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RING TANGENTIAL TOOL TOPOLOGICAL REPRESENTATION OF PERIPHERAL SURFACES

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ABSTRACT

The ring tangential tools are bounded by revolution primary peripheral surfaces, used for generation of the cylindrical helical surfaces with constant pitch.

In this paper, it is presented an algorithm, based on the topological representation of the tool's primary peripheral surface. The application method for this algorithm was developed in the CATIA graphical design environment, for the profiling of the ring tool, as surfaces reciprocally enveloping with cylindrical helical surfaces. It is presented a numerical example, based on a dedicated software, for the numerical determination of the axial section form of the tools' type. Also, is presented a solution for the form correction of the tool's axial section, considering the existence of the singular point onto the profile of the helical surface to be generated.

KEYWORDS: ring tool, helical surfaces generation, topological representation, CATIA

1. Introduction

The ring tool is a tool bounded by a revolution primary peripheral surface. The ring tools are tools designated for the generation of the cylindrical helical surfaces with constant pitch (threads) on specialized machine-tools or using specialized technological equipments, for longitudinal lather machines.

The ring tool is frequently made as an enwrapping milling tool. The advantage of this technological solution is the increased productivity of this process.

Although the tools of this type generate in the cutting motion a revolving surface, the issue of profiling the primary peripheral surface of this surfaces reciprocally enveloping with cylindrical helical surfaces with constant pitch, is a problem different from the profiling of the side mill.

The profiling method of this tool's type uses the fundamental theorems of the surfaces generation, Olivier and Gohman [1], [8], or the complementary methods as "the minimum distance method" [8], "the in-plane generating trajectories method" [3].

Also, the development of the graphical design environment opens the way to solve these problems using 3D design environment [4]-[7].

2. Ring tangential tool. Algorithm

The problem of profiling the ring tangential tool, Figure 1, is, in principle, similar to the known problem of the side mill tool's profiling.

In principle, the Nikolaev condition for the determination of the characteristic curve — the tangency curve between a cylindrical helical surface with constant pitch, Σ, and a revolution surface with $\vec{A}$ axis, with position known in the reference system of the Σ surface, is:

$$\left(\vec{A}, \vec{N}_{\Sigma}, \vec{r}_{1}\right) = 0, \quad (1)$$

where: $\vec{A}$ is the versor of the rotation axis of the tool bounded by a revolution surface;

$\vec{N}_{\Sigma}$ — is the normal at the helical surface;

$\vec{r}_{1}$ — is the vector which links the current point onto the Σ surface with a point of the $\vec{A}$ axis (frequently, the origin of the reference system joined with this axis, here $X_1Y_1Z_1$).

The condition (1), with geometrical significance that the three vectors are in-plane, may be regarded as equivalent to: the contact points between the Σ helical surface and the primary peripheral surface of the revolution tool, representing the characteristic curve of the helical surface in its revolving motion around the $\vec{A}$ axis, represent the geometric locus of intersection points between normals draw from the points belonging to the $\vec{A}$ axis to the helical surface.

This is equivalent to the statement: the characteristic curve of a cylindrical helical surface with constant pitch, Σ, in the rotation motion around a fixed axis, $\vec{A}$, consists of all the points belongs to the Σ surface, which represent the projection of the $\vec{A}$ axis to the Σ surface.

The specific problem is that the tool's axis position is different from the position of the side mill, regarding the blank.

The generation process kinematics supposes the following motions:

I is the rotation motion of the blank;

II — translation motion of the blank correlated with the motion *I*;

III — the rotation movement of the ring tangential tool (the cutting motion).

The assembly of motions *I* and *II* defines a helical motion with axis and helical parameter identical with the axis and the helical parameter of the surface to be generated.

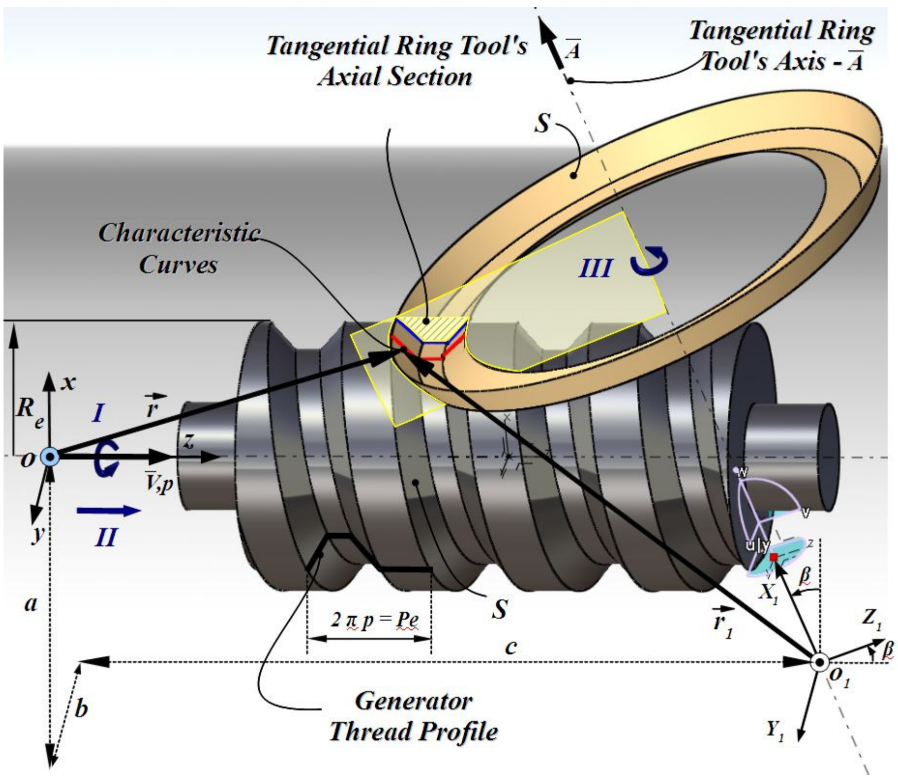

Fig. 1. *The generation process kinematics with the ring tangential tool*

There are defined the reference systems:

XYZ is the reference system where is defined the helical surface (the *Z* axis is the axis of the helical surface).

$X_1Y_1Z_1$ — reference system joined with the ring tangential tool (the X_1 axis is the axis of the ring tangential tool).

If, in the *XYZ* reference system, it is defined the Σ helical surface:

$$\Sigma : \vec{r} = x(u,v)\cdot\vec{i} + y(u,v)\cdot\vec{j} + z(u,v)\cdot\vec{k} \qquad (2)$$

with *u* and *v* variable parameters, then, by the coordinates transformation, see Figure 1,

$$\begin{Vmatrix} X_1 \\ Y_1 \\ Z_1 \end{Vmatrix} = \begin{Vmatrix} \cos\beta & 0 & -\sin\beta \\ 0 & 1 & 0 \\ \sin\beta & 0 & \cos\beta \end{Vmatrix} \cdot \begin{Vmatrix} x+a \\ y+b \\ z-c \end{Vmatrix} \qquad (3)$$

the helical surface Σ refers to the reference system $X_1Y_1Z_1$, by equations:

$$\Sigma \begin{vmatrix} X_1 = \left[x(u,v)-a\right]\cos\beta - \\ -\left[z(u,v)-c\right]\sin\beta; \\ Y_1 = y(u,v)-b; \\ Z_1 = \left[x(u,v)-a\right]\sin\beta + \\ +\left[z(u,v)-c\right]\cos\beta. \end{vmatrix} \quad (4)$$

The condition for the determination of the characteristic curve (1), is similar to those known for the side mill, defining:

$\vec{A} = \vec{i}$ the versor of the ring tool;

$\vec{N}_\Sigma$ — the normal to the Σ surface, in the reference system $X_1Y_1Z_1$;

$$\vec{r}_1 = X_1(u,v)\cdot\vec{i} + Y_1(u,v)\cdot\vec{j} + Z_1(u,v)\cdot\vec{k}, \quad (5)$$

the current vector on the Σ surface, in the reference system $X_1Y_1Z_1$, equations (4).

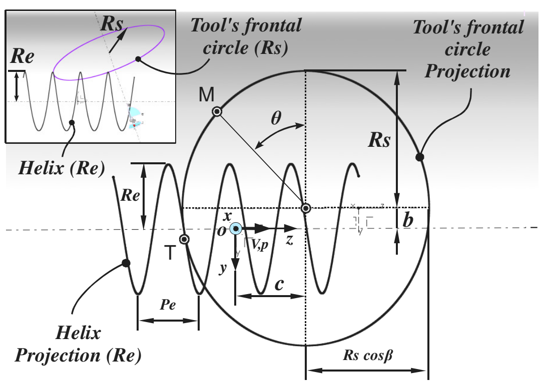

Fig. 2. *The ring tangential tool’s axis position*

The (1) and (4) equations assembly represents the characteristic curve, in principle, in the form:

$$(C_\Sigma)_{X_1Y_1Z_1} \begin{vmatrix} X_1 = X_1(u); \\ Y_1 = Y_1(u); \\ Z_1 = Z_1(u). \end{vmatrix} \quad (6)$$

By revolving the characteristic curve around the X_1 axis is determined the primary peripheral surface of the ring tangential tool. The constants a, b, c and β are determined from the condition that the trajectory of the S point, corresponding to the external diameter of the Σ surface, should be tangent at the helix, see Figure 2.

Also, the projection of the helix corresponding to the R_e blank radius, in the same plane yz, is a curve with the form:

$$L_E \begin{vmatrix} y = R_e \sin\varphi; \\ z = p\cdot\varphi, \end{vmatrix} \quad (7)$$

with φ variable and p helical parameter

$$(\, p = {p_e}/{2\pi}\,).$$

From the condition that the two curves (6) and (7) should be tangent in the M point, is determined the equations assembly:

- the condition of common point:

$$R_S\cos\theta + b = R_e\sin\varphi; \quad (8)$$

$$R_S\cos\beta\sin\theta + c = p\cdot\varphi; \quad (9)$$

- the condition of common tangent:

$$-R_S\sin\theta = R_e\cos\varphi; \quad (10)$$

$$R_S\cos\beta\cos\theta = p; \quad (11)$$

The (8), (9), (10) and (11) equations assembly determine the values b, c, φ and θ (the linear value a and the angle β have to be accepted from the constructive point of view, $a = R_e$).

3. Applications

Ring tangential tool for trapezoidal thread

Furthermore it is presented an application of the proposed algorithm for the determination of the primary peripheral surface of the ring tangential tool, for generation of a trapezoidal thread, with generatrix of helical surface presented in Figure 3.

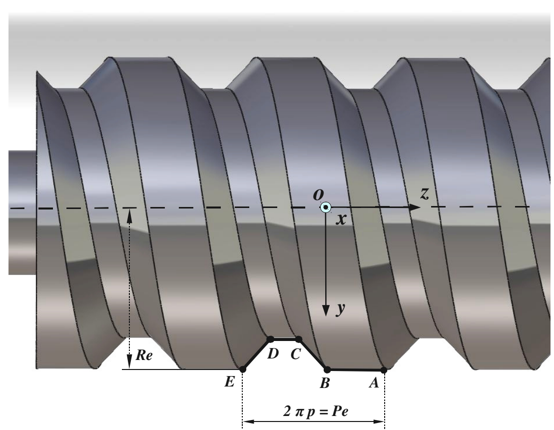

Fig. 3. *Axial section of the thread (the generatrix of helical surface)*

The 3-D method to profile the tangential-tool – HSGT (Helical Surface Generating Tool) is grounded on the Generative Shape Design environment facilities. The worked piece (in fact, the generated surface) is 3-D modeled, as it can be observed in Figure 3.

The worked piece reference system, xyz and the tangential-tool reference system, $X_1Y_1Z_1$, the last one as Euler system, are created (see Fig. 1).

By giving the “Projection” command, the tangential-tool axis projection onto the Σ surface is realized; thus, the characteristic curve is determined.

By subsequently using the “Revolve” command, the tool primary peripheral surface – S results, after rotating the characteristic curve around Z_1 axis.

The tangential-tool axial section is then obtained as intersection between the surface S and a plain which includes the Z_1 ($\vec{A}$) axis – by applying the “Intersection” command.

From the point of view of the algorithm of the HSGT *(Helical Surface Generating Tool)* application, the ring tangential tool’s case is similar to those of the end mill tool, with the difference that the origin of the reference system of tool is not situated on the *X* axis but is disjunctive regarding this, according to the helix angle for the surface to be generated, Figure 4.

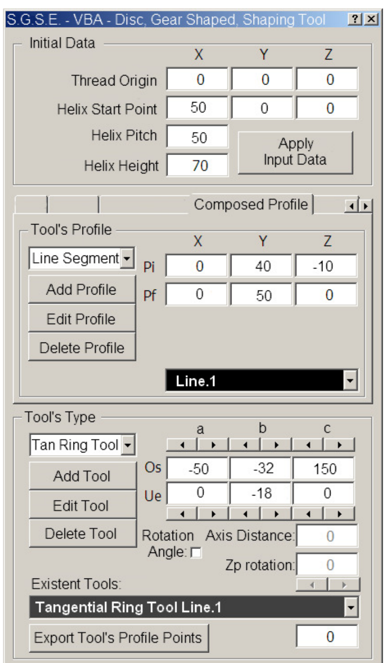

Fig. 4. *HSGT application – ring tangential tool, trapezoidal thread*

The input data for the profile of the thread, the helix pitch and the distance between the tool’s axis and the thread’s axis are inserted in the HSGT application, presented in Figure 4, according to Table 1.

Table 1. *Input parameters of the trapezoidal thread (straight lined segments)*

Symbol	Description	Y [mm]	Z [mm]
A	Initial point of thread head	50	20
B	Initial point of thread flank	50	0
C	Initial point of thread bottom	40	-10
D	Final point of thread bottom	40	-20
E	Final point of thread flank	50	-30
S_e	Helix sense	right	
p_e	Helix pitch	50 mm	
a	X coordinate of tool’s origin	-50 mm	
b	Y coordinate of tool’s origin	-32 mm	
c	Z coordinate of tool’s origin	150 mm	
U_e	Tool’s rotation around Y axis	-18°	

In Figure 5, are represented: the surfaces of the trapezoidal thread’s flank, characteristic curves on the thread’s flanks, primary peripheral surfaces of the ring tangential tool and the axial section.

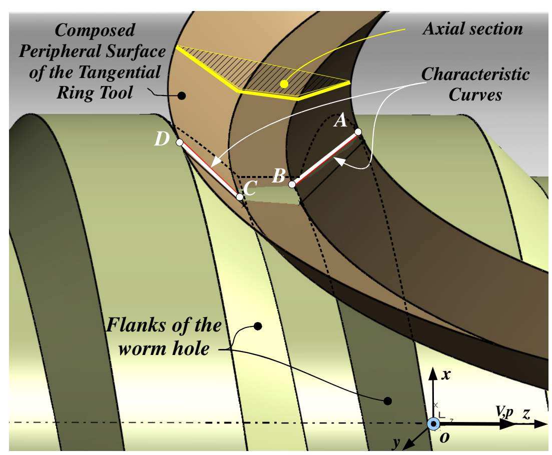

Fig. 5. *3D model of the helical surface; 3D model of the ring tangential tool’s primary peripheral surface*

The form of the axial section of the ring tangential tool (the plane X_1Y_1), is represented in Figure 6, according to the coordinates from the Table 2.

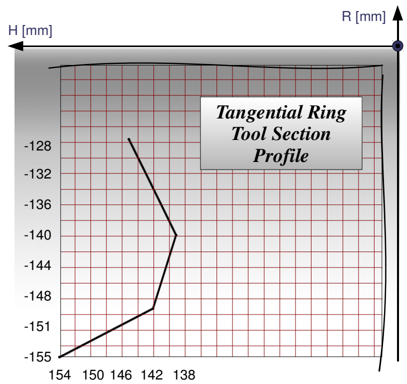

Fig. 6. *Axial section of the ring tangential tool's primary peripheral surface*

We have to notice that the axial tool's profile is asymmetric. Obviously, in the points *B* and *C*, see figure 5, on the composed profile of the tool emerged discontinuities which may be solved by link this zones and accepting a deformation of the thread bottom, according to a required target.

Table 2. *Coordinates of points on the characteristic curve and the axial section of the ring tangential tool*

Profile	Nr. Crt.	X [mm]	Y [mm]	Z [mm]	Nr. Crt.	X [mm]	Y [mm]	Z [mm]
Characteristical curve	1	49,8636	-2,2714	-32,9523	⋮	⋮	⋮	⋮
	2	48,7572	-2,4421	-34,0805	22	41,0566	-2,1476	-21,8034
	3	47,6514	-2,6096	-35,2082	23	42,1841	-1,8678	-20,6269
	4	46,5465	-2,7738	-36,3353	24	43,3095	-1,5754	-19,4514
	5	45,4424	-2,9348	-37,4619	25	44,4325	-1,2698	-18,2769
	6	44,3391	-3,0928	-38,5881	26	45,5527	-0,9501	-17,1035
	7	43,2367	-3,2477	-39,7139	27	46,6698	-0,6156	-15,9313
	8	42,1353	-3,3997	-40,8392	28	47,7833	-0,2653	-14,7603
	9	41,0350	-3,5489	-41,9642	29	48,8928	0,1018	-13,5906
	10	39,9357	-3,6952	-43,0888	30	49,9977	0,4868	-12,4226
Profile		**H[mm]**		**R[mm]**		**H[mm]**		**R[mm]**
Axial section	1	154,6437		-155,3787	⋮	⋮	⋮	⋮
	2	153,2467		-154,6915	22	139,6756		-138,5401
	3	151,8497		-154,0045	23	140,3727		-137,1912
	4	150,4526		-153,3176	24	141,0713		-135,8431
	5	149,0555		-152,6308	25	141,7714		-134,4958
	6	147,6583		-151,9441	26	142,4729		-133,1492
	7	146,2611		-151,2576	27	143,1760		-131,8034
	8	144,8639		-150,5711	28	143,8806		-130,4584
	9	143,4666		-149,8846	29	144,5869		-129,1143
	10	142,0693		-149,1981	30	145,2948		-127,7710

Ring tangential tool for ball thread

In Figure 7, are presented the model of the ball thread and its axial section, an assembly of circle's arc, filleted, as well as the reference systems:

xyz is the reference system associated with the ball thread;

$X_1Y_1Z_1$ — reference system associated with the ring tangential tool's primary peripheral surface;

$x_0y_0z_0$ and $x_0'y_0'z_0'$ — additional reference systems, see Figure 8.

The generation movement assembly, the movements *I*, *II* and *III*, has the significances given in Figure 1.

In this way, the helix belonging to the ball thread flute and situated onto the cylinder with radius R_e:

$$x = R_e \cos\varphi;$$
$$y = R_e \sin\varphi; \qquad (12)$$
$$z = -p\varphi,$$

is transferred, by coordinates transformation:

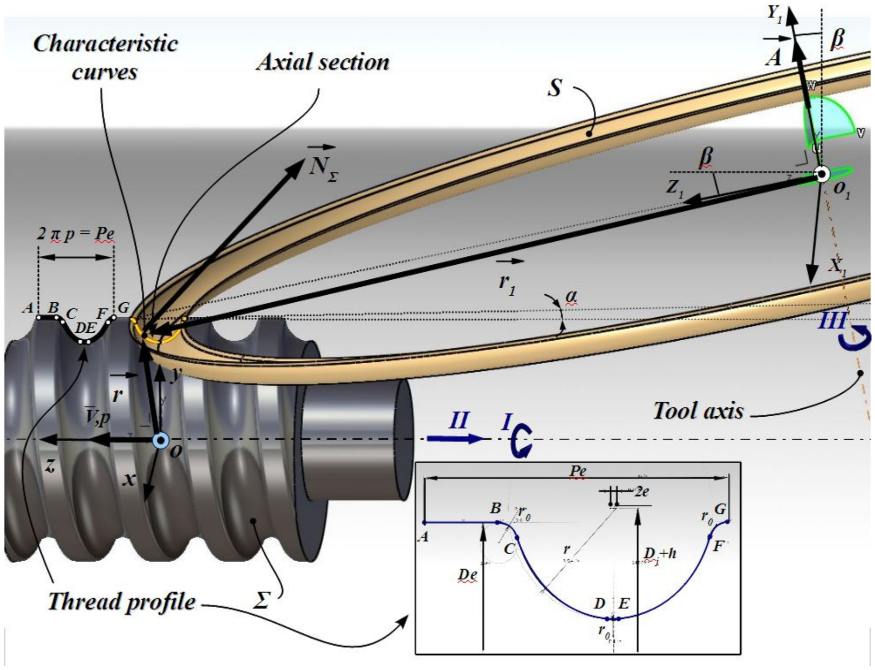

Fig. 7. *Ball thread; axial profile and reference systems*

$$\begin{Vmatrix} X_1 \\ Y_1 \\ Z_1 \end{Vmatrix} = \begin{Vmatrix} 1 & 0 & 0 \\ 0 & \cos\beta & \sin\beta \\ 0 & -\sin\beta & \cos\beta \end{Vmatrix} \cdot \left[\begin{Vmatrix} \cos\alpha & 0 & -\sin\alpha \\ 0 & 1 & 0 \\ \sin\alpha & 0 & \cos\alpha \end{Vmatrix} \cdot \begin{Vmatrix} R_e\cos\varphi \\ R_e\sin\varphi \\ p\varphi \end{Vmatrix} - \begin{Vmatrix} 0 \\ R_e \\ 0 \end{Vmatrix} \right] - \begin{Vmatrix} 0 \\ 0 \\ -R_S \end{Vmatrix} \tag{13}$$

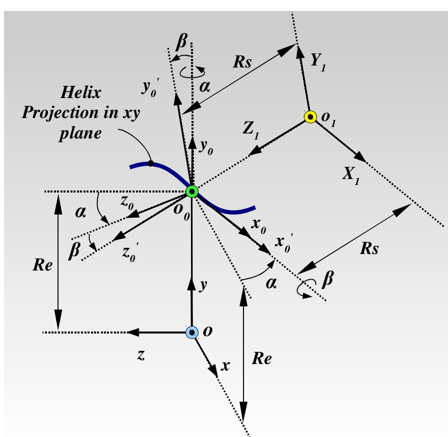

Fig. 8. *Ball thread; axial profile and reference systems*

The helix, in the reference system $X_1Y_1Z_1$, associated with the ring tangential tool with the circle:

$$X_1 = R_S\cos\theta;\quad Y_1 = 0;\quad Z_1 = R_S\sin\theta, \tag{14}$$

of the ring tangential tool's primary peripheral surface, allow to determine the parameters: α, β, θ, and φ.

Other solution may be obtained by knowing the angle of helix for the cylinder with radius R_e,

$$a = arctg\frac{p}{R_e} \tag{15}$$

and the normal plane to the helix in the point O_0, see figure 8.

The plane of the circle R_S is revolved around the axis x_0 (x_0'), with the angle β determined from constructive point of view from the condition to avoid the interference between the tool and the opposite flank, see figure 7. The *X* axis is symmetrical with the arcs with radius *r*.

In table 3, are presented the input parameters, correlated with the application *HSGT*.

In figures 9 and 10 and in table 4, are presented the forms and the coordinates of the characteristic curve and the axial section for the helical surfaces assembly which compose the ball thread flute. Obviously, in this case isn't possible to define singular points on the profile.

Table 2. *Input parameters of the ball thread*

Symbol	Description	Value
p	Helical parameter	2.546 mm
r	Flank radius	5.4 mm
e	Half-distance between the centres of circles with radius *r*	0.155 mm
D_j	Diameter of centres cylinder of the axial profile	49 mm
h	Distance between the D_j diameter and the centre of circle with radius *r*	0.17 mm
D	External diameter of thread	48 mm
r_0	Fillet radius	1 mm
S_e	Helix sense	right
D_{axis}	Distance between axis	150 mm
β	Tool’s angle in plane *XZ*	10°
α	Tool’s angle in plane *ZX*	6.0566°

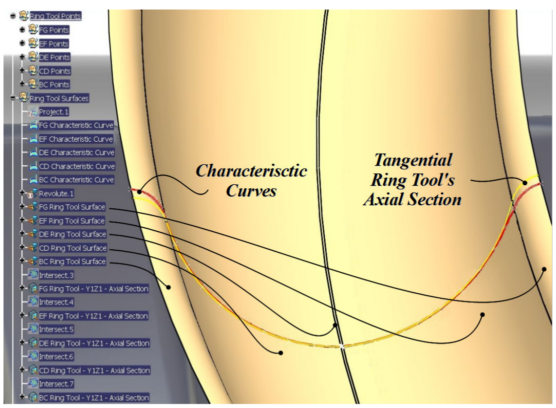

Fig. 9. *Characteristic curve and axial section of ring tangential tool*

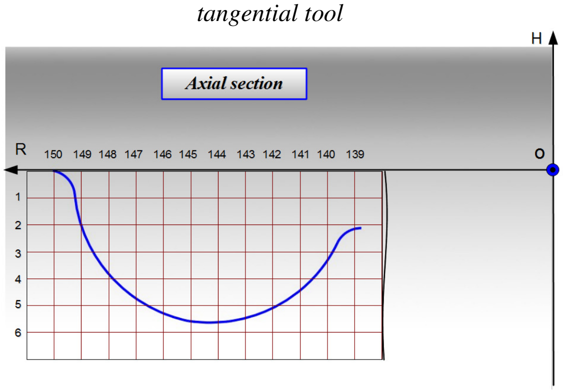

Fig. 10. *Axial section of ring tangential tool*

Table 3. *Characteristic curve and axial section for ball thread*

	Characteristic curve			*Axial section*	
	X [mm]	**Y [mm]**	**Z [mm]**	**H [mm]**	**R [mm]**
BC	-0,6212	23,9919	6,0892	0,0083	149,9998
	-0,6067	23,9803	5,9335	-0,0068	149,9219
	-0,5912	23,9451	5,7814	-0,0417	149,8203
	-0,5729	23,8875	5,6370	-0,1106	149,6762
	-0,5498	23,8090	5,5032	-0,2018	149,5450
	-0,5193	23,7127	5,3834	-0,3132	149,4299
	-0,4779	23,6022	5,2802	-0,4411	149,3344
	⋮	⋮	⋮	⋮	⋮
CD	-0,4956	19,2670	0,1007	-5,6947	144,9707
	-0,4269	19,3498	0,8527	-5,4819	145,6996
	-0,3632	19,5389	1,5856	-5,1677	146,3908
	-0,3066	19,8305	2,2848	-4,7587	147,0306
	-0,2587	20,2181	2,9363	-4,2634	147,6061
	-0,2216	20,6938	3,5274	-3,6919	148,1061
	-0,1971	21,2478	4,0466	-3,0558	148,5209
	⋮	⋮	⋮	⋮	⋮
DE	-0,5304	19,2660	0,0349	-5,7069	144,9026
	-0,5266	19,2659	0,0420	-5,7058	144,9101
	-0,5226	19,2658	0,0496	-5,7046	144,9178
	-0,5186	19,2658	0,0572	-5,7034	144,9256
	-0,5149	19,2658	0,0641	-5,7021	144,9330
	-0,5109	19,2659	0,0717	-5,7008	144,9405
	-0,5072	19,2661	0,0788	-5,6993	144,9481
	⋮	⋮	⋮	⋮	⋮

	Characteristic curve			*Axial section*	
	X [mm]	Y [mm]	Z [mm]	H [mm]	R [mm]
EF	-0,5806	23,2537	-4,9944	-2,6631	139,2834
	-0,8775	22,6030	-4,7420	-3,3295	139,6569
	-0,9286	21,9173	-4,3945	-3,9368	140,1209
	-0,9144	21,2824	-3,9567	-4,4725	140,6654
	-0,8728	20,7159	-3,4352	-4,9264	141,2804
	-0,8161	20,2298	-2,8392	-5,2885	141,9530
	-0,7503	19,8344	-2,1806	-5,5517	142,6705
	⋮	⋮	⋮	⋮	⋮
FG	-0,5806	23,2537	-4,9944	-2,6631	139,2834
	-0,5604	23,3697	-5,0358	-2,5535	139,2232
	-0,5610	23,4829	-5,0905	-2,4521	139,1498
	-0,5673	23,5882	-5,1584	-2,3607	139,0643
	-0,5763	23,6840	-5,2385	-2,2809	138,9683
	-0,5872	23,7694	-5,3305	-2,2134	138,8626
	-0,5992	23,8422	-5,4322	-2,1599	138,7497
	⋮	⋮	⋮	⋮	⋮

4. Conclusions

The profiling of the ring tangential tool is similar to the profiling of the side mill tool. The particular position of tool’s axis may limit the length of the machined thread.

The specific application *HSGT* allows for the determination of the characteristic curve (in particular for composed characteristic curves for complex surfaces) and allows to solve problems due to singular points. The profile, in the tool's axial section is rigorously determined in the specific *HSGT* application.

The proposed method, developed in the CATIA graphical design environment, for the profiling of the ring tangential tool's primary peripheral surfaces allows determining the characteristic curves and the axial section. The *HSGT* application is based on the decomposition of the helical movement — the self generating movement of the surface to be generated— a cylindrical helical surface with constant pitch. These are presented analytical solutions for the determination of the constructive parameters of the generating tool.

Also, were presented two applications for cylindrical helical surface with constant pitch, used in machine part's construction.

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Reprezentarea topologică a suprafeţei periferice primare a sculei inelare pentru generarea suprafeţelor elicoidale

—Rezumat—

Sculele inelare cuprinzătoare sunt scule mărginite de suprafeţe periferice primare de revoluţie, utilizate pentru generarea suprafeţelor elicoidale de pas constant.

În prezenta lucrare, se prezintă un algoritm, bazat pe reprezentarea topologică a suprafeţei periferice primare a sculei ce urmează a fi profilată. Metoda de aplicare a acestui algoritm a fost dezvoltată în mediul de proiectare grafică CATIA şi este destinată profilării sculelor inelare tangenţiale, ca suprafeţe reciproc înfăşurătoare ale unor suprafeţe elicoidale de pas constant. Sunt prezentate două exemple numerice, în baza unui produs soft dedicat, pentru determinarea numerică a formei secţiunii axiale a acestui tip de scule. Aplicaţia *HSGT* are la bază principiul descompunerii mişcării elicoidale – mişcarea de autogenerare a suprafeţei de generat – o suprafaţă elicoidală cilindrică şi de pas constant.

Aplicaţia specifică *HSGT* permite determinarea cu uşurinţă a curbei caracteristice (a curbelor caracteristice compuse, pentru suprafeţele complexe), permiţând şi tratarea problemelor datorate punctelor singulare.

De asemenea, este prezentată o soluţie pentru corecţia formei secţiunii axiale a sculei, ţinând seama de existenţa punctelor singulare pe profilul suprafeţei elicoidale de generat. Profilul, în secţiunea axială a sculei inelare tangenţiale este determinat cu rigurozitate, în cadrul aplicaţiilor *HSGT* specifice.

S-au prezentat şi soluţii analitice pentru determinarea parametrilor constructivi şi de poziţie a sculei generatoare.