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Comparison Between the CAD Method and the Analytical Method
—Rotary Cutter Tool's Profiling—

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ABSTRACT

This paper is concerned with a CAD method, developed in the CATIA design software for the tool profiling, generated by enwrapping, for the rotary cutter tool, in particular.

The method is based on the creation of a virtual mechanism which keeps the rolling condition of centrodes associated with enveloping profiles, making sure that both the tool profile and the blank profile meet one of the fundamentals theorems of gearing.

An algorithm was elaborated, alongside with specialized software, in the CATIA design environment, for the determination of the rotary cutter generation method. The present paper deals with the numerical validation of the results, relying on a unanimously accepted analytical method.

Application examples are presented for simple analytical profiles.

KEYWORDS: enveloping surfaces, rotary cutter tool, graphical design method

1. Introduction

The profiling of tools generated by enveloping using the rolling method — the rotary cutter tool and the gear shaped tool— may be carried out relying on certain methods:

- analytical methods, based on fundamental methods of surfaces enwrapping – first Olivier theorem, Gohman theorem, normals theorem (Willis), [1], [2], [10], [13]-[15];
- complementary analytical methods – "minimum distance" method, the "substitutive circles family" method, the "in-plane generating trajectories" method [3]-[5];
- graphical-analytical methods [6];
- graphical methods, using the capabilities of CAD software [7], [16]

We mention that the methods proposed and used for the study of reciprocally enveloping surfaces respect the enveloping fundamental theorem.

The proposed solutions lead to comparable results, in most cases identical, for the crossing profile tool's shape, which is generated by rolling ordered curls profiles associated with a couple of rolling centrodes.

2. Kinematics Method in CATIA Design Environment

A new solution of the rotary cutter profiling has been enhanced relying on the CATIA software performances, making a kinematic entity reproducing the rolling movement of centrodes: a circle with radius R_{rp}, associated with the space of the rotary cutter and a straight line, associated with the space profile curl.

The proposed solution is based on the facilities of the *Part* environment (*Part Environment*), in which the elements of a mechanism are synthesized, a mechanism which is able to simulate the enwrapping condition, the condition of the normals in this case. These elements, created in the *Part* environment, are introduced in a file of the *Assembly* environment, assuring the positioning of the mechanism elements in the start position, and then, in the *DMU Kinematics* environment (*Digital Mock Up*) to be defined the predefined kinematics couples.

The mechanism movement is werked out by the command *Simulation*, establishing a number of intermediary positions *Shots*, created on the *Replay* command, a movie of the successive positions of the mechanism.

Using the *Trace* command, any point trajectory can be traced starting from any of the mechanism elements, including the global reference system, that may determining the gearing line between the profile to be generated and the rotary cutter tool’s profile.

The proposed solution has the advantage to use the capabilities of versatile software, which may offer very rigorous numerical results.

At the same time, being a graphical method, rough errors, due to the passing curves, which may be wrongly regarded as the profile’s zone, are easy to be identified and eliminated.

As they are regarded as one type of the piece’s profile for which as many types of virtual mechanism in the CATIA environment (M.G.M.C) are designed.

Analytical method

In principle, the problems of tool’s profile determination reciprocally enveloping with an ordered profile’s curl, associated with a straight lined centrode, presume the meeting of the generating process kinematics.

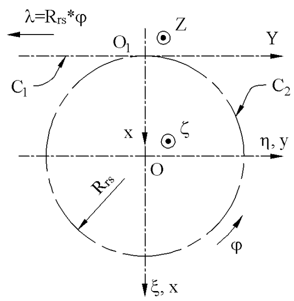

Fig. 1. *Generating kinematics and reference systems*

The two rolling centrodes, C_1 —straight line, associated with the profiles ordered curls and C_2 — associated with the rotary cutter tool, are in the rolling movement, so that the following condition should be taken into account:

$$\lambda = R_{rs} \cdot \varphi \,, \tag{1}$$

where λ is the linear velocity in the translation of the C_1 centrode;

$R_{rs} \cdot \varphi$ — the value of the velocity in point O_1—the gearing pole, from C_2 centrode, in the rotation movement around z axis; φ — the variable angular parameter.

In the rotation of C_1 centrode, the rotations around Z axis, and the movements along the C2 centrode, are even.

They are defined as reference systems:

xyz is the global reference system, with *z* axis overlapped to the rotation axis of the C_2 centrode;

XYZ — mobile reference system, joined with the ordered curls profile Σ;

$\xi\eta\zeta$ — mobile reference system, joined with C_2 centrode of the rotary cutter tool, initially overlapped to the global reference system, *xyz*.

The kinematics of the rolling process of the two centrodes, C_1 and C_2, tangents in point O_1 — gearing pole— presumes that the velocities of the points belong to the two centrodes, temporarily situated in point O_1, to be equals.

In this way, the global motion of the $\xi\eta\zeta$ reference system, joined with the centrode C_2, is described by the transformation,

$$x = X + a \,, \tag{2}$$

where:

$$X = \begin{pmatrix} X & Y & Z \end{pmatrix}^T ; \; x = \begin{pmatrix} x & y & z \end{pmatrix}^T \tag{3}$$

represent the matrix of the current points in the space *XYZ*, respectively, *xyz*;

$$a = \begin{pmatrix} -R_{rs} & -\lambda & 0 \end{pmatrix}^T \tag{4}$$

is the matrix formed relying on the coordinates of the point O_1, in the global reference system, with λ as instantaneous velocity in the translation movement of the C_1 centrode and R_{rs} the value of the circular centrode C_2 (rolling radius).

Also, the revolution movement of C_1 centrode is described by the transformation

$$\begin{pmatrix} x & y & z \end{pmatrix}^T = \omega_3^T(\varphi) \cdot \begin{pmatrix} \xi & \eta & \zeta \end{pmatrix}^T \tag{5}$$

where $\begin{pmatrix} \xi & \eta & \zeta \end{pmatrix}^T$ is the matrix of the current point in the space $\xi\eta\zeta$, and

$$\omega_3(\varphi) = \begin{pmatrix} \cos\varphi & \sin\varphi & 0 \\ -\sin\varphi & \cos\varphi & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{6}$$

is the rotation transformation matrix, around Z axis, with the angle φ (counter clockwise rotation).

The assembly of the equations (3) and (6), with respect to the rolling condition (1), determines the relative motion,

$$\begin{pmatrix} \xi \\ \eta \\ \zeta \end{pmatrix} = \begin{pmatrix} \cos\varphi & \sin\varphi & 0 \\ -\sin\varphi & \cos\varphi & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \left[\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} + \begin{pmatrix} -R_{rs} \\ -\lambda \\ 0 \end{pmatrix} \right] \tag{7}$$

while the Σ profile, belongs to the profile’s ordered curl, associated with the C_1 centrode, in the form of,

$$\Sigma = \begin{pmatrix} X(u) & Y(u) & Z(u) \end{pmatrix}^T \tag{8}$$

with u variable parameter, describing a profile’s family in the two space:

$$(\Sigma)_{\varphi_1} \left| \begin{aligned} &\xi(u,\varphi) = \left[X(u) - R_{rs} \right] \cos\varphi - \\ &\qquad - \left[Y(u) - R_{rp} \cdot \varphi \right] \sin\varphi; \\ &\eta(u,\varphi) = -\left[X(u) - R_{rs} \right] \sin\varphi + \\ &\qquad + \left[Y(u) - R_{rs} \cdot \varphi \right] \cos\varphi; \\ &\zeta(u,\varphi) = 0. \end{aligned} \right. \tag{9}$$

The enveloping condition, defined in an analytical form and relying on the fundamental theorems or the complementary methods, is usually associated with (9).

If the in-plane specific condition generating trajectories is accepted in the form of,

$$\eta'_u \cdot \xi'_\varphi - \eta'_\varphi \cdot \xi'_u = 0\,, \qquad (10)$$

where $\eta'_u, \xi'_\varphi, \eta'_\varphi, \xi'_u$ represents the partial derivative, calculated using (9), then the equations assembly (9) and (10), represent the rotary cutter tool's profile.

Regarding the tool's reference system, for $\varphi = const.$, the coordinates of the contact point between the tool and the blank are determined.

Due to the fact that the (10) condition represents in principle a link between the parameters u and φ,

$$u = u(\varphi) \qquad (11)$$

the profile's family (9) is transformed in the form of:

$$\Sigma_{(\varphi)} \begin{vmatrix} \xi = \xi(\varphi); \\ \eta = \eta(\varphi). \end{vmatrix} \qquad (12)$$

The form (12) represents the rotary cutter tool's profile.

In order to validate the CAD method, as it was created, the realization of a comparison was proposed for the simple straight line profiles.

3. The Generating of Straight Lined Profiles

In order to obtain the tool's profile, it is necessary for the varous profiles to follow two stages. The first stage is to choose the profile's dimensions and the diameter of the rolling circle as input data.

This thing may be done introducing sa a text or Excel file, the value following the CATIA software automatically modifying the whole mechanism, with the new values. During the same stage, the mechanism is created, the rolling of this and the determination of the tool's profile. The coordinates of the points belong to profile will be exported in a *txt* or Excel file.

M.G.M.C. for straight line segment

The virtual mechanism specific for this case, is presented in figure 2 and Table 2.

The *Piece* element is a straight line which represents the centrode associated with the piece and which rolls without sliding with the circle which is the *Rotary Cutter Tool's* centrode.

The *Base* element is the fixed element which allows the piece's translation and the sledge rotation. The *Sledge* element has a link with the *Base* and a link with the *Piece*. This couple is a translation couple of the piece's element along a guide of the fixed element *Base*.

The tool's profile is obtained by the command *Trace* and selected as the tracking element the *ContactPoint* point on *Sledge*, which will draw in the rotary cutter's reference system, the tool's profile. This profile is automatically saved in a file named *Scula.part* and inserted in the assembly file, or, saved in the same *Rotary Cutter Tool's* file.

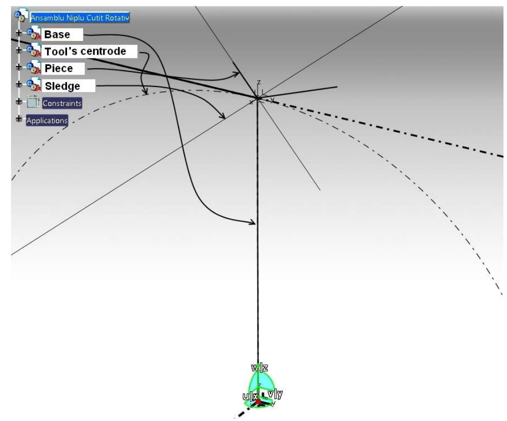

Fig. 2. *Assembly file with kinematics couples and tool's profile*

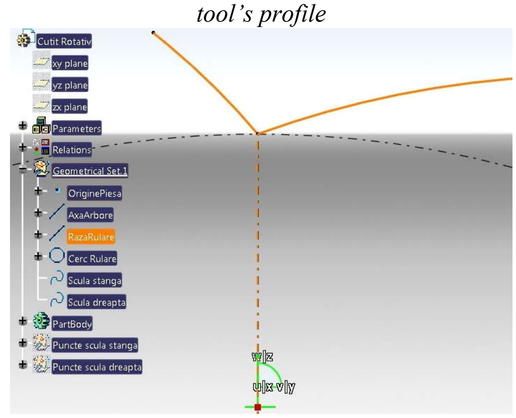

Fig. 3. *Tool's profile in the $\xi\eta\zeta$ reference system*

The profile of the piece is given in the figure 4. The profile's dimensions are: R_{rs}=50 mm; ε_1=40°; ε_2=70°; p_1=4 mm; p_2=13.7 mm.

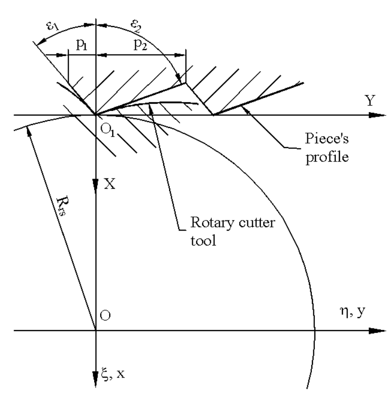

Fig. 4. *Piece's profile*

Table 2. *Couples used in DMU Kinematics environment*

Crt. no.	*Joint type*	*Mechanism elements*	
1	Fix	Base	-
2	Revolute	*Base*	Axa (*Tool*)
3	Prismatic	*Base*	Dreapta de rulare (*Piece*)
4	Rack-gear = Prismatic + Revolute	GhidajDreaptaRulare, AxaArbore and Plan YZ (*Base*)	DreaptaRulare, AxaArbore şi Plan YZ (*Piece*)
5	Prismatic	*Sledge*	Profile side L (*Piece*)
6	PointCurve	PolulAngrenarii (*Base*)	Normal (*Sledge*)
7	PointCurve	PunctContact (*Sledge*)	Profile side L (*Piece*)

Table 3. *Points coordinates on tool’s profile (Kinematics method)*

Crt. no.	ξ [mm]	η [mm]	Crt. no.	ξ [mm]	η [mm]	Crt. no.	ξ [mm]	η [mm]
1	0	50	**50**	7.084	51.977	**97**	14.456	52.887
2	0.137	50.049	**51**	7.235	52.006	**98**	14.618	52.895
3	0.275	50.099	**52**	7.387	52.036	**99**	14.780	52.902
4	0.413	50.148	**53**	7.539	52.065	**100**	14.943	52.909
5	0.551	50.197	**54**	7.691	52.094	**101**	15.105	52.916

Table 4. *Points coordinates on tool’s profile (classical method)*

Crt. no.	ξ [mm]	η [mm]	Crt. no.	ξ [mm]	η [mm]	Crt. no.	ξ [mm]	η [mm]
1	50.000	0.000	**50**	7.085	51.977	**97**	14.459	52.887
2	0.137	50.050	**51**	7.237	52.007	**98**	14.621	52.895
3	0.275	50.099	**52**	7.389	52.036	**99**	14.783	52.902
4	0.413	50.148	**53**	7.540	52.065	**100**	14.944	52.909
5	0.552	50.197	**54**	7.692	52.094	**101**	15.108	52.915

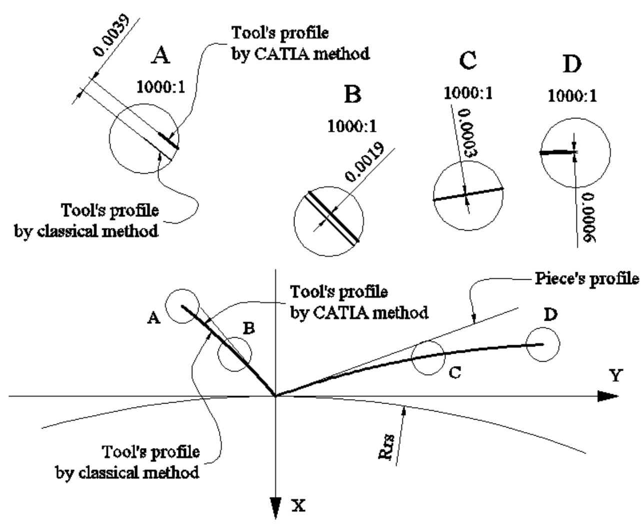

Fig. 5. *Rotary cutter tool’s profile by the two methods: the CATIA and the classical method*

In figure 5 and table 4, are presented the two profiles of the rotary cutter tool, determined by the two methods: kinematics method, proposed in this paper versus an analytical classical method.

5. Conclusions

The presented study proves the capabilities of the proposed method to describe the rotary cutter profile form in a rigorous way.

Using the capabilities of the CATIA design environment, it is easy to draw the interference trajectories between the profile to be generated and the generating tool and, at the same time the gearing line, only by changing the element regarding the contact point between the two conjugated profiles.

The proposed validation issue may be extended to the other generating processes by enveloping, by the rolling method (generation with gear-shaped tool or generation with worm mill tool).

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Comparație între metoda CAD şi metoda analitică
—Profilarea sculei cuțit rotativ—

Rezumat

Se propune o metodă CAD, dezvoltată în mediul de proiectare CATIA, pentru profilarea sculelor generatoare prin înfăşurare, în speță scula cuțit rotativ.

Metoda bazată pe imaginarea unor mecanisme virtuale, care, respectând condiția de rulare a centroidelor asociate profilurilor în înfăşurare, asigură că profilurile sculei şi semifabricatului satisfac una dintre teoremele fundamentale ale angrenării.

A fost elaborat, în mediul de proiectare CATIA, un algoritm şi un soft specializat pentru determinarea profilului cremalierei generatoare. În lucrare, se propune, verificarea numerică a rezultatelor obținute referitoare la forma profilului sculei cuțit rotativ, în raport cu o metodă analitică, unanim acceptată.

Sunt prezentate exemple de aplicare pentru un profil analitic simplu.

Comparaison entre la méthode CAD et méthode analytique
—Outil couteau rotatif profilage—

Résumé

Dans le présent document est proposé une méthode de CAO, développé en logiciel de conception CATIA, pour le profilage de l'outil, qui a généré par enveloppant, en particulier pour l'outil couteau rotatif.

La méthode est basée sur la création d'un mécanisme virtuel de maintien de l'état glissant de centrodes associés à enveloppant profils assurer que le profil de l'outil et blanc du profil de rencontrer l'un des théorèmes fondamentaux de l'engrenage.

Il a été élaboré, dans un environnement de conception CATIA, algorithmes et de logiciels spécialisés pour la détermination de la couteau rotatif de production. Dans le présent document est proposé à la validation numérique des résultats avec une méthode d'analyse, à l'unanimité acceptée.

Ils sont présentés des exemples d'application pour les profils d'analyse simple