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CONSTRUCŢII DE MAŞINI

MODELING THE AREA AND VOLUME OF THE UNDETACHED CHIP AT THE CHANNELS MILLING USING A 3D SOFTWARE

BY

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Abstract. In predicting machining error, the milled surface integrity and vibrations have a key role. Simulations for milling process with spherical head, based on models for the cutting force of complex surfaces have been developed, so far, by a lot of researchers. Many researchers starting with Koenigsberger and Sabberwal (1961), Armarego and Epp (1970) have used a mechanistic model for the cutting forces as a function of cutting coefficients, axial depth of cut and the chip thickness. The product between axial depth of cut and chip thickness is the uncut chip area. We can establish a connection between the edge and the cutting force coefficients multiplied by axial depth of cut and respectively, the uncut chip area and cutting force. The edge and cutting force coefficients are established for every pair of material–tools using cutting tests with an axial depth constant of the cutting and, of a variable feed and a spindle speed. Using a 3D CAD software we can model chips for different axial depths of cut, feed per tooth and the radial depth of cut and its calculate by the volume who is proportional with MRR (Material Removal Rate).

Key words: uncut chip thickness; cutting force; uncut chip area; MRR.

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1. Introduction

We can model uncut chip using analytical relations as (Terai & Mizugaki, 2004), using a very complicated mathematical algorithm with many iterations and complicated systems of differential equations or use a 3D CAD software as Iwabe *et al*. (2006). In Romania the subject was treated first time by Cozma (2007a; 2007b). For a ball end milling process using 3D CAD software, generated chip model for different axial depth of cut and feed per tooth and uncut chip area variations are presented in Figs. 1,…,6.

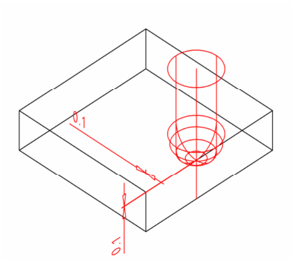

Fig. 1 – 3D CAD model.

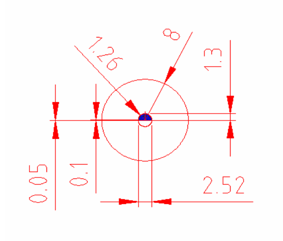

Fig. 2 – Chip with dimensions.

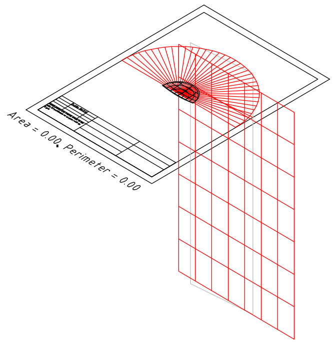

Fig. 3 – Chip and cutting plane.

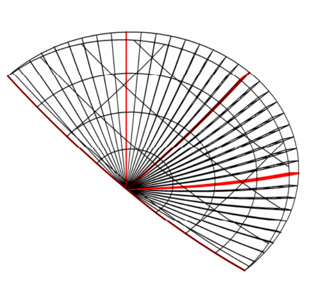

Fig. 4 – Uncut chip with areas variation obtained with 3D software.

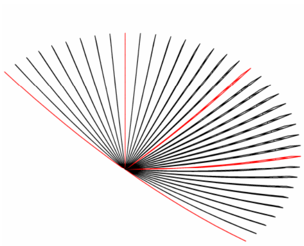

Fig. 5 – Uncut chip sections.

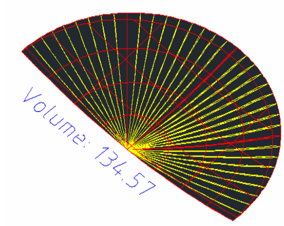

Fig. 6 – Uncut chip volume.

2. Numerical Values and Graphical Presentation of Uncut Chip Areas Variation

Samples of tables with calculated data for uncut chip areas and perimeter are presented in Table 1.

Table 1
Variation of Uncut Chip Area and Perimeter for:
Axial Depth of Cut 0.1 mm, and Feed per tooth 0.1 m

Cutting plane increment [degree]	Uncut chip area [mm^2] Scale 20:1	Real uncut chip area [mm^2]	Perimeter Scale 20:1	Real perimeter value [mm]
0	0.000	**0.0000**	25.3	1.2650
5	0.350	**0.0009**	50.78	2.5390
10	0.690	**0.0017**	50.96	2.5480
15	1.040	**0.0026**	51.39	2.5695
85	3.980	**0.0100**	52.64	2.6320
90	4.000	**0.0100**	52.65	2.6325
95	3.980	**0.0100**	52.640	2.6320
175	0.350	**0.0009**	50.780	2.5390
180	0.000	**0.0000**	25.300	1.2650

Graphical representation of data from Table 1 is presented in Fig. 7

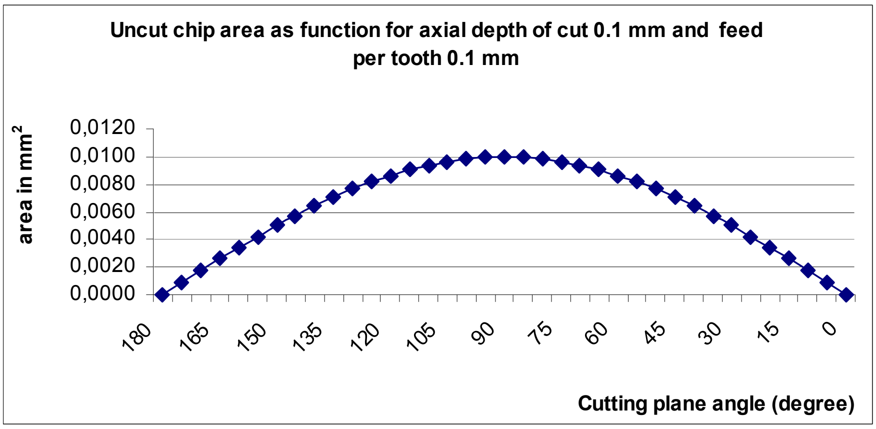

Fig. 7 – Graphical variation of uncut chip area for:
axial depth of cut 0.1 mm and feed per tooth 0.1 mm/tooth.

Keeping constant axial depth of cut (0.1 mm) and varying feed per tooth (0.1-0.5 mm) we obtained for uncut chip area numerical values from Table 2 and graphical representation from Fig. 8:

Table 2

Numerical Values of Uncut Chip Area and Perimeter for:
Axial Depth of Cut 0.1 mm, and Feed per tooth (*0.1- 0.5*) *mm*

Vertical plane rot [°]	Uncut chip area *f*=0.1 mm (20:1)	Real uncut chip area [mm^2]	Uncut chip area *f*=0.2 mm (20:1)	Real uncut chip area [mm^2]	Uncut chip area *f*=0.3 mm (20:1)	Real uncut chip area [mm^2]	Uncut chip area *f*=0.4 mm (20:1)	Real uncut chip area [mm^2]	Uncut chip area *f*=0.5 mm (20:1)	Real uncut chip area [mm^2]
0	0.000	0.0000	0.040	0.0001	0.000	0.0000	0.000	0.0000	0.000	0.0000
5	0.350	0.0009	0.730	0.0018	1.030	0.0026	1.360	0.0034	1.680	0.0042
10	0.690	0.0017	1.420	0.0036	2.060	0.0052	2.710	0.0068	3.340	0.0084
85	3.980	0.0100	7.960	0.0199	11.900	0.0298	15.800	0.0395	19.660	0.0492
90	4.000	0.0100	7.980	0.0200	11.940	0.0299	15.870	0.0397	19.740	0.0494
5	3.980	0.0100	7.960	0.0199	11.900	0.0298	15.800	0.0395	19.660	0.0492
175	0.350	0.0009	0.730	0.0018	1.030	0.0026	1.360	0.0034	1.680	0.0042
180	0.000	0.0000	0.040	0.0001	0.000	0.0000	0.000	0.0000	0.000	0.0000

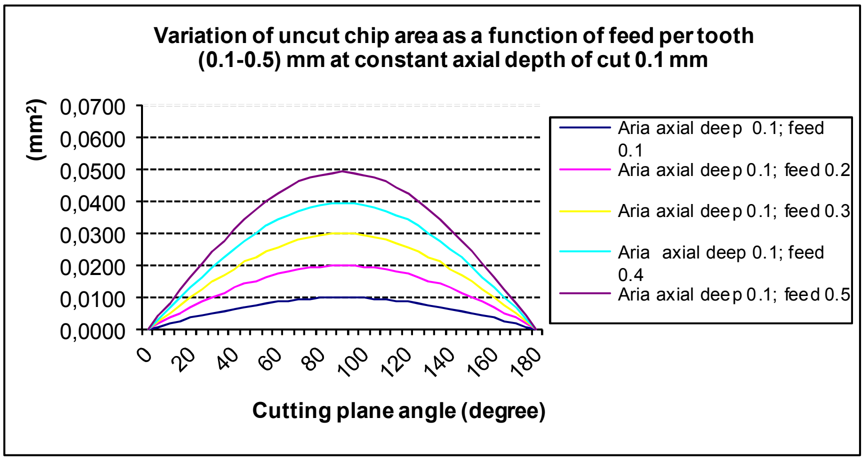

Fig. 8 − Graphical variation of uncut chip area for:
axial depth of cut 0.1 mm, and feed per tooth (0.1- 0.5) mm.

Similar results were obtained using different feed per tooth (0.1-0.5 mm) for different values of axial deep of cut and are graphically presented in Figs. 9,…,12.

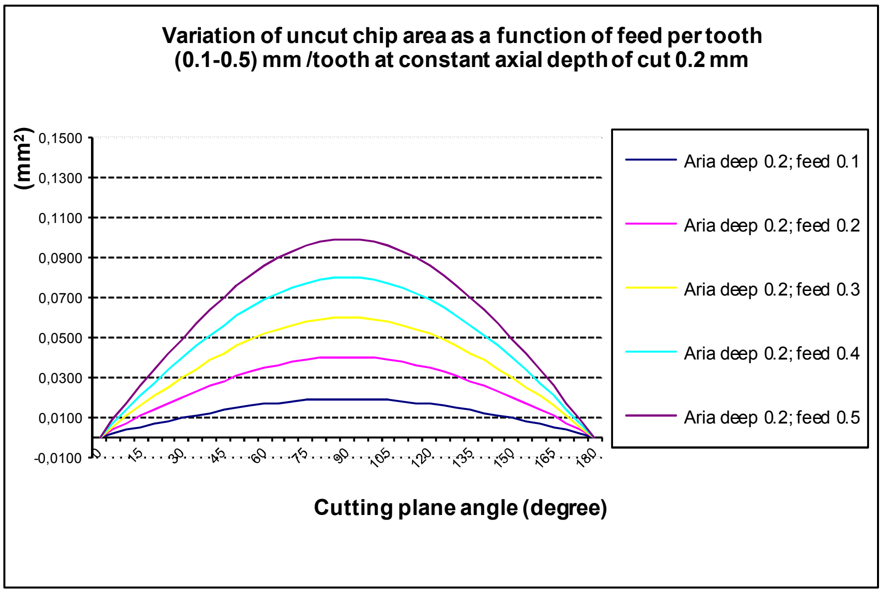

Fig. 9 − Graphical variation of uncut chip area for:
axial depth of cut 0.2 mm, and feed per tooth (0.1- 0.5) mm/tooth.

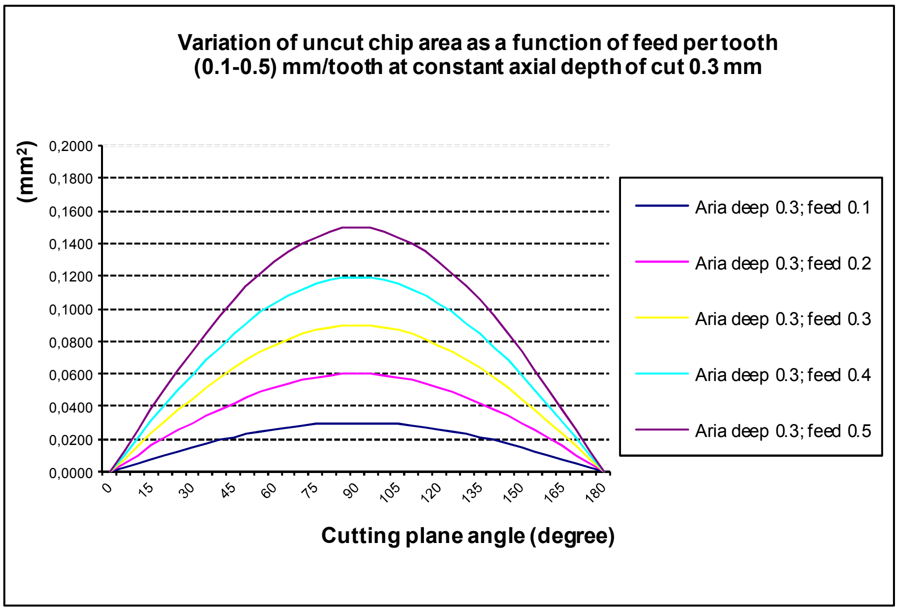

Fig. 10 − Graphical variation of uncut chip area for:
axial depth of cut 0.3 mm, and feed per tooth (0.1- 0.5) mm/tooth.

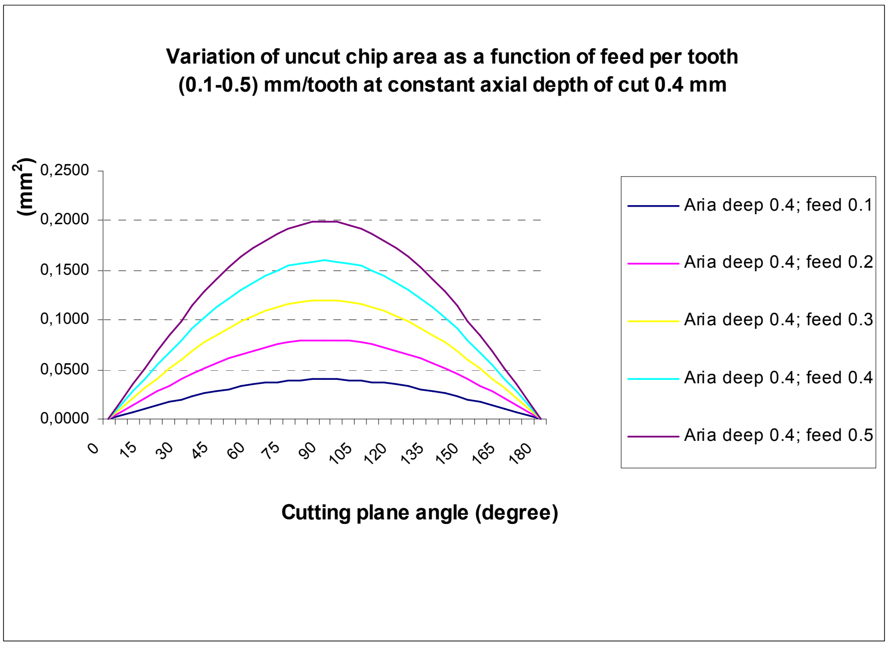

Fig. 11 − Graphical variation of uncut chip area for:
axial depth of cut 0.4 mm, and feed per tooth (0.1- 0.5) mm/tooth.

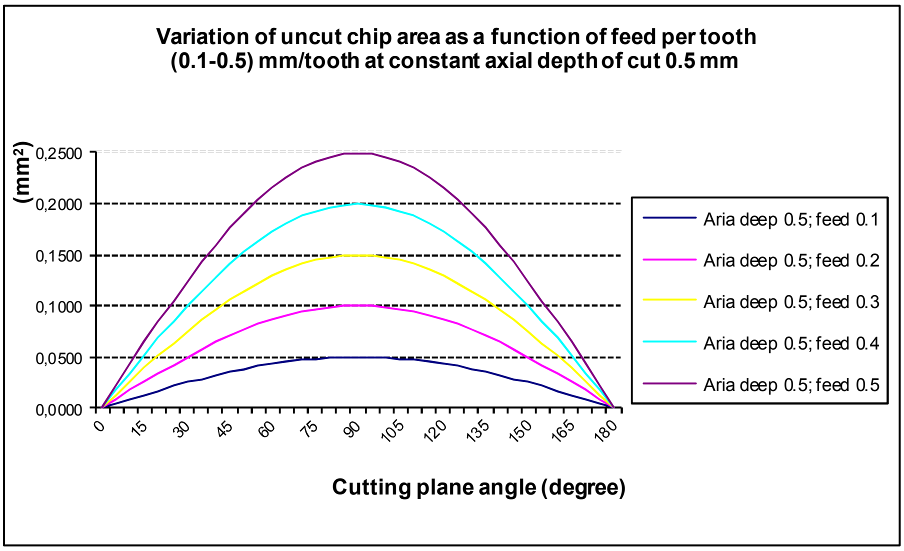

Fig. 12 − Graphical variation of uncut chip for:
axial depth of cut 0.5 mm, and feed per tooth (0.1- 0.5) mm/tooth.

Keeping feed per tooth constant (0.1 mm) and varying axial depth of cut (0.1-0.5 mm) we obtained for uncut chip area numerical values from Table 3 and graphical representation from Fig. 13.

Table 3

Numerical Values of Uncut Chip Area and Perimeter for: Feed per tooth 0.1 mm/tooth, and Axial Depth of Cut (*0.1- 0.5*) *mm*

Vertical plane rot [°]	Uncut chip area *dp*=0.1 mm (20:1)	Real uncut chip area [mm^2]	Uncut chip area *dp*=0.2 mm (20:1)	Real uncut chip area [mm^2]	Uncut chip area *dp*=0.3 mm (20:1)	Real uncut chip area [mm^2]	Uncut chip area *dp*=0.4 mm (20:1)	Real uncut chip area [mm^2]	Uncut chip area *dp*=0. 5mm (20:1)	Real uncut chip area [mm^2]
0	0.000	0.0000	0.000	0.0000	0.000	0.0000	0.000	0.0000	0.000	0.0000
5	0.350	0.0009	0.660	0.0017	1.050	0.0026	1.390	0.0035	1.740	0.0044
10	0.690	0.0017	1.320	0.0033	2.080	0.0052	2.780	0.0070	3.470	0.0087
85	3.980	0.0100	7.570	0.0189	11.950	0.0299	15.940	0.0399	19.920	0.0498
90	4.000	0.0100	7.600	0.0190	12.000	0.0300	16.000	0.0400	20.000	0.0500
95	3.980	0.0100	7.570	0.0189	11.950	0.0299	15.940	0.0399	19.920	0.0498
175	0.350	0.0009	0.660	0.0017	1.050	0.0026	1.390	0.0035	1.740	0.0044
180	0.000	0.0000	0.000	0.0000	0.000	0.0000	0.000	0.0000	0.000	0.0000

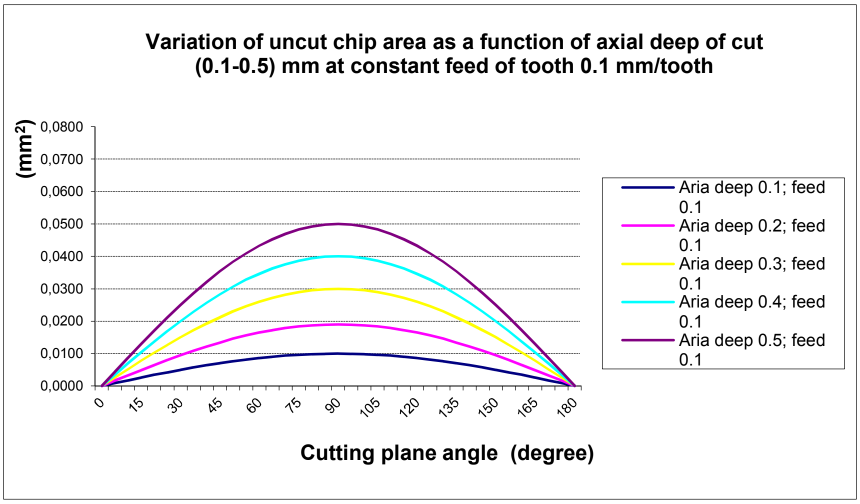

Fig. 13 − Graphical variation of uncut chip area: at constant feed per tooth 0.1 mm/tooth and axial depth of cut (0.1- 0.5) mm.

Equivalent graphical results were obtained using different axial deep of cut (0.1-0.5 mm), for constant feed per tooth, in Figs. 14,…,17.

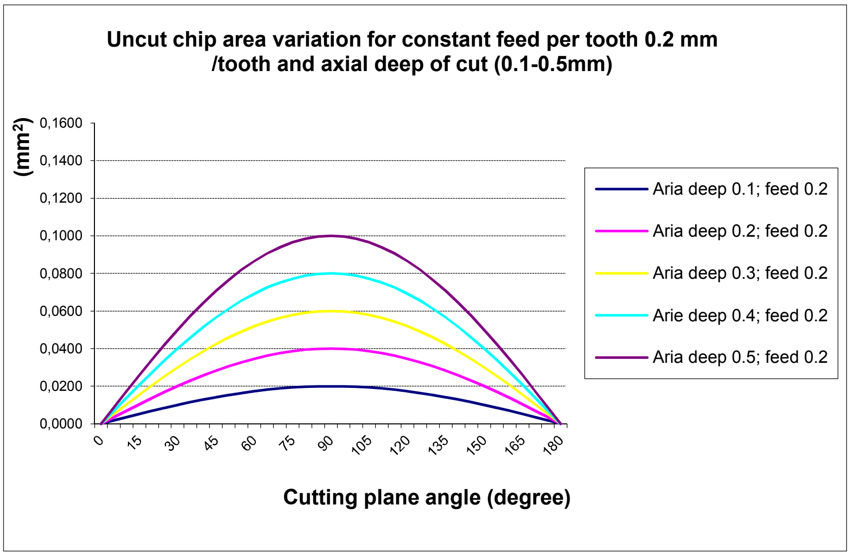

Fig. 14 − Graphical variation of uncut chip area: at constant feed per tooth 0.2 mm/tooth and axial depth of cut (0.1- 0.5) mm.

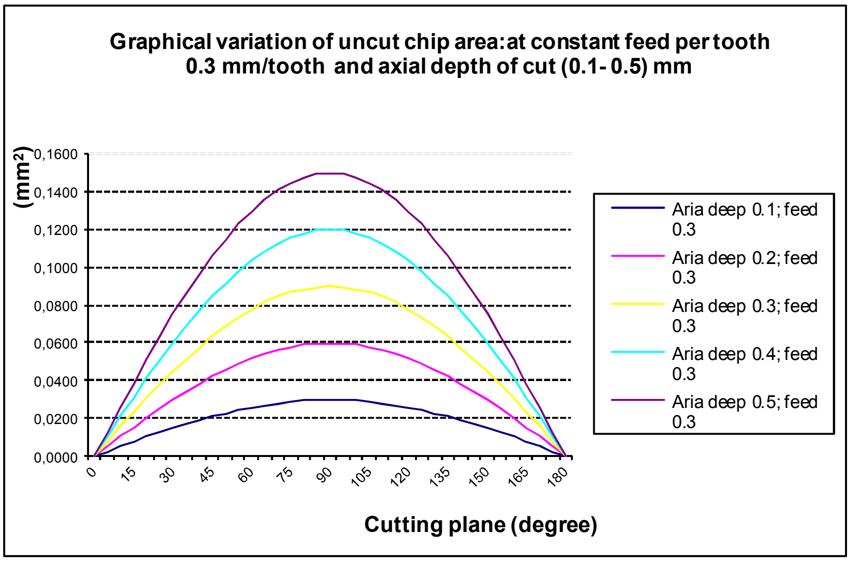

Fig. 15 − Graphical variation of uncut chip area: at constant feed per tooth 0.3 mm/tooth and axial depth of cut (0.1- 0.5) mm.

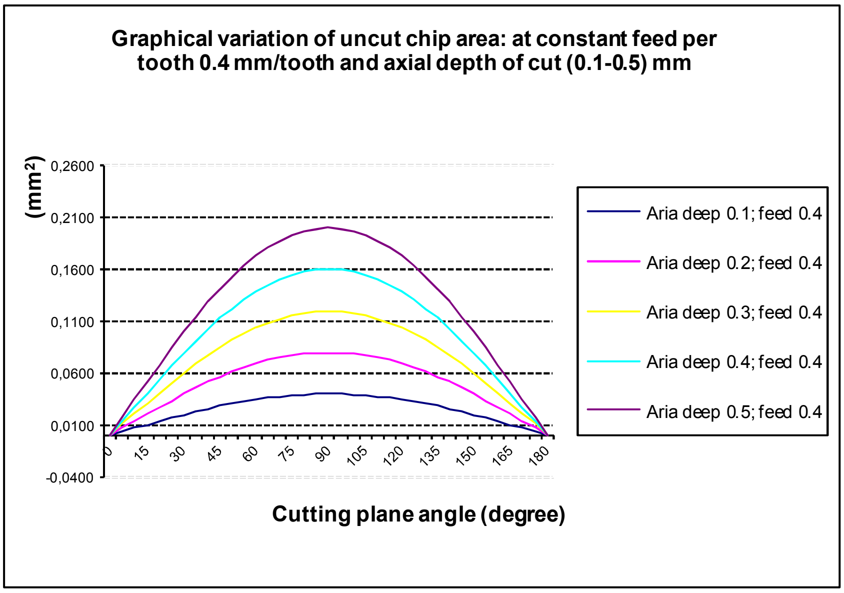

Fig. 16 − Graphical variation of uncut chip area: at constant feed per tooth 0.4 mm/ tooth and axial depth of cut (0.1- 0.5) mm.

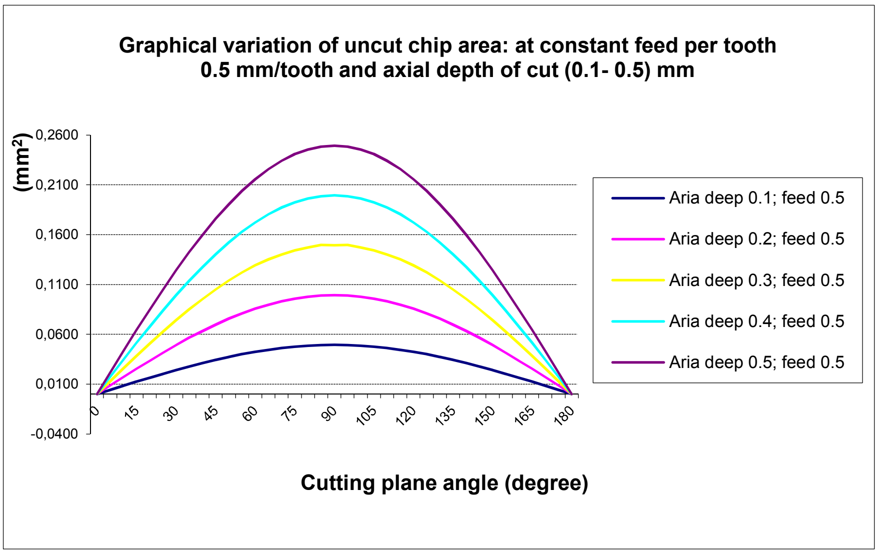

Fig. 17 − Graphical variation of uncut chip area: at constant feed per tooth 0.5 mm/ tooth and axial depth of cut (0.1- 0.5) mm.

Table 4

Variation Domain for Uncut Chip Area in Ball end Milling Process for: Constant Axial Depth of Cut x Variable Feed per tooth and Constant Feed per tooth x Variable Axial Deep of Cut

Axial depth of cut=ct. [mm]	Feed per tooth [mm/tooth]	Uncut chip area variation [mm^2]	Feed per tooth=ct. [mm/tooth]	Axial depth of cut [mm]	Uncut chip area variation [mm^2]
0.1	0.1 → 0.5	0.01- 0.0494	0.1	0.1 → 0.5	0.10-0.050
0.2	0.1 → 0.5	0.019-0.0994	0.2	0.1 → 0.5	0.020-0.100
0.3	0.1 → 0.5	0.030-0.1494	0.3	0.1 → 0.5	0.0299-0.1499
0.4	0.1 → 0.5	0.040-0.1994	0.4	0.1 → 0.5	0.0397-0.1992
0.5	0.1 → 0.5	0.050-0.2494	0.5	0.1 → 0.5	0.0494-0.2494

In Table 4 we have only geometrical variation of uncut chip area in ball end milling process for: constant axial depth of cut related to variable feed per tooth or constant feed per tooth related to variable axial deep of cut. Technological parameters such as: spindle speed, cutting direction (up or down milling), lead and tilt tool angles which have no effect on defining parameters of uncut chip area were neglected). If we compare graphical representation of uncut chip area variations from Fig. 8 with Fig. 13 can remark that for constant axial cutting deep of 0.1 mm and variable feed per tooth in domain (0.1-0.5 mm) *versus* constant feed per tooth of 0.1 mm and variable axial cutting deep in domain (0.1-0.5 mm) maximum area has the same numerical value (variation of area domain is 0.010-0.0494 mm^2).

Example:

− axial deep of cut = 0.1 mm x feed per tooth = 0.4 mm/tooth, maximum uncut chip area = 0.0397 mm^2;

− axial deep of cut = 0.4 mm x feed per tooth = 0.1 mm/tooth, maximum uncut chip area = 0.0400 mm^2.

Similar results were obtained for all other combinations of axial deep of cut x feed per tooth. As a purely geometrical result, considering relation between uncut chip area and cutting forces, the last one must be equal. Taking into consideration technological parameters since 1941 Martelotti (Martelotti, 1941) recommends increasing feed per tooth *versus* axial depth of cut for minimum cutting forces.

3. Numerical Values and Graphical Presentation of Uncut Chip Volume Variation

Numerical variations of uncut chip volume related to axial deep of cut x feed per tooth is presented in Tables 5 and 6:

Table 5
Variation of Uncut Chip Volume for Constant Axial Deep of Cut x Variable Feed per tooth

Axial deep of cut [mm]	Feed per tooth [mm/tooth]	Uncut chip volume [mm^3] Scale 20:1	Real uncut chip volume [mm^3]
0.1	0.1	134.57	0.0168
0.1	0.2	268.5	0.0336
0.1	0.3	401.17	0.0501
0.1	0.4	531.95	0.0665
0.1	0.5	660.24	0.0825
0.2	0.1	351.95	0.0440
0.2	0.2	759.18	0.0949
0.2	0.3	1136.53	0.1421
0.2	0.4	1511.21	0.1889
0.2	0.5	1882.32	0.2353
0.3	0.1	696.94	0.0871
0.3	0.2	1392.79	0.1741
0.3	0.3	2086.44	0.2608
0.3	0.4	2766.81	0.3459
0.3	0.5	3462.79	0.4328
0.4	0.1	1071.04	0.1339
0.4	0.2	2140.81	0.2676
0.4	0.3	3208.06	0.4010
0.4	0.4	4271.5	0.5339
0.4	0.5	5329.87	0.6662
0.5	0.1	1494.01	0.1868
0.5	0.2	2986.65	0.3733
0.5	0.3	4476.41	0.5596
0.5	0.4	5961.94	0.7452
0.5	0.5	7441.78	0.9302

Table 6
Variation of Uncut Chip Volume for Constant Feed per tooth x Variable Axial Deep of Cut

Feed per tooth [mm/tooth]	Axial deep of cut [mm]	Uncut chip volume [mm^3] Scale 20:1	Real uncut chip volume [mm^3]
0.1	0.1	134.57	0.0168
0.1	0.2	351.95	0.0440
0.1	0.3	696.94	0.0871
0.1	0.4	1071.04	0.1339
0.1	0.5	1494.01	0.1868

Table 6
Continuation

Feed per tooth [mm/tooth]	Axial deep of cut [mm]	Uncut chip volume [mm^3] Scale 20:1	Real uncut chip volume [mm^3]
0.2	0.1	268.5	0.0336
0.2	0.2	759.18	0.0949
0.2	0.3	1392.79	0.1741
0.2	0.4	2140.81	0.2676
0.2	0.5	2986.65	0.3733
0.3	0.1	401.17	0.0501
0.3	0.2	1136.53	0.1421
0.3	0.3	2086.44	0.2608
0.3	0.4	3208.06	0.4010
0.3	0.5	4476.41	0.5596
0.4	0.1	531.95	0.0665
0.4	0.2	1511.21	0.1889
0.4	0.3	2786.81	0.3484
0.4	0.4	4271.5	0.5339
0.4	0.5	5961.94	0.7452
0.5	0.1	660.24	0.0825
0.5	0.2	1882.32	0.2353
0.5	0.3	3462.79	0.4328
0.5	0.4	5329.87	0.6662
0.5	0.5	7441.78	0.9302

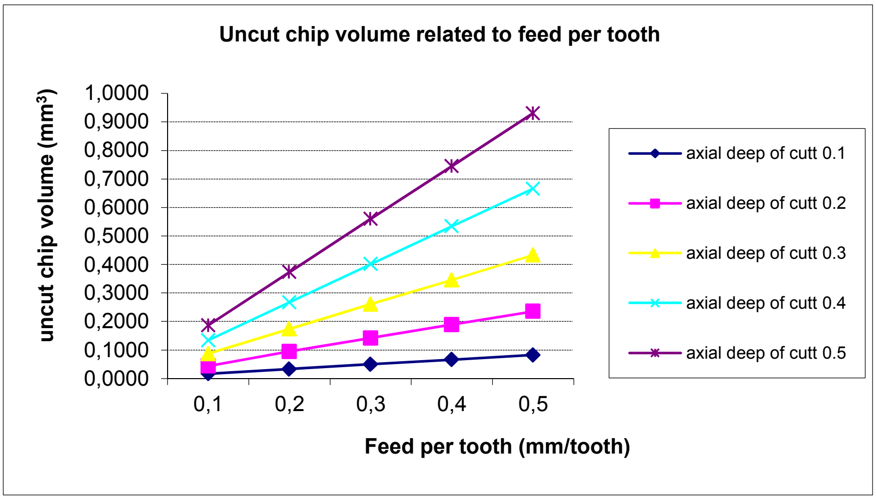

Fig. 18 − Graphical representation of uncut chip volume variation related to feed per tooth for different axial deep of cut values.

Graphical variations of data from Tables 5 and 6 is presented in Figs. 18 and 19.

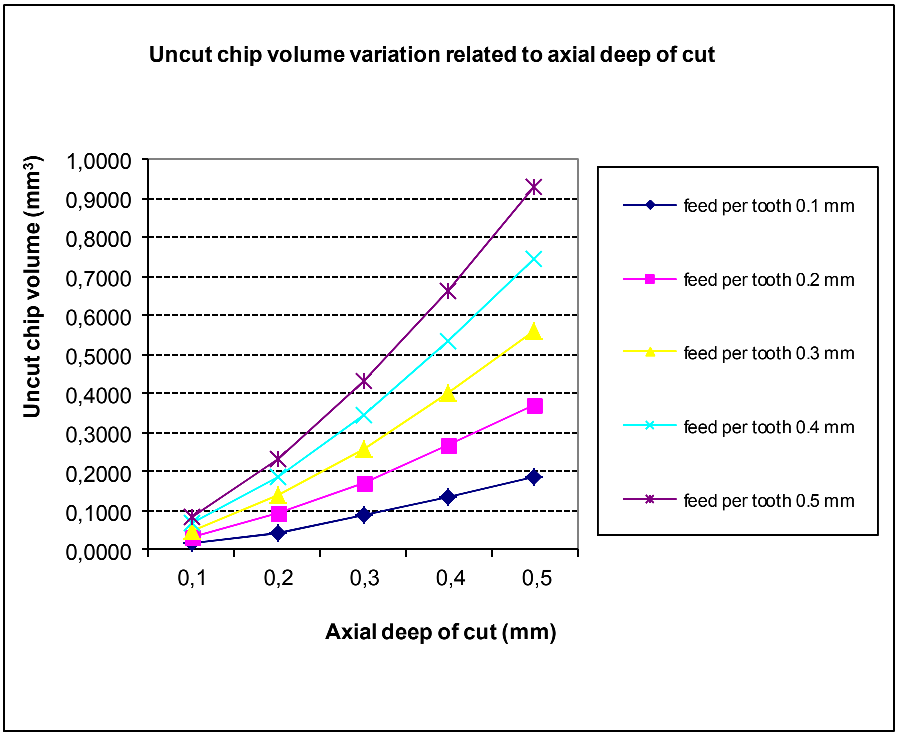

Fig. 19 – Graphical representation of uncut chip volume variation related to axial deep of cut for different feed per tooth values.

4. Conclusions

Conducted researches presented in the paper, allow the following assessments and conclusions relating to modeling area and the volume of the undetached chips in the milling process:

1) if we consider numerical values and relations presented in Table 7 we can observe a superior rise of uncut chip volume with variation of axial deep of cut (regression slope coefficient);

2) taking into account only MRR (material removal rate), which is proportional with uncut chip volume, it will be a mistake;

3) considering only great values for MRR means grater values for axial deep of cut and greater cutting forces.

Table 7

Variation of Uncut Chip Volume for: Constant Feed per tooth x Variable Axial Deep of Cut Values and Constant Axial Deep of Cat x Feed per tooth Values and Linear Regression Equations of Data

Feed per tooth [mm/tooth]	Axial deep of cut [mm]	Uncut chip volume [mm^3]	Regression equations
ct = 0.1 mm	0.1-0.5 mm (variably)	0.0168-0.1868 mm^3	y = 0.4299x-0.0353
ct=0.2 mm		0.0336-0.3733 mm^3	y = 0.8521x-0.0669
ct=0.3 mm		0.0501-0.5596 mm^3	y = 1.2779x-0.1007
ct=0.4 mm		0.0665-0.7452 mm^3	y = 1.7024x-0.1341
ct=0.5 mm		0.0825-0.9302 mm^3	y = 2.1263x-0.1685
0.1-0.5 mm (variably)	ct=0.1 mm	0.0168-0.0825 mm^3	y = 0.1643x-0.0006
	ct=0.2 mm	0.0440-0.2353 mm^3	y = 0.7466x-0.0019
	ct=0.3 mm	0.0871-0.4328 mm^3	y = 0.8632x-0.0012
	ct=0.4 mm	0.1339-0.6662 mm^3	y = 1.3309x-0.0013
	ct=0.5 mm	0.1868-0.9302 mm^3	y = 1.8587x-0.0014

Technologically we must achieve an optimization of cutting process parameters to ensure a maximum productivity with great surface integrity and minimum energy consumption. To achieve that goal we must use a plan of experience to verify above geometrical results with real results from cutting tests.

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MODELAREA ARIEI ŞI A VOLUMULUI AŞCHIEI NEDETAŞATE LA FREZAREA CANALELOR FOLOSIND UN SOFT 3D

(Rezumat)

Scopul studiului este de a determina pentru anumite condiții de aşchiere precise (freză sferică cu raza R = 8 mm, adâncimi de aşchiere din gama 0.1-0.5 mm, avans pe dinte din gama 0.1-0.5 mm) volumul şi aria exactă a secțiunilor prin aşchie. Este cunoscut faptul că între forța de aşchiere (cu cele două componente, cea de frecare de pe tăiş şi cea de forfecare de la producerea aşchiei) şi lungimea tăişului în contact cu aşchia respectiv secțiunea prin aşchie există o dependență lineară. Aceasta poate fi exprimată printr-o relație matematică sub forma unei sume de produse dintre elementele enunțate mai sus şi o serie de coeficienți (determinați experimental).

Folosind modelarea 3D se pot determina valorile instanee ale secțiunii prin aşchie şi volumul acesteia, care vor fi folosite ulterior la calculul forțelor de aşchiere şi a cantității de material aşchiat în unitatea de timp. Studiul scoate în evidență variația secțiunii aşchiei pentru diferite regimuri, funcție de avans şi adâncimea de aşchiere. S-a dovedit matematic egalitatea ariilor secțiunilor şi implicit a forțelor de aşchiere între regimurile care folosesc ca parametru principal adâncimea de aşchiere şi respectiv avansul pe dinte. Aceasta permite alegerea regimurilor de prelucrare cu adâncimi mici şi viteze de avans mari în detrimentul celor definite prin adâncimi de aşchiere mari şi avansuri pe dinte mici (cu forțe de aşchiere mari).

Regimul cu adâncimi de aşchiere mici şi avansuri pe dinte mari este specific prelucrărilor cu viteze mari de aşchiere (HSM). Strict din punct de vedere geometric volumul aşchiei creşte mai repede cu adâncimea decât cu viteza de avans ceea ce duce la necesitatea unor determinări experimentale. Scopul lor este de a găsi un optim al parametrilor de aşchiere care să asigure o calitate crescută a suprafeței prelucrate şi în acelaşi timp o productivitate crescută cu consum energetic minim.