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A 3D METHOD FOR PROFILING THE SHAPING TOOL FOR THE GENERATION OF HELICAL SURFACES

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ABSTRACT

It is proposed a graphical method for profiling the shaping tool used to generate cylindrical helical surface with constant pitch. The method, developed in the CATIA graphical design environment, is based on the helical movement decomposition into an assembly of equivalent movements, rotation and translation.

A dedicated software application allows for modeling of the helical surface, determining the characteristic curve and the crossing section of the cylindrical surface, reciprocally enveloping with the helical surface. These are presented applications for the generation of helical surface as trapezoidal thread and ball thread.

KEYWORDS: helical surface, cylindrical surface, shaping tool

1. Introduction

The cylindrical helical surfaces with constant pitch are frequently used in the construction of machine parts which transmit movements (helical teethed wheels, translation screws) or which circulate fluids under pressure (helical pumps, helical compressors). The generation of the helical surfaces is made using tools bounded by surfaces of revolution — the case of side mill, in some other cases, when the helical flute has symmetrical flanks, are used end mill tools [1], [7].

For the situation when the machining technology requires the construction of a simple tool (usually with a single cutting edge), as example for the prototypes machining or for repairs, it is possible to use for the generation of a complex helical surface, profiled shaping tools [1], [2], [3], [6].

The shaping tools profiling, tools which in the cutting motion (alternative rectilinear) generate a cylindrical surface, requires the determination of the condition that this surface should be reciprocally enveloping with the cylindrical helical surface with constant pitch.

There are known analytical methods for the determination of a cylindrical surface reciprocally enveloping with a helical surface: 1st Olivier’s theorem (the contact between the two surfaces is a contact of first degree, [2], [4]), Gohman’s theorem [2], the method of helical movement decomposition — Nikolaev’s condition [2], [4].

Also, there may be used specific theorems of the “minimum distance method” [5], as well as, of the “in-plane generating trajectories” [6].

As well, there are known graphical methods for profiling the generating tool for a cylindrical surface, developed in AutoCAD, based on the principle of solid body intersection [1].

In this paper, is presented a way to profile a cylindrical surface, reciprocally enveloping with a cylindrical helical surface with constant pitch, based on the capabilities of the CATIA design environment, method which allows for the graphical determination of the characteristic curve and the crossing section of the cylindrical surface, section which represents the profile of the shaping tool.

The method is rigorous, intuitive and easy to apply, based on a dedicated software, elaborated in *Visual Basic Application*.

2. Generation kinematics using the shaping tool

The generation of the helical surface with shaping tool is a manufacturing possibility used for a prototype machining or for reparations, the machining productivity being relatively low.

The tool, usually a profiled cutting tool, executing an alternative rectilinear movement, with a single cutting travel stroke, generates a cylindrical surface, which is reciprocally enveloping with the helical surface to be generated.

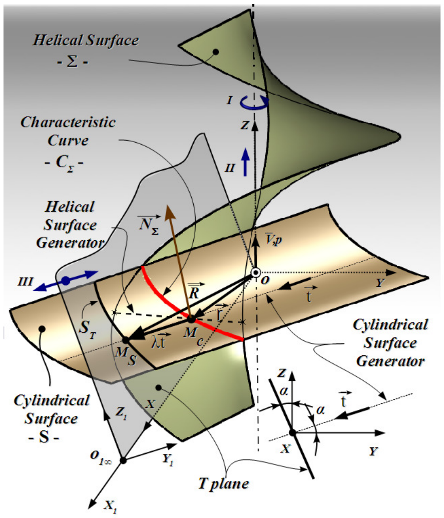

Fig. 1. *Generation kinematics*

The minimum kinematics of the process, Figure 1, supposes the movements:

I and *II* are rotation and translation movements, around and along the helical surface axis, usually uniform motions, generating a helix with axis and helical parameter identical with those of the surface to be generated;

III — alternative rectilinear tool's motion. In this motion, the cutting edge generate the cylindrical surface.

The contact curve between the cylindrical surface and the helical one represents the geometrical locus of the points, belonging to the helical surface, where the two surfaces are tangent. This represents the characteristic curve of the helical surface in movement along the cylindrical surface generatrix.

For a helical surface, in principle in the form:

$$\Sigma \begin{vmatrix} X = X(u,v); \\ Y = Y(u,v); \\ Z = Z(u,v), \end{vmatrix} \tag{1}$$

defined in the *XYZ* reference system, with *u* and *v* independent variable parameters, and a direction of the generatrix of the generating cylindrical surface,

$$\vec{t} = -\cos\alpha \cdot \vec{j} - \sin\alpha \cdot \vec{k}\,, \tag{2}$$

is defined the specific enveloping condition,

$$\vec{N}_\Sigma \cdot \vec{t} = 0\,. \tag{3}$$

In the equation (3), the normal at the surface Σ is

$$\vec{N}_\Sigma = N_X \cdot \vec{i} + N_Y \cdot \vec{j} + N_Z \cdot \vec{k}. \tag{4}$$

In this way, the condition for the determination of the characteristic curve becomes, see (2) and (4),

$$N_Y \cdot \cos\alpha + N_Z \cdot \sin\alpha = 0\,, \tag{5}$$

equivalent to dependency,

$$v = v(u)\,. \tag{6}$$

The assembly of the equations (1) and (6) represents the characteristic curve onto the cylindrical helical surface on type, see Figure 1:

$$C_\Sigma \begin{vmatrix} X = X(u); \\ Y = Y(u); \\ Z = Z(u). \end{vmatrix} \tag{7}$$

The (7) curve represents a directrix curve of the cylindrical helical surface — surface generated by the cutting edge of the shaping tool.

Crossing section of the cylindrical surface

The characteristic curve (7) is a spatial curve and, as follows, is difficult to be used in the practice of the cutting tool's machining as a major cutting edge, due to the difficulties to measure this kind of curves.

It is accepted as the simplest solution to materialize the cutting edge of the shaping tool by the crossing section of the cylindrical surface (the section with a plane which contains the *X* axis and is perpendicular to the versor of the cylindrical surface, see Figure 1.

In this way, the cylindrical surface is described by:

$$\vec{R} = \vec{r} + \lambda \cdot \vec{t}\,, \tag{8}$$

with λ arbitrary parameter and *r* the versor of the current point from the characteristic curve, see (7), or in analytical form:

$$S \begin{vmatrix} X = X(u); \\ Y = Y(u) - \lambda \cdot \cos\alpha; \\ Z = Z(u) - \lambda \cdot \sin\alpha. \end{vmatrix} \tag{9}$$

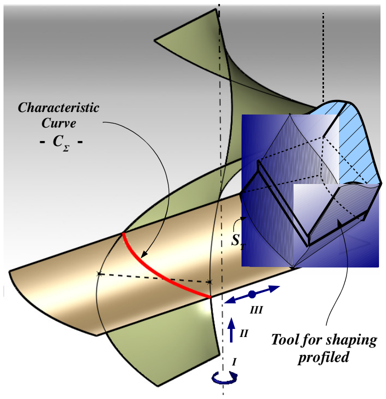

Fig. 2. *The characteristic curve and the shaping tool*

The section of the *S* surface with the plane *T*, plane which contains the X axis and is normal to $\vec{t}$,

$$Y \cdot \cos\alpha + Z \cdot \sin\alpha = 0\,, \tag{10}$$

leads to the determination of the crossing section S_T, in principle, see (9), in the form:

$$S_T \left| \begin{array}{l} X = X(\lambda); \\ Y = Y(\lambda); \\ Z = Z(\lambda). \end{array} \right. \tag{11}$$

The *ST* curve — the crossing section — unlike the characteristic curve is an in-plane curve. This thing makes it easy to be used as cutting edge for the cutting tool — the shaping tool, see Figure 2.

3. The 3D method for shaping tool profiling

The enveloping condition, (5), is equivalent to a similar condition regarding the generation of the helical surface, by enveloping with a tool bounded by a revolution primary peripheral surface but with an infinite diameter [2].

In this way, if it is accepted that the relative position of a revolution surface, regarding the helical surface should be generated, then the specific enveloping condition is in the form [3], [4]

$$\begin{vmatrix} 0 & -\sin\alpha & \cos\alpha \\ N_X & N_Y & N_Z \\ X(u,v)-a & Y(u,v) & Z(u,v) \end{vmatrix} = 0 \tag{12}$$

which, for $a \to \infty$ (the side mill is at infinite distance), is equivalent to (5).

In this way, the cylindrical tool may be regarded as a revolution surface with a very large diameter.

In CATIA design environment, using the specific command from the *Generative Shape Design*, is modeled the helical surface. By command Projection is projected the Z_1 axis of the reference system joined with the side mill, substitute for the cylindrical surface, onto the helical surface, obtaining the characteristic curve.

The primary peripheral surface of cylindrical surface is modeled with the Extrude command. With the Intersection command, is intersected the previously modeled cylindrical surface, obtaining the form of the cutting edge of the shaping tool (see Figures 1 and 2).

All this algorithm was synthesized in a specific application *THSG–VBA* (***T****ools for* ***H****elical* ***S****urfaces* ***G****eneration*), in order to automate these steps.

4. Shaping tool's profiling for generation of a trapezoidal thread

It is proposed the application of the presented methodologies for the determination of the cylindrical tool for the generation of a trapezoidal thread, with the input parameters given in Table 1..

In Figure 3, is presented the 3D model of the helical surface and of the reciprocally enveloping cylindrical surface.

Table 1. *Input parameters for the trapezoidal thread*

Point	Description	Y [mm]	*Z [mm]*
A	Start point of thread crest	50	*20*
B	Start point of thread flank	50	*0*
C	End point for the bottom of thread	40	*-10*
D	End point for the bottom of thread	40	*-20*
E	End point for thread flank	50	*-30*
S_e	Flute helix sense	*right*	
p_e	Thread pitch	*50 mm*	
a	The coord. of the origin (X direction)	*100000 mm*	

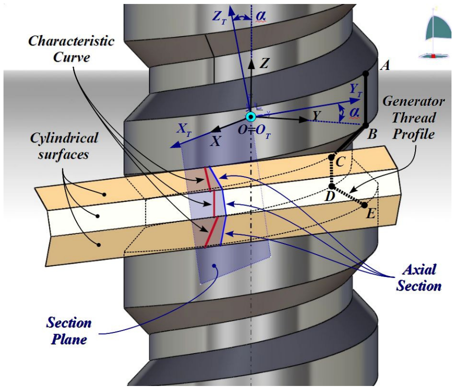

Fig. 3. *Primary peripheral surface of the shaping tool*

It is obvious that the singular points from the helical surface generatrix generate discontinuities onto the characteristic curve, points C_{CC}, C'_{CC} and D_{CC}, D'_{CC}, see Figure 4.

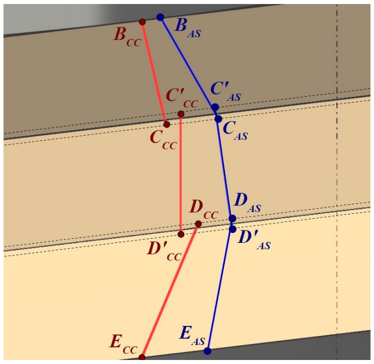

Fig. 4. *Composed profile of the crossing section*

This makes necessary a modification of the ideal crossing section, with repercussions at the generated profile, see Figure 5.

The axial section was referenced to a translated reference system, with the origin in the point with coordinates O_S (40, 0, -27.5).

The coordinates of the characteristic curve and of the crossing section of the cylindrical surface are presented in Table 2.

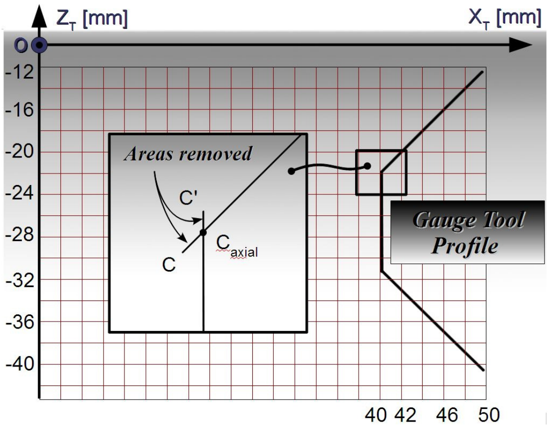

Fig. 5. *Axial section of cylindrical tool*

Table 2. *Coordinates of points from the characteristic curve and the crossing section of the shaping tool for generation of a trapezoidal thread*

		X[mm]	Y[mm]	Z[mm]
Characteristic curve	**BC**	50,0001	-0,0012	-12,5002
		48,8842	-0,1785	-13,6448
		⋮	⋮	⋮
		41,0817	-1,4109	-21,6675
		39,9687	-1,5852	-22,8155
	CD	40,0002	0,0008	-32,4999
		40,0002	0,0008	-31,3888
		⋮	⋮	⋮
		40,0002	0,0003	-23,6112
		40,0002	0,0002	-22,5001
	DE	39,9687	1,5863	-32,1844
		41,0818	1,4120	-33,3325
		⋮	⋮	⋮
		48,8843	0,1801	-41,3551
		50,0003	0,0028	-42,4997
		X_T	Y_T	Z_T
Axial section	**BC**	50,0001	0,0000	-12,3447
		48,8840	0,0000	-13,4473
		⋮	⋮	⋮
		41,0815	0,0000	-21,1767
		39,9687	0,0000	-22,2828
	CD	40,0002	0,0000	-22,2204
		40,0002	0,0000	-23,3177
		⋮	⋮	⋮
		40,0002	0,0000	-30,9988
		40,0002	0,0000	-32,0961
	DE	39,9687	0,0000	-32,0337
		41,0815	0,0000	-33,1399
		⋮	⋮	⋮
		48,8841	0,0000	-40,8693
		50,0003	0,0000	-41,9719

5. Shaping tool’s profiling for the generation of a ball thread

Based on the generating principles previously presented, is determined the form of the primary peripheral surface of the shaping tool for the generation of a ball thread.

In Figure 6, are presented the reference systems, the 3D model of the ball thread and the primary peripheral surface of the shaping tool, reciprocally enveloping with the ball thread.

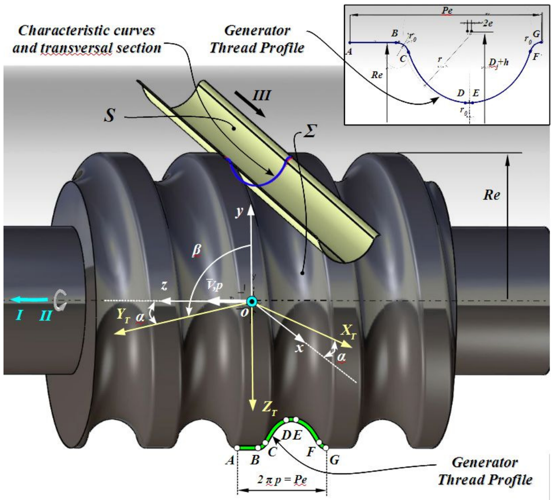

Fig. 6. *Composed profile of the crossing section*

In Figure 7 and Table 3, are presented the form and coordinates of the characteristic curve and of the crossing section.

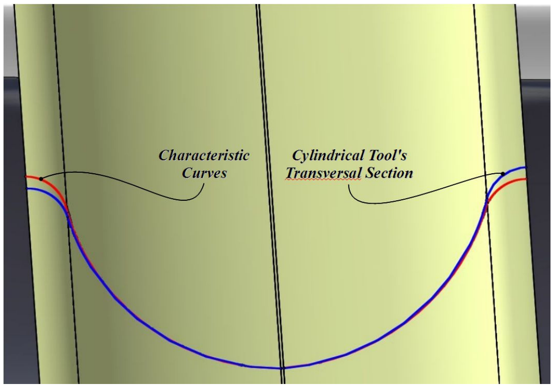

Fig. 7. *Characteristic curve and crossing section*

In Figure 8, it is presented the crossing section form of the cylindrical surface in the $X_TY_TZ_T$ reference system.

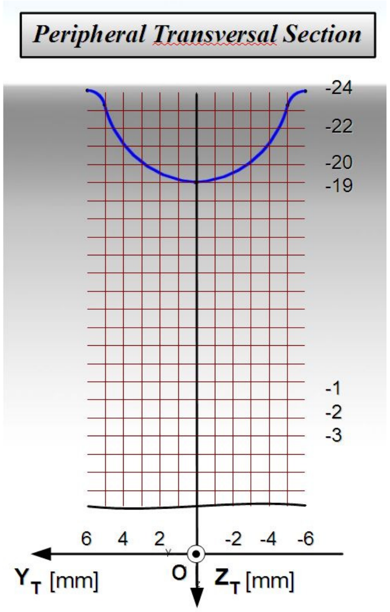

Fig. 8. Composed profile of the ball thread's crossing section

This reference system has the origin on the ball thread axis and the plane $X_T Z_T$ perpendicular to the cylindrical surface's generatrix.

Table 3. *Coordinates of points from the characteristic curve and the crossing section of the shaping tool for the generation of a ball thread*

Profile	***Crt. no.***	***X [mm]***	***Y [mm]***	***Z [mm]***
Characteristic Curves	**1**	-0,6388	23,9915	6,0911
	2	-0,6382	23,9793	5,9358
	⋮	⋮	⋮	⋮
	11	-0,3277	23,2586	5,0938
	⋮	⋮	⋮	⋮
	20	-0,4954	19,2670	0,1007
	21	-0,4993	19,2666	0,0934
	⋮	⋮	⋮	⋮
	30	-0,5308	19,2660	0,0349
	31	-0,6036	19,3451	-0,7176
	⋮	⋮	⋮	⋮
	149	-0,6391	23,9793	-5,8002
	150	-0,6391	23,9915	-5,9555
Profile		**X_T [mm]**	**Y_T [mm]**	**Z_T [mm]**
Axial Section of Cylindrical Tool	**1**	0	-5,9894	-23,9833
	2	0	-5,8450	-23,9731
	⋮	⋮	⋮	⋮
	11	0	-5,0266	-23,2451
	⋮	⋮	⋮	⋮
	20	0	-0,0213	-19,2733
	21	0	-0,0136	-19,2731
	⋮	⋮	⋮	⋮
	30	0	0,0402	-19,2733
	31	0	0,0479	-19,2735
	⋮	⋮	⋮	⋮
	149	0	5,8430	-24,0055
	150	0	5,9897	-24,0169

6. Shaping tool's profiling for the generation of a cycloid hub

In Figure 9, it is presented the cycloid worm with two starts, which has as generatrix in the frontal plane the epicycloids generated by a point from the roulette with radius *r*, rolling onto the base with radius *R*.

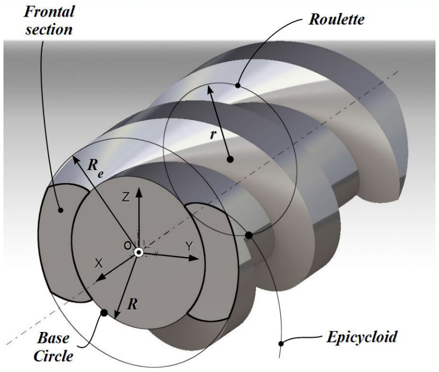

Fig. 9. *The cycloid worm with two starts*

In Figure 10, they are presented the cylindrical surface reciprocally enveloping with the cycloid worm, the characteristic curve and the crossing section of the composed cylindrical surface (surface generated by the shaping tool, in the rectilinear movement, III).

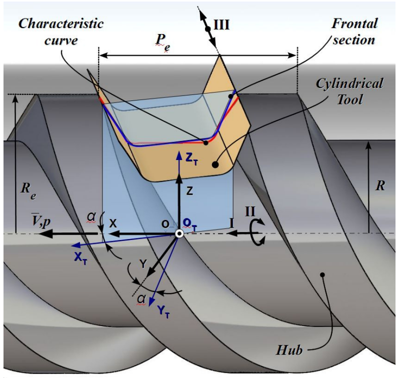

Fig. 10. *The cylindrical surface, the characteristic curve and the crossing section*

In Table 4 and Figure 11, are presented the coordinates and the form of the crossing section of cylindrical surface (the profile of the shaping tool).

7. Conclusions

The proposed method allows for the easy profiling of the generating tool for helical surface, determining in graphical and numerical form the characteristic curve and the axial section.

The presented examples for the profiling of the helical surface as: trapezoidal thread, ball thread and cycloid hub, prove the capability of this method to approach a wider problem. Moreover the presented helical surfaces are composed surfaces, and in some situations are possible to highlight problems due to the presence of singular points, for which are given profiling solutions for shaping tool.

Table 4. *Coordinates of points from the characteristic curve and the crossing section of the shaping tool for the generation of a trapezoidal thread*

Profile	***Crt. no.***	***X [mm]***	***Y [mm]***	***Z [mm]***
Characteristic Curves	***1***	8,6607	0,0662	14,9999
	2	7,9821	0,5452	14,3732
	⋮	⋮	⋮	⋮
	11	4,3759	0,4975	10,0414
	⋮	⋮	⋮	⋮
	20	-1,5605	-0,0083	10,0000
	21	-2,6010	-0,0138	10,0000
	⋮	⋮	⋮	⋮
	30	-4,6530	-3,1375	11,3306
	31	-5,3119	-2,5993	11,9297
	⋮	⋮	⋮	⋮
	149	-7,9820	-0,5453	14,3731
	150	-8,6607	-0,0662	14,9999
Profile		***X_T [mm]***	***Y_T [mm]***	***Z_T [mm]***
Axial Section of Cylindrical Tool	***1***	-7,6818	0,0000	14,9999
	2	-7,3141	0,0000	14,3856
	⋮	⋮	⋮	⋮
	11	-3,2218	0,0000	10,0000
	⋮	⋮	⋮	⋮
	20	1,0739	0,0000	10,0000
	21	1,7899	0,0000	10,0000
	⋮	⋮	⋮	⋮
	30	5,5486	0,0000	11,2717
	31	5,8934	0,0000	11,8987
	⋮	⋮	⋮	⋮
	149	7,3142	0,0000	14,3857
	150	7,6818	0,0000	14,9999

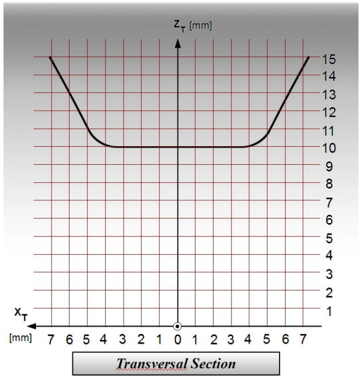

Fig. 11. *The crossing section of the shaping tool*

The method may highlight very accurate by the problems linked to the discontinuities emerged due to the singular points from the profiles.

The method is intuitive and very easy to apply.

Acknowledgement

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Metodă 3D pentru profilarea sculelor cilindrice generatoare a suprafeţelor elicoidale

—Rezumat—

În prezenta lucrare, se propune o metoda grafică pentru profilarea sculelor cilindrice (scule de rabotat sau mortezat) destinate generării suprafeţelor elicoidale de pas constant. Metoda, dezvoltată în mediul de proiectare CATIA, este bazată pe descompunerea mişcării elicoidale într-un ansamblu de mişcări echivalente, respectiv mişcări de rotaţie şi translaţie.

A fost elaborată o aplicaţie soft dedicată, ce permite modelarea suprafeţei elicoidale, determinarea curbei caracteristice şi a secţiunii transversale a suprafeţei cilindrice, reciproc înfăşurătoare cu suprafaţa elicoidală. Sunt prezentate aplicaţii referitoare la generarea suprafeţelor elicoidale de tip filet trapezoidal şi filet pentru şurub cu bile.