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EXPERIMENTAL RESEARCHES REGARDING THE FORCES' COMPONENTS IN FACE MILLING (I)

BY

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Abstract. Mathematical models developed to evaluate face milling forces are considering the factors influencing on a tooth level and their interdependence, but also the influences of specific elements in face milling, the manufacturing variants of face milling (full and incomplete symmetrical milling, asymmetrical milling), the number of teeth that simultaneously cut and the relative position between cutter and workpiece (cut - up and cut - down milling). In order to use the new valuation models of face milling forces in design, one consider necessary to carry out experimental tests to show their validity and applicability in real situations, but also to find out the manner they could be improved if necessary.

Key words: cutting force's components acting on a tooth; number of teeth that simultaneously cut; face milling forces.

1. Introduction

Methodology of experimental researches carried out in order to verify the proposed theoretical models of face milling forces (Bocăneţ & Cozmîncă, 2014) considers the following steps:

− verifying the mechanical and chemical features of the workpieces - 2

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workpieces measuring about 100×50×40 mm were used, (according to the Inspection Certificate made by Romanian company "SC Mechel - Targovişte", the material samples are *C45*);

− performing experimental tests in order to verify the Brinell hardness of the material samples by using the universal hardness tester Wilson Wolpert, type 751 N;

− measuring the workpiece dimensions and preparing it for machining;

− selecting and preparing the piezoelectric dynamometer equipment in order to carry out the measurements – a 4-components piezoelectric dynamometer Kistler, 9272 type, was used; dynamometer can be used to measure three orthogonal force's components F_x, F_y and F_z in drilling, turning and milling, and also M_z torque. In order to carry out the measurements an adapted part was made for attaching the workpiece to dynamometer. For data acquisition and assessment one used the software DynoWare, 2825A02 type, version 2.4.1.6., from Kistler company;

− performing the tests by processing the workpiece in every variant of face milling and measuring the radial depth of cut and the number of teeth that simultaneously cut for each variant – one used the romanian milling machine FUS 25, face milling cutter EMP02-063-A22-AP11-08 from ZCC-CT company, equipped with inserts APKT117304-PM type (http://www.zccct-europe.com/);

− collecting chips after processing in every variant of face milling in order to find out the experimental value of chips contraction coefficient C_d;

− processing the experimental measurements of F_Z, F_X and F_Y forces from every face milling machining in order to verify the proposed valuation models.

The values of force's components in face milling will be determined in different working conditions, both in terms of variation of milling specific elements (milling depth, number of teeth that simultaneously cut, contact angle between cutter and workpiece), and cutting regime (feed per tooth). Preliminary experimental tests were carried out in *Department Machine - Tools*, *Cutting tools laboratory* of the *Faculty of Machine Manufacturing and Industrial Management.*

2. Preliminary Results of Measurements Regarding the Cutting Force's Components in Asymmetrical Face Milling with Contact Angle Ψ > 90° and Symmetrical Incomplete Milling

Several experimental measurements were performed in order to verify the proposed valuation models of forces in asymmetrical face milling with contact angle $\Psi > 90°$ and symmetrical incomplete milling using three different feedrates. For both types of milling the adopted working regime is the following one: *speed* n = 200 rpm; *cutting velocity* (*peripheral velocity*) v = 39.56 m/min; *axial cutting depth* B = 1 mm; *feed per tooth* s_{z1} = 0.08 mm/tooth; s_{z2} = 0.04 mm/tooth; s_{z3} = 0.02 mm/tooth. It will differ the radial depth of cut (t), the number of teeth that simultaneously cut (z_s) and the contact angle (Ψ) between cutter and workpiece so we'll have the following values: t = 45 mm, z_s = 2.5 – calculated (Cozmîncă *et al.*, 2010) and Ψ = 115.37° for face milling with $\Psi > 90°$; and t = 50 mm, z_s = 2.5 – calculated (Cozmîncă *et al.*, 2010) and Ψ = 125.96° for symmetrical incomplete face milling. The machining was performed without using coolant.

Next there are presented the experimental results of every milling, in form of records and graphics from which one can see details regarding the cutting regime and the variation of cutting force in face milling.

Depending on the relative position between cutter and workpiece and the values of feed per tooth, for asymmetrical face milling with contact angle $\Psi > 90°$ we performed a series of experimental determinations according to the working scheme (Figs. 1 and 2) and to the screenshots taken during forces measurements (Fig. 3).

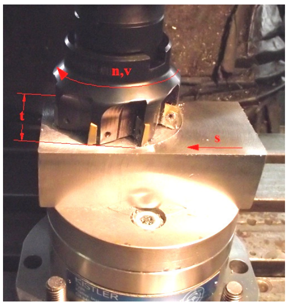

Fig. 1 – Processing by asymmetrical cut-down face milling with contact angle $\Psi > 90°$.

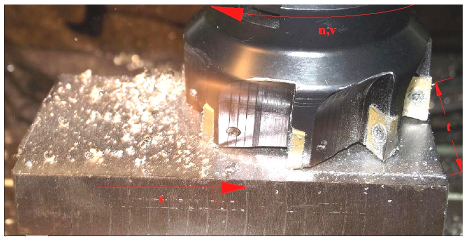

Fig. 2 – Processing by asymmetrical cut-up face milling with contact angle $\Psi > 90°$.

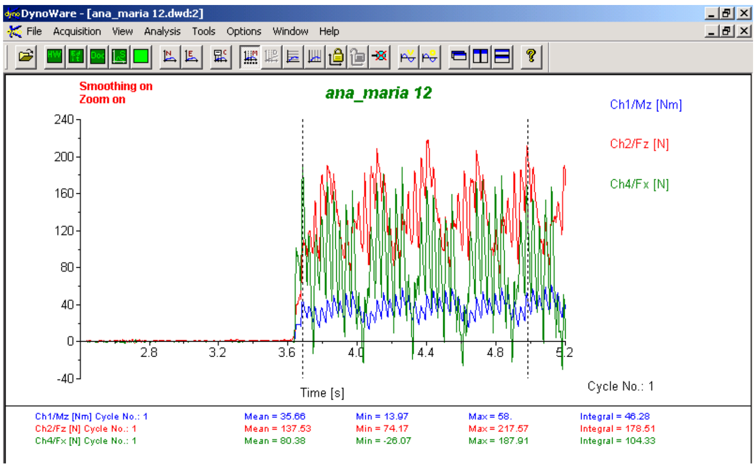

Fig. 3 – Variation of cutting forces in asymmetrical cut down face milling, $\Psi > 90°$, for feed per tooth s_{z1} = 0.08 mm/tooth.
Cutting conditions: v = 39.56 m/min; s = 0.64 mm/rev; t = 45 mm; B = 1 mm; work: C 45.

Depending on the relative position between cutter and workpiece and the values of feed per tooth, for symmetrical incomplete face milling we performed a series of experimental determinations according to the working scheme (Figs. 4 and 5) and to the screenshots taken during forces measurements (Fig. 6).

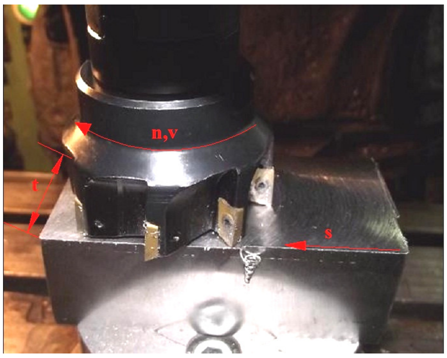

Fig. 4 – Processing by symmetrical and incomplete cut-down face milling.

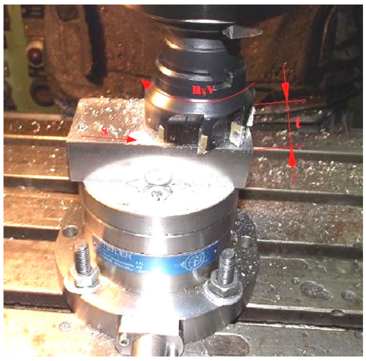

Fig. 5 – Processing by symmetrical and incomplete cut-up face milling.

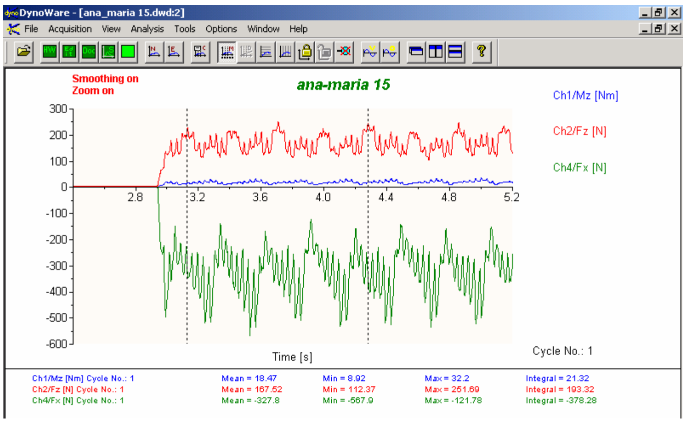

Fig. 6 – Variation of cutting forces in symmetrical cut-up face milling, for feed per tooth s_{z1} = 0.08 mm/tooth.
Cutting conditions: v = 39.56 m/min; s = 0.64 mm/rev; t = 50 mm; B = 1 mm; work: C 45.

Forces measuring time was 15 sec and on some of the diagrams one can observe the cutter's entrance in working process and the stabilization effect of cutting process. For extracting the minimum, maximum and average values of force's components one choose a period of time from 1 to 4.5 sec when the process was considered to be stabilized. On graphics can be observed the positive values in cut-down milling and negative values in cut-up milling for F_X component, depending on how the compression and stretching efforts vary with feedrate direction. The manner that instantaneous forces evolve within diagrams highlights the complex nature of the milling process. These evolutions of forces are strictly related to the cutting process.

3. Considerations Regarding the Comparative Analysis of New Valuation Models of Face Milling Forces and the Measurement Results

Studying data and records of experimental measurements, further we conducted some comparison charts between the values obtained using the analytical models for evaluation of forces in face milling (Matei & Milea, 2010; Matei (Bocăneţ), 2012; Bocăneţ & Cozmîncă, 2014) and those obtained by measuring, for each variant of milling that was subject of experimental verifications.

When determining the theoretical values of face milling forces in these two cases we considered the cutting forces acting on an insert, working conditions of the tests (radial cutting depth *B*, feedrate *s*, cutting velocity *v*), geometrical parameters of the cutter and chips contraction coefficient, both theoretically and experimentally determined. In order to calculate the average value of force's components acting on the insert, from the proposed analytical models, the following values for working regime, geometrical parameters of cutter and material characteristics, were used: B = 1 mm; $\gamma = 7°$, $\lambda = 8°$, K = 89°, $\sigma_0 = 78.7$ daN/mm^2 and n = 1 (from eq. $F_N = \sigma_0 \cdot t \cdot s \cdot C_d^n$ of deformation force) (Cozmîncă, 1995; Cozmîncă *et al.*, 2009) for free cutting of steels.

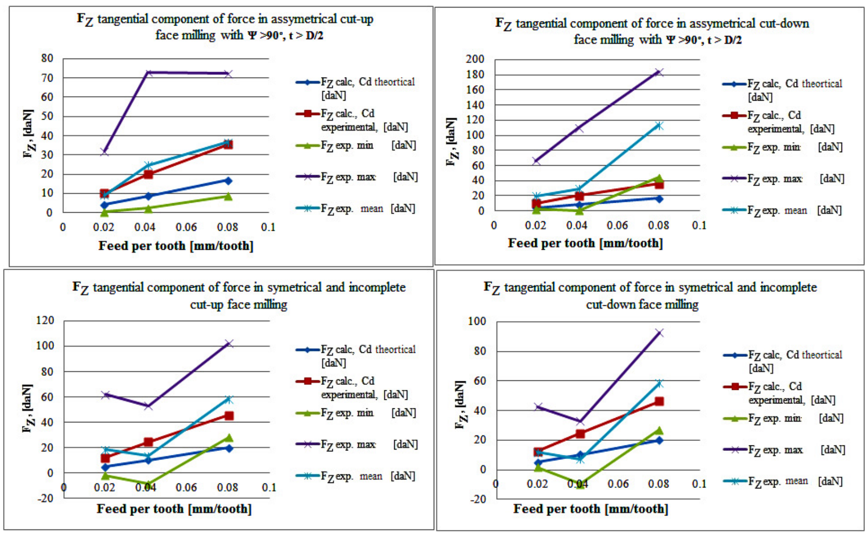

Fig. 7 – Values of tangential component F_Z of force depending on variant of face milling and feed per tooth.

First there were analyzed the resulting values for tangential component of force F_Z in face milling, depending on the relative position cutter - workpiece and feed per tooth, thus obtaining the diagrams from Fig. 7, from which one can see the experimental minimum, maximum and average values of force's component but also the values obtained using theoretical relationships (Bocăneţ & Cozmîncă, 2014) where C_d was determined both analytically and experimentally.

The experimental values of F_Z component follows, a large majority, the same pattern, with a few exceptions, due to the many factors that may occur during milling process. In most cases, the values F_Z, obtained using the proposed analytical model for cut-up and cut-down face milling, are close to the average values experimentally determined.

Next there were analyzed the values of radial component of the force F_X in face milling, depending on the relative position cutter - workpiece and feed per tooth. The diagrams from Fig. 8 were obtained from which there can be seen the experimental minimum, maximum and average values of force's component but also the values obtained using theoretical relationships (Bocăneţ & Cozmîncă, 2014) where C_d was determined both analytically and experimentally.

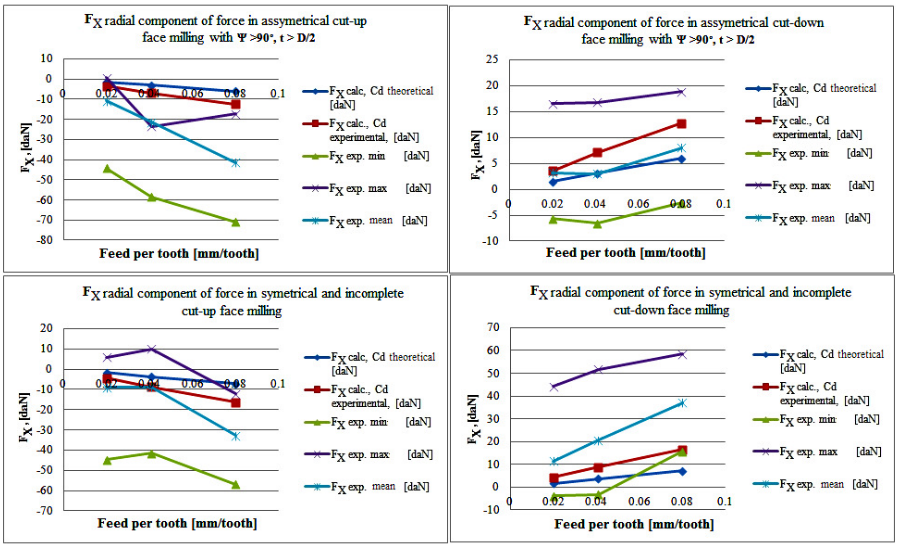

Fig. 8 – Values of radial component F_X of force depending on variant of face milling and feed per tooth.

The values obtained by theoretical calculation of F_X component have different trends for cut-up and cut-down milling, such as in cut-up milling they are higher than the average values experimentally determined, approaching very much to maximum values, which requires testing the values of F_x component acting on a tooth, and in cut-down milling the values obtained by theoretical calculation are closer to the average values experimentally determined, being situated on both sides of it, closer to the maximum and minimum values according to different influences during processing.

For the last part there were studied the values for F_Y axial component of force in face milling, depending on the relative position between cutter - workpiece and feed per tooth. The diagrams from Fig. 9 were obtained. One can see the experimental minimum, maximum and average values of force's component but also the values obtained using theoretical relationships (Bocăneţ & Cozmîncă, 2014) where C_d was determined both analytically and experimentally.

For F_Y component theoretically determined we obtained lower values than the average ones, approaching often to minimum values experimentally determined. This requires that the valuation models should use values higher than 1 for the exponent "*n*" of the contraction coefficient C_d (Bocăneţ & Cozmîncă, 2014; Matei (Bocăneţ), 2012). In order to do this, a second set of experimental measurements is considered to be necessary, namely processing with a single tooth.

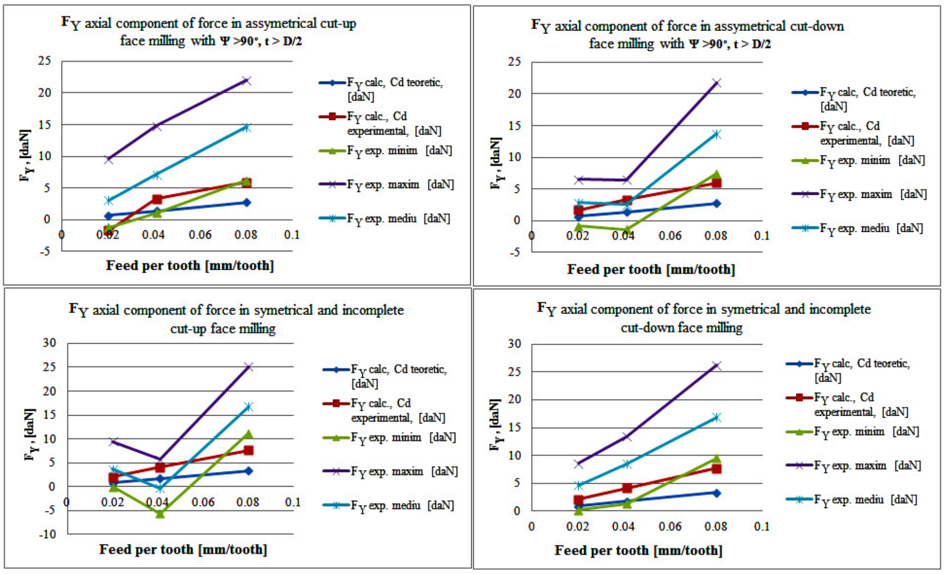

Fig. 9 – Values of axial component F_Y of force depending on variant of face milling and feed per tooth.

4. Conclusions

The graphics generated using DynoWare after carrying out the measurements reveal the complex nature of milling process, since many factors are involved in processing, specific to technological system (own mode of vibration and rigidity, working environment) or to milling process, as the shocks generated by the entry and exit of cutting inserts, occurrence and removal of built-up edge, tool's geometry variations due to wear, chip thickness variation.

Since in symmetrical and asymmetrical milling when processing with more than 50% of the cutter (contact angle between cutter and workpiece is $\Psi > 90^{o}$) cut-up and cut-down milling are combined, prevailing one of them, as future researches we intend to make a new set of test, when milling with less than 50% of the cutter, cases when one can have either cut-up or cut-down milling. The tests will consider the experimental working steps shown above, and ultimately, the possibility to improve the proposed mathematical models and their validation based on the results of experimental investigations.

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CERCETĂRI EXPERIMENTALE PRIVIND COMPONENTELE FORŢEI DE AŞCHIERE LA FREZAREA FRONTALĂ SIMETRICĂ ŞI ASIMETRICĂ (I)

(Rezumat)

Modelele de evaluare a componentelor forţei la frezarea frontală în aceste două cazuri au la bază influenţele factorilor care apar la nivelul unui dinte, dar şi interdependeţele dintre acestea, influenţele elementelor specifice frezelor, variantele de frezare posibile (frezare simetrică plină, frezare simetrică incompletă şi frezare asimetrică), numărul de dinţi care aşchiază simultan şi poziţia relativă freză – semifabricat (frezare în sensul avansului şi frezare în contra avansului). Dacă influenţele

la nivelul unui dinte au fost deja verificate experimental, elementele specifice procedeului de frezare frontală care au stat la baza studiului teoretic trebuie şi ele verificate experimental, fiecare în parte şi în măsura în care este posibil. Mărimea componentelor forței la frezarea frontală a fost determinată în condiții de lucru diferite, atât în ceea ce priveşte variația elementelor specifice frezării (adâncime de frezare, număr de dinți care aşchiază simultan, unghi de contact dinte – semifabricat), cât şi regimul de aşchiere (avans pe dinte). Determinările experimentale preliminare au fost realizate în cadrul Departamentului Maşini – Unelte şi Scule, laboratorul de Scule aşchietoare al Facultății Construcții de Maşini şi Management Industrial.