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PROFILING METHOD FOR THE SCREW-DIE TOOL USED TO GENERATE THE DENTAL IMPLANTS THREAD

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ABSTRACT

The thread of dental implants screw has to meet special requirements and it has specific axial profiles. The constructive shapes of dental implants screw are diverse but still they have some common features: thread (cylindrical or conical), entering cone, self-threading flutes. The thread is usually machined by turning with profiled cutters, on NC machine tools. In this paper, a method to profile the screw-die tools, used to generate by rolling the thread for a dental implant type of screw is presented. The profiling problem was solved by two methods: an analytical method, based on the fundamental theorem concerning the enwrapped surfaces, and a graphical method, based on a CAD environment for graphical design. The paper includes comparative numerical examples, obtained by running the two methods in the case of the same thread profile.

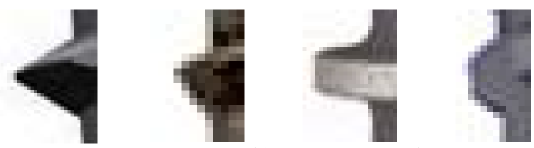
KEYWORDS: dental implant screw thread, rolling, screw-die tool profiling, analytical method, CAD method

1. INTRODUCTION

In dentistry practice, the constructive solutions for dental metallic implants are diverse and depend on the implant purpose, as well as on manufacturer. The most specific part of the dental implant is the screw having as purpose to fix it onto the jaw [1, 2], Fig. 1.

Fig.1. Types of screw for dental metallic implants

A look to the axial profiles of the screw thread, exemplified in Fig. 2, reveal the existence of a large diversity of shapes. This further leads to the conclusion that a methodology to profile the thread generating tool should be developed, especially when the thread is manufactured by other means than turning with profiled cutters [3-5] (e.g. by rolling).



a) b) c) d)

Fig.2. Examples of screw thread axial profile:
a) triangular symmetric; b) triangular asymmetric;
c) squared; d) trapezoidal.

We further suggest an algorithm to profile the screw-die tool, which can be used to generate a thread with triangular, symmetric profile (Fig. 2-a), by rolling. Tool profiling will be realized by using, separately, two different methods: the first one is analytical and based on the fundamental principles of enwrapped surfaces, while the second is graphical and developed under CATIA environment [6, 7].

Obviously, the proposed methodology use could be extended to profile the same type of tool, designed to manufacture threads having other shapes for the axial profile.

2. SCREW-DIE TOOL PROFILING – ANALYTICAL METHOD

2.1. Thread flank equations

In Fig. 3 there are presented the thread profile to be generated, in axial section, together to the reference system to which this profile is referred.

The specific geometrical elements of this thread profile are:

- The helix pitch, p_E [mm];
- The profile flank angle, α_p [°];
- The profile fillet radii, to the top, r_t, and to the foot, r_f [mm];
- The top and foot cylinders radii, R_0 respective r_0 [mm];
- The thread profile height, H [mm].

The parametric equations of the thread flank profile, in axial section, referred to XYZ system (Fig. 3), are presented below in Table 1.

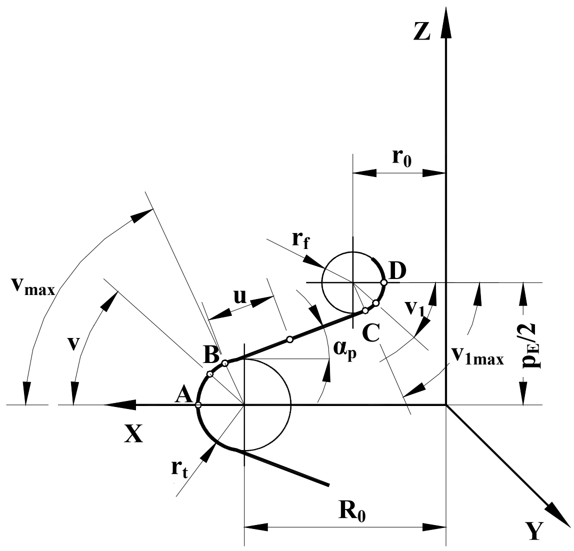


Fig.3. Thread axial profile

Table 1. Parametric equations of thread flank profile in axial section

Sector	Equations	Variable	Limits
AB	$X = R_0 + r_t \cdot \cos v;$ $Y = 0;$ $Z = r_t \cdot \sin v.$	v	$v_{min} = 0$ $v_{max} = \pi/2 - \alpha$
BC	$X = R_0 + r_t \cdot \cos v_{max} - u \cdot \cos \alpha_p;$ $Y = 0;$ $Z = r_t \cdot \sin v_{max} + u \cdot \sin \alpha_p.$	u	$u_{min} = 0$ u_{max} – from condition $\lvert X_A - X_D \rvert = H$
CD	$X = r_0 + r_f \cdot \cos v_1;$ $Y = 0;$ $Z = \frac{p_E}{2} - r_f \cdot \sin v_1.$	v_1	$v_{1min} = 0$ $v_{1max} = \pi/2 - \alpha$

The analytical expression of thread flank surface, in the helical motion along $\vec{V}$ axis (here Z axis) of p helical parameter, results from the relation

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} \cos\varphi & -\sin\varphi & 0 \\ \sin\varphi & \cos\varphi & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} X_{flank} \\ Y_{flank} \\ Z_{flank} \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ p \cdot \varphi \end{pmatrix}, \quad (1)$$

where by X_{flank}, Y_{flank}, Z_{flank} we mean the equations of profile sectors, as defined in Table 1, while φ is a variable angular parameter. The parametric equations of the thread flank surface, for each one among the three profile sectors, are presented in Table 2.

Our purpose is to find the profile of the screw-die tool, delimited by a composed cylindrical surface as peripheral primary surface (see Table 2).

In Fig. 4 there are shown, in principle, the reference system used to define the ensemble of surfaces that follows to be generated, and the direction of the generatrix lines from the screw-die cylindrical surface.

We must notice that in this picture, *XYZ* system position is rotated with 90° respect its previous position, from Fig. 3.

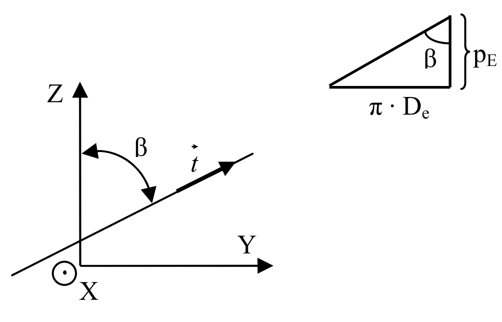


Fig. 4. Direction of cylindrical surface generatrix

It follows that the $\vec{t}$ versor of tool surface generatrix lines has the expression

$$\vec{t} = sin\beta \cdot \vec{j} + cos\beta \cdot \vec{k}\ , \qquad (2)$$

β meaning the angle between tool cylindrical surfaces generatrix and *Z* axis,

$$\beta = arctan\left(\frac{\pi \cdot D_e}{p_E}\right). \qquad (3)$$

In relation (3) D_e means the exterior diameter of the thread that has to be generated.

Table 2. Parametric equations of the thread flank

Flank	Equations	Variables
Σ_{AB}	$X = (R_0 + r_t \cdot cos\, v)cos\,\varphi;$ $Y = (R_0 + r_t \cdot cos\, v)sin\,\varphi;$ $Z = r_t \cdot sin\, v + p \cdot \varphi.$	v, φ
Σ_{BC}	$X = (R_0 + r_t \cdot cos\, v_{max} - u \cdot cos\,\alpha_p)cos\,\varphi;$ $Y = (R_0 + r_t \cdot cos\, v_{max} - u \cdot cos\,\alpha_p)sin\,\varphi;$ $Z = r_t \cdot sin\, v_{max} + u \cdot sin\,\alpha_p + p \cdot \varphi.$	u, φ
Σ_{CD}	$X = (r_0 + r_f \cdot cos\, v_1)cos\,\varphi;$ $Y = (r_0 + r_f \cdot cos\, v_1)sin\,\varphi;$ $Z = \frac{p_E}{2} - r_f \cdot sin\, v_1 + p \cdot \varphi.$	v_1, φ

2.2. The enveloping condition

The condition of contact between the cylindrical surface generatrix (tool primary peripheral surface) and the helical surface (the flanks of the thread to be generated), requires to the points from the helical surfaces (see Table 2), according to Gohman theorem [8-10], to satisfy the condition

$$\overrightarrow{N_\Sigma} \cdot \vec{t} = 0 \qquad (4)$$

where $\overrightarrow{N_\Sigma}$ is the normal to the helical surface to be generated, while $\vec{t}$ is the versor of the cylindrical surface generatrix, (2).

The normal to each one of the surfaces Σ_{AB}, Σ_{BC}, Σ_{CD} can be found starting from the equations presented in Table 2; it has, in principle, the shape:

$$\overrightarrow{N_\Sigma}_{AB,BC,CD} = \begin{vmatrix} \vec{i} & \vec{j} & \vec{k} \\ \dot{X}_v & \dot{Y}_v & \dot{Z}_v \\ \dot{X}_\varphi & \dot{Y}_\varphi & \dot{Z}_\varphi \end{vmatrix}, \qquad (5)$$

or, in the end

$$\overrightarrow{N_\Sigma}_{AB,BC,CD} = N_{\Sigma_X} \cdot \vec{i} + N_{\Sigma_Y} \cdot \vec{j} + N_{\Sigma_Z} \cdot \vec{k}\,, \qquad (6)$$

with N_{Σ_X}, N_{Σ_Y}, N_{Σ_Z} - the normal direction parameters of surfaces (see Table 2), determined according to (5). Hence, by having in view the previous definitions for $\overrightarrow{N_\Sigma}$ and $\vec{t}$, the enveloping condition (4) becomes:

$$N_{\Sigma_Y} \cdot sin\beta + N_{\Sigma_Z} \cdot cos\beta = 0. \qquad (7)$$

2.3. The primary peripheral surface of the cylindrical tool

The equations ensemble resulted by putting together the equations of helical surfaces Σ_{AB}, Σ_{BC}, Σ_{CD} (see Table 2) and the enveloping condition, specific to each one among them, gives the specific characteristic curves. For example, in the case of Σ_{AB} surface, the specific characteristic results as below:

$$C_{AB}\begin{cases} \Sigma_{AB}\begin{vmatrix} X = X(v,\varphi); \\ Y = Y(v,\varphi); \\ Z = Z(v,\varphi); \end{vmatrix} & (8) \\ q(v,\varphi) = 0\,, & (9) \end{cases}$$

see Table 2 and condition (7) applied in the case of this surface. The characteristic curves of the other two surfaces can be expressed similarly.

The condition (9) enables the elimination of one among the two parameters, v and φ, by finding the dependence

$$v = v(\varphi), \tag{10}$$

such as the characteristic curve can be rewritten as

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

This is a curve belonging to both Σ and S surfaces – the helical flank, and, respectively, the tool primary peripheral surface (the cylindrical surface) – see Fig. 5.

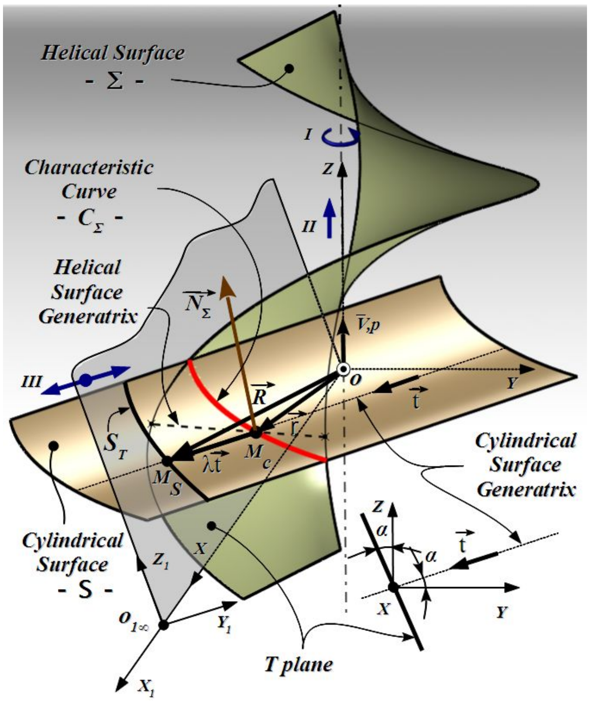


Fig. 5. The characteristic curve C_Σ and the surface S of the cylindrical tool

The parametrical equations of the cylindrical surface can be now written by considering the following two vectors:

$$\vec{r_c} = X(\varphi)\cdot\vec{i} + Y(\varphi)\cdot\vec{j} + Z(\varphi)\cdot\vec{k}\,, \tag{12}$$

as position vector of the current point on the characteristic curve (having a specific expression for each sector AB / BC / CD), and

$$\lambda\vec{t} = \lambda\cdot\sin\alpha\cdot\vec{j} + \lambda\cdot\cos\alpha\cdot\vec{k}\,, \tag{13}$$

vector defined along the cylindrical surface generatrix, with λ – variable parameter.

Hence, the parametric equations of the cylindrical surface – the tool flank S – for each one of the three sectors have the shape:

$$S_{AB/BC/CD}\left|\begin{array}{l} X = X(\varphi); \\ Y = Y(\varphi) - \lambda\cdot\sin\alpha; \\ Z = Z(\varphi) - \lambda\cdot\cos\alpha, \end{array}\right. \tag{14}$$

with λ an α – variable parameters.

The surface (14) transversal section, meaning the tool profile (physical or virtual template) used to realize the cylindrical surface (the generator tool), results as intersection between the surface (14) and the plane (see Fig. 5),

$$Y\cdot\sin\alpha + Z\cdot\cos\alpha = 0\,, \tag{15}$$

condition equivalent to a dependence like

$$Q(\lambda,\varphi) = 0\,, \tag{16}$$

or

$$\lambda = \lambda(\varphi). \tag{17}$$

The ensemble (14) – (17) gives the plane profile of the transversal section,

$$\left|\begin{array}{l} X = X(\lambda); \\ Y = Y(\lambda); \\ Z = Z(\lambda). \end{array}\right. \tag{18}$$

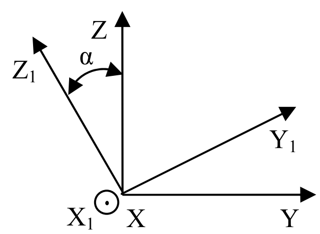


Fig. 6. The co-ordinates transform

After application of the co-ordinates transform presented in Fig. 6,

$$\begin{pmatrix} X_1 \\ Y_1 \\ Z_1 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & \sin\alpha \\ 0 & -\sin\alpha & \cos\alpha \end{pmatrix}\cdot\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \tag{19}$$

the plane profile of the transversal section, S_T, results:

$$S_T\left|\begin{array}{l} X_1 = X(\lambda); \\ Y_1 = Y(\lambda)\cdot\cos\alpha + Z(\lambda)\cdot\sin\alpha \equiv 0; \\ Z_1 = -Y(\lambda)\cdot\sin\alpha + Z(\lambda)\cdot\cos\alpha. \end{array}\right. \tag{20}$$

The profile from plane X_1Z_1 represents the control template (the tool profile) used to generate the cylindrical surface of the screw-die tool.

3. NUMERICAL APPLICATION

We further present a numerical application to exemplify the cylindrical tool (screw-die tool) profiling, in the case of an existing dental implant thread, whose measured dimensions are (Fig. 7):

- helix pitch, $p_E = 0.6$ mm;
- profile angle, $\alpha_p = 30^o$;
- foot fillet radius, $r_f = 0.07$ mm;
- top fillet radius, $r_t = 0.15$ mm;
- exterior diameter, $D_e = 3.5$ mm;
- interior diameter, $D_i = 2.9$ mm;
- number of thread starts, $i = 1$.

The thread transversal section and the transversal profile of the cylindrical surface (screw-die tool) that generates this thread profile were determined on the base of a dedicated MatLab application, whose algorithm is presented in Fig. 8.

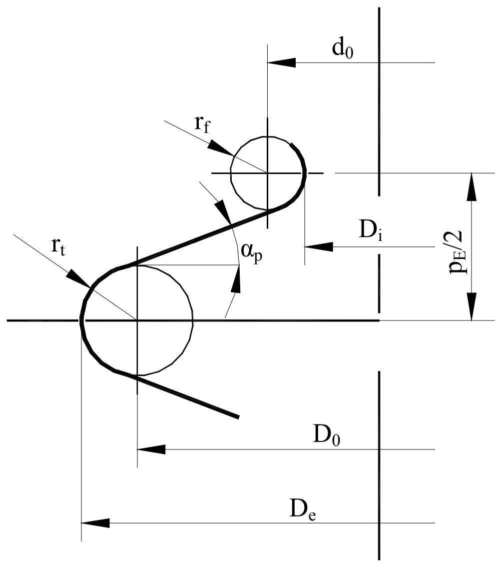


Fig. 7. Thread axial profile

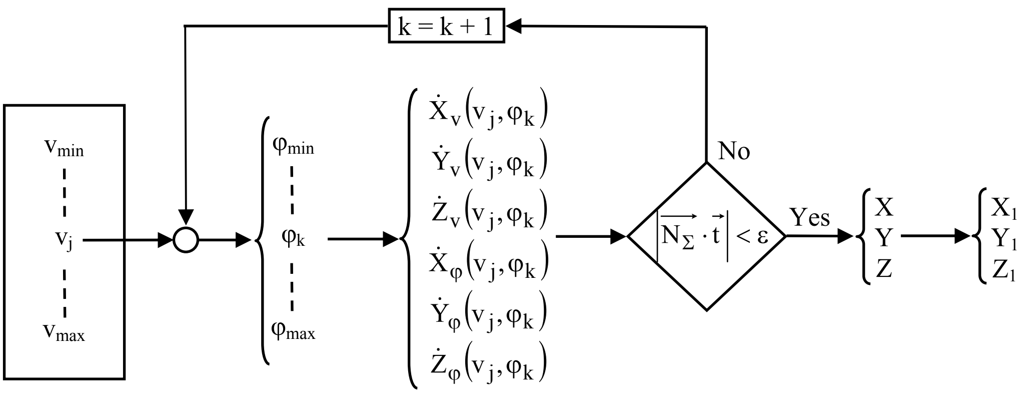


Fig. 8. Algorithm to find the screw-die tool profile

Table 3-a. The thread transversal section and the screw-die tool profile (AB sector)

Thread transversal section			Screw-die tool profile		
X [mm]	Y [mm]	Z [mm]	X_1 [mm]	Y_1 [mm]	Z_1 [mm]
1.7499	0.0000	0.0000	1.7499	0.0000	0.0000
1.7493	-0.0001	0.0142	1.7493	0.0000	0.0142
1.7472	-0.0015	0.0283	1.7472	0.0000	0.0283
1.7439	-0.0022	0.0421	1.7439	0.0000	0.0421
1.7392	-0.0030	0.0555	1.7392	0.0000	0.0556
1.7333	-0.0037	0.0685	1.7333	0.0000	0.0686
1.7261	-0.0044	0.0808	1.7261	0.0000	0.0809
1.7179	-0.0050	0.0924	1.7179	0.0000	0.0925
1.7085	-0.0056	0.1032	1.7085	0.0000	0.1033
1.6982	-0.0061	0.1130	1.6982	0.0000	0.1131
1.6870	-0.0066	0.1218	1.6870	0.0000	0.1220
1.6749	-0.0070	0.1295	1.6749	0.0000	0.1297

Table 3-b. The thread transversal section and the screw-die tool profile (BC sector)

Thread transversal section			Screw-die tool profile		
X [mm]	Y [mm]	Z [mm]	X_1 [mm]	Y_1 [mm]	Z_1 [mm]
1.6749	-0.0070	0.1295	1.6749	0.0000	0.1297
1.6577	-0.0076	0.1394	1.6577	0.0000	0.1396
1.6404	-0.0081	0.1494	1.6404	0.0000	0.1496
1.6231	-0.0086	0.1593	1.6231	0.0000	0.1596
1.6058	-0.0092	0.1693	1.6058	0.0000	0.1696
1.5885	-0.0097	0.1793	1.5885	0.0000	0.1795
1.5712	-0.0103	0.1892	1.5712	0.0000	0.1895
1.5539	-0.0108	0.1992	1.5539	0.0000	0.1995
1.5366	-0.0114	0.2092	1.5366	0.0000	0.2095
1.5193	-0.0119	0.2191	1.5193	0.0000	0.2195
1.5020	-0.0125	0.2291	1.5020	0.0000	0.2294
1.4848	-0.0130	0.2391	1.4848	0.0000	0.2394

Table 3-c. The thread transversal section and the screw-die tool profile (CD sector)

Thread transversal section			Screw-die tool profile		
X [mm]	Y [mm]	Z [mm]	X_1 [mm]	Y_1 [mm]	Z_1 [mm]
1.4848	-0.0130	0.2391	1.6749	0.0000	0.2394
1.4792	-0.0132	0.2426	1.6577	0.0000	0.2430
1.4740	-0.0134	0.2467	1.6404	0.0000	0.2471
1.4692	-0.0137	0.2513	1.6231	0.0000	0.2516
1.4649	-0.0139	0.2563	1.6058	0.0000	0.2566
1.4610	-0.0142	0.2616	1.5885	0.0000	0.2620
1.4577	-0.0145	0.2674	1.5712	0.0000	0.2678
1.4549	-0.0149	0.2734	1.5539	0.0000	0.2738
1.4528	-0.0152	0.2797	1.5366	0.0000	0.2801
1.4512	-0.0156	0.2861	1.5193	0.0000	0.2865
1.4503	-0.0159	0.2927	1.5020	0.0000	0.2931
1.4499	-0.0163	0.2993	1.4848	0.0000	0.2997

In Table 3-a/b/c, there are presented co-ordinates of points from both thread transversal section and screw-die tool profile, while in Fig. 9 we can see the shape of screw-die tool profile.

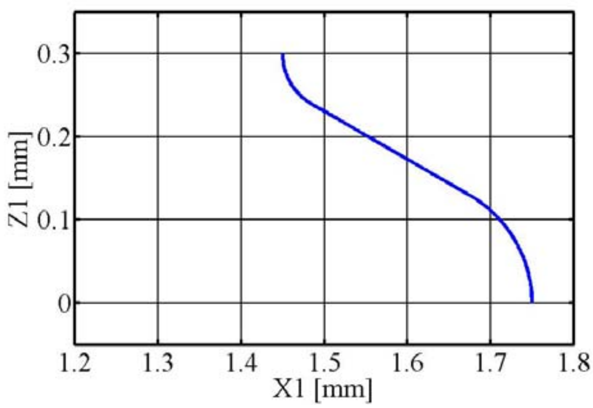


Fig. 9. Screw-die tool profile

4. 3-D GRAPHICAL METHOD TO PROFILE THE SCREW-DIE TOOL

The graphical method is based on the premise that the cylindrical tool (materialized by the screw-die tool) could be considered as a disc-tool having a very large diameter (e.g. 100,000 mm). Hence, to find the characteristic curve and the helical surface at the contact with the cylindrical tool, the disc-tool profiling algorithm developed in [11] can be used, Fig. 10, if *a* parameter takes a very large value (in theory $a \to \infty$).

To solve the profiling problem of the screw-die tool, approached by this paper, we used CATIA environment. Within *Generative Shape Design* module, the helical surface was firstly modeled. Then, by applying *Projection* command, the axis 2 of the disc-tool (substituting the cylindrical surface) is projected onto the helical surface, finding this way the characteristic curve. Obviously, a very large value (more than 100,000 mm) should be assigned to *a* distance (Fig. 10).

The cylindrical surface – the screw-die tool flank – is modeled by using the *Extrude* command to the characteristic curve determined as above mentioned (Fig. 11).

Finally, the normal section of the cylindrical surface previously determined is found with *Intersection* command. This section gives the cylindrical surface transversal profile, as depicted in Fig. 12. The co-ordinates of points placed on this profile, obtained for the same values of the generated thread, are exemplified in Tab. 4.

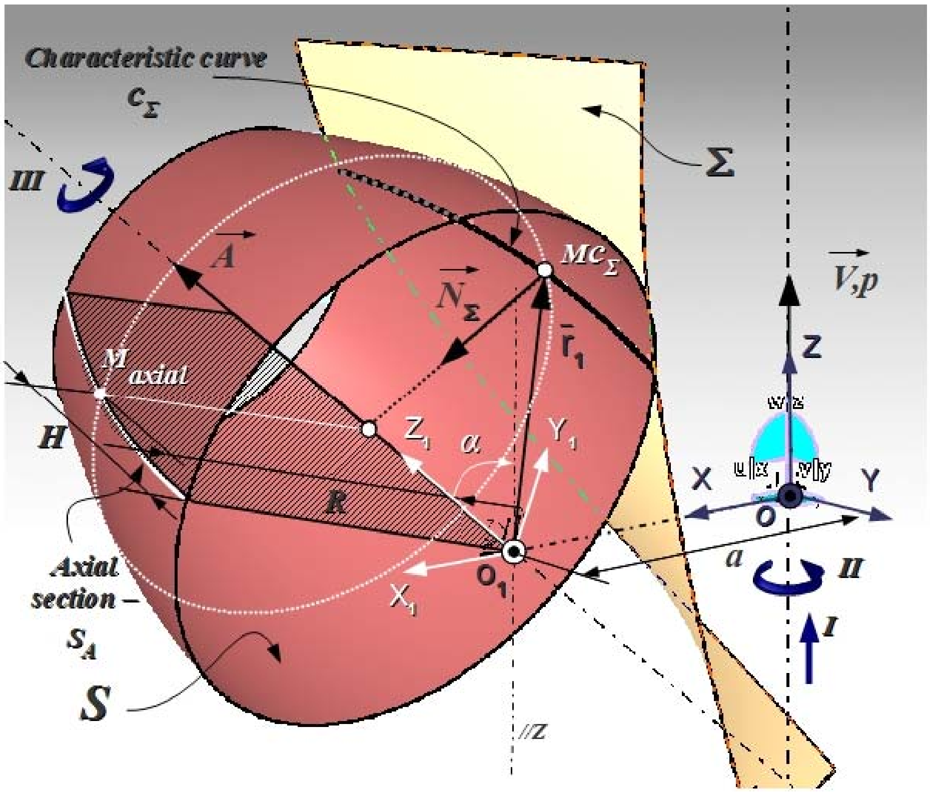


Fig. 10. The revolution surface in contact with the helical one

Table 4. Characteristic curve and transversal section

Characteristic curve			Transversal section		
X_1 [mm]	Y_1 [mm]	Z_1 [mm]	X_1 [mm]	Y_1 [mm]	Z_1 [mm]
0.0164	0.2998	0.3000	0	0.2998	0.3000
0.0146	0.2691	0.2968	0	0.2693	0.2969
0.0127	0.2393	0.2873	0	0.2399	0.2875
0.0104	0.2119	0.2715	0	0.2128	0.2721
0.0073	0.1886	0.2506	0	0.1895	0.2515
0.0021	0.1700	0.2250	0	0.1712	0.2270
-0.0013	0.1548	0.1985	0	0.1554	0.1997
-0.0046	0.1394	0.1718	0	0.1399	0.1728
-0.0081	0.1236	0.1444	0	0.1244	0.1460
-0.0116	0.1078	0.1171	0	0.1090	0.1191
-0.0150	0.0924	0.0905	0	0.0935	0.0923
-0.0183	0.0771	0.0639	0	0.0782	0.0658
-0.0216	0.0613	0.0366	0	0.0625	0.0386
-0.0098	0.0427	0.0146	0	0.0428	0.0148
-0.0028	0.0151	0.0017	0	0.0149	0.0016

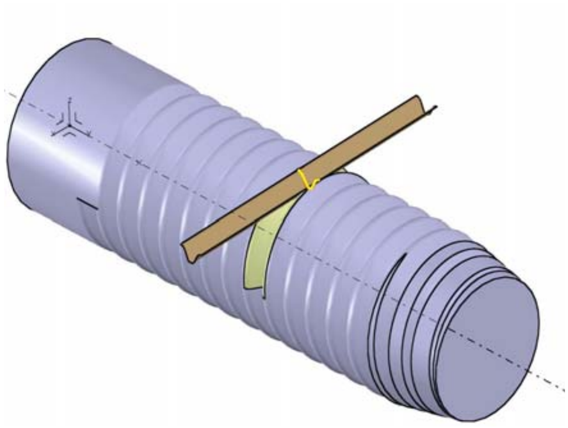


Fig. 11. Characteristic curve and cylindrical surface model, for the considered dimensions

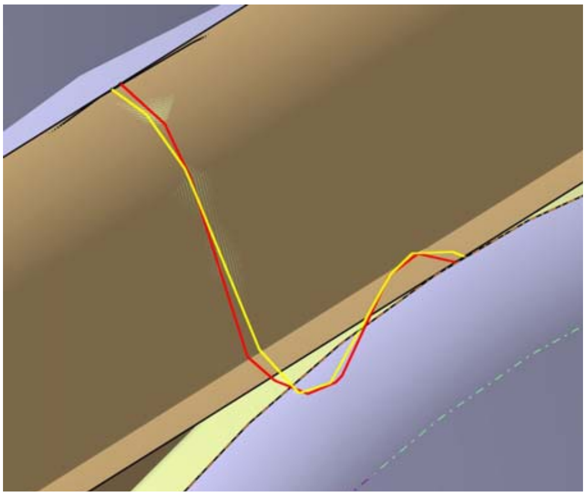


Fig. 12. Cylindrical surface transversal section

5. CONCLUSION

Obviously, both profiling methods applied in the cylindrical tool case lead to similar numerical results, despite their very different approach. At the same time, both methods are rigorous, the graphical method having also the advantage of being very suggestive.

The constructive shape of the screw-die tool used to generate the dental implant screw thread can be observed, in principle, in Fig. 13.

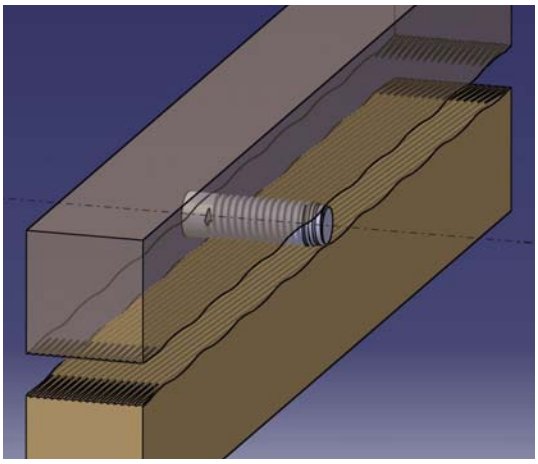


Fig. 13. Screw-die tool model

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