THEORETICAL OUTLINE OF A METHODOLOGY FOR CUTTING FORCES EVALUATION

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The design of the chip removing process and of the elements in the technological systems structure must be realized based on the real values of the cutting forces. The study of the technological systems dynamics can't be imagine without knowing the average values and the variation laws of the forces that evolves during the cutting process. Now, cutting forces evaluation can be accomplish in different accuracy conditions, according to the working proceeding. Consequently, this paper presents the theoretical bases of an original methodology that allows evaluating the cutting forces level at single-point free cutting, using the chips plastic strain coefficient values.

1. Introduction. Analyzing the specialty works we can conclude that the cutting forces evaluation is made by now using models that considers the working process type, the theoretical chip's section and the nature of the working material. Some of the models might takes account on the wear of the tool's rake face, the approach and the rake angles, the nose angle, the tool's material and, for milling process, also the cutting speed [1], [2], [3], [4], [5], [6], [7].

The structure of those models includes a number of constants, exponents and correction coefficients that indicate the influence level of the process parameters. It's values was established long time ago, analytically or by experimental tests, for certain working conditions, but they don't cover all the practical situations and, most of all, ignores the interdependencies between the individual influences exerted by the working parameters [8]. The most used general equation for cutting forces determining looks like the following one:

$$F = C \cdot t^{x} \cdot s^{y} \cdot (HB)^{n} \cdot k_1 \cdot k_2 \cdot ...k_n$$

We can also notice that most of those cutting forces models are neglecting some important process parameters, such as the main cutting speed, the throat angle of the cutting edge, the inclination angle of the edges, the cutting medium and the nature of the cutting material. The constants, exponents and coefficients values were established in certain experimental conditions and then were applied in designing for other cutting conditions, materials or tools geometries. So, it is obvious that the errors in cutting forces evaluations will be high, and that interferes with the actual requisitions on accuracy and quality.

2. The basics of the theoretical model for cutting forces evaluation. The proposed methodology for cutting forces evaluation is based on the model of the three-dimensional orthogonal cutting, for a single point, referring to the real cutting plane v - v_1, with availability to extend it to any tool type and working process. The variation range of the main parameters v, s, γ, λ, so that we may determine its influence levels considering also the significant interdependencies between the individual influences.

In order to simplify the relations for the cutting forces components F_z, F_x, F_y, we propose using only the working parameters and cutting process specific quantities that includes the influences exerted by all the process parameters. That is the reason why, instead of the friction and shear angles, that frequently appears in the structure of actual models, being difficult to determine with sufficient accuracy, we consider the chips plastic strain coefficient. This coefficient includes in fact the effects of all the process parameters on the cutting forces developed. [9], [10]. Using the experimental values of the chips plastic strain coefficient, the values of the cutting forces may be appreciate, depending on the working parameters, without their explicit presence into the calculus models.

In case of the single-point free cutting, in order to develop the models for the cutting force components F_z, F_x, F_y depending on the physical components, F_N, F and F_f, and the tooth geometry, we translate consecutively the physical components of the rake face and then of the side flank in the edge plane, T, and afterwards in the base plane, B. In the plane T we find the F_z component, and in the B plane, the F_x and F_y components (Fig.1).

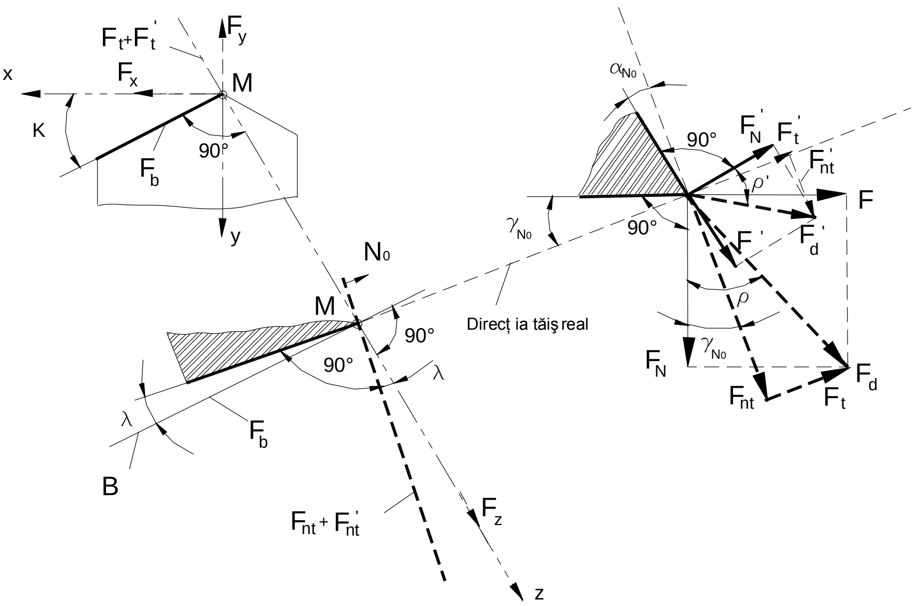

Fig. 1. Physical and geometrical model of the forces on the single-point cutting tool

The resultants $\overline{F_d} = \overline{F_N} + \overline{F}$ and $\overline{F_d^{'}} = \overline{F_N^{'}} + \overline{F^{'}}$, corresponding to the rake face and the side flank, are decomposed on two rectangular convenient directions, i.e. the real edge direction and a direction perpendicular on that (Fig.1). Finally, the equations (1) result.

$$\begin{gathered} \overline{F_d} = \overline{F_t} + \overline{F_{nt}} \\ F_t = F_d \cdot sin\left(\rho - \gamma_{N_0}\right) \;;\; F_{nt} = F_d \cdot cos\left(\rho - \gamma_{N_0}\right) \\ \overline{F_d^{'}} = \overline{F_t^{'}} + \overline{F_{nt}^{'}} \\ F_t^{'} = F_d^{'} \cdot cos\left(\rho^{'} - \alpha_{N_0}\right) \;;\; F_{nt}^{'} = F_d^{'} \cdot sin\left(\rho^{'} - \alpha_{N_0}\right) \end{gathered} \tag{1}$$

Depending on the FN şi FN’ components and on the friction angles, ρ and ρ’, the resultants Fd and Fd’ run into the intermediate equations (2) and (3).

$$F_d = F_N / cos\ \rho \tag{2}$$

$$F_d' = F_N' / cos\ \rho' \tag{3}$$

Using the relations (2) and (3), the components F_t, F_{nt}, F_t' şi F_{nt}' result as equations (4) – (7) show.

$$F_t = \frac{F_N}{\cos\rho} \cdot \sin\left(\rho - \gamma_{N_0}\right) \tag{4}$$

$$F_{nt} = \frac{F_N}{\cos\rho} \cdot \cos\left(\rho - \gamma_{N_0}\right) \tag{5}$$

$$F_t' = \frac{F_N'}{\cos\rho'} \cdot \cos\left(\rho' - \alpha_{N_0}\right) \tag{6}$$

$$F_{nt}' = \frac{F_N'}{\cos\rho'} \cdot \sin\left(\rho' - \alpha_{N_0}\right) \tag{7}$$

By translation on plane T, the components Ft and Ft' were projected on point M, and the components Fnt and Fnt' constitutes the main component, Fz, according to relation (8).

$$Fz = (Fnt + Fnt')\cos\lambda \tag{8}$$

On the direction of B mark of the base plane (xy), the components Fnt şi Fnt' determines the intermediary component Fb (relation (9)).

$$Fb = (Fnt + Fnt')\sin\lambda \tag{9}$$

The component Fb, and also Ft and Ft' from the T plane, are translated in the (xy) plane and the design components Fx, Fy result, according to relations (10)-(11).

$$Fx = Fb\cos K + (Ft + Ft')\sin K \tag{10}$$

$$Fy = -Fb\sin K + (Ft + Ft')\cos K \tag{11}$$

Using the relations (4)-(7), the models (8), (10) and (11) become (12)-(14) as follows:

$$F_z = \left[\frac{F_N}{\cos\rho} \cdot \cos\left(\rho - \gamma_{N_0}\right) + \frac{F_N'}{\cos\rho'} \cdot \sin\left(\rho' - \alpha_{N_0}\right)\right] \cdot \cos\lambda \tag{12}$$

$$F_x = \left[\frac{F_N}{\cos\rho}\cos\left(\rho - \gamma_{N_0}\right) + \frac{F_N'}{\cos\rho'}\sin\left(\rho' - \alpha_{N_0}\right)\right]\sin\lambda\cos K + \\ + \left[\frac{F_N}{\cos\rho}\sin\left(\rho - \gamma_{N_0}\right) + \frac{F_N'}{\cos\rho'}\cos\left(\rho' - \alpha_{N_0}\right)\right]\sin K \tag{13}$$

$$F_y = -\sin K\left[\frac{F_N}{\cos\rho}\cos\left(\rho - \gamma_{N_0}\right) + \frac{F_N'}{\cos\rho'}\sin\left(\rho - \gamma_{N_0}\right)\right]\sin\lambda + \\ + \left[\frac{F_N}{\cos\rho}\sin\left(\rho - \gamma_{N_0}\right) + \frac{F_N'}{\cos\rho'}\cos\left(\rho' - \alpha_{N_0}\right)\right]\cos K \tag{14}$$

Still, based on the adopted notations, i.e. the relations (15)-(18), the equations (12)-(14) takes the (19) configuration.

$$A = \frac{cos(\rho - \gamma_{N_0})}{cos\,\rho} = cos\,\gamma_{N_0} + tg\rho \cdot sin\,\gamma_{N_0} \tag{15}$$

$$B = \frac{sin(\rho' - \alpha_{N_0})}{cos\,\rho'} = tg\rho' \cdot cos\,\alpha_{N_0} - sin\,\alpha_{N_0} \tag{16}$$

$$C = \frac{sin(\rho - \gamma_{N_0})}{cos\,\rho} = tg\rho \cdot cos\,\gamma_{N_0} - sin\,\gamma_{N_0} \tag{17}$$

$$D = \frac{cos(\rho' - \alpha_{N_0})}{cos\,\rho'} = cos\,\alpha_{N_0} + tg\rho' \cdot sin\,\alpha_{N_0} \tag{18}$$

$$\begin{aligned} F_z &= \left(A \cdot F_N + B \cdot F'_N\right) \cdot cos\,\lambda \\ F_x &= \left(A \cdot F_N + B \cdot F'_N\right) \cdot sin\,\lambda \cdot cos\,K + \left(C \cdot F_N + D \cdot F'_N\right) \cdot sin\,K \\ F_y &= -\left(A \cdot F_N + B \cdot F'_N\right) \cdot sin\,\lambda \cdot sin\,K + \left(C \cdot F_N + D \cdot F'_N\right) \cdot cos\,K \end{aligned} \tag{19}$$

Taking into account the relations (20)-(21) between the real angles and the constructive ones, used for designing, the A, B, C, D constants from equations (19) results from the relations (22)-(25).

$$tg\gamma_{N_0} = tg\gamma_N \cdot cos\,\lambda \tag{20}$$

$$tg\alpha_{N_0} = tg\alpha_N \cdot cos\,\lambda \tag{21}$$

$$A = \frac{1 - tg\rho \cdot tg\gamma_N \cdot cos\,\lambda}{\left(1 + tg^2\gamma_N \cdot cos^2\,\lambda\right)^{0,5}} = \frac{1 - k_1 \cdot tg\rho}{k_2} \tag{22}$$

$$B = \frac{tg\rho' - tg\alpha_N \cdot cos\,\lambda}{\left(1 + tg^2\alpha_N \cdot cos^2\,\lambda\right)^{0,5}} = \frac{tg\rho' - k_3}{k_4} \tag{23}$$

$$C = \frac{tg\rho - tg\gamma_N \cdot cos\,\lambda}{\left(1 + tg^2\gamma_N \cdot cos^2\,\lambda\right)^{0,5}} = \frac{tg\rho - k_1}{k_2} \tag{24}$$

$$D = \frac{1 - tg\rho' \cdot tg\alpha_N \cdot cos\,\lambda}{\left(1 + tg^2\alpha_N \cdot cos^2\,\lambda\right)^{0,5}} = \frac{1 - k_3 \cdot tg\rho'}{k_4} \tag{25}$$

We now can observe that the A, B, C, D constants values are dependent on the friction angles, ρ and ρ′, and on the constructive angles αN, γN and λ. The values of the constants are as follows: A>1, B<<1, C≤1, D<1. For most practical cases, the constructive angles take values in a large range, i.e. αN = 4° … 16° ; γN = - 40° … + 40° şi λ = 0° … ± 40° [3], [11].

If we are considering the relations (22)-(25), the coefficients k1 – k4 are dependent on the constructive angles αN, γN and λ, as show the relations (26)-(29).

$$k_1 = tg\gamma_N \cdot \cos\lambda \tag{26}$$

$$k_2 = \left(1 + tg^2\gamma_N \cdot \cos^2\lambda\right)^{0,5} \tag{27}$$

$$k_3 = tg\alpha_N \cdot \cos\lambda \tag{28}$$

$$k_4 = \left(1 + tg^2\alpha_N \cdot \cos^2\lambda\right)^{0,5} \tag{29}$$

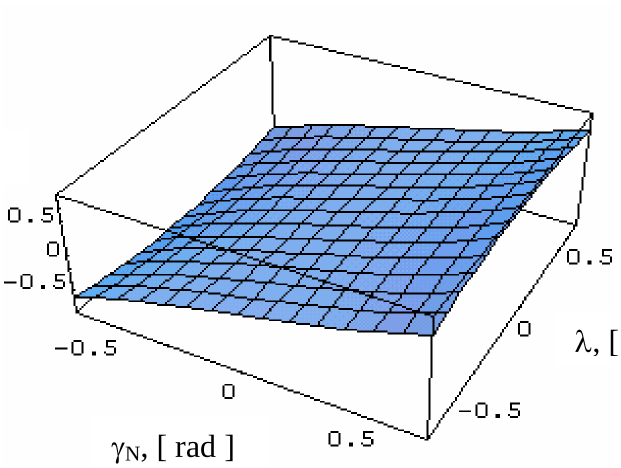

Fig.2. The function $k_1 = f(\gamma_N, \lambda)$

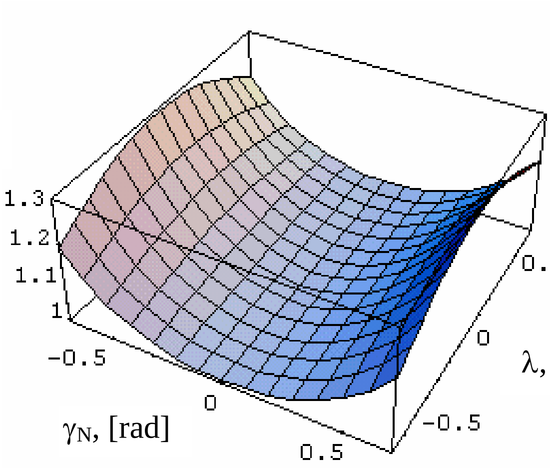

Fig.3. The function $k_2 = f(\gamma_N, \lambda)$

The diagrams shown in Fig.2 – 5 were obtained using the MATHEMATICA soft and are presenting the dependencies k1 = f (γN, λ), k2 = f (γN, λ), k3 = f (αN, λ), k4 = f (αN, λ). The analysis of these diagrams determines the conclusion that the coefficients k1 – k4 are decreasing when the absolute value of the inclination angle, λ increases. The same time, at the increasing of the absolute value of the rake angle, γN, the coefficient k1 decreases and k2, k3 and k4 increase. When the clearance angle, αN, grows, k3 and k4 increase as a result. Also, we must take account that at a minimum wear on the back side of the tool, αN = 0. In this situation, according to relations (26) – (29), k3 = 0 and k4 = 1.

Using the relations (19) for establishing F_z, F_x, F_y values in designing activities involve the necessity to determine with accuracy the values of the intermediary data, i.e. the physical components of the cutting force, F_N and F_N', and the friction angles, ρ and ρ′.

For the F_N' component on the active back side of the tool the model from relation (30) is available [12] and it's convenient to apply it because all of the data in it's structure, i.e. σ_{p02}, t, α_N, K, λ, are known as independent quantities and we don't need experimental tests to determine them.

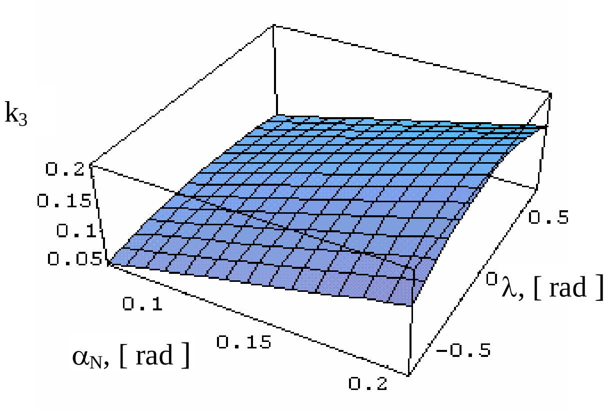

Fig.4. The function $k_3 = f(\alpha_N, \lambda)$

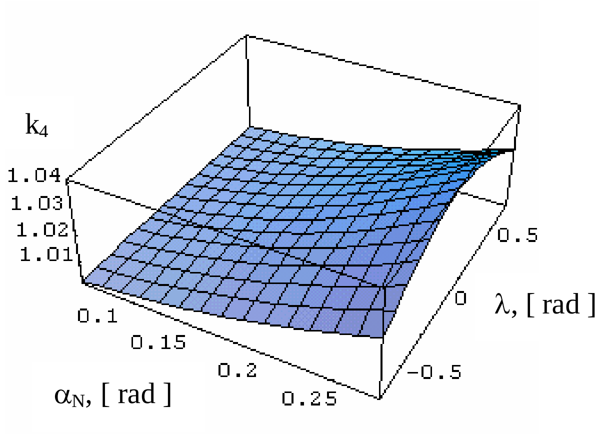

Fig.5. The function $k_4 = f(\alpha_N, \lambda)$

$$F_N^{'} = 0{,}0067 \cdot \sigma_{p02} \cdot \frac{t \cdot \left(1 + tg^2\alpha_N \cdot cos^2\lambda\right)^{0,5}}{tg\alpha_N \cdot sin K \cdot cos^2\lambda} \tag{30}$$

The F_N component, as relation (31) shows, can be evaluated with high accuracy using experimental values of the chips plastic strain coefficient, C_d.

$$F_N = \sigma_{p_{02}} \cdot t \times s \cdot C_d^n \tag{31}$$

The values of the “n” exponent in this relation could be obtained using the equation (32), where F_z results from dynamometrical measurements, accomplished in the same cutting conditions that we consider for determining C_d values, namely $\lambda = 0$ and $\gamma = 0$.

$$\sigma_{p_{02}} \cdot t \cdot s \cdot C_d^n = F_z; \tag{32}$$

Using the relation (32) and the models (19) involves knowing the values of the friction angles, ρ and ρ', in order to achieve the constants A, B, C and D values, relations (22) – (25). For the friction angle ρ' on the back side of the tool the model (33) was developed, with $F_N^{'}$ component referring, that results from relation (30). The components F_{z1}, F_{x1}, F_{y1} we propose to be determined by the same dynamometrical measurements used for F_z, but according to Şaturov–Poduraev method [13] that constitutes the fundamentals of the geometrical model presented in Fig. 6.

$$tg\rho^{'} = \mu^{'} = F^{'} / F_N^{'} = \frac{\left(F_{z_1}^2 + F_{x_1}^2 + F_{y_1}^2 - F_N^{'2}\right)^{0,5}}{F_N^{'}} \tag{33}$$

The resultant values of friction angle ρ' must fluctuate between 6° and 11°, only for high cutting speed (v > 150 m /min) might reach 26°.

The relation (34) is proposed for the friction angle ρ on the rake face of the tool, where the C_d values results experimentally or from theoretical - experimental models [14].

$$\rho = 45° + \frac{\gamma}{2} - arctg \frac{cos\gamma}{C_d - sin\gamma} \tag{34}$$

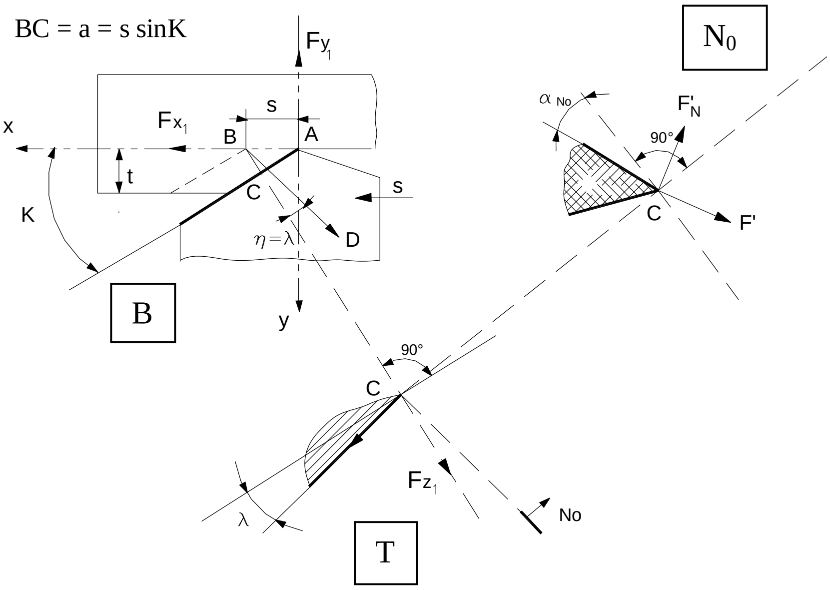

Fig. 6. Physical-geometrical model for the components of $F_d^{'}$ force on the active back side

3. Conclusions. In order to apply the (19) models for determining the designing components of cutting force, F_x, F_y, F_z, the chips plastic strain coefficient C_d values are necessary, adapted to the specific working conditions.

The C_d values may result from two methods, namely:

- By measuring (weighing) a certain number of chips that result from the cutting process, developed in the adopted working conditions and then determining C_d with known relations: $C_d = a_1/ a$, $C_d = L/ L_a$ sau $C_d = G_a/ \rho \cdot l \cdot t \cdot s$.
- Using analytical models for C_d evaluation, resulting by experimental data processing after cutting the chosen material: $C_d = f(t, s, v, \gamma, \lambda, \ldots)$ or $C_d = f(\sigma_{p02})$.

Applying the proposed physical-geometrical models of the cutting process, that are considering all of the physical components of the cutting force and the real cutting plane, may guarantee simplicity, security and maximum accuracy to the designing components F_z, F_x, F_y evaluation.

The experimental tests for C_d values and F_z, F_x, F_y, F_{z1}, F_{x1}, F_{y1} components are strictly necessary only for establishing the variation range of he intermediary data from relations (19).

The proposed models for determining the components F_z, F_x, F_y for a single-point tool could be used in constructive and tecnological designing activities and also for cutting process parameters optimization.

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EXPERT SYSTEM FOR DESIGN FOR ASSEMBLY – THE KEY TO ASSESS COMPETITIVE PRODUCT

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Expert System for Design For Assembly (DFA) within a concurrent engineering environment is presented in this article. A prototype system that supports new techniques for design for assembly gives users the possibility to assess and reduce the total production cost at an early stage during the design process. Kappa PC development toolkit was chosen as toolkit for the development of the system. The system enables designers to minimize the number of components of a product, select the most economic assembly technique for that specific product, determine the cost and time of assembly through product analysis, and determine the design efficiency Knowledge Base System for Design For Assembly.

In Today's competitive product market the reduction of product manufacturing costs is of a great significant. As products become more complex and highly integrated. Designers or design teams find it increasingly necessary to have a system with a common language, independent of traditional engineering disciplines. There is no doubt of the impact of product design on manufacturing cost ,Therefore designer decision on product design will focus an important part of product manufacturing .It is estimated by researches that more than 70% of the product cost is defined during the product design phase [1].

In other words as shown in table 1, while design accounts for only 5% of the total cost of a product's development, that 5% investment in design for manufacture accounts for 70% of the product's final manufacturing cost. Obviously, great gains can be made through careful attention to product design or re-design [2].