Proceedings in MANUFACTURING SYSTEMS

Proceedings in Manufacturing Systems, Volume 7, Issue 1, 2012 ISSN 2067-9238

ASPECTS REGARDING THE MODELLING OF THE CHIP GEOMETY IN END MILLING

Corina CONSTANTIN[1,*], George CONSTANTIN[2]

[1)] PhD Student, Machine and Production Systems Department, University "Politehnica" of Bucharest, Romania
[2)] PhD, Prof, Machine and Production Systems Department, University "Politehnica" of Bucharest, Romania

Abstract: *Due to the fact that the milling process still remaining a challenge for researchers, the paper deals with the concept of chip geometry model built on the basis of geometric definition of the cutting tool, namely the inserts. This model type is considered for its integration into a global model of the cutting process. This research tries to give new methods for defining the uncut chip area and length, namely CAD methods, replacing the analytical ones very complex for some cutting tools. The main purpose of the work is to obtain functions of two variables (cutting depth and feed per tooth) for the uncut chip area, uncut chip length and uncut chip thickness using multiple regression algorithms. The achievement of the relation is important in cutting force estimation and also in optimization of cutting parameters. These functions of two variables (a_p and f_z) approximate the actual average chip area, length and thickness values with relative errors less than 10 %. The cutting tool used is CoroMill R 365-080Q27-S15M with cutting tool inserts R365-1505ZNE-PM 4230 (Sandvik Coromant). The fit between data obtained though CAD methods and data calculated through the model is very good, the functions for uncut chip area, length and thickness being reliable.*

Key words: *milling, milling cutter, insert, cutting edge curve, uncut chip area, uncut chip length, uncut chip thickness.*

1. INTRODUCTION

Milling machining process is widely used in industry, being very important for engineers to understand how it influences the process input (cutting conditions and tool geometry) process performance, such as [2]:

- process stability;
- cutting tool wear;
- cutting tool breakage;
- processed surface errors;
- processed surface quality.

Knowing the maximum and mean values of the cutting forces and also how they evolve is very important for an engineer to optimize the cutting process before the actual machining is done. This involves the modelling of the cutting relations as input-output type.

Determining the average cutting forces is seen as a quasi-static process. It takes into account the average values of the process and provides constant sets, each of them corresponding to a component of the cutting force (F_{xmed}, F_{ymed}, F_{zmed}).

To determine the maximum value it is necessary to take in consideration the cutting force, namely its components, as variables functions that depend on the time and the parameters of the system mass and dynamic parameters of the elastic system main spindle -tool holder-tool-workpiece. The maximum values are necessary due to their strong influence over the tool breakage, machining errors and surface quality.

Modelling of cutting force in milling can be done in several ways, resulting the following specific models [2]:

- chip geometry model CGM built on the basis of time dependent variables;
- empirical model of the cutting forces CFM;
- empirical model of the structural answer of the processing system with more than one degrees of freedom – MSSRM;
- nonlinear model of the displacement feedback DFM;
- topological model of the surface STM.

The link between different models integrated into a global model is showed in Fig. 1:

- It was found that modelling is based on chip geometry model which has as input the time-varying cutting conditions vector and the tool geometry and as output the chip application and its average thickness.
- The outputs of CGM are considered as inputs in the model of the cutting force CFM and in addition the vector of time varying cutting conditions and tool geometry. The outputs of CFM are the axial (F_z (t)), tangential (F_x (t)) and normal (F_y (t)) components of the cutting force.

[*] Corresponding author: str. Kogalniceanu, nr. 9-13, Iasi, Romania, Tel.: +40.232.213.573
E-mail addresses: *corina11@gmail.com* (C. Constantin), *george.constantin@icmas.eu* (G. Constantin)

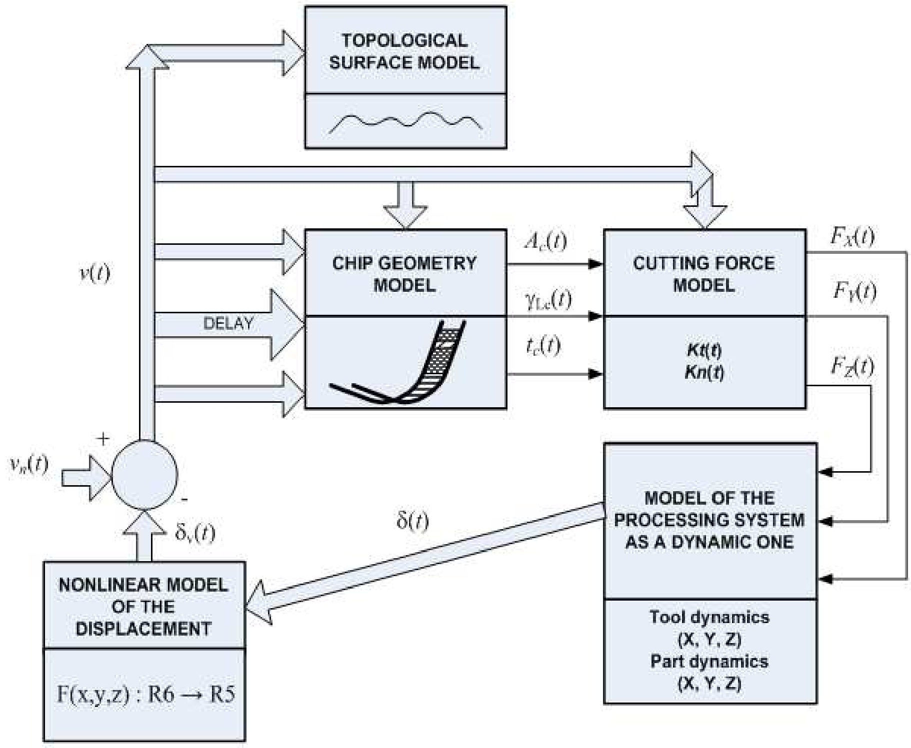

Fig. 1. Schematic for integration of partial models in the dynamic model [2].

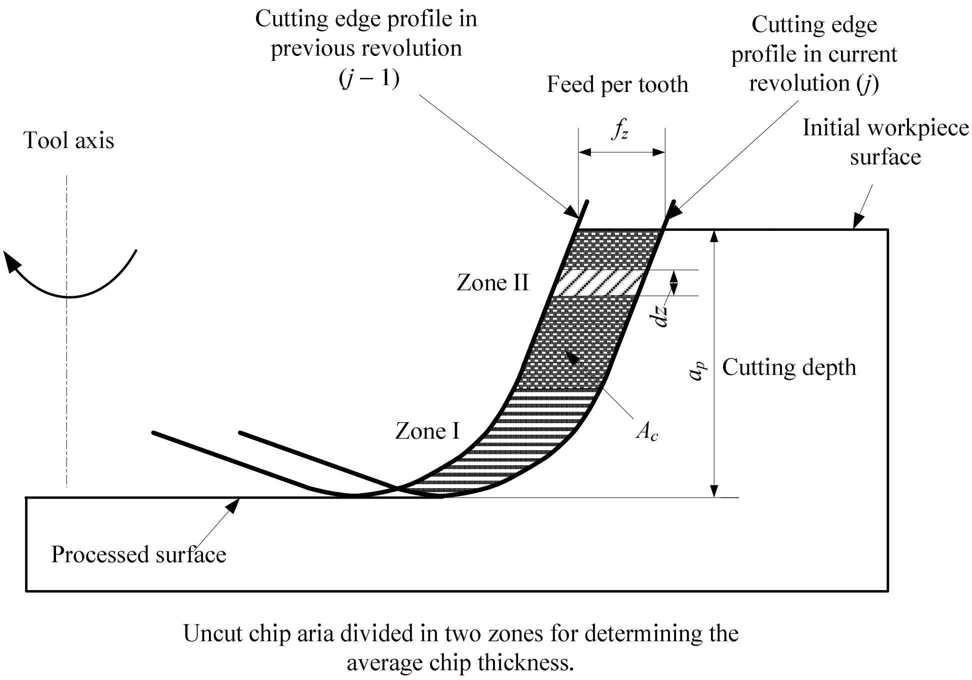

Fig. 2. Uncut chip area divided in two zones for determining the average chip thickness.

- The cutting force components are inputs in the response structural model MRSSP of the processing system, which has as outputs the vector of tool and workpiece displacements.
- The next model is the displacement feedback MRD having as inputs the outputs from MSSRM and generates as outputs the vector of the variations of cutting conditions and the tool geometry.
- The last model is the topological surface STM model which has as input the vector of the variable cutting conditions and the tool geometry generated by MRD and generates as outputs the errors and quality of the finished surface.

2. CHIP GEMETRY MODEL – CGM

When calculating cutting forces it is considered the specific cutting force parameter as the ratio of cutting force and cross-sectional area of the chip (cutting force in N per area unit in mm^2) with the expression:

$$k_c = F / A_C\ , \tag{1}$$

where

F is the cutting force;

A_C – rated aria of the chip cross section (Fig. 2).

So it can be considered the expression of the average area length A_c.

For the case study considered, namely improved OLC 45 steel milling, the CoroMill 365 cutter 80 mm diameter with new carbide inserts of 15 mm (R365-1505ZNE-PM, GC 4230) was used, for which complex cutting edge curve graphics have been defined.

For improved OLC 45 steel it was considered the cutting edge projection of the insert on the axial plane perpendicular to the *XY* plane of the machine (Fig. 3).

3. MODEL OF THE UNCUT CHIP AREA

The values of the area A_c were obtained by considering a reference curve of the cutting edge at the pass $j - 1$ and more than one passes according to different values of the feed per tooth $f_z \in \{0.08;\ 0.092;\ 0.105;\ 0.121\}$, in mm [1]. As well, different horizontal levels of the depth of cut were considered $a_p \in \{0.5;\ 0.63;\ 0.78;\ 0.97\}$, in mm. The area A_c is defined as being contained between the passes $j - 1$ and j corresponding to the value of the feed per tooth f_z, basic level (the segment tangent to the lower point of the cutting edge) and the level corresponding to the depth of cut a_p [1].

The CAD means [3] allow the determination of the area defined by the graphic elements or by a sequence of points belonging to these elements enough for the approximation of the actual surface.

For example, Fig. 3 presents the area and its value A_c = 0.039 mm^2 corresponding to a_p = 0.5 mm and f_z = 0.08 mm.

Considering all possibilities of combining (4 × 4) all values A_c presented in Table 1 were determined.

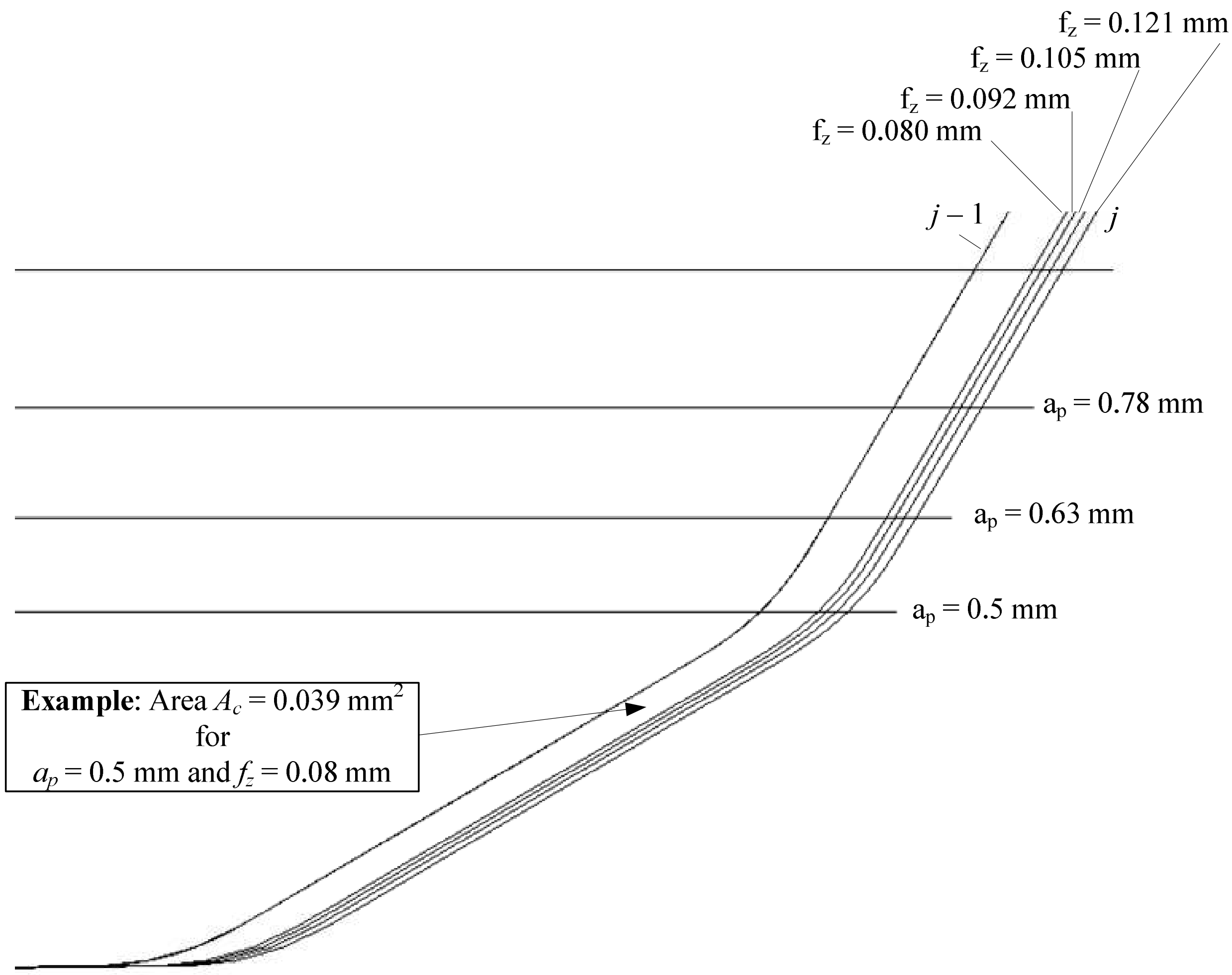

Fig. 3. CAD model used for determining the uncut chip in milling.

Table 1

Values of the area A_c derived from the CAD model

a_p [mm]	f_z [mm]	A_c [mm^2]
0.5	0.08	0.039
0.5	0.092	0.044
0.5	0.105	0.051
0.5	0.121	0.059
0.63	0.08	0.049
0.63	0.092	0.056
0.63	0.105	0.065
0.63	0.121	0.075
0.78	0.08	0.061
0.78	0.092	0.07
0.78	0.105	0.081
0.78	0.121	0.093
0.97	0.08	0.076
0.97	0.092	0.087
0.97	0.105	0.101
0.97	0.121	0.116

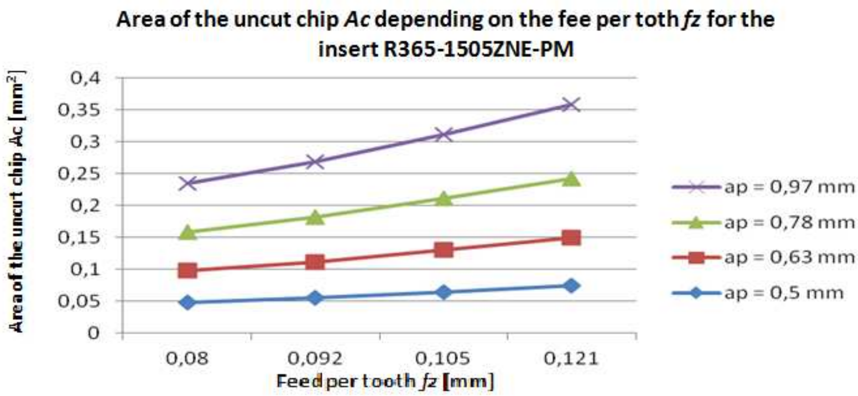

Fig. 4. Diagrams of the area A_c depending on the feed per tooth f_z for the cutting insert R365-1505ZNE-PM.

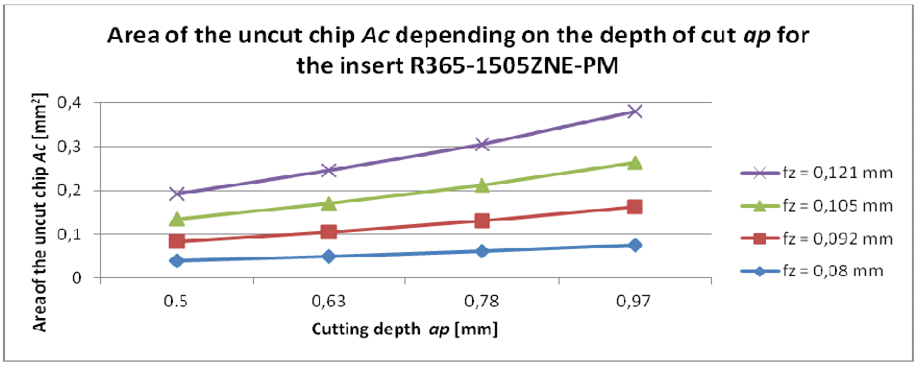

Fig. 5. Diagrams of the area A_c depending on the depth of cut a_p for the cutting insert R365-1505ZNE-PM.

On the basis of the value set one proposes for the area A_c a first degree function of two variables (a_p and f_z) having the form:

$$A_c = a_1 + a_2\, a_p + a_3\, f_z. \tag{2}$$

The set a_i specific to a certain cutting tool having a specific profile (cutting edge curve) can be determined through the multiple regression method in which one considers as input the line matrices:

$$\begin{aligned} \mathrm{ap} &= [ap_1 \ldots ap_n]; \\ \mathrm{fz} &= [fz_1 \ldots fz_n]; \\ \mathrm{Ac} &= [Ac_1 \ldots Ac_n]; \end{aligned} \tag{3}$$

which need to have the same dimension (for the considered case this is 16).

The coefficient vector is determined using the Matlab [4] operator (\):

$$\mathrm{ai} = \mathrm{X} \setminus A_c. \tag{4}$$

where X is the line matrix obtained on the basis of the matrices ap and fz that contains the set of the equations on which the determination of the parameters a_i is based.

For the model validation, the maximum absolute error calculated with regard to the model it is determined:

$$\mathrm{MaxErr} = \max(\mathrm{abs}(\mathrm{Y} - \mathrm{ac})). \tag{5}$$

Where Y is the matrix

$$\mathrm{Y} = \mathrm{X}{*}\mathrm{a}. \tag{6}$$

For the case study considered the following parameter values were obtained:

$$a_1 = -0.0737.\ a_2 = 0.0995.\ a_3 = 0.7262. \tag{7}$$

The maximum error obtained is MaxErr = 0.0053, and the relative one is 8.3 %.

Therefore, the function expression $A_c = f\,(a_p.\ f_z)$ for the considered case (Table 1) has the form:

$$A_c = -0.0737 + 0.0995\, a_p + 0.7262\, f_z\ [\mathrm{mm}^2]. \tag{8}$$

The charts of the function A_c depending on the feed per tooth f_z and depth of cut a_p have the forms in Figs. 4 and 5.

In Fig. 6 the comparison between the charts of the uncut chip area A_c modelled-measured depending on the feed per tooth f_z for the insert R365-1505ZNE-PM is presented.

4. DETERMINATION OF THE LENGTH l_c OF THE UNCUT CHIP AREA IN MILLING

Different regions of the transversal section of the chip are highlighted from Fig. 2, namely zone I having a nonlinear variation on the axis Z and zone II having an almost constant variation. The mathematical law of the cutting edge profile should be known for (8.3) defining a mathematical relation of the area A_c on the direction of the depth of cut a_p of the form:

$$A_C = \int_0^{lc} h_c(l)\,\mathrm{d}l\,. \tag{9}$$

where l is the surface length (cutting edge length) as variable and h_c is the chip thickness (surface width) on perpendicular direction to the cutting edge curve.

Two lengths l_{cI} and l_{cII} corresponding to the regions defined in Fig. 7 are retrieved, each of them belonging to the passes $j-1$ and j respectively, and involved in relation:

$$l_C = \frac{l_{cI\ j-1} + l_{cII\ j-1} + l_{cI\ j} + l_{cII\ j}}{2}\,. \tag{10}$$

The CAD method [4] for determining the length l_c (Fig. 7) [1] substitutes the mathematical relation that defines the cutting edge length on the two zones considered, namely l_{cI} and l_{cII} for two passes ($j-1$ and j), allowing the direct determination of the graphic element lengths that are complex [5 and 6] of polyline type (association of filleted lines and arcs) corresponding to the cutting edge at the passes $j-1$ and j. The method is similar, namely the arithmetic average of the lengths on the two passes at the level a_p is obtained and at the same level, the method is repeated for each feed per tooth value f_z:

$$l_{cm\ j} = \frac{l_{c\ j-1} + l_{c\ j}}{2}\,. \tag{11}$$

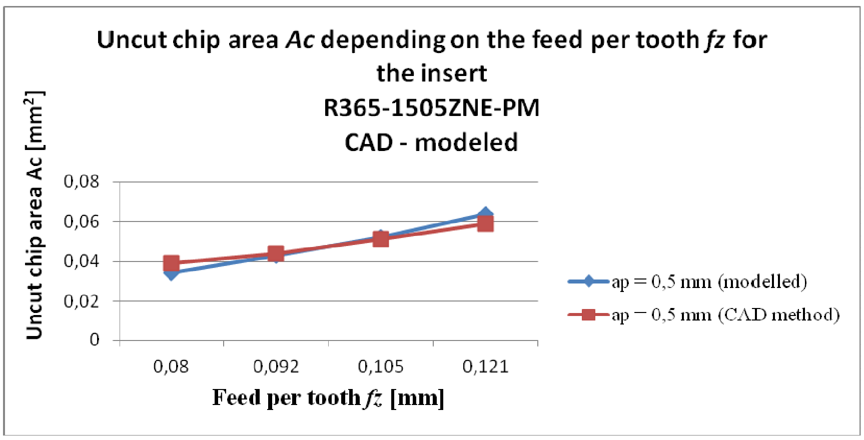

Fig. 6. Comparison between the uncut chip areas A_c depending on the feed per tooth f_z for the cutting insert R365-1505ZNE-PM (modelled – CAD).

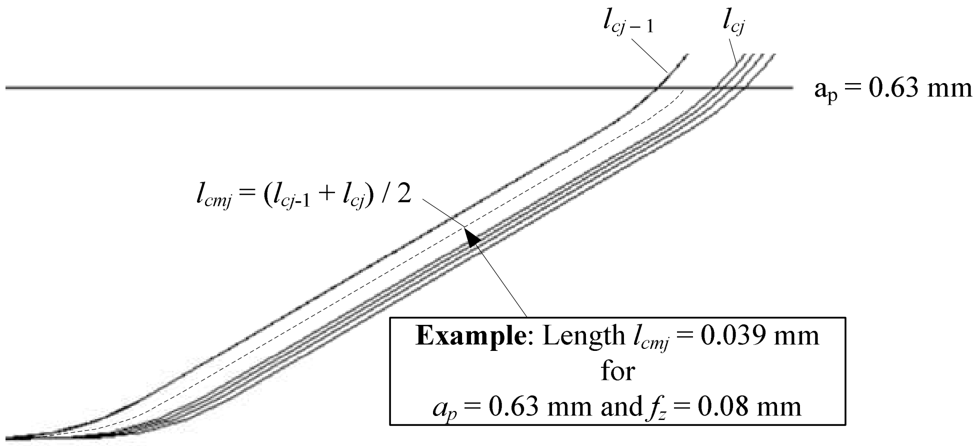

Fig. 7. CAD model used for determining the length of the uncut chip length in milling.

Table 2

Values of the length l_c of the area obtained from the CAD model

a_p [mm]	f_z [mm]	l_c [mm]
0.5	0.08	1.079
0.5	0.092	1.085
0.5	0.105	1.0915
0.5	0.121	1.0995
0.63	0.08	1.239
0.63	0.092	1.245
0.63	0.105	1.2515
0.63	0.121	1.2595
0.78	0.08	1.414
0.78	0.092	1.42
0.78	0.105	1.4265
0.78	0.121	1.4345
0.97	0.08	1.635
0.97	0.092	1.641
0.97	0.105	1.6475
0.97	0.121	1.6555

For example, in Fig. 6 it is illustrated the determination of the length $l_{cm\,j}$ of 0.039 mm indicated on figure for a depth of cut a_p = 0.5 mm and a feed per tooth f_z = 0.08 mm/tooth.

Considering all possibilities of combination (4 × 4) all values for the length l_c were determined and presented in Table 2.

On the basis of the value set one proposes for the length l_c a first degree function of two variables (a_p and f_z) having the form:

$$l_c = a_1 + a_2\, a_p + a_3\, f_z \qquad (12)$$

Applying a multiple regression method, similar to the case when determining the A_c area function, the following parameter values were obtained:

$$a_1 = 0.4520.\ a_2 = 1.1803.\ a_3 = 0.5.\ (13)$$

The maximum absolute error is MaxErr = 0.0035 and the relative one is 0.28%.

On the basis of the value set one proposes the first degree $l_c = f\,(a_p.\ f_z)$ function (Table 2):

$$l_c = 0.4520 + 1.1803\, a_p + 0.5\, f_z \ \text{[mm]}. \qquad (14)$$

Fig. 8 presents the diagram of the length l_c of the uncut chip area depending on the feed per tooth for different depths of cut a_p. It can be seen that the two curves are almost overlapping.

5. DETERMINATION OF THE AVERAGE CHIP THICKNESS IN MILLING

The average chip thickness in the normal plane to the feed direction can be determined as a ratio between the chip area A_c and the profile length of the cutting edge l_c:

$$h_{cm} = \frac{A_c}{l_c} \qquad (15)$$

For the considered data set the values of the average chip thickness h_{cm} were determined and the results presented in Table 3 [1].

Table 3

Values of the thickness h_{cm} of the area obtained from the CAD model

a_p [mm]	f_z [mm]	h_{cm} [mm]
0.5	0.08	0.036144578
0.5	0.092	0.040552995
0.5	0.105	0.046724691
0.5	0.121	0.053660755
0.63	0.08	0.039548023
0.63	0.092	0.04497992
0.63	0.105	0.051937675
0.63	0.121	0.059547439
0.78	0.08	0.043140028
0.78	0.092	0.049295775
0.78	0.105	0.056782334
0.78	0.121	0.064830952
0.97	0.08	0.04648318
0.97	0.092	0.053016453
0.97	0.105	0.061305008
0.97	0.121	0.070069465

	l_c (calculated)
1	1.0821
2	1.0881
3	1.0946
4	1.1026
5	1.2355
6	1.2415
7	1.248
8	1.256
9	1.4126
10	1.4186
11	1.4251
12	1.4331
13	1.6368
14	1.6428
15	1.6493
16	1.6573

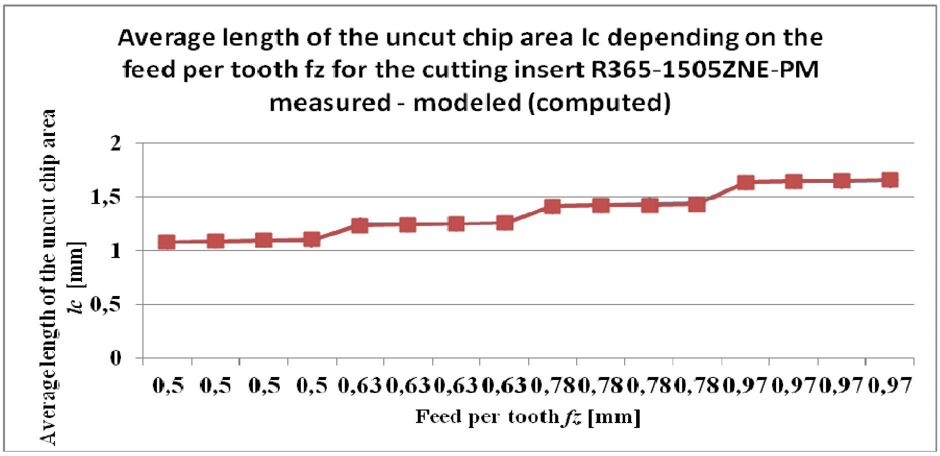

Fig. 8. Comparison between the uncut chip length l_c depending on the feed per tooth f_z (measured – modelled).

	h_{cm} (computed)
1	0.0349
2	0.041
3	0.0477
4	0.0558
5	0.0386
6	0.0447
7	0.0514
8	0.0595
9	0.0429
10	0.049
11	0.0556
12	0.0638
13	0.0483
14	0.0544
15	0.061
16	0.0692

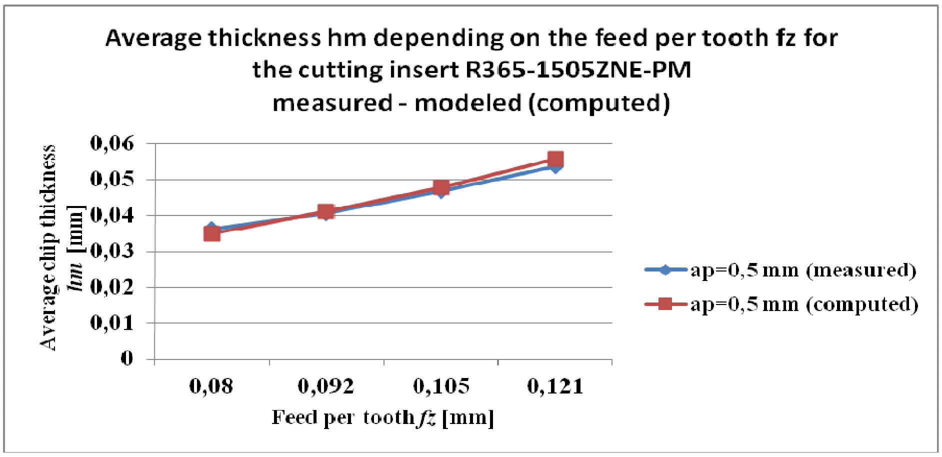

Fig. 9. Comparison between the thickness h_{cm} depending on the feed per tooth f_z for the insert R365-1505ZNE-PM (measured – modelled).

The set of values determined from the relationship (8.16) is processed in Matlab to obtain the first degree function $h_m = f\,(a_p.\ f_z)$:

$$h_{cm} = a_1 + a_2\, a_p + a_3\, f_z. \quad (16)$$

Using the multiple regression method the following parameter values are obtained:

$$a_1 = -0.0201.\ a_2 = 0.0285.\ a_3 = 0.5097. \quad (17)$$

The maximum absolute error is MaxErr = 0.0022 and the relative one is 3.9%.

The expression of the $h_{cm} = f\,(a_p.\ f_z)$ function in the considered case (table 8.3) is:

$$h_{cm} = -0.0201 + 0.0285\, a_p + 0.5097\, f_z\ \text{[mm]}. \quad (18)$$

Figure 9 presents the diagrams of the thickness h_{cm} depending on the feed per tooth for the depth of cut a_p = 0.5 mm.

These models obtained for the studied cutting tool and insert are the basis for the next model type namely the cutting forces model.

6. CONCLUSIONS

Based on the classic model of the chip geometry it was proposed for a type of cutting insert (R365-1505ZNE-PM from the Sandvik Coromant Company) a CAD method for determining the chip area in milling. A CAD method for the determination of the area A_c as a function of two variables (a_p and f_z) that approximates the actual values with a relative error of 8% is proposed based on the set of values. The method can be extended to any type of cutting insert and any geometric configuration.

Based on the geometry of the cutting insert R365-1505ZNE-PM a CAD method was developed for the determination of the uncut chip length l_c in milling. So based on the set of values a first degree function of two variables (a_p and f_z) that approximates the actual values with a relative error of 0.28% is proposed. Using the known relationship of the uncut chip thickness in the normal plane to the feed direction the values of the h_{cm} function were determined. These values led to the determination of a first degree function of two variables (a_p and f_z) which approximates the actual average chip thickness values with a relative error of 3.9%.

The values of the uncut chip thickness are determined for the purpose of being inserted as constants in the mathematical model of the cutting force besides the specific cutting force coefficients $K_n = f(a_p. f_x. v_c)$ and $K_t = f(a_p. f_x. v_c)$.

REFERENCES

[1] C. Constantin. *Cercetări privind modelarea și simularea procesului de așchiere* (Researches regarding modelling and simulation of the cutting process applied to milling). PhD Thesis. University „Politehnica” of Bucharest. 2012.

[2] *W.J. Endres*. A Dynamic Model of the Cutting Force System in the Turning Process. University of Illinois at Urbana-Champaign. 1990.

[3] G. Constantin, R. Constantin, G. Tasca, G. Musca, M. Vasilescu, *Proiectarea asiatată 2D şi 3D a maşinilor şi sistemelor de producţie* (2D and 3D design of machines and production systems), Edit. Academiei Oamenilor de Ştiinţă din România, Bucharest, 2011, ISBN 978-606-8371-46.

[4] *Genetic programming & Symbolic Regresion for MATLAB*, https://sites.google.com/site/gptips4matlab/, accesed: 15.01.2012.

[5] S. Engin, Y. Altintas, *Generelizad modeling of milling mechanics and dynamics: Part II – Inserted Cutters*, pp. 1–8, http://www.google.de/url?sa=t&rct=j&q=chip%20geometry%20model%20in%20milling&source=web&cd=18&cad=rja&ved=0CFgQFjAHOAo&url=http%3A%2F%2Fwww.malinc.com%2Fpdf%2FGeneralTool_Inserted-Mill.pdf&ei=n_WDUMfROoXQsgbbwYCQBg&usg=AFQjCNF1lmyqSQpDQ49neh54UHQA-U12aw.

[6] K. Weinert, T. Surmann, *Geometric simulation of the milling process for free formed surfaces*, Kolloquium - Forschergruppe FreiFormFlächen, pp. 1–10, http://www.google.de/url?sa=t&rct=j&q=chip%20geometry%20model%20in%20milling&source=web&cd=14&ved=0CDgQFjADOAo&url=http%3A%2F%2Ftiefbohren.de%2Fcontent%2Fdocuments%2Fpublications%2Farticles%2Fattachments%2F349.pdf&ei=n_WDUM-fROoXQsgbbwYCQBg&usg=AFQjCNEWHm5n2pjmfGnp3DKVdzB9jBX0zw.