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PROFILING METHODOLOGY FOR SIDE MILL TOOLS FOR GENERATION OF HELICAL COMPRESOR ROTOR USING REVERSE ENGINEERING

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ABSTRACT

In this paper it is presented the issue of profiling tools bounded by revolution primary peripheral surfaces, side mill tool and end mill tool, for generation of the gap between the lobes of the helical rotor.

The determination of the rotor form was done by measuring on the MicroHite 3D coordinate measuring machine, with precision of 0.001.

Using the capabilities of the CATIA design environment, methods for the determination of the worm’s profile and side mill profiling (or end mill tool for generation of the gap between two successive teeth) were elaborated.

They are presented the axial profiles of the tool, in numerical and graphical form.

KEYWORDS: helical compressor rotor, reverse engineering, CATIA

1. Introduction

The generation of helical surfaces, as surfaces belongs to the machine parts such as gears, worms for pumps and helical compressors assume also the elaboration of profiling methods for milling tools (or for profiled grinding wheels).

The issue assumes the knowing of the form of the surfaces which composes the helical surfaces, usually, in analytical form. For this, specific methods, based on the surfaces enveloping fundamental theorems [5], were elaborated and are frequently used.

Also, derived methods, as the in-plane trajectory method, were elaborated.

The development of the graphical design environment allows the elaboration of solutions using the CAD environments capabilities.

In practice, there are situations when the knowing in analytical form of the compressor rotors flanks is not possible. In this case the problem of generating tools profiling may be approach using the reverse engineering.

The axial profiles of the rotors are measured on 3D coordinate measuring machines, with sufficient precision, and further, the form of there is modeled by 3D representation. Methods, developed in the CATIA design environment, are applied for the determination of the tools’ primary peripheral surface profile [4].

2. Reverse engineering — profiling of generating tools for an existent compressor rotor

The goal is to make a method for profiling tools which generate the rotors of a helical compressor knows as physical object.

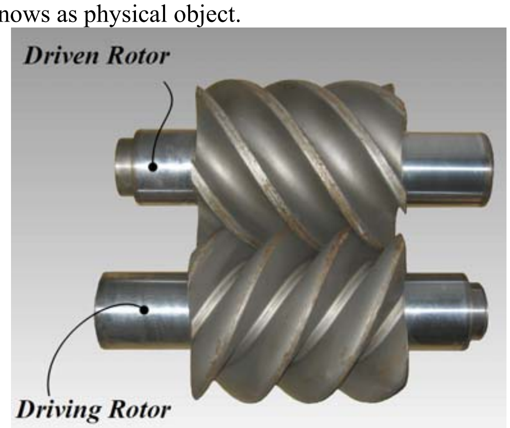

Fig. 1. *Axial profile of the rotors*

The presented rotors were obtained from an existent helical compressor. Regarding the rotors' form, drive and driving, they are not information available.

The reconstruction of the solid models for the two rotors is making by measuring of their axial section on a 3D coordinates measuring machine which exist in the laboratory of the Manufacturing Science and Engineering, Robotics and Welding of the "Dunărea de Jos" University of Galați, Figure 2.

The measuring precision of this machine is 0.001 mm.

Fig. 2. *The measuring of the rotor's axial profile*

In Table 1, they are presented the measured coordinates of the driven rotor's axial section, corresponding with the gap's flank and with the gap profile's bottom.

Table 1. *The coordinates of points from the driving rotor's profile*

AB	Y [mm]	Z [mm]	BC	Y [mm]	Z [mm]	CD	Y [mm]	Z [mm]
1	248.451	130.873	**1**	287.360	84.873	**1**	309.915	84.873
2	249.737	130.736	**2**	287.493	84.146	**2**	310.149	85.908
3	251.016	130.546	**3**	287.609	83.414	**3**	310.394	86.939
4	252.279	130.266	**4**	287.708	82.681	**4**	310.665	87.965
5	253.518	129.897	**5**	287.767	81.943	**5**	310.957	88.985
...	...	...	**...**	...	...	**...**	...	...
46	285.925	89.840	**46**	309.507	81.943	**46**	329.337	128.297
47	286.338	88.615	**47**	309.567	82.681	**47**	329.866	129.216
48	286.715	87.378	**48**	309.665	83.414	**48**	330.511	130.053
49	287.055	86.130	**49**	309.781	84.145	**49**	331.401	130.618
50	287.360	84.873	**50**	309.915	84.873	**50**	332.428	130.873

The measured profile was obtained in the *YX* plane of the driving rotor.

In Figure 3, they are presented the form of the measured profile of the driving rotor.

The profile is composed from an assembly of curves' arcs known in numerical form, corresponding to: left flank, *AB*; right flank *CD*; profile's bottom *BC*.

The measured coordinates were approximate in the CATIA design environment - *Digitized Shape Design* by spline curves, passing through the all measured points, for each portion of profile. The spline curves were generated with an in-home *VBA* application developed in the CATIA design environment.

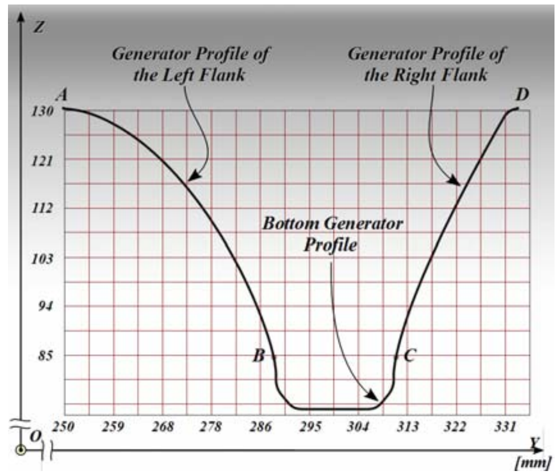

Fig. 3. *Axial profile of the driving rotor*

The *BC* profile, Figure 3, is a curves assembly for which is possible to define a symmetry axis and, therefore, is possible to design an end mill generating tool for this zone.

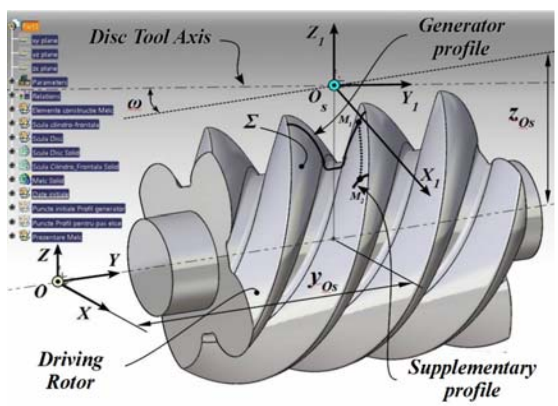

Fig. 4. *Profiles in parallel planes, measured on the driving rotor flank*

A specific problem in the helical surfaces measuring is the determinations of the worm axial section pitch (or the helical parameter). The rotor dimensions don't allow the direct determination of the pitch due to the fact that the total length of the rotor is inferior to the value of the helical pitch. Therefore, it was adopted a solution for the determination of the helical parameter *p*, by measuring of a two curves situated in parallels planes, on the same flank of the driven rotor, Figure 4.

In Table 2, the coordinates of the second curve measured on the rotor flank are presented. The curve is approximated by a spline curve in the *Digitized Shape Design* CATIA design environment, Figure 4.

Table 2. *The coordinates of points from the supplementary profile, measured on the rotor flank*

Crt. no.	X [mm]	Y [mm]	Z [mm]	Nr. Crt.	X [mm]	Y [mm]	Z [mm]
1	80.060	293.140	100.000	**7**	79.990	289.600	95.000
2	80.000	292.430	99.000	**8**	80.000	288.900	94.000
3	80.000	291.720	98.000	**9**	80.000	288.210	93.000
4	80.000	291.010	97.000	**10**	79.990	287.490	92.000
5	80.000	291.010	97.000	**11**	79.990	286.790	91.000
6	80.000	290.310	96.000	**12**	80.000	286.080	90.000

By intersecting the measured curves on the rotor flank, see Tables 1 and 2, with a revolution cylinder with radius *r*=125 mm, the coordinates of two points from the same helix are determined. The two points are displaced along the helix axis with the dimension *L*, Figure 5,

$$L = z_2 - z_1 . \quad (1)$$

It is determined the helical parameter of the driving rotor lobe flank helix, with the relation:

$$p = \frac{L}{\varphi} \text{ [mm]}, \quad (2)$$

see Figure 5, (φ in radians). In this way, the helical pitch of the flank is calculated with relation:

$$p_e = 2\pi p \text{ [mm]}. \quad (3)$$

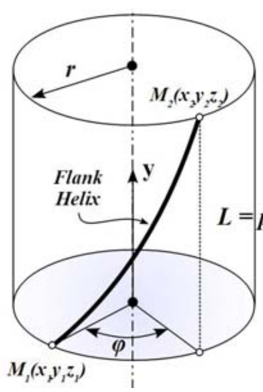

Fig. 5. *The determination of the helical parameter of the driving rotor helix*

For an accurate determination the algorithm is repeated for various values of the *r* radius and curves segments measured in planes parallel with the axial plane, for the same flank of the rotor. For the measured rotor, the helical pitch of the worm's lobe is p_e=335.892 mm.

3. The modeling of tools for generation of the driven rotor

Being known the axial section of the driven rotor, the 3D model of this may be obtained, see Figure 6. The driven rotor's model is a worm with four starts and was obtained in the *Generative Shape Design* environment, by the commands: *Helix*, for the modeling of worm; *Sweep*, for the obtaining of the flanks helical surfaces — *Σ*.

In Figure 6, it is defined the position of the reference system regarding which it is defined the rotor helical surface model, *XYZ* and, as well as, the reference system of the future side mill tool, the $X_1Y_1Z_1$ reference system.

The axis of the side mill tool (Y_1) is inclined regarding the worm axis with the angle ω and is positioned at distance $a=z_{0s}$, to this (see Figure 6).

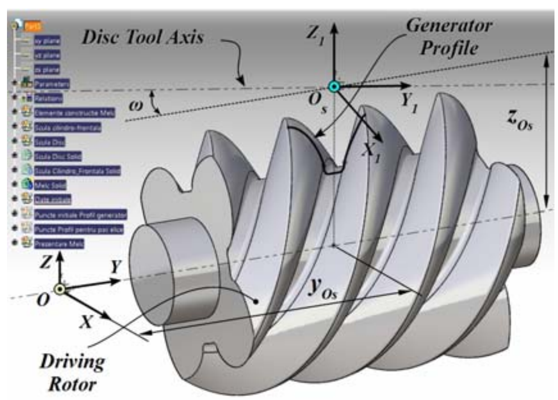

Fig. 6. *The model of the driving rotor; reference systems*

Table 3. *The input parameters for the modeling of the side mill tool*

Crt. no.	Input parameters	Value
1	Distance between axis z_{Os}	165 mm
2	Inclination angle ω	23,155 °
3	The position of the origin of the system joined with the side mill tool and end mill tool (regarding the worm's origin)	x=0 y=298,637 mm z=165 mm
4	Worm pitch *Pe*	335,892 mm

For the input data from the Table 3, it is determined the projection of the side mill tool onto the Σ solid model of the driving worm, determining the characteristic curve from, see Figure 7.

In Figure 7 and Table 4, the forms and the coordinates of the characteristic curves corresponding to the anti-homologus flanks, the arcs *AB* and *CD*, are presented.

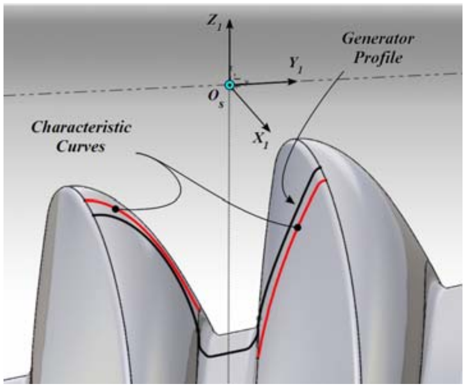

Fig. 7. *Characteristic curves on the rotor's flanks*

The side mill tool primary peripheral surface modeling was made in the *Generative Shape Design* environments, using the *Revolve* command for the rotation of the characteristic curves around the Y_1 axis of the side mill's reference system, Figure 8.

For the *CD* segment of profile, it was modeled an end mill tool bounded by a revolution surface with Z_1 axis, symmetry axis of the bottom of the gap between the two successive teeth of the rotor, see Figure 9.

The form and the coordinates of the characteristic curve for the end mill tool are presented in the Figure 9 and Table 5.

Table 4. *Coordinates of points from the characteristic curves of flanks AB and CD*

AB	X [mm]	Y [mm]	Z [mm]	CD	X [mm]	Y [mm]	Z [mm]
1	-14.825	254.520	130.031	**1**	2.303	304.023	251.470
2	-14.320	255.932	129.908	**2**	2.460	304.388	250.348
3	-13.792	257.323	129.684	**3**	2.616	304.753	249.224
4	-13.267	258.683	129.316	**4**	2.773	305.121	248.102
5	-12.757	260.010	128.824	**5**	2.933	305.494	246.982
...				**...**	...	...	...
46	-19.517	298.725	85.249	**46**	10.996	324.349	202.709
47	-20.421	299.564	84.388	**47**	11.226	324.887	201.672
48	-21.338	300.401	83.538	**48**	11.476	325.472	200.665
49	-22.220	301.233	82.646	**49**	11.835	326.311	199.914
50	-23.037	302.054	81.687	**50**	12.285	327.362	199.599

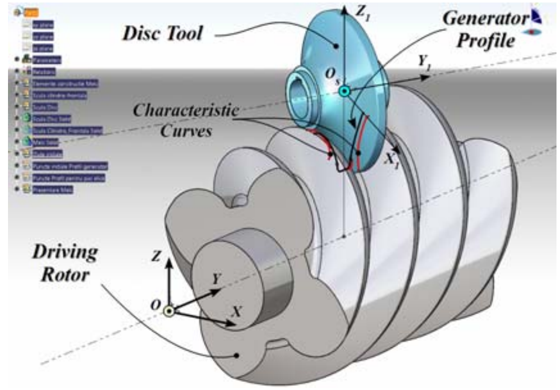

Fig. 8. *Driving worm – the solid model of the side mill tool*

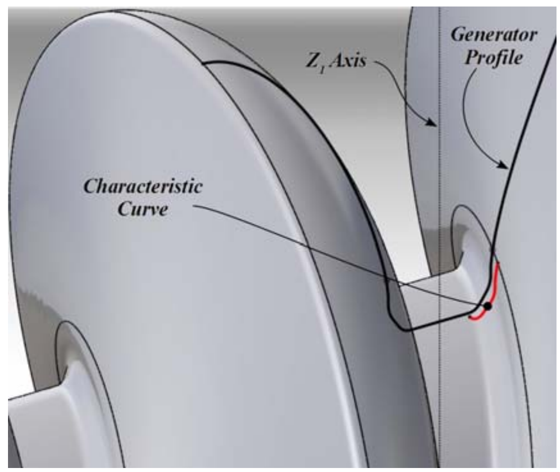

Fig. 9. *Driving worm – characteristic curve at the bottom of profile*

Table 5. *Coordinates of points from the characteristic curve of the bottom of profile, curve BC*

Crt. no.	X [mm]	Y [mm]	Z [mm]	Crt. no.	X [mm]	Y [mm]	Z [mm]
1	5.008	306.759	84.725	**7**	2.847	303.688	75.333
2	4.992	306.710	84.487	**8**	2.614	303.633	75.292
3	4.990	306.657	84.250	**9**	2.372	303.618	75.271
4	4.989	306.612	84.010	**10**	2.130	303.638	75.260
5	4.978	306.575	83.770	**11**	1.891	303.683	75.256
6	4.961	306.539	83.530	**12**	1.655	303.746	75.254

By revolving this characteristic curve around the Z_1 axis is obtained the solid model of the end mill tool's primary peripheral surface, Figure 10.

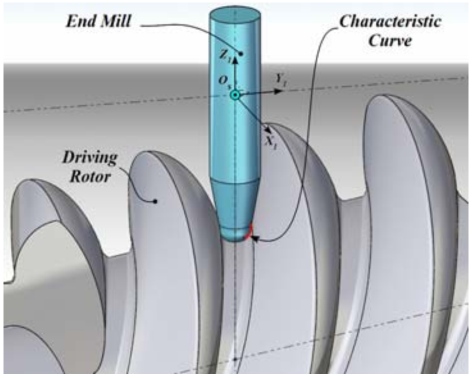

Fig. 10. *Driving worm – end mill tool*

The necessity to model two different tools, for the generation of the helical flute of the driving worm, is imposed because it is not possible the obtaining an unique characteristic curve for a side mill tool, which generate the whole of the teeth gaps (the side mill tool's primary peripheral surface is impossible to be generated because will result an self intersecting surface.

The successive positioning of the two tools, side mill and end mill, impose the exactly determination of the coordinates for the reference position, the O_S point, for the two tools, at the determination of a composed characteristic curve, see Table 3.

The determination of the tools' axial section

The issue of the generating tools modelling for the driven rotor teeth assume, in the all situations, the determination of the axial section of these, as profile of the secondary order tool or as template for the control of the side mill or end mill tool.

In Figure 11 and Table 6, the form and coordinates of the axial section side mill tool are presented. The axial section is obtained by the *Section* command from the solid model of the side mill tool.

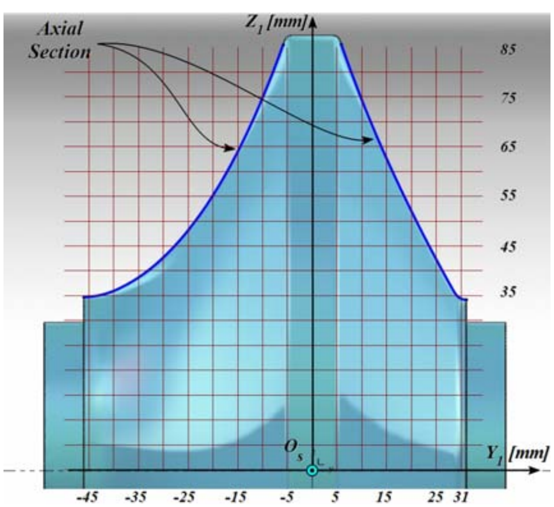

Fig. 11. *Side mill tool – the axial section*

Table. 6. *Coordinates of points from the axial section of the side mill tool*

AB	Y[mm]	Z[mm]	BC	Y[mm]	Z[mm]	CD	Y[mm]	Z[mm]
1	-46.393	35.166	**1**	9.541	-80.275	**1**	5.857	86.470
2	-45.001	35.269	**2**	9.495	-80.495	**2**	6.255	85.348
3	-43.619	35.455	**3**	9.452	-80.717	**3**	6.652	84.224
4	-42.260	35.768	**4**	9.415	-80.939	**4**	7.052	83.102
5	-40.932	36.192	**5**	9.380	-81.162	**5**	7.458	81.982
...	...	...	**...**	...	...	**...**	...	...
46	-7.856	81.072	**46**	6.224	-89.480	**46**	27.965	37.709
47	-7.358	82.375	**47**	6.024	-89.584	**47**	28.550	36.672
48	-6.870	83.682	**48**	5.813	-89.663	**48**	29.185	35.665
49	-6.391	84.992	**49**	5.594	-89.716	**49**	30.098	34.914
50	-5.917	86.304	**50**	5.371	-89.746	**50**	31.241	34.599

Similarly, being known the solid model of the end mill tool generating the worm teeth bottom zone, Figure 10, is determined the axial section of the end mill tool, Figure 12 and Table 7.

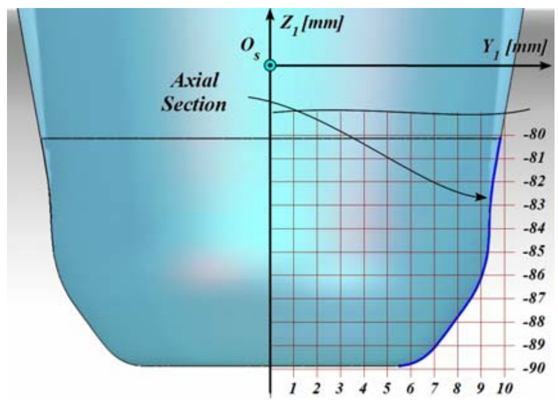

Fig. 12. *End mill tool – axial section*

Table 7. *Coordinates of the profile of axial section of end mill tool*

Crt. no.	Y [mm]	Z [mm]	Crt. no.	Y [mm]	Z [mm]
1	9.541	-80.275	**46**	6.224	-89.480
2	9.495	-80.495	**47**	6.024	-89.584
3	9.452	-80.717	**48**	5.813	-89.663
4	9.415	-80.939	**49**	5.594	-89.716
5	9.380	-81.162	**50**	5.371	-89.746
...	...	...			

4. Conclusions

The graphical method, developed in the CATIA design environment, allow the using of reverse engineering regarding the profiling of tools which generate cylindrical helical surfaces with constant pitch. These surfaces are constitutive surfaces of the helical rotors flanks, knows by measuring on 3D coordinate measuring machines.

Obviously, the coordinates of points measured on profiles were processed by numerical programs, which exist in CATIA, and, as follows, the processing result may be influenced by the substitutive curve’s type accepted by software.

The worm solid were modeled and further, were determined the characteristic curves at generation with tools bounded by revolution surfaces, side mill and end mill tools, reciprocally enveloping with the flute of the helical compressor rotors.

The algorithm allows the numerical and graphical representation of the generating tools axial section as final result of such action.

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Metodologie de profilare a sculelor disc pentru rotorul de compresor elicoidal prin inginerie inversă

—Rezumat—

În lucrare, se abordează problematica profilării sculelor mărginite de suprafețe periferice primare de revoluție, scula disc şi cilindro-frontală, pentru generarea golului între lobii rotorului elicoidal.

Determinarea formei rotorului s-a făcut prin măsurare pe maşina de măsurat de tip MicroHite 3D, cu precizia de 0.001 mm.

S-au elaborat metodici, utilizând facilitățile mediului de programare CATIA, pentru determinarea pasului melcului şi profilarea sculei disc (sau cilindro-frontale), generatoare a golului între doi dinți succesivi.

Sunt prezentate profilurile axiale ale sculelor, în formă grafică şi numerică.