Influence of the Rotating Piston Shape on the Flow Rate of a New Type of Rotating Working Machine

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Abstract: *The paper presents a new constructive solution for a rotating pump that contains two profiled rotors; each rotor has two pistons that may be triangular or curvilinear (oval). The area difference of the two pistons in a cross section is calculated; there is a difference in area which at each piston rotation, will reduce the flow rate circulated by the curved pistons.*

Keywords: *Rotating volumetric pump, profiled rotor, pistons.*

1. Introduction

At piston machines, the reciprocating motion of the piston is converted to rotation motion through a crank-rod mechanism; this mechanism generates energy losses due to frictions occurring during its operation. Researcher's attention is directed toward eliminating this mechanism by constructing rotating machines which operates both as motor machines (rotating thermal motors) and as working machines (pumps, fans, compressors).
Researches in the field of rotating machines extend in the sense that these machines transform a form of energy into another form of energy with minimal losses; in these machines there are no alternative rectilinear motion, there are no valves.
A more difficult problem is to produce a rotating machine that can be used as a working machine or a force machine, i.e. theoretically a "reversible" machine [1].
Such a type of machine must ensure:
- transforming the useful moment with minimal loss when operates as a working machine.
- the full use of the energy of the working agent to drive the shaft when it is working as a power machine.

The term "working machine" in the article title refers to the fact that this type of machine can function as a pump, fan, or low-pressure compressor, i.e. the machine can deliver liquids or gases with or without suspensions. In this paper, the operation of the working machine is analysed only as a volumetric pump with profiled rotors.

2. The construction solution and the operating principle of the rotating volumetric pump

The machine (fig.1) has two identical profiled rotors (2, 5) of special shape which rotate with the same speed within a case (1, 4). The synchronous rotation of the two rotors is provided by a cylindrical gear consisting of two inclined gearwheels located inside or outside the machine.
The gearwheels have the same division diameter and are mounted on shafts 7 and 9; it provide a rotational movement so that the rotating pistons (6) of the upper rotor penetrate into the cavities (10) of the lower rotor.

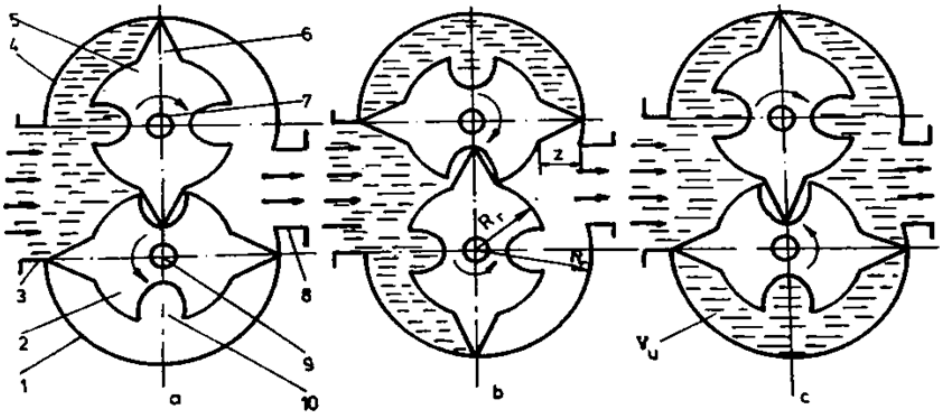

Fig. 1. The operating principle of the rotating volumetric machine
a,b, c, the rotors position after a 90° rotation
1- lower case; 2- lower rotor; 3-sucction chamber; 4- upper case; 5-upper rotor; 6- rotating piston; 7-driven shaft; 8- discharge chamber; 9-driving shaft; 10-cavity in which the upper rotor piston enters

From Figure 1 one can observe that at a 360° rotation of one of the shafts two such volumes will be transported from the suction to the discharge [2]:

$$V_u = \left(\pi \cdot R_c^2 - \pi \cdot R_r^2\right) \cdot l \ [m^3 / rot] \quad (1)$$

where: R_c- case radius [m]; R_r- rotor radius [m]; l- rotor length [m].
Replacing $R_c = R_r + z$, where z is the height of the rotating piston results:

$$V_u = \pi l z \cdot \left(2R_r + z\right) [m^3 / rot] \quad (2)$$

The volumetric flow rate of fluid delivered by a rotor will be:

$$\dot{V} = \pi \cdot l \cdot z\left(2R_r + z\right) \cdot \frac{n}{60} \ \left[m^3 / s\right] \quad (3)$$

where: n - machine speed [rot / min];
For the entire machine, which has two identical rotors, the flow rate will be:

$$\dot{V} = 2 \cdot \dot{V} = \pi \cdot l \cdot z\left(2R_r + z\right) \cdot \frac{n}{30} \ \left[m^3 / s\right] \quad (4)$$

The theoretical power required to drive the machine will be [2]:

$$P_m = \dot{V}_m \cdot \Delta p \left[W\right] \quad (5)$$

where: $\Delta p = p_r - p_a$ [N/m^2]
p_r-pressure to discharge; p_a - suction pressure.
From equation (4) one can observe that:
- the volumetric flow rate increases linearly with the rotor length, the rotor radius (l, R_r) and the speed (n);
- the volumetric flow rate increases with the square of the piston height (z).

From Figure 1 one can observe that the shape of the rotating piston also influences the volumetric flow rate through the value of V_u; the rotating piston may have the form of a triangle as in Figure 1 or may be curvilinear (Figure 2).

3. Analysis of the shape of the rotating piston

The rotating piston may be in the form of a blade (Figure 2.a), a triangle (Figure 2.b), or it may be curvilinear (Figure 2.c).

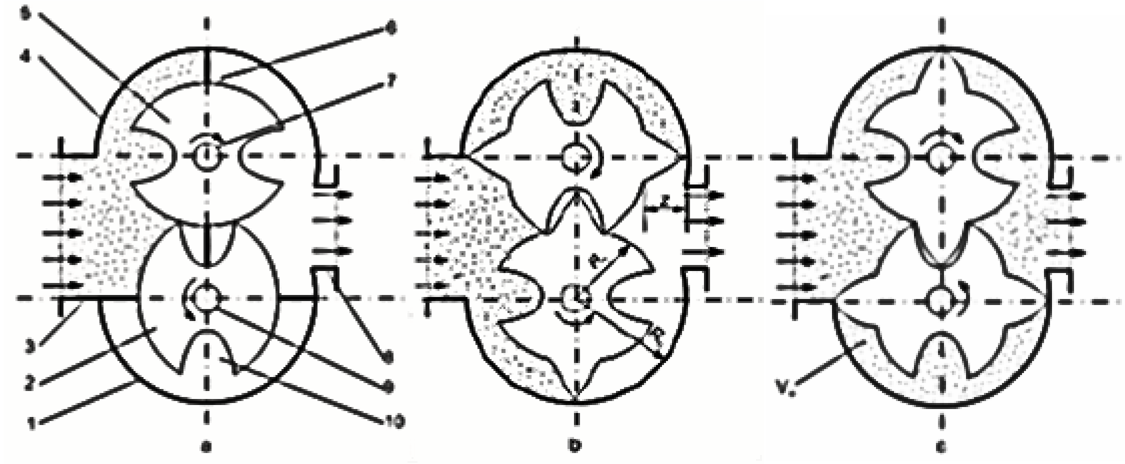

Fig. 2. Section through the rotating machine.
1- lower case; 2- lower rotor; 3-sucction chamber; 4- upper case; 5-upper rotor; 6- rotating piston; 7-driven shaft; 8- discharge chamber; 9-driving shaft; 10-cavity in which the upper rotor piston enters

Blade -type pistons do not withstand high working pressures, therefore, in the analysis of the shape of the rotating piston, the triangular and curvilinear pistons are more robust [3].
Figure 3 shows a section through a portion of the upper rotor in which a triangular piston is attached; with dashed line the curvilinear piston is drawn.
The figure shows that the area of the curvilinear piston section is greater than the area of the triangular piston; as a result, there will be a difference in the flow rate from the rotating machine.
The main dimensions of the profiled rotors are (Figure 3):
- Rotor radius: $R_r = 50mm$;
- Height of the rotating piston: z = 30mm;
- Case radius: $R_c = 80mm$;
- Rotor length: l = 50mm;
- Diameter of the driven shaft on the rotor mounting area: d = 30mm.

In rotational motion, the pistons of a rotor penetrate into the adjacent rotor cavities.
Both rotating pistons and cavities have a special shape determined on the basis of mathematical equations; these equations have been established by the research team as a result of numerous efforts.
Based on these equations, the profile contour coordinates were established in the xOy axis system; this allows the construction of rotors on C.N.C.

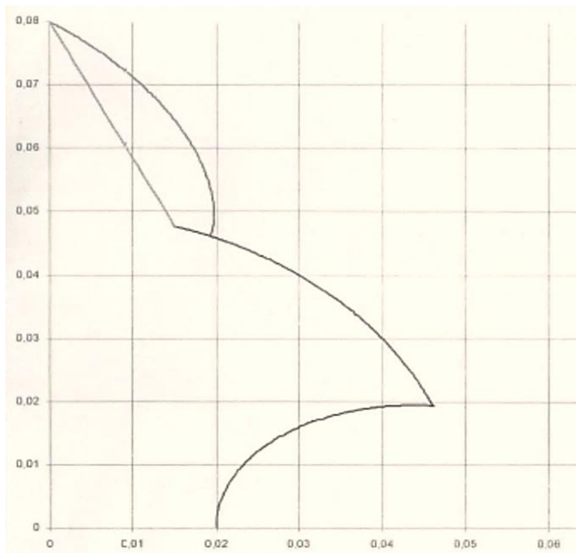

Fig. 3. The contour of a piston quarter

Figure 3 shows the contour of a piston quarter in both studied versions:
A. Triangular profile;
B. Curvilinear profile;

4. Computation of the section area of the triangular and curvilinear piston

In order to establish the rotor contour, a series of different mathematical relations were developed on the three rotor portions (Figure 4):
- contour of the curvilinear piston (A, B)
- the contour of the circular portion (B, C)
- the outline of the cavity in the rotor (C, D)

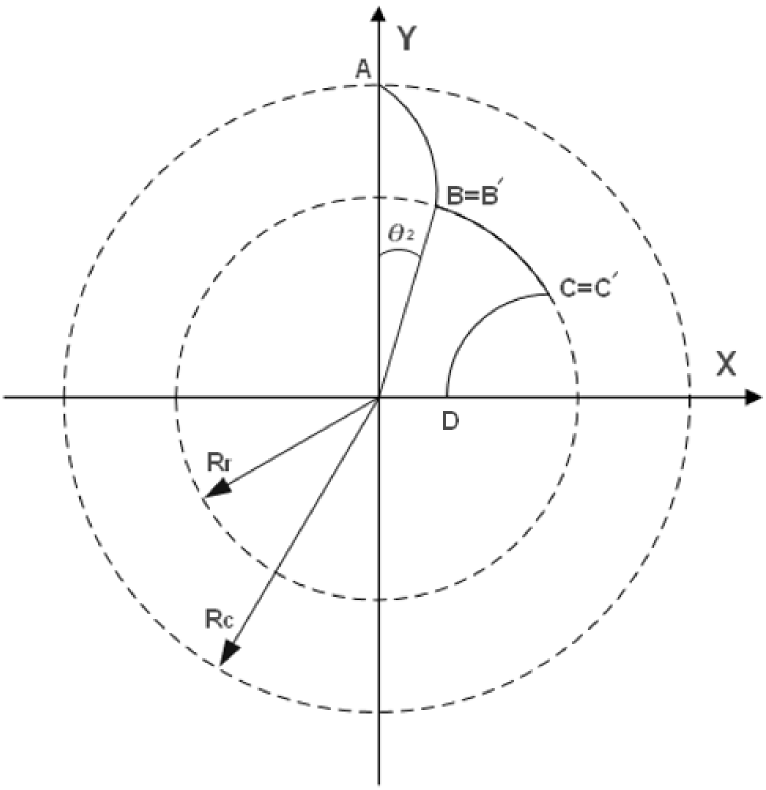

Fig. 4. Computing notations

A computational program [4] [5] was developed, resulting the coordinates (x_i y_i) of the curvilinear piston contour.
Data calculated in meters with an accuracy of five decimal are specified in Table 1.

Table 1: Calculated data

No.	x	y	No.	x	y	No.	x	y
1(A)	0,00	0,08	42	0,01684	0,06112	83	0,01967	0,04793
2	0.00049	0,07964	43	0,01704	0,06069	84	0,01956	0,04776
3	0,00111	0,07921	44	0,01723	0,06026	85	0,01963	0,04761
4	0,00172	0,07876	45	0,01742	0,05984	86	0,01961	0,04746
5	0,00232	0,07832	46	0,01759	0,05942	87	0,01959	0,04732
6	0,00291	0,07787	47	0,01776	0,059	88	0,01956	0,04719
7	0,00349	0,07742	48	0,01792	0,05859	89	0,01954	0,04707

8	0,00406	0,07696	49	0,01807	0,05818	90	0,01952	0,04695
9	0,00461	0,0765	50	0,01821	0,05778	91	0,0195	0,04684
10	0,00516	0,07604	51	0,01835	0,05739	92	0,01947	0,04674
11	0,00569	0,07558	52	0,01848	0,057	93	0,01945	0,04665
12	0,00621	0,07511	53	0,0186	0,05661	94	0,01943	0,04657
13	0,00672	0,07464	54	0,01871	0,05623	95	0,01941	0,04649
14	0,00722	0,07417	55	0,01882	0,05586	96	0,01939	0,04642
15	0,00771	0,0737	56	0,01892	0,05549	97	0,01937	0,04636
16	0,00818	0,07323	57	0,01901	0,05513	98	0,01936	0,0463
17	0,00865	0,07275	58	0,0191	0,05477	99	0,01934	0,04626
18	0,0091	0,07228	59	0,01918	0,05442	100	0,01933	0,04622
19	0,00954	0,0718	60	0,01925	0,05408	101	0,01932	0,04618
20	0,00998	0,07132	61	0,01932	0,05374	102	0,01931	0,04616
21	0,0104	0,07085	62	0,01938	0,05341	103	0,01930	0,04614
22	0,01081	0,07037	63	0,01944	0,05308	104(B)	0,01929	0,04613
23	0,01121	0,06989	64	0,01949	0,05277			
24	0,01159	0,06942	65	0,01954	0,05246			
25	0,01197	0,06894	66	0,01958	0,05215			
26	0,01234	0,06846	67	0,01965	0,05156			
27	0,01269	0,06799	68	0,01967	0,05128			
28	0,01304	0,06752	69	0,0197	0,051			
29	0,01338	0,06704	70	0,01971	0,05074			
30	0,0137	0,06657	71	0,01973	0,05047			
31	0,01402	0,06611	72	0,01974	0,05022			
32	0,01432	0,06564	73	0,01975	0,04997			
33	0,01462	0,06518	74	0,01975	0,04974			
34	0,0149	0,06471	75	0,01975	0,0495			
35	0,01518	0,06425	76	0,01975	0,04928			
36	0,01544	0,0638	77	0,01974	0,04906			
37	0,0157	0,06334	78	0,01974	0,04885			
38	0,01595	0,06289	79	0,01973	0,04865			
39	0,01618	0,06244	80	0,01972	0,04846			
40	0,01641	0,062	81	0,0197	0,04827			
41	0,01663	0,06156	82	0,01969	0,0481			

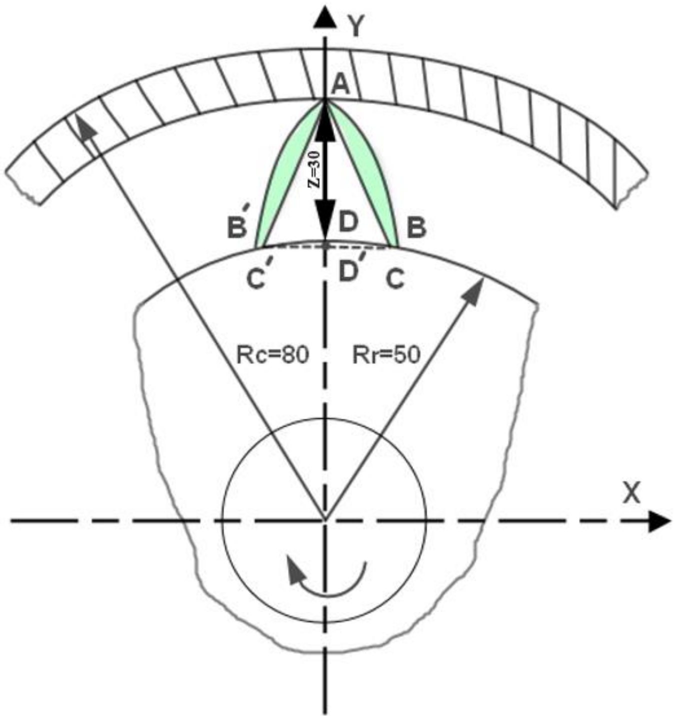

Fig. 5. Computing notations

For triangular piston:
A (x = 0; y = 80)
C (x = 15.8; y = 47.64); C '(x = -15.8; y = 47.64)
For the curvilinear piston:
A (x = 0; y = 80)
B (x = 19.29; y = 46.13); B '(x = -19.29; y = 46.13)
R_c - case radius: R_c = 80 mm
R_r - rotor radius: R_r = 50 mm
z - piston height: z = 30 mm
• For the triangular piston, approximating the BB 'circular arc with a straight line, the section area will be [6][7]:

$$A_{tr} = \frac{BB' \cdot AD}{2} = \frac{31.6 \cdot 30}{2} = 474 \left[mm^2 \right] \qquad (6)$$

• For the curvilinear plunger, in a first approximation, it is considered as an C'AC triangle of area:

$$A_{curb} = \frac{CC' \cdot AD}{2} = \frac{38.58 \cdot 33.87}{2} = 653.35 \left[mm^2 \right] \qquad (7)$$

CC' = 38 .58 mm; AD= 80-46.13=33.87 mm^2
The difference between the two areas is:

$$A_{curb} - A_{tr} = 653.35 - 474 = 179.35 \text{ mm}^2$$

If the piston has a length of 50 mm, the volume difference between the pistons will be:

$$\Delta V_1 = 1\ (A_{curb} - A_{tr}) = 50\ (179.35) = 8967.61 \text{ mm}^3$$

This difference occurs for a rotor rotation of 180^0; for a complete rotation:

$$\Delta V_1 = 28967.61 = 17935.23 \text{ mm}^3\text{/ rot}$$

$$\Delta V_1 = 0.017935 \text{ m}^3\text{/ rot}$$

For a more accurate calculation of the section area of the curvilinear piston, the "trapezoidal method" mathematical analysis is used.
The calculation points in Table 2 are chosen for 0,10,20,30 ...... 100,104 and shall be calculated as follows:

$$A_{20-30} = \frac{9.98+13.70}{2}(7.18-6.65) = 62.75 \left[mm^2\right] \quad (8)$$

Table 2: Calculation points

$A_{0,10}$	$A_{10,20}$	A_{20-30}	A_{30-40}	A_{40-50}	A_{50-60}	A_{60-70}	A_{70-80}	A_{80-90}	A_{90-100}	$A_{100-104}$
10.32	31.79	62.75	67.72	73.04	70.05	65. 06	39.02	29.62	14.17	1.73

TOTAL: A = 465.27 mm^2, for 1/2 for the area of the curvilinear piston.

$$A_{curb} = 2 \cdot 465.27 = 930.54\ mm^2$$

A difference in area of:

$$\Delta A = 930.54 - 474 = 456.54\ mm^2$$

$$\Delta V_2 = \Delta A \cdot l = 456,54 \cdot 50 = 22827\ mm^2/rot$$

$$\Delta V_2 = 0.0228\ m^3/rot$$

5. Conclusions

From the above calculations, the versions of the rotating piston used to increase the flow rate of the fluid are:

- $\Delta V_2 > \Delta V_1$
- Curved piston rotor
- Triangular piston rotor
- A blade type piston rotor

The advantages of this new type of machine are:

a. The construction solution can be made as follows:
- As working machine: pump, fan, blower;
- As a power machine: steam or combustion engine, pneumatic engine, hydrostatic engine.

b. When operating as a pump, this solution eliminates the disadvantages of other types of rotating pumps (gearwheels, pallet) in which the conveyed fluid must be free of solid particles; this type of rotating volumetric pump has no valves and can be used for the following fluids: with impurities, viscous fluids, rheological fluids, wastewater.

c. The rotating machine construction solution allows its use as a fan or blower for the transport of dry or wet gases.

d. Used as a blower this machine is more advantageous than the Roots compressor.

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