de așchiere este importantă atât pentru cercetătorii teoretici cât şi pentru cei experimentali ai proceselor de așchiere.

Evaluarea forței de așchiere (tangențiale) se poate face atât cu dinamometre rotative cât şi staționare.

Utilizarea dinamometrelor staționare presupune o prelucrare a datelor, în afara procesului de așchiere.

În lucrare se prezintă o metodă experimentală pentru determinarea forței de așchiere (tangențiale), care utilizează un dinamometru piezoelectric staționar tip KISTLER 9272 (destinat în special pentru operații de strunjire şi găurire) şi a unui algoritm care utilizează forța activă, calculată în afara procesului de așchiere.