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EXPERIMENTAL RESEARCHES REGARDING CUTTING FORCES IN SYMMETRICAL FACE MILLING

BY

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Abstract. Knowing the forces values in metal cutting is an essential requirement due of their connection with the cutting tool design, energy and tools consumption, vibrations in process, workpiece machinability and accuracy of the final product. This study presents an experimental investigation of the cutting forces occurring in symmetrical face milling, taking into account different working conditions, both in terms of variation of milling specific elements (radial depth of cut, number of teeth that simultaneously cut, contact angle between cutter and workpiece) and cutting regime (feed per tooth).

Keywords: symmetrical face milling; analytical models; forces measurement; forces analysis.

1. Introduction

The large number of theoretical and experimental researches in the field of face milling shows the importance that this process has within the specific technologies in machines manufacturing. Theoretical and experimental studies related to the dynamic of face milling process were intended to evaluate the cutting forces and moments and the influence that they have on the technological system stability (Sekulić *et al.*, 2007; Salguero *et al.*, 2013; Zheng

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Minli *et al*., 2008). Also, the forces in face milling have been extensively used in the study of several aspects of the cutting process such as the manner that they could be used for controlling the cutting process, detecting the wear and/or breakage of the cutting tool and the development of new types of tools and milling machines (Kuljanic and Sortino, 2005; Korkut *et al.*, 2007; Guzeev and Pimenov, 2011; Bhattacharyya *et al*., 2008). The cutting forces developed during processing and because of them, the quality of the machined surface, are influenced by a number of factors, including the feed rate, depth and width of cut, the cutting geometry, hardness of the material being cut, the cutter's number of teeth and the relative position between tool and workpiece. Thus, most analytical models for calculating cutting forces in face milling include these parameters and also the rotational movement of the cutter (Bhattacharyya and Sengupta, 2009; Aykut *et al.*, 2007; Sekulić *et al.*, 2007; Budak, 2006; Cozmîncă, 1995; Kaymakci *et al.*, 2012; Kumar Pradeep Baro *et al*., 2005; Yang Yang *et al*., 2013).

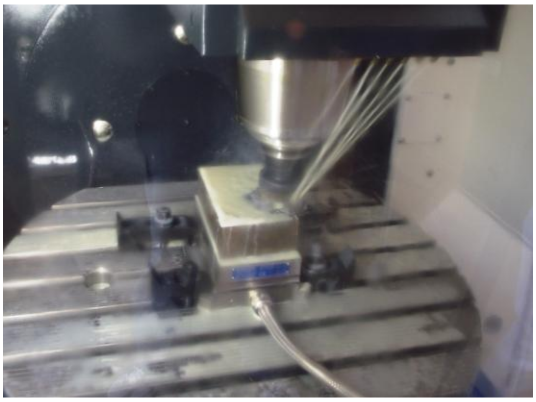
This study is intended to experimentally verify the theoretical models for the evaluation of cutting force components in symmetrical face milling which are considering, in addition to the parameters described above, the specific elements of each variant milling, such as symmetrical full (complete) and incomplete milling, the number of teeth that simultaneously cut and the relative position between the cutting teeth and part, such as cut-up and cut-down milling (Bocăneţ and Cozmîncă, 2014).

2. Methodology of Experimental Researches on Cutting Force's Components in Symmetrical Face Milling

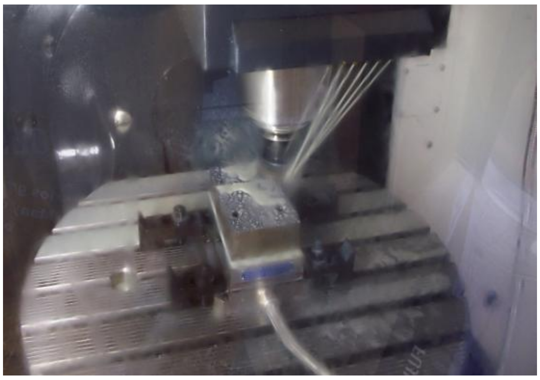
The methodology of experimental researches carried out in order to verify the proposed theoretical models of symmetrical face milling forces is the same used in a previous study related to verifying the cutting forces in asymmetrical face milling (Bocăneţ and Cozmîncă, 2015). The universal milling machine CNC *DMU 50 eco* and face milling cutter from ZCC-CT Company, equipped with inserts, type *APMT11T3DSR-MM,* were used in order to process the part and the dynamometer Kistler, 9257BA type, was used for measuring the three components of cutting force. Some experimental measurements were performed in order to verify the valuation models of forces in symmetrical face milling, both in cut-up and cut-down milling, for three different values of feed rate. For both types of milling, namely full and incomplete, the adopted working regime was the following one: *speed* n = 505 rpm; *cutting velocity* (*peripheral velocity*) v_c = 100 m/min; *axial cutting depth* a_p = 1 mm; *feed per tooth* f_1 = 0.10 mm/tooth; f_2 = 0.14 mm/tooth; f_3 = 0.18 mm/tooth. The processing variables are the radial depth of cut (a_e), the number of teeth that simultaneously cut (z_s) and the contact angle (Ψ) between cutter and workpiece, so one had the following values: a_e = 49 mm, Ψ = 124.5°, z_s = 2.5

– calculated (Cozmîncă *et al*., 2010) for incomplete symmetrical face milling, a_e = 63 mm, Ψ = 180°, z_s = 4.5 – calculated (Cozmîncă *et al*., 2010) for complete (full) face milling. The machining was performed using coolant.

Fig. 1 illustrates some images captured during the experimental tests.



a



b

Fig. 1 – Symmetrical face milling: *a* – complete (full); *b* – incomplete.

As in the previous study (Bocăneţ and Cozmîncă, 2015) the positioning and fastening of the part on dynamometer were made using four screws which required the construction of four holes, with negative impact on the measurement of force's components in milling. Also, between the orientation and positioning of coordinates systems, namely the orientation of cutting force's components from the normal plane to cutter's axis, according to which the models for evaluating F_Z, F_X and F_Y were developed (Bocăneţ and Cozmîncă, 2014), and respectively, the orientation of dynamometer's coordinates system according to which the dynamometer is measuring the force's components, there are differences and therefore, in order to correctly appreciate the forces values, equalization of the two systems is necessary. To experimentally verify the analytical models for face milling forces evaluation, a set of data was registered, where the tangential force F_y is corresponding to component F_Z, F_x is the radial force corresponding to component F_X and F_z is the axial force corresponding to component F_Y in face milling (Bocăneţ and Cozmîncă, 2015).

3. Results Regarding the Cutting Force's Components in Symmetrical Face Milling

A preliminary form of registered data is presented in Fig. 2 and the analysis of the resulted graphic highlights the following:

– the time for measuring the forces was 30 seconds;

– due to the presence of holes for positioning and fastening the part on dynamometer, in order to measure the minimum, maximum and mean values of forces, a period of time from 1 to 4.5 seconds was chosen (depicted in Fig. 3), when the process is considered to be stabilized;

– registrations show the evolution of forces for every cutting in or out of the insert;

– the shape of evolutionary forces diagrams shows the complex nature of the milling process, since many factors are involved during processing, both of technological system and of milling process (shocks generated by the entry and exit of the cutting inserts, appearance and removing the material deposition on the cutting edge, changes of tool geometry due to wear, chip thickness variation, etc).

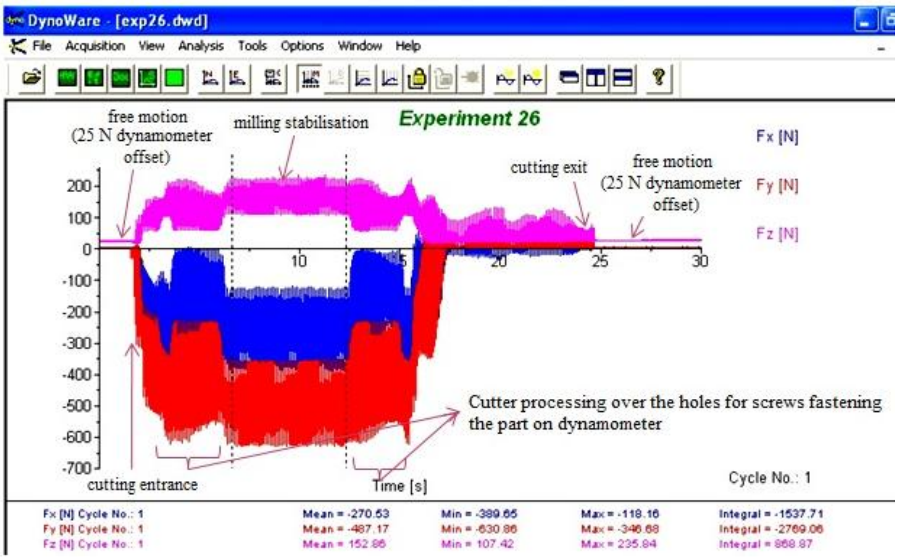


Fig. 2 – Forces variation in incomplete symmetrical cut – down face milling, using f_{z1} = 0.1 mm / tooth for a measuring period of time of 30 s.

Some of the results are presented below.

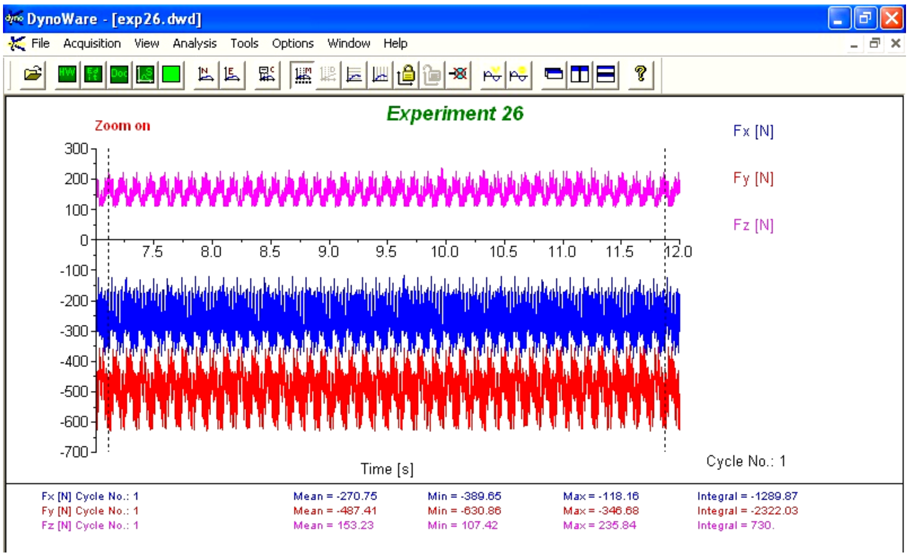


Fig. 3 − Detail on Fig. 2 in the stabilized area of cutting
Cutting conditions: v_c = 100 m/min; f_{z1} = 0.1 mm / tooth; a_e = 49 mm;
a_p = 1 mm; workpiece material: C 45.

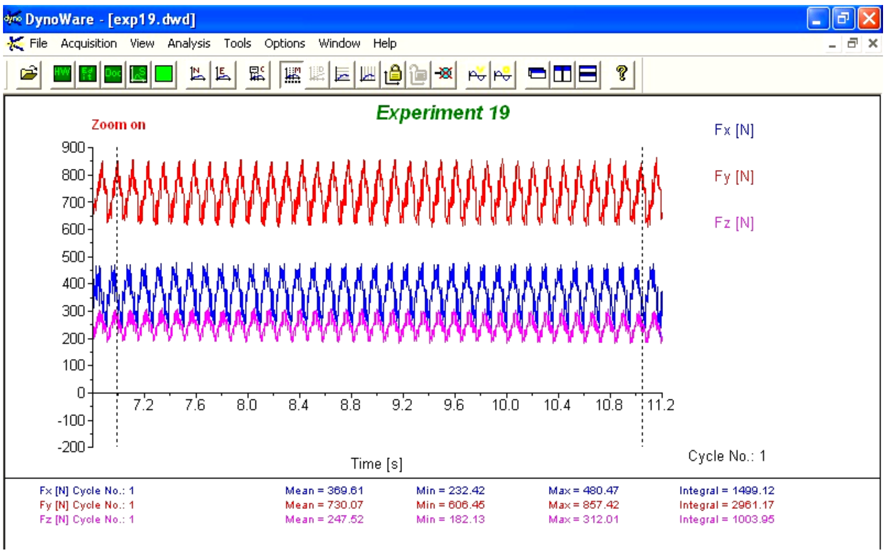


Fig. 4 − Variation of cutting forces in full symmetrical cut-up face milling, feed per tooth f_{z1} = 0.14 mm/tooth.
Cutting conditions: v_c = 100 m/min; v_{f2} = 565 mm/min; a_e = 63 mm; a_p = 1 mm; workpiece material: C 45.

4. Comparative Analysis of the Forces Analytical Models in Symmetrical Face Milling and Measurement Results

Furthermore, some comparison charts between the values obtained using the analytical models for the evaluation of forces in symmetrical face milling (Matei (Bocăneț), 2012; Bocăneț and Cozmîncă, 2014) and those obtained by measuring, were conducted (Figs. 5-7).

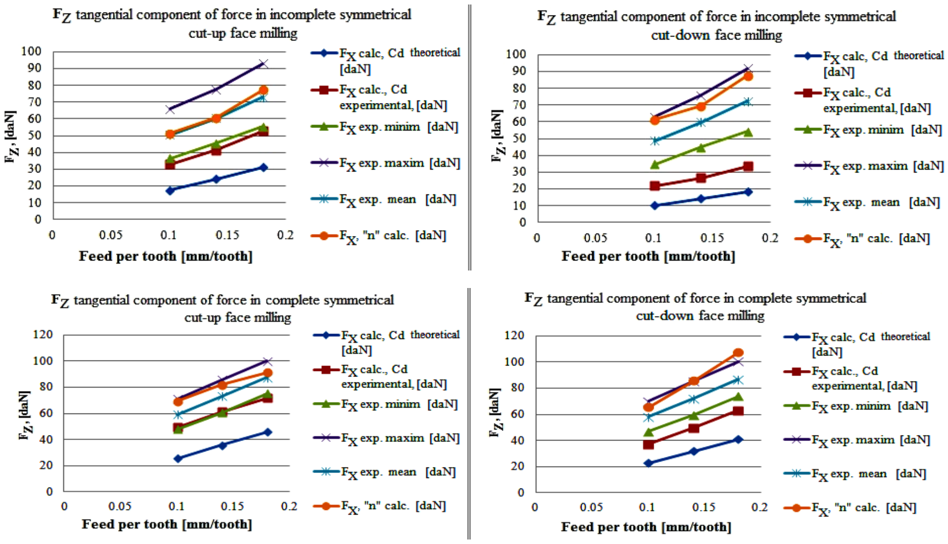


Fig. 5 – Values of tangential component F_Z of the force, theoretically and experimentally determined.

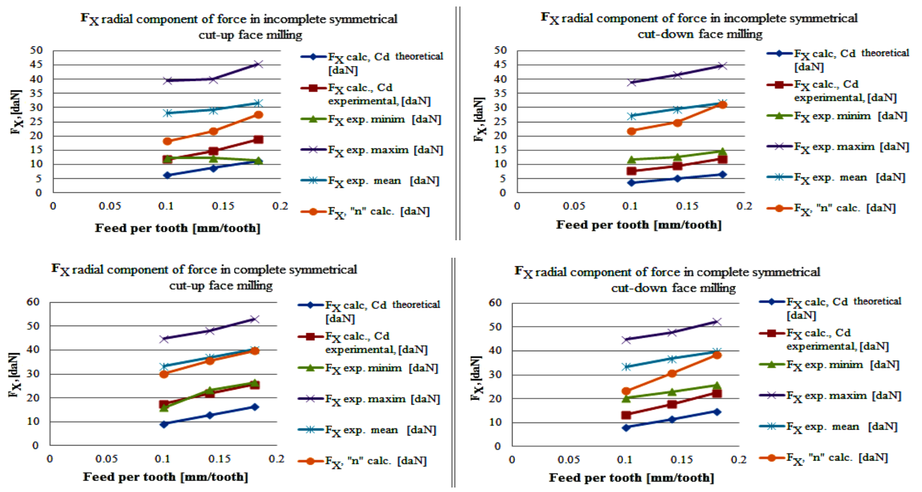


Fig. 6 – Values of radial component F_X of the force, theoretically and experimentally determined.

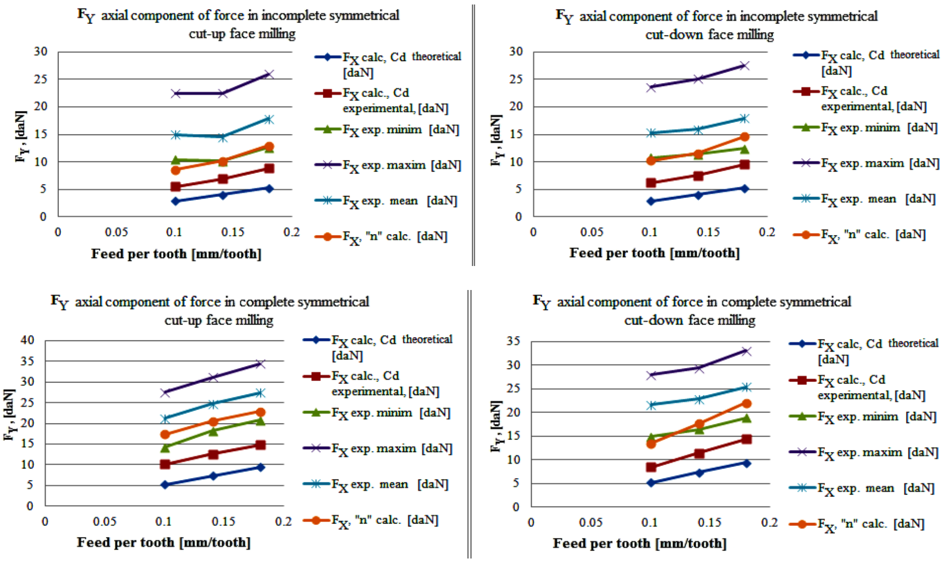


Fig. 7 − Values of axial component F_Y of the force, theoretically and experimentally determined.

When calculating the theoretical values of face milling forces, there were considered the cutting forces acting on an insert, working conditions of the tests (radial cutting depth a_p, feed rate *f*, cutting velocity v_c), geometrical parameters of the cutter and chips contraction coefficient C_d, both theoretically and experimentally determined.

The comparison charts show that the calculated values of forces components F_Z, F_X and F_Y are positioned between the maximum and minimum experimental values of forces, but because of the multiples factors which may interfere, in some cases they exceed this limits.

Some possible causes of these differences come from the hypothesis used for developing the analytical models, such as it was considered a mean value of the cutting force acting on an insert, a value equal for all the inserts that were simultaneously in cut and the average value of chip's thickness was used (Cozmîncă, 1995; Bocăneț and Cozmîncă, 2014; Bocăneț and Cozmîncă, 2015), while in practice the chip's thickness varies along the contact angle.

5. Conclusions

The comparison charts of the values obtained by theoretical calculation and experimental values obtained for symmetrical face milling force's components, show that, in most of the cases, the theoretical values are positioned on one side or another of the mean experimental value, approaching to the maximum or minimum values according to the different influences that occur during processing.

It was shown that this fact appears due to using of an average value for the force acting on an insert, but also because of using the average value of 1.5 for the exponent "n" of the chip's contraction coefficient C_d from the relationship of deformation force.

Since the exponent "n" takes different values for each component of the force, depending on the variant of milling and feed per tooth, for a proper appreciation of its value an experimental verification is required. In order to do this correction it is necessary to carry out a new set of experimental measurements for face milling using a cutter with a single tooth.

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CERCETĂRI EXPERIMENTALE PRIVIND COMPONENTELE FORŢEI DE AŞCHIERE LA FREZAREA FRONTALĂ SIMETRICĂ

(Rezumat)

Studiile teoretice și experimentale legate de dinamica procesului de frezare frontală urmăresc evaluarea forțelor și momentelor de așchiere, influența pe care o au acestea asupra stabilității sistemului tehnologic. Forțele la frezarea frontală au fost intens utilizate și în studierea altor aspecte ale procesului de așchiere așa cum sunt modul în care pot fi utilizate pentru controlul și reglarea procesului de așchiere, detectarea uzurii și/sau ruperii sculei așchietoare, dezvoltarea unor noi tipuri constructive de scule așchietoare și mașini de frezat.

Din diagramele de comparaţie între valorile obţinute prin calcul teoretic cu ajutorul modelelor analitice şi valorile experimentale obţinute pentru componentele forţei la frezarea frontal simetrică, se poate observa că, în majoritatea cazurilor, valorile teoretice se situează de o parte şi de alta a valorilor medii experimentale, apropiindu-se de valorile maxim sau minime în funcţie de diferitele influenţe care apar în timpul prelucrărilor.