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

BY

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Abstract. Mathematical models used to evaluate face milling forces are considering the factors influencing on an insert level and their interdependence, but also the influences of specific elements in face milling, the manufacturing variants of face milling the number of teeth that simultaneously cut and the relative position between cutter and workpiece. 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

In order to carry out the experimental researches same methodology as in previous paper was used. Therefore a series of experimental tests was performed, for every variant of asymmetrical face milling with contact angle between cutter and workpiece, $\Psi \leq 90^{o}$, both in cut-up and cut-down milling, for three different values of feederate. For both types of milling the adopted

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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 = 31.5 mm, z_s = 2 – calculated (Cozmîncă *et al.*, 2009) for face milling with Ψ = 90°; and t = 15 mm, z_s = 1.5 – calculated (Cozmîncă *et al.*, 2009) and Ψ = 58.41° for face milling with Ψ < 90°. The machining was performed without using coolant.

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

In order to carry out the experimental verifications of the analytical models proposed for the evaluation of face milling forces (Bocăneț & Cozmîncă, 2014), for each processing, a set of data was registered, where tangential force F_Z is given by the torque M_z and can be calculated, according to Fig. 1, using relationship (1); F_X is the radial component of cutting force in cut-down milling, and with the sign changed for cut-up milling (when the feederate direction of cutter is along the negative axis X); and F_Y is the radial component of cutting force in face milling.

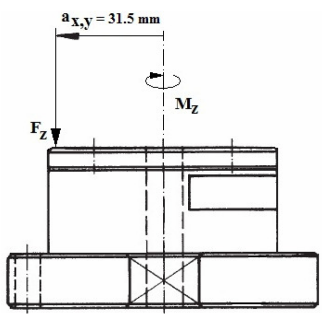

Fig. 1 – Measuring M_z torque.

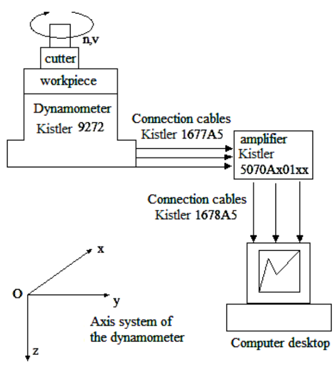

Fig. 2 – Block diagram of the experimental system.

$$M_z = F_z \cdot a_{x,y} \tag{1}$$

Experimental system components by name and type are presented in the block diagram form Fig. 2.

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 Ψ = 90° we performed a series of experimental determinations according to the working scheme (Figs. 3 and 4) and to the screenshots taken during forces measurements (Fig. 5).

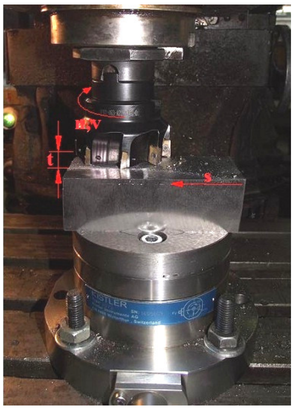

Fig. 3 – Processing by asymmetrical cut-down face milling with contact angle Ψ = 90°.

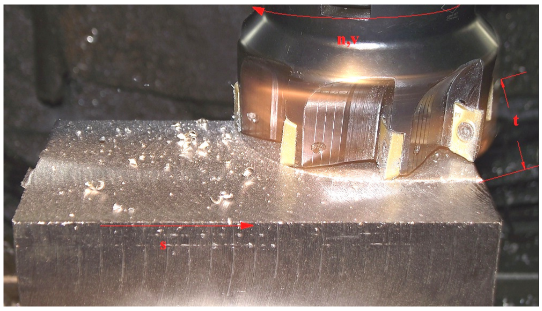

Fig. 4 – Processing by asymmetrical cut-up face milling with contact angle Ψ = 90°.

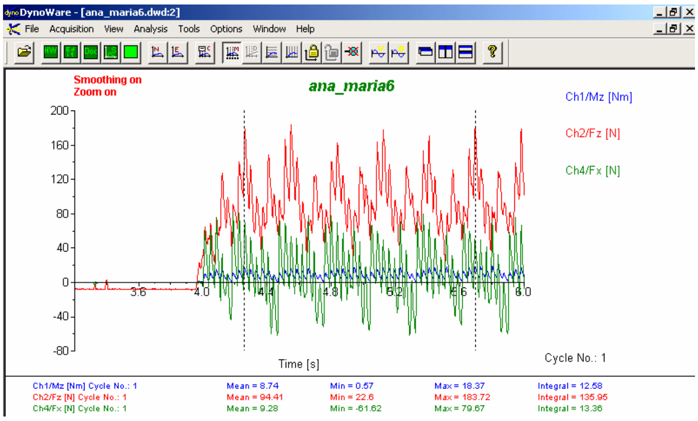

Fig. 5 – Cutting conditions and variation of cutting forces in asymmetrical cut-down face milling with Ψ = 90°, for feed per tooth s_{z1} = 0.08 mm/tooth.
Cutting conditions: v = 39.56 m/min; s = 0.64 mm/rev; t = 31.50 mm;
B = 1 mm; work: C 45.

Depending on the relative position between cutter and workpiece and the values of feed per tooth, for asymmetrical face milling with contact angle Ψ < 90° we performed a series of experimental determinations according to the working scheme (Figs. 6 and 7) and to the screenshots taken during forces measurements (Fig. 8).

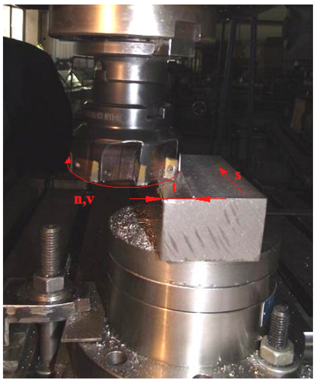

Fig. 6 – Processing by asymmetrical cut-down face milling with contact angle Ψ < 90°.

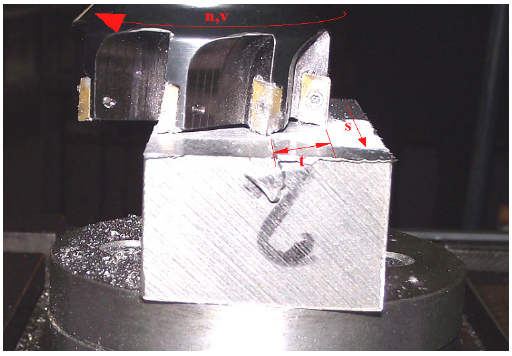

Fig. 7 – Processing by asymmetrical cut-up face milling with contact angle Ψ < 90°.

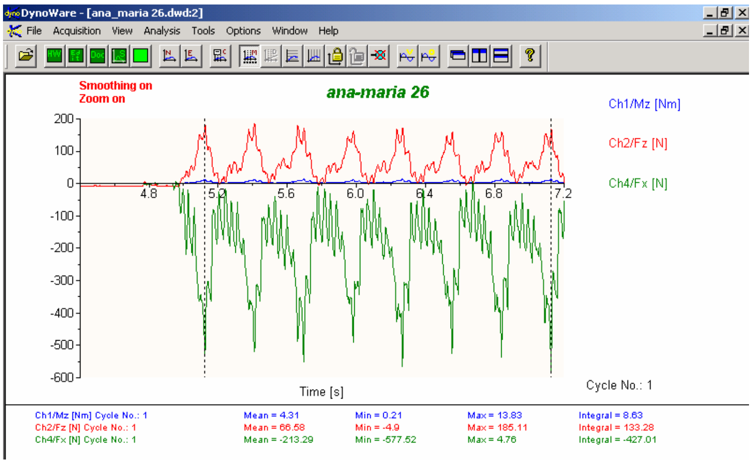

Fig. 8 – Cutting conditions and variation of cutting forces in asymmetrical cut-up face milling with Ψ < 90°, for feed per tooth s_{z1} = 0.08 mm/tooth.
Cutting conditions: v = 39.56 m/min; s = 0.64 mm/rev; t = 15 mm; B = 1 mm; work: C 45.

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; the cutter makes three complete revolutions leading to the appearance of 24 events/sec.

In order to extract 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, and must be strictly related to the cutting process.

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

Analyzing 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 (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 relationship of deformation force (Bocăneţ & Cozmîncă, 2014; Cozmîncă *et al.*, 2009)) for free cutting of steels.

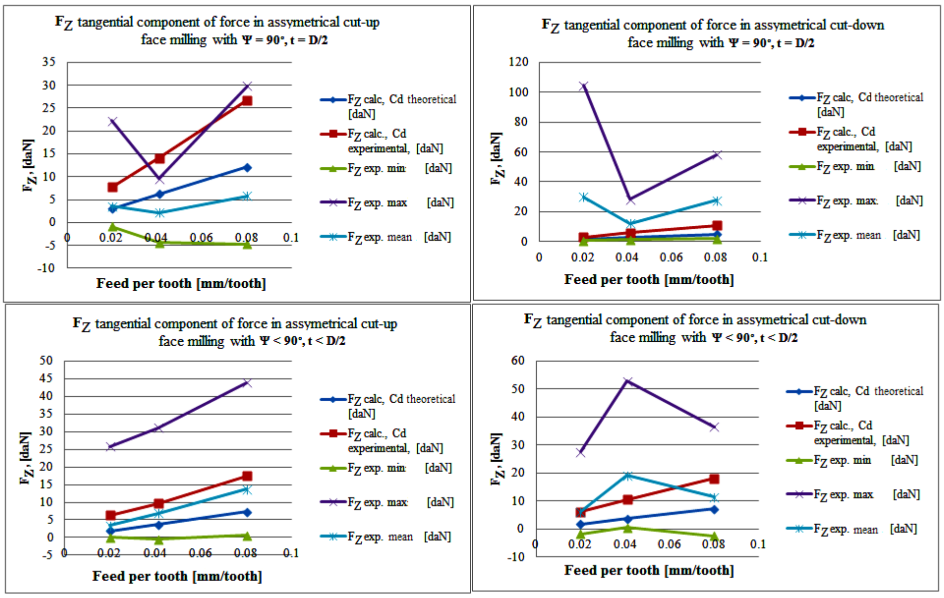

Fig. 9 – Values of tangential component F_Z of force depending on variant of face milling and feed per tooth.

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. 9, from which one can see the experimental minimum, maximum and average values of force's component but also the values obtained using theoretical relationships (Bocăneț & Cozmîncă, 2014) where C_d was determined both analytically and experimentally.

From the obtained diagrams one can see that the experimental values of F_Z component follows 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, but there are stronger variations in asymmetrical face milling with contact angle $\Psi = 90°$.

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. 10 were obtained from which one can see the experimental minimum, maximum and average values of force's component but also the values obtained using theoretical relationships (Bocăneț & Cozmîncă, 2014) where C_d was determined both analytically and experimentally.

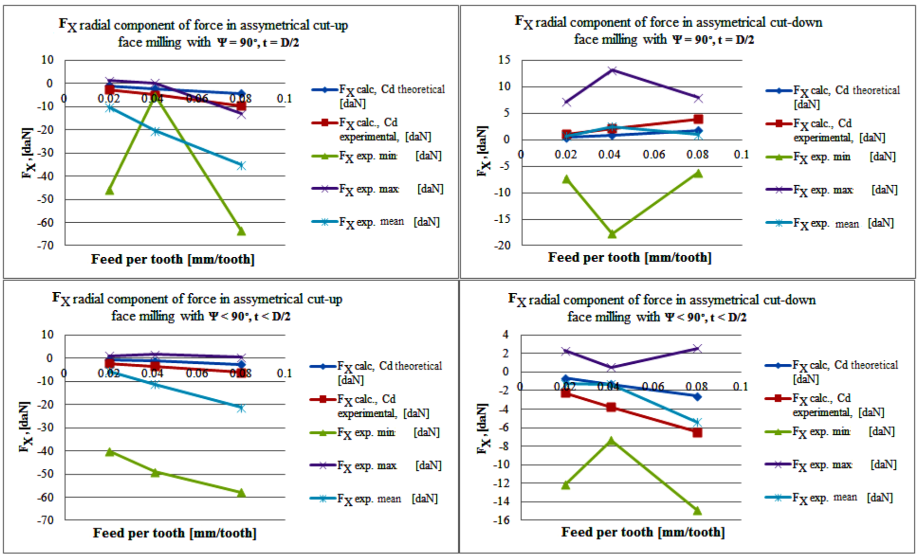

Fig. 10 – Values of radial component F_X of force depending on variant of face milling and feed per tooth.

Examining the diagrams one can see that the values obtained by theoretical calculation of F_X component have the same evolution as in symmetrical and asymmetrical face milling when cutting with more then 50% of the tool (Bocăneț & Croitoru, 2014) and one reason for the differences that occur on the comparative analysis graphics could be that we considered the average chip thickness for the mathematical models used to determine the average value of forces acting on a tooth, while in practice it is well known that the chip thickness varies along the arc of contact.

Ultimatetly there were studied the values for F_Y axial component of force in face milling, depending on the relative position between cutter and workpiece and feed per tooth. The diagrams from Fig. 11 were obtained. For F_Y component theoretically determined we obtained lower values than the average ones, approaching often to minimum values experimentally determined, proving once again that the valuation models should use values higher than *1* for the exponent "*n*" of the contraction coefficient C_d (Bocăneț & Cozmîncă, 2014; Matei (Bocăneț), 2012, Matei & Milea, 2010). In order to do this, a second set of experimental measurements is considered to be necessary, namely processing with a single tooth.

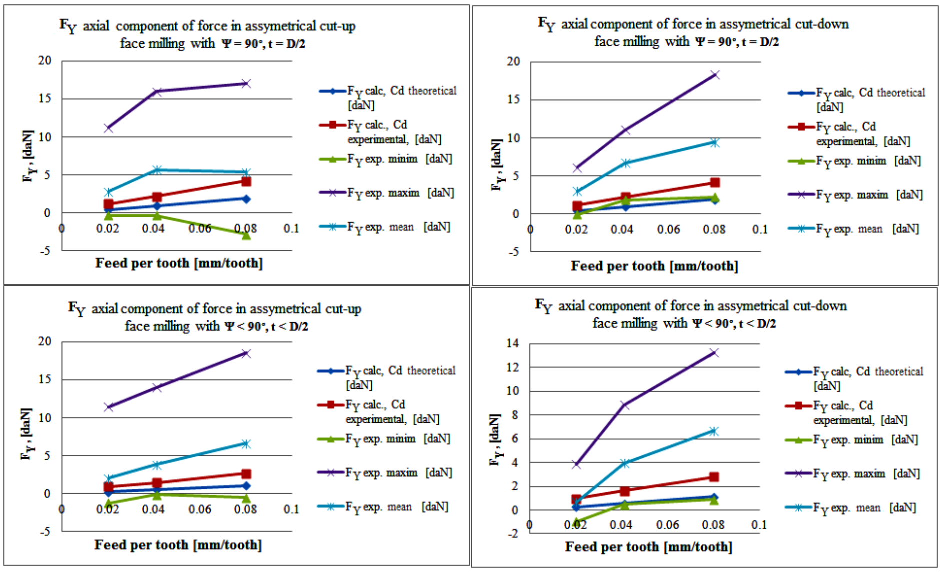

Fig.11 – Values of axial component F_Y of force depending on variant of face milling and feed per tooth.

4. Conclusions

The comparison charts of values obtained by theoretical calculation using the proposed models and experimental values obtained for face milling force's components show that in most cases the theoretical values are smaller than the average experimental ones. Therefore, to assess these values a value higher than 1 for the exponent “n” of chips contraction coefficient should be used in the valuation models of forces acting on a tooth (Bocăneț & Cozmîncă, 2014).

In order to do this correction is necessary to carry out a new set of experimental measurements for face milling using a cutter with a single tooth. Values thus obtained are compared with the theoretical - experimental relationships and defines the real values of the exponent “n”. In most cases, the exponent “n” will probably take values much higher than 1 and will differ for each of the three forces components F_z, F_x and F_y acting on the tooth. With this correction of the exponent “n”, it becomes possible to use in face milling the theoretical values of components F_z, F_x and F_y acting on a tooth, previously experimentally verified in turning (Cozmîncă, 1995; Cozmîncă *et al*., 2010).

Following the conclusions we have reached to this point, we intend to continue our researches with a second set of experimental measurements in order to verify the analytical models proposed for the evaluation of face milling forces. In this regard, in order to achieve the experimental measurements, we’ll use the values for working parameters considered in the previous approach, but with a more stable technological system, using coolant and we’ll measure forces using a specific milling operation three component dynamometer Kistler type 9257BA.

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CERCETĂRI EXPERIMENTALE PRIVIND COMPONENTELE FORȚEI DE AŞCHIERE LA FREZAREA FRONTALĂ SIMETRICĂ ŞI ASIMETRICĂ (II)

(Rezumat)

Pentru utilizarea în proiectare a modelelor matematice propuse pentru evaluarea componentelor forței de aşchiere la frezarea frontală asimetrică având unghiul de contact dintre freză şi semifabricat $\Psi \leq 90^{o}$, este necesară realizarea unor determinări experimentale de natură să arate validitatea şi gradul de aplicabilitate al acestora, dar şi modul în care pot fi îmbunătățite.

Modelele de evaluare a componentelor forței la frezarea frontală au la bază influențele factorilor care apar la nivelul unui dinte, dar şi interdependețele dintre acestea, influențele elementelor specifice frezelor, variantele de frezare posibile (frezare simetrică plină, frezare simetrică incompletă şi frezare asimetrică), numărul de dinți care aşchiază simultan şi poziția relativă freză – semifabricat (frezare în sensul avansului şi frezare în contra avansului). Dacă influențele 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.