A Study Concerning the Shaping of Disk Cutter, in Order To Generate the Male Rotor, Screw Compressor Component, Using the "Minimum Distance" Method

Camelia Lacramiora Popa, Viorel Popa

***Abstract*— Rotors screw compressor surfaces are complex helical surfaces, which have in the frontal cross section a generator constituted of elementary curved segments, such as arcs and cycloidal curves, the last mentioned, representing trajectories of single points of the profiles. The most important problem to generate these types of helical surfaces consists in profiling the tool that will generate the helical grooves of screw compressor rotors. The disk cutter (cylinder frontal tool type) is bordered by revolution surfaces, in consequence, the problem to be solved, is to determine the surface of revolution conjugated with the compound helical surface. Development of graphic design environments helps to approach the matter also in graphic form, with the advantage of precise determination of the profiles in enveloping. In the following, a graphic solution to solve this problem will be presented for a pair of rotors elliptical profile, screw compressor components. The frontal view of male rotor will be determinate knowing the transverse profile of female rotor. The 3D model of the rotor makes possible to apply the same theorem, leading to the surface of revolution enveloping the helical surface. An application will be also presented to determine the axial profile of the disk cutter, following the proposed algorithm.**

***Index Terms*— complementary theorems, enveloping condition, helical surfaces, screw compressor**

I. INTRODUCTION

The screw compressor is a rotary machine with positive displacement, with simple construction that comprises a pair of meshing rotors, bounded by cylindrical helical surfaces of uniform pitch. Increasing demands for efficient screw compressors requires economic and high efficiency designs, that imply the need to be able to define the rotor lobe profiles.

There are known solutions of the problem by using fundamental theorems of surfaces enveloping: Olivier or Gohman, and the specific theorem of Nikolaev [1], [2], based on the decomposition of helical movement.

The complementary theorems have been also presented, including: "minimum distance" method, and "substitution family circles" method" [3].

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The graphic design environments help to approach the problem in graphic form, which means the advantage of precise determination of the profiles in enveloping, and at the same time being extremely intuitive, and rigorous methods [4]-[6].

We consider a pair of rotors, the configuration is as follows: 6 lobs female rotor, 4 lobs male rotor.

Kinematics compressor construction includes the following movements:

I - centrode rotation C_1 (circle radius r_1), in connection with $X_1Y_1Z_1$, angle φ_1;

I - centrode rotation C_2 (circle radius r_2), in connection with $X_2Y_2Z_2$, angle φ_2;

The rolling condition of the two centrodes, C_1 and C_2 imposes the next relation between φ_2 and φ_1:

$$r_1\varphi_1 = r_2\varphi_2. \qquad (1)$$

II. COMPRESSOR ROTORS FRONT PROFILE

Fig. 1 reveals the front profile of the two rotors, screw compressor components, with semi elliptic shape. The reference systems will be as follows:

$x_1y_1z_1$ is the global system, z_1 axis is overlapped with the male rotor axis;

$x_2y_2z_2$ – global system, z_2 axis is overlapped with the female rotor axis;

$X_1Y_1Z_1$- mobile system jointed with the centrode C_1, which belongs to the front section of the male rotor;

$X_2Y_2Z_2$ -mobile system jointed with the centrode C_2, which belongs to the front section of the female rotor.

III. MALE ROTOR

Fig.1 provides also the description of the compound male rotor profile.

Profile $N_1A_1M_1$ is an elliptic arc, semi axis ***a,*** and ***b,*** (***a*** is small semi axis), defined by the equations as follows:

$$X_1 = -a\cos\theta - r; \quad Y_1 = +b\sin\theta. \qquad (2)$$

$-\theta_{N_1} < \theta < +\theta_{N_1}$; with θ angular parameter.

B_2 is a point that belongs to the male rotor profile.

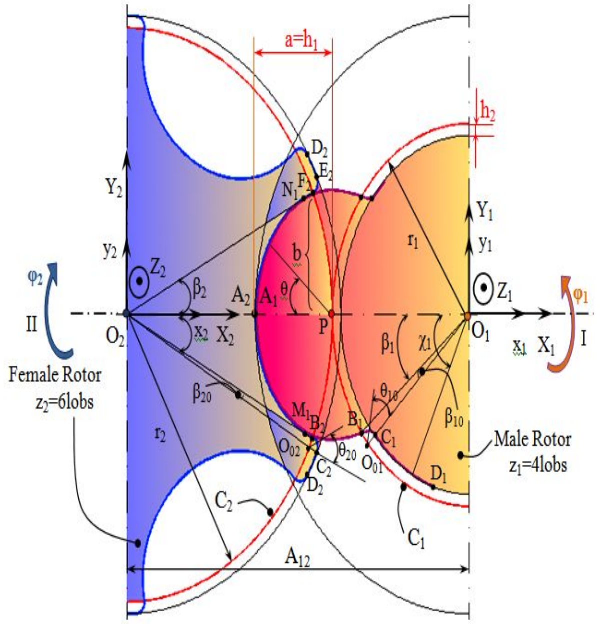

Fig.1. Front profile of the two rotors, semi elliptic shape

θ_{N_1} is determined by the intersection of the elliptical arc (2) with epicycloidal arc (8).

Profile M_1B_1 is an epicycloidal arc generated by point B_2 belonging to the female rotor. Point B_2 is singular point on female rotor profile.

We define the absolute movements:

$$x_1 = \omega_3^T(\varphi_1)X_1, \quad (3)$$

$$x_2 = \omega_3^T(-\varphi_2)X_2, \quad (4)$$

$$x_1 = x_2 - \left\| \begin{matrix} A_{12} \\ 0 \end{matrix} \right\|. \quad (5)$$

The relative movement result as a consequence:

$$X_1 = \omega_3(\varphi_1)\left[\omega_3^T(-\varphi_2)X_2 - \left\| \begin{matrix} A_{12} \\ 0 \end{matrix} \right\|\right]. \quad (6)$$

The reverse movement results as follows:

$$X_2 = \omega_3(-\varphi_2)\left[\omega_3^T(\varphi_1)X_1 + \left\| \begin{matrix} A_{12} \\ 0 \end{matrix} \right\|\right]. \quad (7)$$

If the coordinates of point B_2 are denoted by X_{2B_2} , Y_{2B_2} , relative to X_2Y_2 system, then, the epicycloid generated by this point is as follows:

$$X_1 = X_{2B_2}\cos(\varphi_1+\varphi_2) + Y_{2B_2}\sin(\varphi_1+\varphi_2) - A_{12}\cos\varphi_1;$$
$$Y_2 = -X_{2B_2}\sin(\varphi_1+\varphi_2) + Y_{2B_2}\cos(\varphi_1+\varphi_2) + A_{12}\sin\varphi_1, \quad (8)$$

where, φ_2 and φ2 are the parameters of angular rotation of the two centrodes in relative motion, C_2 radius r_2 , and C_1, radius r_1; i is the gear ratio, as follows:

$$i = \frac{r_1}{r_2} = \frac{\varphi_2}{\varphi_1}; \quad (9)$$

$$A_{12} = r_1 + r_2. \quad (10)$$

Profile B_1C_1 is a circle arc, radius r_0, center in O_{01}, on centrode C_1 (Fig. 2). L is the current point on circle radius r_0, so equations of arc B_1C_1 are as follows:

$$X_1 = -r_1\cos(\beta_1+\beta_{10}) + r_0\cos(\theta_{01}+\beta_1+\beta_{10});$$
$$Y_1 = -r_1\sin(\beta_1+\beta_{10}) + r_0\sin(\theta_{01}+\beta_1+\beta_{10}).$$

(11)

The arc C_1D_1 radius (r_1-r_0) is described by equations of the following form:

$$X_1 = -(r_1-r_0)\cos\chi_1;$$
$$Y_1 = -(r_1-r_0)\sin\chi_1. \quad (12)$$

with χ_1 variable parameter.

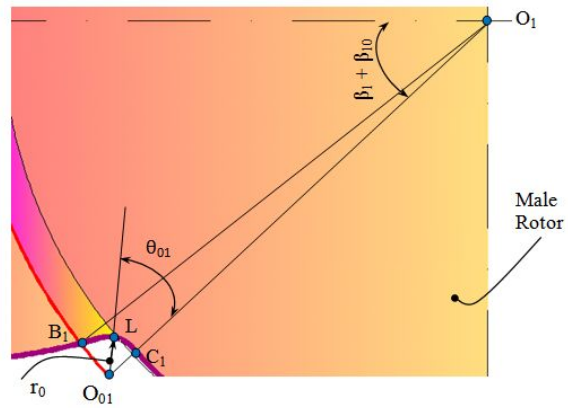

Fig.2. Arc B_1C_1 profile

The male rotor profile is described by the successive positions of the two centrodes, in the rolling process, and of the point L.

IV. CONSTRUCTIVE DIMENSIONS

The rotor constructive dimensions will be set suitable with [7] and Fig.1.

We chose constant parameters as follows:

r_1 = 32mm; r_2= 48mm; $A_{22} = r_1+r_2$ = 80mm;

h_1 = 0.5625x32 = 18mm;

h_2 = 0.0625x32 = 2mm;

a = 18mm;

b = 20mm;

r_0 = 2mm;

$D_{e1} = D_{e2} = 2r_1+2h_1$ = 100mm;

Ratio L/D_{e1} =1.

The calculated twist angle (slope) of the helix (axial pitch) is: $\beta=69.0945^0$ (Fig.3).

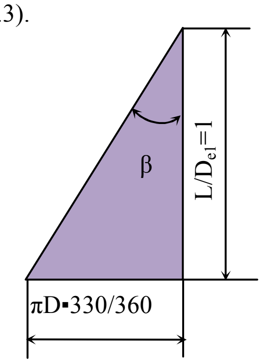

Fig.3.The helix developed

The axial pitch of male rotor is as follows:

$$tg\beta = \frac{\pi D_{e_1}}{p_{ax}}; p_{ax_{cd}} = \frac{\pi \cdot D_{e_1}}{tg\beta} = 24.44801\text{mm}. \qquad (13)$$

The axial pitch of female rotor is as follows:

$$p_{ax_{cs}} = \frac{\pi \cdot D_{e_2}}{tg\beta} = \frac{\pi \cdot 96}{2.6179938} = 76.8000\text{mm}. \qquad (14)$$

We define the helical parameters:

- male rotor:

$$p_1 = \frac{24.44801}{2\pi} = 3.8910216\text{mm}, \qquad (15)$$

- female rotor:

$$p_2 = \frac{76.8000}{2\pi} = 12.2223099\text{mm}. \qquad (16)$$

and angle $PO_1D_1 = \frac{2\pi}{8} = \frac{\pi}{4}$, (17)

for male rotor with 4 lobs,

and $PO_2D_2 = \frac{2\pi}{12} = \frac{\pi}{6}$, (18)

for female rotor with 6 lobs.

The axis of the future disk cutter will be determinate being in tangency to the counterclokwise helix.

V. THE DISK TOOL PROFILE

The front composed generator of helical surface, cylindrical and constant pitch has been defined in Fig. 4, and was basis for generating 3D model of helical surface, as in Fig. 5.

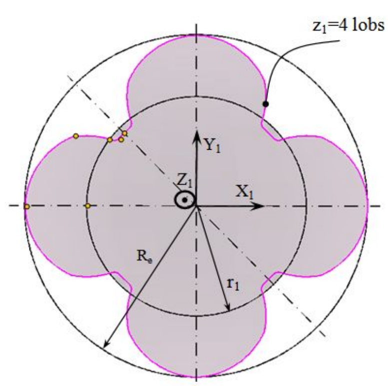

Fig.4. Male rotor front profile

3D model of the male rotor helical surface can be generated knowing the front profile, as we present in Fig.5.

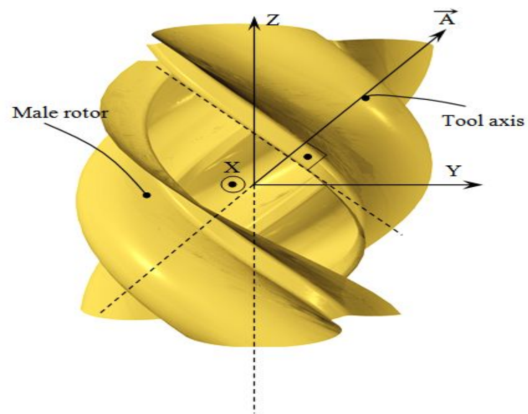

Fig.5. The 3D model of the male rotor helical surface

The position of axis belonging to the future disk tool has been defined as perpendicular on helix outer diameter of helical surface (Fig.6).

We defined the angle β of axis tool, $\vec{A}$, with the helical surface, in the reference system XYZ, related to (13).

The "minimum distance" theorem [3] formulates that the characteristic of helical surface in rotation around the axis of disk tool, $\vec{A}$, is the locus of points belonging to helical surface, to which the distance, considered in perpendicular plans to the revolution axis, to this axis, is minimum.

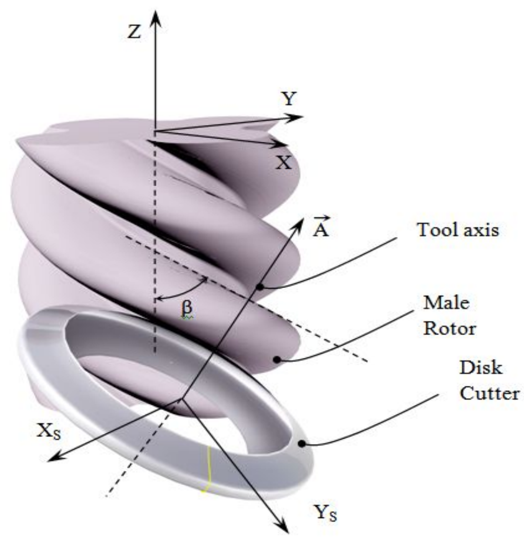

Fig.6.Tool axis position

The revolution surface (disk cutter), mutually envelope with one helical surface, cylindrical and constant pitch, is made up of the family circles, which have the common axis identical with the future tool axis.

The contact between a helical surface, cylindrical and constant pitch and a revolution surface (the primary peripherical surface of disk cutter) is based on the specific theorem [3].

VI. PROFLING THE DISK CUTTER BASED ON GRAPHICAL PRODEDURE

The 3D modelling of primary revolution surface of disk tool in AUTOCAD environment, is shown in Fig.7.

Table I describes the coordinates of the axial section of the disk tool which generates the helical grove of the male rotor.

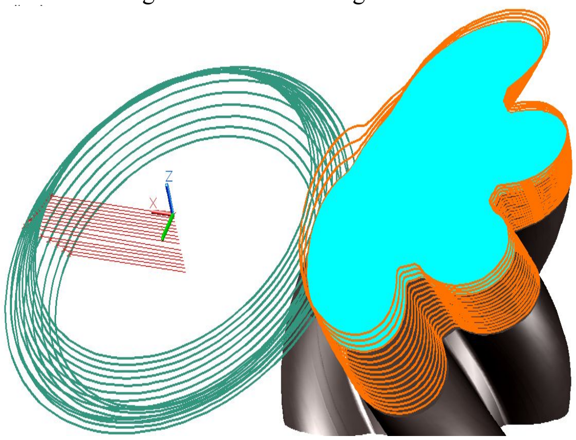

Fig.7. Male rotor solid and the revolution surface of disk cutter

TableI. The axial section coordinates of the disk cutter

R(mm)	49.1556	50.2371	…	48.4941	46.4847
Z(mm)	0	-1	…	-15	-16

AUTOCAD application description

We considered the 3D solid of the male rotor, shown in Fig. 7.

The succession of commands it will be as follows:

-UCS command for rotating the coordinates system with the complement of twist angle of the helix;

-SLICE command for determination the transverse plan;

-SECTION command for definition the intersection surface with the transverse plan;

-UCS command for the new coordinates system in the transverse plan;

-EXPLODE the section defined previously;

-CIRCLE command for determination the circles radius minimal and tangent to the curve-the minimum distance.

-Repeat the entire sequence above.

CONCLUSIONS

The proposed algorithm for the disk tool profiling generation of a rotor allows the determination the tool's axial section.

The paper consists in presentation in AUTOCAD environment, a graphical algorithm to profiling the disk cutter which generates the male rotor, screw compressor component; after parameterization of the tool, dimensions, and the helical surface, can be written a specific code in LISP, allowing the automatization.

Graphic interpretation of points is made with a polyline edited with Spline option. Increasing number of points leads to a polyline closer to the theoretical shape of the axial section of the tool.

The minimum distance method has been used, for both, the determination of male rotor transverse profile, and theoretical shape of the axial section of the tool. The 3D modelling of disk cutter, which generates the helical groove of rotor, was also achieved.

The graphical method allows to express an accurate and fast approach of the mutually envelope profiles, which are in rolling process.

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