Determination of Energy Performance for a New Type of a Rotating Machine That Transports Fluids

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Abstract: *The paper presents a mathematical model of establishment for a constructive solution regarding:*
- the maximum flow rate transported by the machine;
- the power required to drive this machine, which is a volumetric pump with two specially processed rotors.
The aspects regarding the transport of multiphase fluids and the advantages of using this rotating machine are revealed.

Keywords: *Rotating machine, profiled rotor, rotating piston, volumetric pump*

1. Introduction

A current direction of research is to improve the performance of rotating machine that carry fluids. Optimizing the interior architecture of work machines is a very important issue, a problem studied both in our country and abroad.
Currently, existing machines in the art evolve over time to flow rate configurations that make them as imperfect as possible [1], [2].
Both motor and work machines evolve over time in the following direction:
- For motor machines, the aim is to produce the maximum mechanical work yielded outside.
- For work machines, the minimum consumption of mechanical work from the outside is sought.
For rotating work machines with profiled rotors, the problem regarding the architecture of the rotor is the optimization of its geometry and the choice of parameters that lead to a more efficient fluid transport.
Minimizing the drive power of volumetric rotor machines and finding a new profiled rotor architecture are key elements in designing and designing a new rotating machine.
The machines are aggregates used for the transformation of energies from one form to another with the help of a movable organ which can be: profiled rotor, piston, and blade.
Depending on their required purpose, the machines can be classified into two categories [3], [4]:
1. Power machines (motor machines) that convert a certain form of energy into mechanical energy; for example: internal combustion engines, steam turbines, gas turbines, etc.
2. Working machines that convert mechanical energy into another form of energy, for example: pumps, fans, compressors.
Both power and working machines are traversed by fluids; according to the flow variation parameters, they are classified as follows (table 1):
a. Hydraulic machines that drive or are driven by fluids, neglecting thermal phenomena.
b. Thermal machines that carry gases or vapors (or are driven by them) in which the thermal processes that occur cannot be neglected.
The achievement of high performance rotating machines (pumps, fans, blowers) is topical.
The researches aims to build machines to ensure the transformation of the motor moment received from the shaft into useful effects, but with small energy losses.
Table 1 presents the classification of rotating machines with profiled rotors according to the purpose pursued and the adopted constructive solution [5], [6].
Table 2 shows the rotating pumps in the category of rotating work machines for fluid conveyance.

Table 1. Classification of rotating machines with profiled rotors.

Working machines	Pumps for driving fluids or with suspensions
	Fans for transporting gases or vapors
	Blowers for gas and vapor compression
Force machines	Hydraulic motor
	Pneumatic motor
	Steam engine or combustion gases

Table 2. Pump categories

Volumetric pumps	Piston pumps	a) Single cylinder pumps
		b) Poly Cylinder pumps
		c) Axial piston pumps
	Rotating pumps	d) Blade pumps
		e) Gear pumps
		f) Screw pumps
		g) Lobe pumps
Non - volumetric pumps	Centrifugal pumps	
	Axial pumps	

A more difficult problem is to make a rotating machine that can be used as a working machine or a force machine that is theoretically a "reversible" machine.
Such a machine must provide:

- transforming the useful moment with minimal losses when it works as a working machine.
- maximum use of the energy of the working agent for shaft actuation when it is working as a force machine.

2. Determination of the maximum flow rate of fluid conveyed for a certain constructive solution

The machine consists of two identical rotors (3, 4) of special shape, which rotate at the same speed inside some casings (2, 5); the synchronous rotation of the two rotors is ensured by a cylindrical gear consisting of two toothed gear wheels with inclined teeth, located inside or outside the machine. The gears have the same diameter of division and are mounted on shafts 7 and 8; they provide a rotation motion so that the rotating pistons (6) of the upper rotor enters into the cavities (10) of the lower rotor.
The fluid in the chamber (1) is taken up by the rotating pistons (6) and transported to the discharge chamber (9).

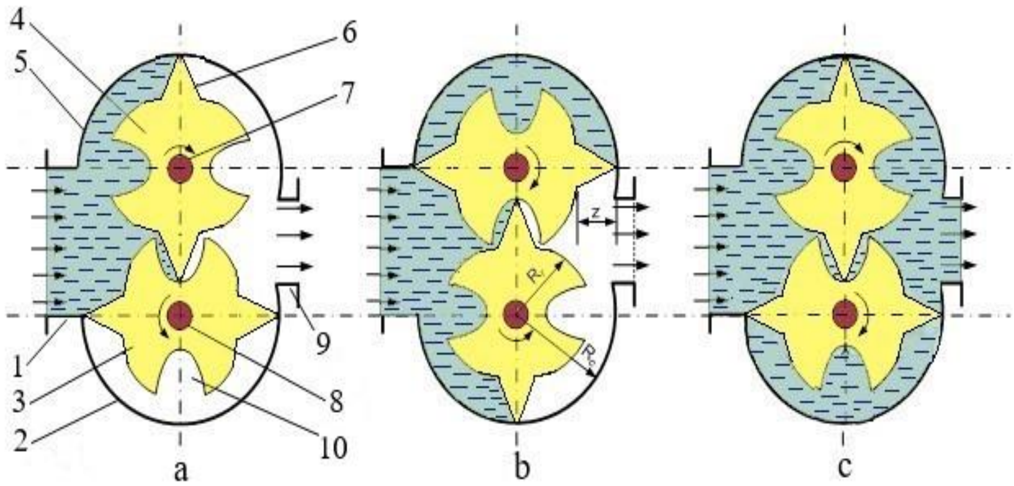

Fig. 1. The operating principle of the rotating volumetric machine
1 - suction chamber; 2 - lower casing; 3 - lower rotor; 4 - upper rotor; 5 - upper casing; 6 - rotating piston; 7 - driven shaft; 8 - discharge chamber; 9 - driving shaft; 10 - cavity in which the upper rotor piston enters

The constructive solution shown in figure 1 ensures a good resistance of the piston and two sealing areas: between the tip of the piston and the inside of the housing and between the tip of the piston and the cavity.

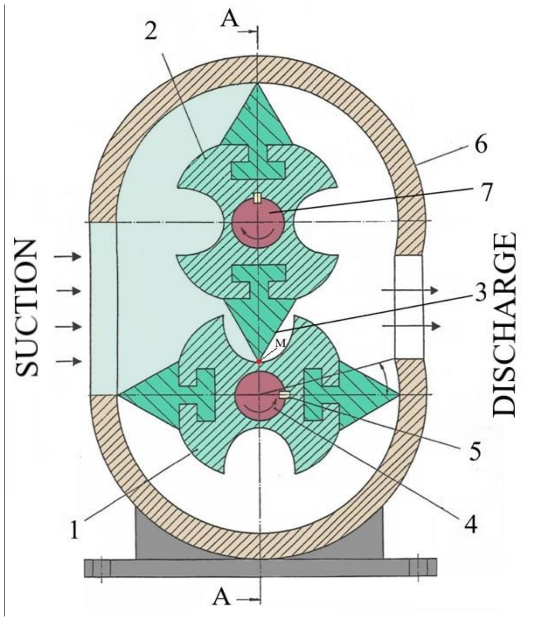

Fig. 2. Cross section through the rotating machine
1 - lower rotor; 2 – upper rotor; 3 - triangular piston; 4 - shaft; 5 - rectangular wedge; 6 - machine casing

Figure 2 shows that between the upper rotor (2) and the lower rotor (1) there is only one contact point noted with M; if the piston (3) is built with a larger base, it will lock in the cavity in the rotor (1). The fluid entering the suction chamber (4) is transported to the discharge chamber (9) by the rotating pistons (3, 6). Figure 3 shows the fluid flow after a 90 ° rotation of the two rotors. The useful volume of the fluid conveyed V_u is between the two rotating pistons and the lower housing. Figure 3 shows a cross section through the rotating machine [6], [7].

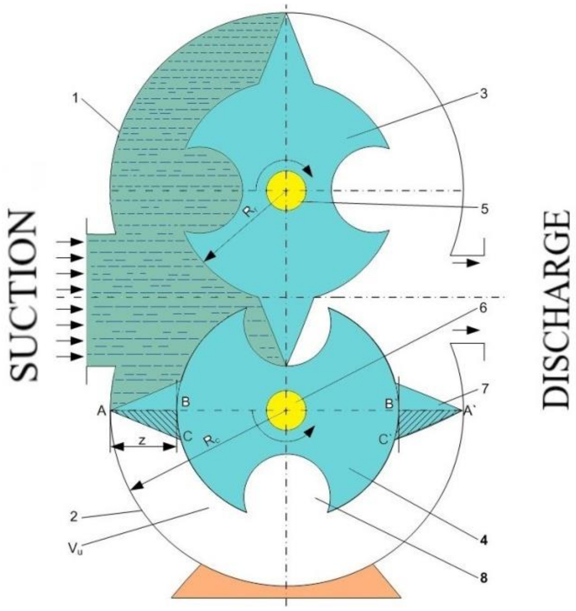

Fig. 3. Cross section through the rotating working machine
1 - upper casing; 2 - lower casing; 3 - upper rotor; 4 - lower rotor; 5,6 - shaft;
7 - rotating piston; 8 - cavity in which the upper rotor piston enters

Figure 3 shows that the useful volume V_u is reduced by the volumes of the prisms ABC and A'B'C'; the two equal prisms give the volume of a piston of triangular section, with the following dimensions: height: z = 30 [mm]; base: b = 30 [mm]; length: l = 50 [mm].

Neglecting the area of the section between the base of the prism and the rotor, the volume of the prism will be

$$V_p = A_{base} \cdot l = \frac{1}{2} \cdot b \cdot z \cdot l = \frac{1}{2} \cdot 0.03 \cdot 0.03 \cdot 0.05; \qquad V_p = 0.0225 \cdot 10^{-3} \quad [m^3/rev] \tag{1}$$

Theoretical flow rate of the machine with triangular pistons $\dot{V} = \pi l z (z + 2R_r) \cdot \frac{n_r}{30}$ [m³/s] will be reduced by V_p.
where: V_p - the prism volume of a piston of triangular section.
The volumetric flow rate of fluid conveyed by a single rotor of length l [m] and speed n_r [rev/min] will be

$$\dot{V}_u = \left[\pi l z \left(z + 2R_r \right) - V_p \right] \quad [m^3/rev]. \tag{2}$$

The rotating machine has two identical rotors, so the fluid flow rate will be:

$$\dot{V} = \left[\pi l z (z + 2R_r) - \frac{1}{2} b z l \right] \cdot \frac{n_r}{30} \quad [m^3/s], \tag{3}$$

$$V = \left[\pi \cdot 0.05 \cdot 0.03 (0.03 + 2 \cdot 0.05) - \frac{1}{2} \cdot 0.03 \cdot 0.03 \cdot 0.05 \right] \cdot \frac{500}{30} \tag{4}$$

$$V = 0.00983\ [m^3/s] = 35.388 [m^3/h] \tag{5}$$

Table 3. Values $\dot{V} = f(n_r)$

n_r [rev/min]	100	200	300	400	500
$\dot{V}$ [m³/s]	0.001966	0.003932	0.005898	0.007864	0.00983
$\dot{V}$ [m³/h]	7.0776	14.1552	21.2328	28.3104	35.388

3. Mathematical determination of the relationship between the rotor radius and the height of the rotating piston

The main dimensions of the pump, which has two identical rotors, must first be determined; must be known [7], [8]: *l* - rotor length [m]; R_r - rotor radius [m]; *z* - height of the rotating piston [m].
The radius of the housing R_c results from the sum of the radius of the rotor R_r and the height of the piston *z* (figure 1).
What is the connection between z and R_r? How big can *z* be in relation to R_r?
To solve this problem we will consider a single piston (5) fixed to the lower rotor (figure 4).
The rotor radius (1) is extended by a length (*z*) and thus the line *01B* reaches the rotor (2) at point *A*. Theoretically, when point *K* reaches point *D*, point A reaches *K*, respectively point *N* reaches *K*, because the length of the circle arcs *AK*, *KD* and *KN* is the same. When the piston (5) exits the gap created in the rotor (2), points *A* and *N* reach point *K*; the sealing between the two rotors being ensured by the direct contact between the lateral surfaces of the rotors.
From the rectangular triangle O_1O_2A results:

$$O_1O_2^2 = AO_2^2 + AO_1^2 \tag{6}$$

$$(2R_r)^2 = R_r^2 + (R_r + z)^2 \tag{7}$$

relations that becomes:

$$z^2+2R_r z - 2R_r^2=0 \quad (8)$$

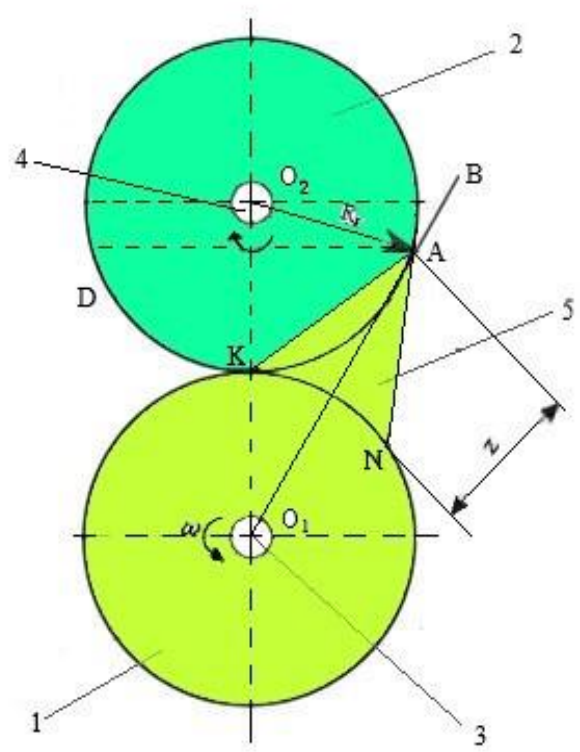

Fig. 4. Calculation notations.
1 - lower rotor; 2 - upper rotor; 3 - driving shaft;
4 - driven shaft; 5 - rotating piston of triangular shape [9]

4. Determination of the driving power of the rotating machine with profiled rotors

For calculating the driving power of the rotating machine, it is known from the literature [13]:

$$P = \dot{V} \cdot \Delta p \ \text{[W]}, \quad (9)$$

where Δp – pressure increase [N/m^2], $\Delta p = \rho g H$ [N/m^2];
H – pumping height [m];
ρ_l – the density of the conveyed fluid [kg/m^3].
In the next paragraph we will analyze this relationship.
Analyzing the formula of the volume flow circulated by the rotating machine:

$$\dot{V}_u = \left[\pi l z\left(z+2R_r\right)-V_p\right]\cdot\frac{n_r}{30} \quad \text{[m}^3\text{/s]} \quad (10)$$

and the driving power of the rotating machine:

$$P = \dot{V} \cdot \Delta p = \left[\pi \cdot l \cdot z \cdot (z+2R_r)\cdot\frac{n_r}{30} - V_p\right]\cdot \Delta p \ \text{[W]}. \quad (11)$$

it is found that the volume flow rate $\dot{V}$ and the driving power *P* of the rotating machine are influenced by the constructive parameters (rotor length, piston height, rotor radius) and functional parameters (rotating machine speed, pressure increase).
From the relationship: $R_c = R_r + z$ [m], it is replaced in the relationship (11): $R_r = R_c - z$ [m] and it results

$$P = \left[\pi l \left(2R_c \cdot z - z^2 \right) - V_p \right] \cdot \frac{n_r}{30} \cdot \Delta p \quad \text{[W]} \tag{12}$$

$$P_H = 0.00983 \cdot 0.3924 \cdot 10^5 = 385.729 \quad [W]. \tag{13}$$

Neglect the volume of the piston prism, perform the function derivative and equal 0.

$$P'(z) = 0 \Rightarrow 2R_c - 2z = 0 \tag{14}$$

It results

$$z = R_c . \tag{15}$$

In conclusion, the driving power of the machine is maximum when $z = R_c$ (figure 5).

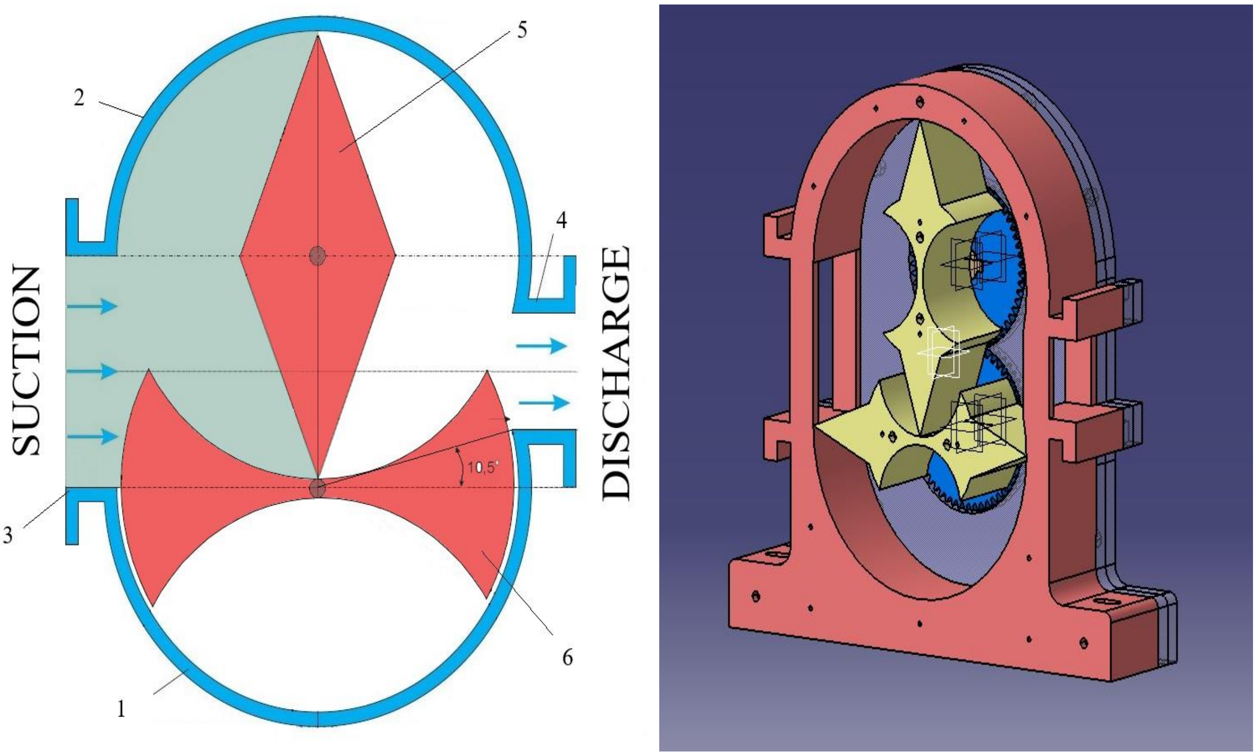

Fig. 5. Cross section through the rotating machine
1 – lower housing; 2 – upper housing; 3 – fluid suction connection;
4 – fluid discharge connection; 5 – upper rotor with two rotating pistons; 6 – lower rotor

5. Conclusions

1. Choosing the shape of the rotors leads to an increase in the flow rate of this rotating machine with profiled rotors.

2. In order to achieve the constructive solution proposed, increased precision is required due to the fact that if there are large clearances between the rotor and the housing, the volume efficiency of the pump will decrease.
3. The driving power is influenced by the flow rate, by the increase of pressure (Δp) made by the rotating machine between suction and discharge, by the nature of the fluid conveyed.

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