MANUFACTURING TECHNOLOGY FOR A NEW TYPE OF PROFILED ROTOR USED BY A ROTATING VOLUMETRIC PUMP

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Abstract: *The paper presents the sketch and the functioning principle of the rotating volumetric pump; a computation relation is established for the theoretical volumetric flow transported by the pump. The paper presents a mathematical model that establishes the coordinates (x_i, y_i) of the outline of a profiled rotor. A software that computes these coordinates is developed for a series of rotor dimensions. Based on these coordinates, the 3D model of the rotor is built using the software package CATIA V5. An appropriate post-processor generates a NC Code program written in ISO language, in order to manufacture the rotor on a vertical CNC center. Finally, the operation sheet regarding the design and manufacturing of the profiled rotor is presented. The demonstration model of the profiled rotor will integrate the construction of a rotating volumetric pump.*

Key words: *rotating piston, profiled rotors, rotating pump.*

1. INTRODUCTION

Thermic and hydraulic rotating working machines have the main advantages:

- for a working machine (pump, fan, compressor), the motor torque transmitted to the machine shaft is fully used (except to the losses due to friction) for the increase of the pressure of the transported fluid;
- the flow rate of the transported fluid increases proportionally with the constructive dimensions and with the rotation speed of the machine;
- there are no valves or alternating rectilinear motions as in the case of piston machines;
- any fluid substance (pure liquids or liquids with suspensions, waste waters, water + ash, water + sand, pure gases or gases with particles in suspension, wet gases, vapors) will be transported from intake to discharge.

The constructive solution presented in continuation is original [1] considering the following aspects:

- as constructive solution, the shape of the rotors is based on a mathematical model;
- - as methodology of computation of the volumetric flow rate of the fluid transported by the pump and of its driving power.

Compared to other rotating working machines, this pump transports higher volumetric flow rates for the same constructive dimensions and the same rotation speed [2] .

A functional model of this pump was presented to the 55th World Exhibition of Innovation, Research and New Technology, Brussels, ”EUREKA 2006”, where it obtained a diploma and a gold medal.

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2. DESCRIPTION OF THE CONSTRUCTIVE SOLUTION AND ESTABLISHMENT OF THE FLOW RATE OF THE FLUID TRANSPORTED BY THE PUMP

The pump consists of two identical profiled rotors (*A*, *B*) which rotate with the same angular speed inside the half-cylinder casings (*C*, *D*) (Fig. 1).

The synchronous speed of the two motors is guaranteed by the use of two gear wheels which mesh, having the same dividing diameter, and which are mounted on the shafts (E, F) outside the pump [1].

The functioning principle of the rotating volumetric pump with two profiled rotors results from fig. 1.

The suctioned fluid (Fig. 1,a) is transported to the discharge and, after a 90° rotation of the two rotors, the systems arrives in the position depicted in Fig. 1,b.

The fluid contained in the available volume V_u (Fig. 1,b), that is the space between the pistons 3’ and 4’, will be transported to the discharge after a 180° rotation [3]:

$$V_u = \frac{\pi R_c^2 - \pi R_r^2}{2} \cdot l\,[m^3] \quad (1)$$

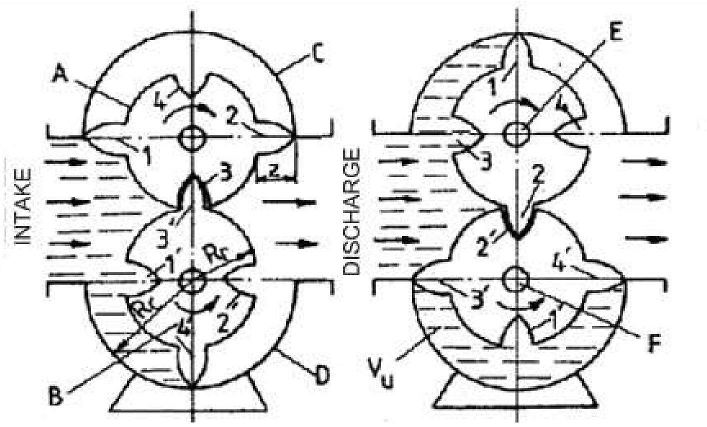
R_c – casing radius [m] ; R_r – rotor radius [m]; l – rotor length [m] (perpendicular on the plane of Fig. 1).

Two such volumes will be transported from intake to discharge during a complete rotation:

$$\dot{V}_u = \pi(R_c^2 - R_r^2)l\,[m^3/rot] \quad (2)$$

Because the casing radius (R_c) is the sum of the rotor radius (R_r) and piston height (z):

$$R_c = R_r + z\ , \quad (3)$$



a b

Fig. 1. Sketch of the rotating volumetric pump:
A, B – rotors; C, D – half-cylinders; E, F – shafts; 1, 2, 3’, 4’ – rotating pistons; 1’, 2’, 3, 4 – cavities in which penetrate the pistons of the adjacent rotor.

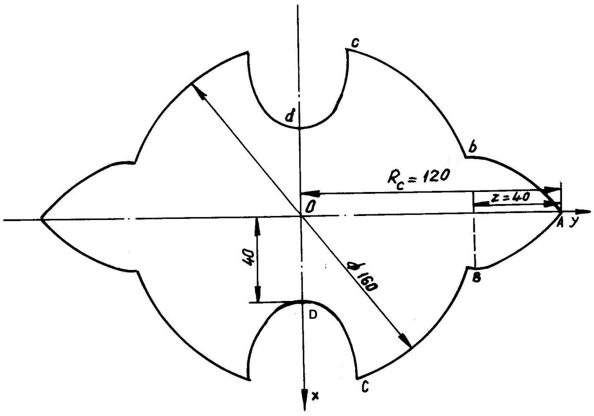


Fig. 2. View of a profiled rotor.

it is obtained that:

$$\dot{V}_u = \pi l z (z + 2R_r)[m^3/rot] . \qquad (4)$$

Because the pump has two identical rotors, the theoretical flow rate of the fluid will be equal to:

$$\dot{V}_t = 2\dot{V}_u \cdot \frac{n}{60} = \pi l z (z + 2R_r)\frac{n}{30}[m^3/s] . \qquad (5)$$

where : n – machine rotation speed [r.p.m.].

It can be noticed from (5) that the flow rate transported by the pump is directly proportional with l, R_r, n and the square of z.

3. THE COMPUTATION OF THE OUTLINE OF THE PROFILED ROTOR

Figure 2 presents in the horizontal plane the profiled rotor with the following dimensions [3]:

- Rotor radius $R_r = 80$ mm;
- Height of the rotating piston: $z = 40$ mm;
- Housing radius: $R_c = R_r + z = 80 + 40 = 120$ mm;
- Distance cavity shaft axle: 40 mm;
- Ratio $\frac{z}{R_c} = \frac{40}{120} = 0.33$

Both the rotating pistons and the cavities are established by a system of equations corresponding to the following zones:

Zone I: The curvilinear profile of the rotating piston A….B.

Zone II: The circular profile of the rotor *B….C*.

Zone III: The concavity profile *C…D*.

3.1. Establishing the coordinates (x_i, y_i) of the curvilinear profile of the piston (*A→B*)

The papers [3] and [4] present the mathematical model used in order to establish the computation relations of the coordinates (x_i, y_i) of the curvilinear path (AB) of the outline of the rotating piston.

Computation software was developed having the following inputs:

$R_c = 0.12$ m;

$z = 0.04$ m;

$R_r = 0.08$ m;

θ varying from 0° to 46.6° (0 to 0.8116 radians);

$\theta_2 = 17.5°$ (0.3054 radians).

The following formulas are applied for computing the coordinates [3, 4]:

$$x = \left[-\left(\frac{R_r}{\cos\theta} - R_r\right)\sin 2\theta\right]\cdot\cos\theta_2 - \left[-\left(\frac{R_r}{\cos\theta} - R_r\right)\cos 2\theta + \frac{R_r}{\cos\theta}\right]\cdot\sin\theta_2 ; \qquad (6)$$

$$y = -\left\{\begin{matrix}\left[-\left(\frac{R_r}{\cos\theta} - R_r\right)\sin 2\theta\right]\cdot\sin 2\theta_2 + \\ \left[-\left(\frac{R_r}{\cos\theta} - R_r\right)\cos 2\theta + \frac{R_r}{\cos\theta}\right]\cdot\cos\theta_2\end{matrix}\right\} ; \qquad (7)$$

Table 1 presents the coordinates (x_i, y_i) of the points that generate the curvilinear path A (point 1) → B (point 93), obtained by varying the angle θ with increments of 0.5°.

Table 1

The coordinates of the rotor outline points situated on the path A→B

No.	*x*	*y*	No.	*x*	*y*	No.	*x*	*y*
1(A)	0.00000	0.12000	42	0.02166	0.09231	83	0.02421	0.07702
2	0.00075	0.11923	43	0.02189	0.09173	84	0.02419	0.07689
3	0.00159	0.11855	44	0.02210	0.09116	85	0.02417	0.07678
4	0.00242	0.11787	45	0.02230	0.09060	86	0.02415	0.07668
5	0.00323	0.11718	46	0.02249	0.09004	87	0.02413	0.07659
6	0.00402	0.11648	47	0.02267	0.08950	88	0.02411	0.07651
7	0.00479	0.11579	48	0.02284	0.08896	89	0.02410	0.07644
8	0.0555	0.11509	49	0.02299	0.08843	90	0.02408	0.07639
9	0.00629	0.11439	50	0.02314	0.08791	91	0.02407	0.07635
10	0.00701	0.11369	51	0.02328	0.08740	92	0.02406	0.07632
11	0.00772	0.11299	52	0.02341	0.08690	93 (B)	0.02406	0.07630
12	0.00841	0.11229	53	0.02353	0.08642			
13	0.00908	0.11158	54	0.02364	0.08594			
14	0.00973	0.11088	55	0.02374	0.08547			
15	0.01037	0.11018	56	0.02383	0.08501			
16	0.01099	0.10947	57	0.02391	0.08456			
17	0.01159	0.10877	58	0.02399	0.08413			
18	0.01218	0.10807	59	0.02406	0.08370			
19	0.01275	0.10737	60	0.02412	0.08329			
20	0.01330	0.10667	61	0.02417	0.08289			
21	0.01384	0.10597	62	0.02422	0.08249			
22	0.01436	0.10528	63	0.02426	0.08211			
23	0.01487	0.10458	64	0.02429	0.08174			
24	0.01536	0.10389	65	0.02432	0.08139			
25	0.01583	0.10321	66	0.02435	0.08104			
26	0.01629	0.10252	67	0.02436	0.08071			
27	0.01673	0.10185	68	0.02438	0.08039			
28	0.01716	0.10117	69	0.02439	0.08008			
29	0.01757	0.10050	70	0.02439	0.07978			
30	0.01797	0.09984	71	0.02439	0.07949			
31	0.01835	0.09917	72	0.02439	0.07922			
32	0.01872	0.09852	73	0.02438	0.07896			
33	0.01908	0.09787	74	0.02437	0.07871			
34	0.01942	0.09723	75	0.02436	0.07847			
35	0.01974	0.09659	76	0.02435	0.07825			
36	0.02006	0.09596	77	0.02433	0.07803			
37	0.02036	0.09533	78	0.02431	0.07783			
38	0.02064	0.09471	79	0.02429	0.07765			
39	0.02092	0.09410	80	0.02427	0.07747			
40	0.02118	0.09350	81	0.02425	0.07731			
41	0.02143	0.09290	82	0.02423	0.07716			

3.2. Establishing the coordinates (x_i, y_i) of the circular path (*B*→*C*)

Use In order to find the coordinates (x_i;y_i) that generate the outline of the circular path *B*→*C* (Fig. 2) of the rotor, computation software was developed having the following inputs:

R_c = 0.12 m;
z = 0.04 m;
R_r = 0.08 m;

θ − varying from 17.5° to 72.5° (0.3054 to 1.265 radians).

The following formulas are applied for computing the coordinates of the profile [3, 4]:

$$x = R_r \cdot \sin\theta\,;$$
$$x = R_r \cdot \cos\theta\,;$$

The coordinates of the points from *B* (94) to *C* (150) are presented in Table 2.

Table 2

The coordinates of the rotor outline points situated on the path B →C

No.	*x*	*y*	No.	*x*	*y*	No.	*x*	*y*
94	0.02406	0.07630	116	0.05035	0.06217	138	0.06997	0.03878
95	0.02472	0.07608	117	0.05142	0.06128	139	0.07064	0.03756
96	0.02605	0.07564	118	0.05248	0.06038	140	0.07128	0.03632
97	0.02736	0.07518	119	0.05353	0.05945	141	0.07190	0.03507
98	0.02867	0.07469	120	0.05456	0.05852	142	0.07250	0.03381
99	0.02997	0.07417	121	0.05557	0.05755	143	0.07308	0.03254
100	0.03126	0.07364	122	0.05657	0.05657	144	0.07364	0.03126
101	0.03254	0.07308	123	0.05755	0.05557	145	0.07417	0.02997
102	0.03381	0.07250	124	0.05851	0.05456	146	0.07469	0.02867
103	0.03507	0.07190	125	0.05945	0.05353	147	0.07518	0.02736
104	0.03632	0.07128	126	0.06038	0.05248	148	0.07564	0.02605
105	0.03756	0.07064	127	0.06128	0.05142	149	0.07608	0.02472
106	0.03878	0.06997	128	0.06217	0.05035	150(C)	0.07630	0.02406
107	0.04000	0.06928	129	0.06304	0.04925			
108	0.04120	0.06857	130	0.06389	0.04815			
109	0.04239	0.06784	131	0.06472	0.04702			
110	0.04357	0.6709	132	0.06553	0.04589			
111	0.04474	0.06632	133	0.06632	0.04474			
112	0.04589	0.06553	134	0.06709	0.04357			
113	0.04702	0.06472	135	0.06784	0.04239			
114	0.04815	0.06389	136	0.06857	0.04120			
115	0.04925	0.06304	137	0.026928	0.04000			

3.3. Establishing the coordinates (x_i,y_i) of the cavity profile (path *C→D*)

For these coordinates, a mathematical model was elaborated [3, 4] and subsequently computation software was developed having the following inputs:

R_c = 0.12 m;

z = 0.04 m;

R_r = 0.08 m;

θ – varying from 0° to 29° (0 to 0.5061 radians).

The following formulas are applied for computing the coordinates of the profile [3, 4]:

$$x = -\left[2 \cdot \cos\theta \cdot \left(R_c \cdot \cos\theta - R_r\right) - R_c\right];$$

$$y = 2 \cdot \left(R_c \cdot \cos\theta - R_r\right) \cdot \sqrt{1 - \cos^2\theta}\ .$$

The coordinates of the points from *C* (151) to *D* (189) are presented in Table 3.

After establishing the whole set of coordinates, it can be noticed that, in the first quarter of the *xOy* plane (Fig. 2), the resulted outline is ABCD; the path *AbCd* is constructed symmetrically about the axis Oy (Fig. 1).

Table 3

The coordinates of the rotor outline points situated on the path C →D

No.	x	y	No.	x	y	No.	x	y
151	0.07635	0.02420	173	0.05204	0.01949	186	0.04044	0.04417
152	0.07417	0.02437	174	0.05063	0.01859	187	0.04019	0.00279
153	0.07203	0.02444	175	0.04929	0.01763	188	0.04005	0.00140
154	0.06993	0.02442	176	0.04804	0.01661	189(D)	0.04000	0.00000
155	0.06787	0.02431	177	0.04688	0.01554			
156	0.06587	0.02410	178	0.04580	0.01442			
157	0.06392	0.0238	179	0.04481	0.01326			
158	0.06203	0.02342	180	0.04390	0.01205			
159	0.06020	0.02296	181	0.04309	0.01081			
169	0.05843	0.02241	182	0.04237	0.00953			
170	0.05672	0.02179	183	0.04175	0.00822			
171	0.05509	0.02109	184	0.04131	0.00689			
172	0.05352	0.02032	185	0.04078	0.00554			

Subsequently the whole outline of the rotor is obtained by mirroring the outline *DCBAbcd* on the *Ox* axis [5, 6].

4. MANUFACTURING TECHNOLOGY OF THE PROFILED ROTOR

The following dimensions are given, according to [3]:

$R_r = 80$ mm;

$Z = 40$ mm;

$R_c = R_r + z = 120$ mm.

The CAD design, as well as the CAM manufacturing for the numerically-controlled machines with 3 to 5 axes, used the software package CATIA V5 [7, 8].

This software package features a powerful post-processing engine that covers the whole manufacturing process, starting from the generation of the processing tool path till the NC Code program generation. Based on the coordinates presented in Tables 1, 2 and 3, using the module Sketcher, the item “Point by Using Coordinates” is selected from the Profile toolbar. The points are inserted in the sketch via their Cartesian coordinates, as shown in Fig. 3.

The toolset Spline is used for joining the defined points. The Transformation tool, with the help of Symmetry commands, allows the complete definition of the rotor outline (Fig. 4).

The *Z*-axis extruding is achieved using a closed-contour sketched profile (Sketcher). The calling of the

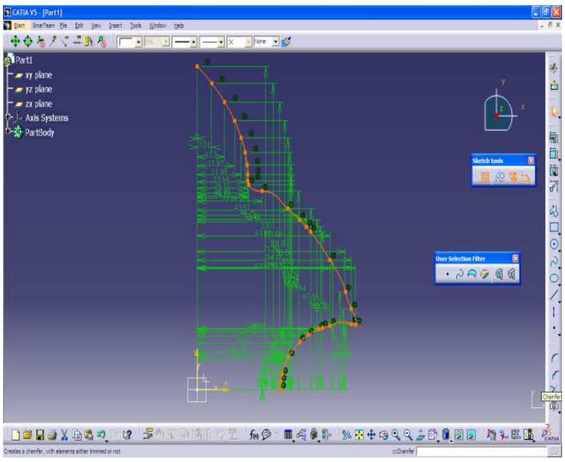


Fig. 3. Defining the outline via Cartesian coordinates and using the Spline application.

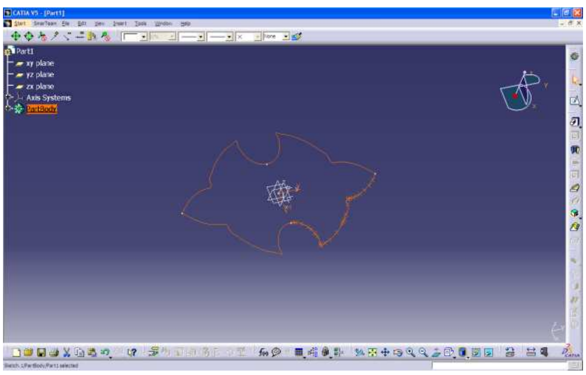


Fig. 4. Definition of the rotor profile.

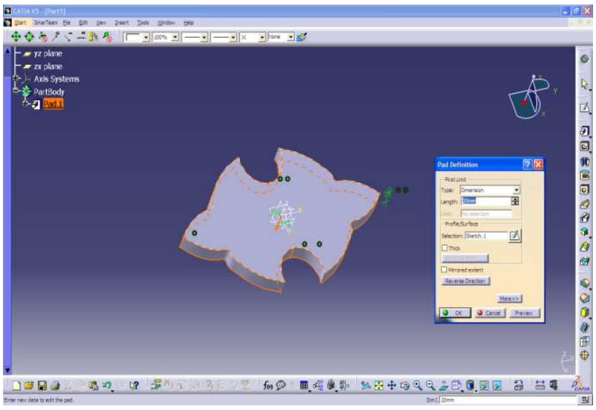


Fig. 5. The three-dimension model of the rotor created using the Pad option.

command “Pad Definition” allows the extruding in a direction normal to the sketch plane.

Another solution is the activation of the option “Mirrored extend” that leads to the extruding of the profile in both directions of the normal, as shown in Fig. 5.

After the definition of the rotor geometry, the working zone corresponding to the NC manufacturing process is opened in a CAT Product document that will initiate a new operation in the manufacturing process and will add a new entity to the structure Part Operation.

The operation parameters can be modified in the dialog box Part Operation, where the type of machine-tool can be chosen (Machine – editor) and the characteristic parameters of the processing machine are specified (numerical control parameters, rotation parameters, parameters corresponding to the tool changing process etc.) (Fig. 6).

In order to associate a reference axis to the manufacturing system during the operation, the icon “Machine axis” is activated.

The “Product” icon is pressed in order to associate an existing product to a certain operation.

The module “Manufacturing Program” allows defining of distinct technological operations in function of the surface category and of the type of processing (roughing or finishing).

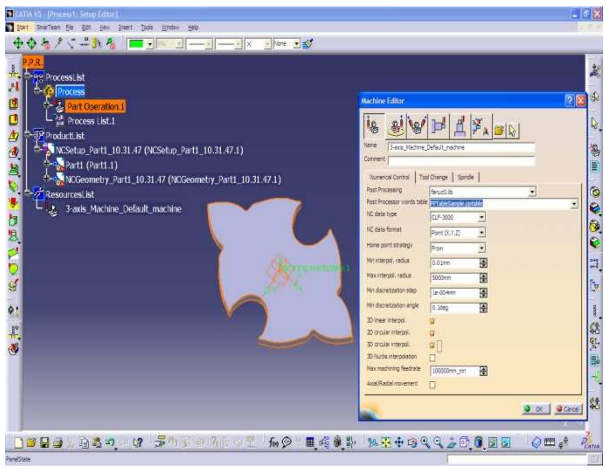


Fig. 6. Selecting the type of processing machine in function of the axis number.

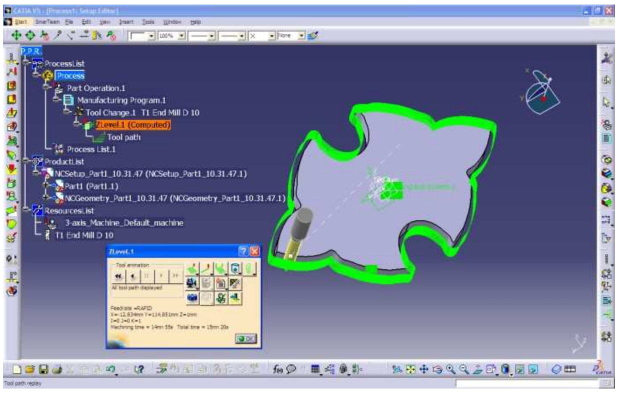


Fig. 7. Simulation of the milling operation using the Video module.

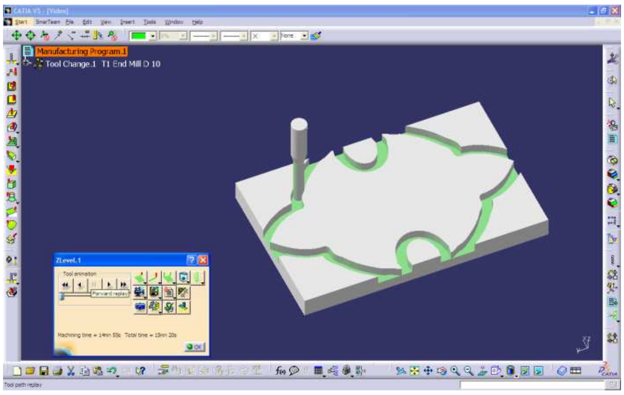


Fig. 8. Processing tool trajectories, using the Photo module.

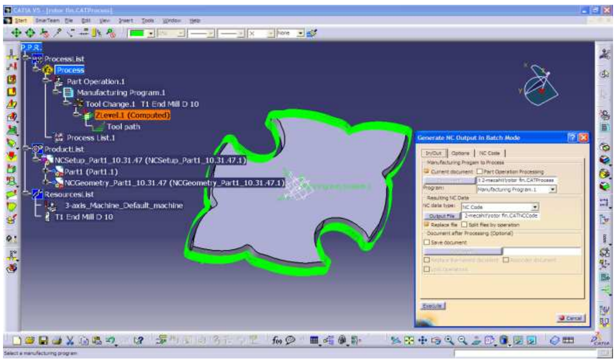


Fig. 9. Generation of the NC Code program.

According to the geometric features of the rotor, the option ZLevel is chosen (manufacturing of a vertical surface) with a Ø10 cylindrical mill (Fig. 7).

When the icon "Generate NC Code" is activated, the machine code needed for the manufacturing process is generated. The active window presented in Fig. 8 is opened. The document CAT Process is selected from the page IN/OUT. The path of the file that will be generated (Output File) is specified. The item "NC Code" is selected from the menu "Data Type". The type of the post-processor corresponding to the numerical control manufacturing center (Fanuc 0) is selected from the page "NC Code" (Fig. 9, Table 4).

Table 4

Example of a program written in NC Code.

%2000 (rotor) N1 M6T1 N2 G54G90S2000M3 N3 G1G43H#4120Z259F3000 N4 X-12.8343 Y114.851 N5 G43 Z9. H1 N6 G1 Z-1.F300. N7 X-9.7161Y118.0405 F1000 …………………………	………………………… N7016 X-20.6757 Y104.9852 N7017 X-18.4829 Y108.1293 N7018 X-15.7126 Y111.6066 N7019 X-12.8343 Y114.851 N7020 Z-40. N7021 G0 Z1. N7022 M30 %

5. CONCLUSIONS

In the case of this type of rotating volumetric pump, the volumetric flow rate of the transported fluid is influenced by the following factors:

- constructive parameters: *l*, *z*, R_r;
- functional parameters : *n*.

The constructive solution is simple and can be used for the transport of oil products. The pump can be used for the transport of waste waters and of polyphase fluids.

The pump can be easily achieved because the manufacturing technology of the rotors and casing is based on a CNC program; the parts are manufactured on a CNC centre.

This type of rotating machine has real advantages compared to other types of profiled rotor machines.

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