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THE INFLUENCE OF THE ROTORS SHAPE ON THE FLOW RATE CONVEYED BY A ROTATING VOLUMETRIC PUMP

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Abstract: *The paper presents a new type of rotating volumetric pump with two profiled rotors, which is based on a patent. The calculation relations for the pump flow rate and its driving power are deduced. The influence of the shape of the rotors on the flow conveyed by the rotary pump takes place in two ways:*
1- by the shape of the rotating pistons
2- through the influence of the main dimensions of the rotating machine (rotor length, rotor radius, rotating piston height).

Keywords: *Rotating machine, volumetric pump, profiled rotors*

1. Introduction

The machines are aggregates used to transform energy from one form to another with the help of a mobile organ (piston, profiled rotor, blade) [1-2].
Machines, according to their intended purpose, are divided into two large categories [3-5]:
1. Power machines (motor machines), which transform a certain form of energy into mechanical energy (internal combustion engines, steam, or gas turbines, etc.).
2. Working machines, which transform mechanical energy into potential pressure energy (fans, pumps, compressors).
Force and working machines that are traversed by fluids, according to the variation of the flow parameters, are classified as follows (table 1):
a. Hydraulic machines, which circulate or are actuated by liquids, where thermal phenomena are neglected.
b. Thermal machines, which circulate gases or vapors (or are acted upon by them) in which the thermal phenomena that occur are not neglected.
The realization of high-performance rotating machines (pumps, fans, blowers) is current.

Table 1: A general classification of rotating machines

Classification by purpose	Depending on the constructive solution	According to the working parameters
Working machines	Machines with profiled rotors	a) Fans, blowers, pumps
	Blade machines	b) Fans, blowers
Force machines	Machines with profiled rotors	c) Internal combustion engines, steam or gas engines, pneumatic engines
	Blade machines	d) Steam turbines, gas turbines

Researches aims to build machines that ensure the transformation of the engine torque received from the shaft into useful effects, but with as little energy loss as possible.
Table 2 presents the classification of rotating machines with profiled rotors according to the purpose pursued and the adopted constructive solution [6].

Table 2: Classification of rotating machines with profiled rotors

	Classification by purpose	**Classification in terms of construction**
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

From the category of rotating working machines for the circulation of liquids, rotating pumps are presented.
In technics, there are two main criteria for classifying pumps [7-9]:
I. According to the operation principle;
II. By training mode.
I. According to the principle of operation, two categories are distinguished:
A. Volumetric pumps;
B. Non-volumetric pumps.
II. According to the driving mode, three categories of pumps are distinguished [10]:
a) Electric pumps;
b) Motor pumps;
c) Turbo pumps.

Table 3: Categories of pumps

A) Volumetric pumps	Piston pumps	a) Single cylinder pumps
		b) Polycylindrical pumps
		c) Pumps with axial pistons
	Rotating pumps	d) Pumps with blades
		e) Gear pumps
		f) Screw pumps
		g) Lobe pumps
B) 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 power machine, that is, in theory, a "reversible" machine [11,12].
Such a type of machine must ensure:
- transformation of the useful moment with minimal losses when it works as a working machine;
- the full use of the energy of the working agent to actuate the shaft when it works as a force machine.

2. Rotating volumetric pump with two profiled rotors with triangular-shaped rotating pistons

In this version, the rotating piston has the shape of a triangle due to the materials strength (figure 1). For the specified values for R_r, z, the base of the piston triangle (i.e., the piston section) was dimensioned.

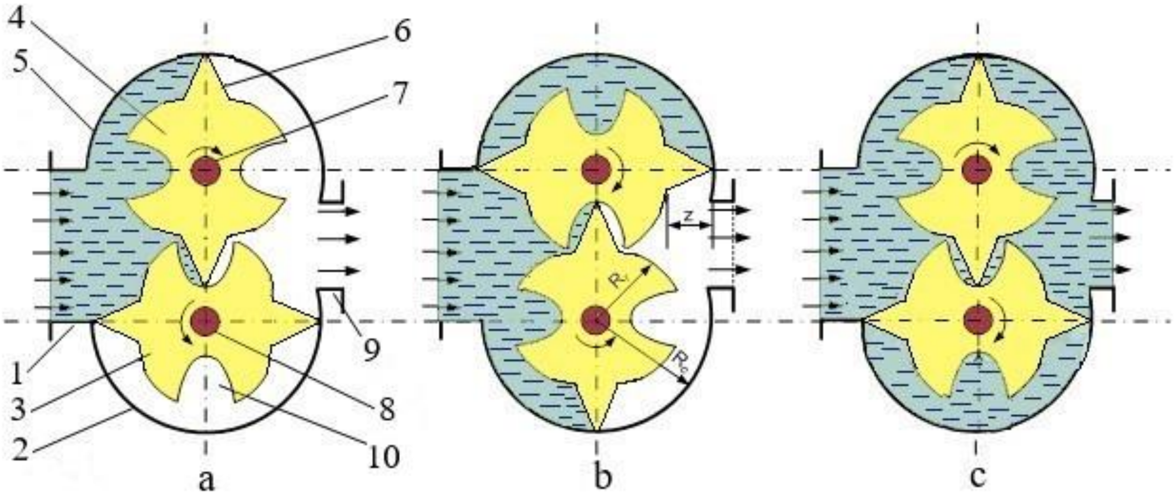

Fig. 1. The operating principle of the rotating volumetric machine
1- suction chamber; 2 - lower casing; 3- lower rotor; 4- upper rotor; 5- upper casing; 6 - rotating piston; 7- driven shaft; 8 - driving shaft; 9- discharge chamber; 10 - cavity into which the piston of the upper rotor enters.

The fluid in the chamber (1) is taken up by the rotating pistons (6) and transported to the discharge chamber (9).
On the shafts 7 and 8 two toothed wheels are mounted (figure 2) which form a cylindrical gear; thus, the penetration of the pistons 6 from the upper rotor into the cavities 10 from the lower rotor (3) is ensured.

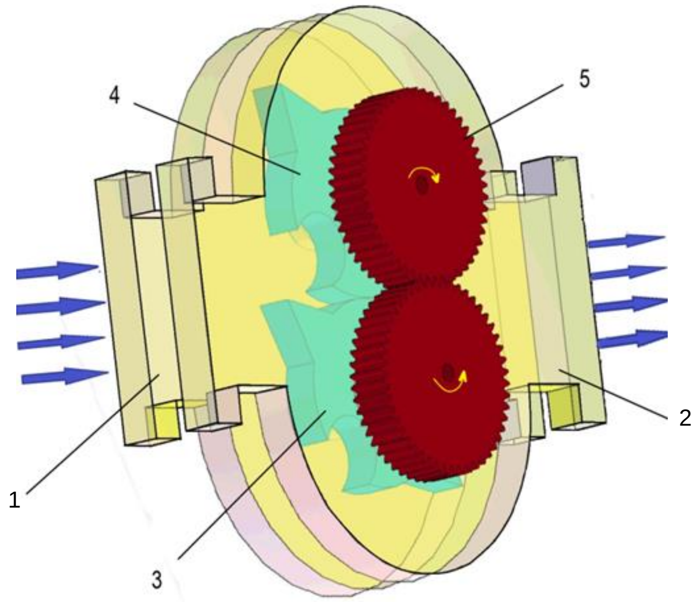

Fig. 2. Cylindrical gear mounted on the shafts of the two rotors
1 – suction chamber; 2 – discharge chamber; 3 – lower rotor; 4 – upper rotor; 5 – cylindrical gear.

Profiled rotors can have different shapes (figure 3):
Variant I: rectangular blades;
Variant II: an isosceles triangle;
Variant III: a curvilinear profile.

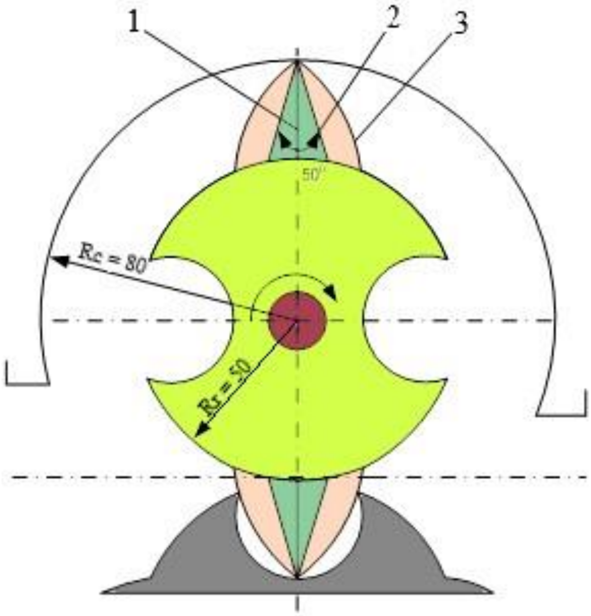

Fig. 3. Rotor with rotating pistons
1- rectangular lamella; 2- triangular profile; 3- curvilinear profile

3. Calculation of the flow rate transported by the machine with profiled rotors with rotating triangular pistons

Figure 4 shows a cross section through the rotating machine.

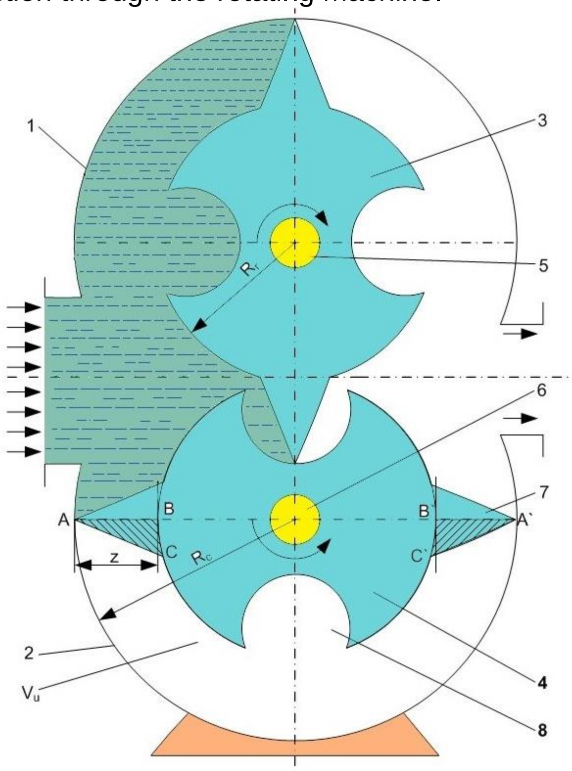

Fig. 4. Cross-section through the rotating working machine
1 - upper casing; 2 - lower casing; 3 - upper rotor; 4 - lower rotor; 5,6 – shafts;
7 - triangular piston; 8 - the cavity into which the piston enters.

The paper will analyze the case where the rotating pistons of the two rotors have a triangular shape.
The contour of the rotor was established after the elaboration of a very complicated calculation program and the construction of the rotors was carried out on a computer numerical control center (C.N.C) [13, 14].
The constructive solution ensures a good resistance of the piston and two sealing zones: between the piston tip and the inside of the casing and between the piston tip and the cavity.
As one can see in figure 4, the useful volume V_u is reduced by the volumes of prisms ABC and A'B'C'; it is equal and together will give the volume of a piston of triangular section, i.e., a prism with dimensions:
-height: z = 30 [mm];
-base: b = 30 [mm];
-length: l = 50 [mm].
The cross-sectional area between the base of the prism and the rotor is neglected. The volume of this prism will be [15]:

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

Compared to the theoretical flow transported by the machine, in version I: $\dot{V}_I = \pi l z (z + 2R_r) \cdot \frac{n_r}{30} \; [m^3/s]$, the theoretical flow of the machine in this version will be reduced by V_{pII}
The fluid flow rate transported by a rotor:

$$\dot{V}_u = \left[\pi l z \left(z + 2R_r \right) - V_{p,II} \right] \; \left[m^3 / rot \right] \tag{2}$$

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

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

For the same data as in variant I, but in addition: b = 0.03 [m], and the same speed, a flow rate is obtained:

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

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

Table 4: The values of $\dot{V} = f(n_r)$ - Variant I

n_r [rev/min]	100	200	300	400	500
$\dot{V}_I$ [m³/s]	0.002041	0.004082	0.006123	0.008164	0.010205
$\dot{V}_I$ [m³/h]	7.3476	14.6952	22.0428	29.3904	36.738

Table 5: The values of $\dot{V} = f(n_r)$ - Variant II

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

Table 6: The values of $\dot{V} = f(n_r)$ - Variant III

n_r [rev/min]	100	200	300	400	500
$\dot{V}_{III}$ [m³/s]	0.00190977	0.00381953	0.0057293	0.00763907	0.0095883
$\dot{V}_{III}$ [m³/h]	6.87516	13.75032	20.62548	27.50064	34.3758

Based on the data from table 4, 5 and 6, the function $\dot{V} = f(n_r)$ - was represented in figure 5.

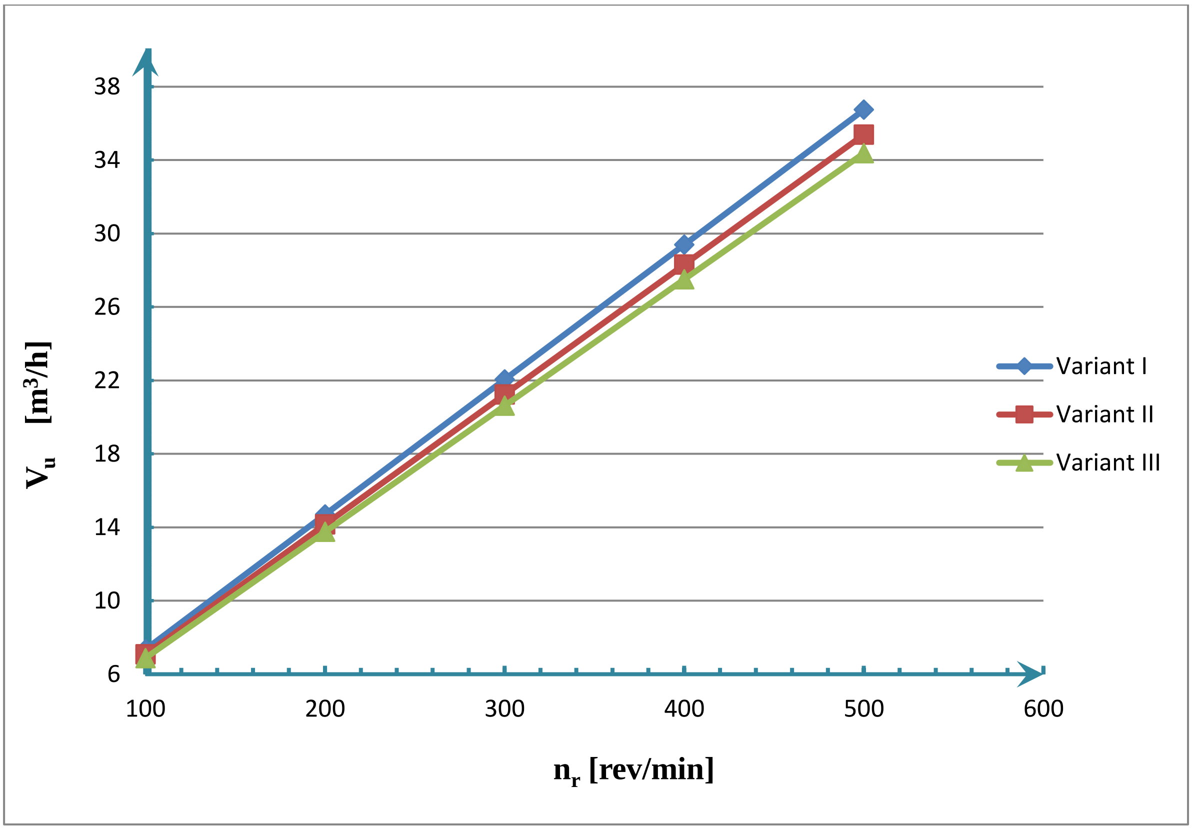

Fig. 5. Graphical representation of the function $\dot{V} = f(n_r)$ for different machine speeds
Variant I - rectangular blade shape piston, R_r = 50 [mm], z =30 [mm];
Variant II - piston in the form of an isosceles triangle, R_r = 50 [mm], z =30 [mm];
Variant III - curvilinear piston, R_r = 50 [mm], z =30 [mm].

From figure 5, one can see that the flow rate transported by the rotating machine is the highest in the case of variant I (the rotor is provided with rectangular blades).

4. Calculation of the theoretical driving power for the volumetric pump

The theoretical driving power of the rotary machine for the three constructive solutions can be calculated as follows [16,17]:

$$P = \dot{V} \cdot \Delta p = \pi \cdot l \cdot z \cdot (z + 2R_r) \cdot \frac{n_r}{30} \cdot \Delta p \quad [W] \tag{6}$$

$$\Delta p = \rho g \Delta H \quad [N/m^2] \tag{7}$$

where:

* $\dot{V}$ – volumetric flow rate [m³/s];

* Δp – pressure increase [N/m²];
* ΔH – pumping height [m];
* ρ_l – density of the transported fluid [kg/m³].

The total pressure increase achieved by the pump (*Δ*p) changes when the pump speed increases; the hydrostatic load and pressure losses occurring in the hydraulic circuit of the pump are evaluated at about 4 mH_2O [18- 20]:

$$\Delta p = \rho_{H_2O} \cdot g \cdot H = 10^3 \cdot 9.81 \cdot 4 = 0.3924 \cdot 10^5 \quad [Pa] \tag{8}$$

Next, based on the values of the flow rates previously obtained, the theoretical driving power is calculated.

For n_r = 500 [rev/min], substituting the values in relation (6) one can obtain:

Variant I - piston in the form of a blade:

$$P = \dot{V} \cdot \Delta p = 0.010205 \cdot 0.3924 \cdot 10^5 = 400.044 \ \ [W] \tag{9}$$

Carrying out similar calculations, the values of P are obtained for n_r = 100, 200, 300, 400 and 500 [rev/min] presented in table 7, 8 and 9.

Table 7: The values of $P = f(n_r)$ - Variant I

n_r [rev/min]	100	200	300	400	500
P [W]	80.088	160.177	240.266	320.355	400.444

Variant II - piston in the form of an isosceles triangle:

$$P = 0.00983 \cdot 0.3924 \cdot 10^5 = 385.729 \ \ [W] \tag{10}$$

Table 8: The values of $P = f(n_r)$ - Variant II

n_r [rev/min]	100	200	300	400	500
P [W]	77.145	154.291	231.437	308.583	385.729

Variant III - curvilinear shaped piston:

$$P = 0.00954883 \cdot 0.3924 \cdot 10^5 = 374.696 \ \ [W] \tag{11}$$

Table 9: The values of $P = f(n_r)$ - Variant III

n_r [rev/min]	100	200	300	400	500
P [W]	74.939	149.878	224.817	299.756	374.696

Based on the data in tables 7, 8 and 9 the function $P = f(n_r)$ was graphically represented in figure 6, for the three constructive variants.

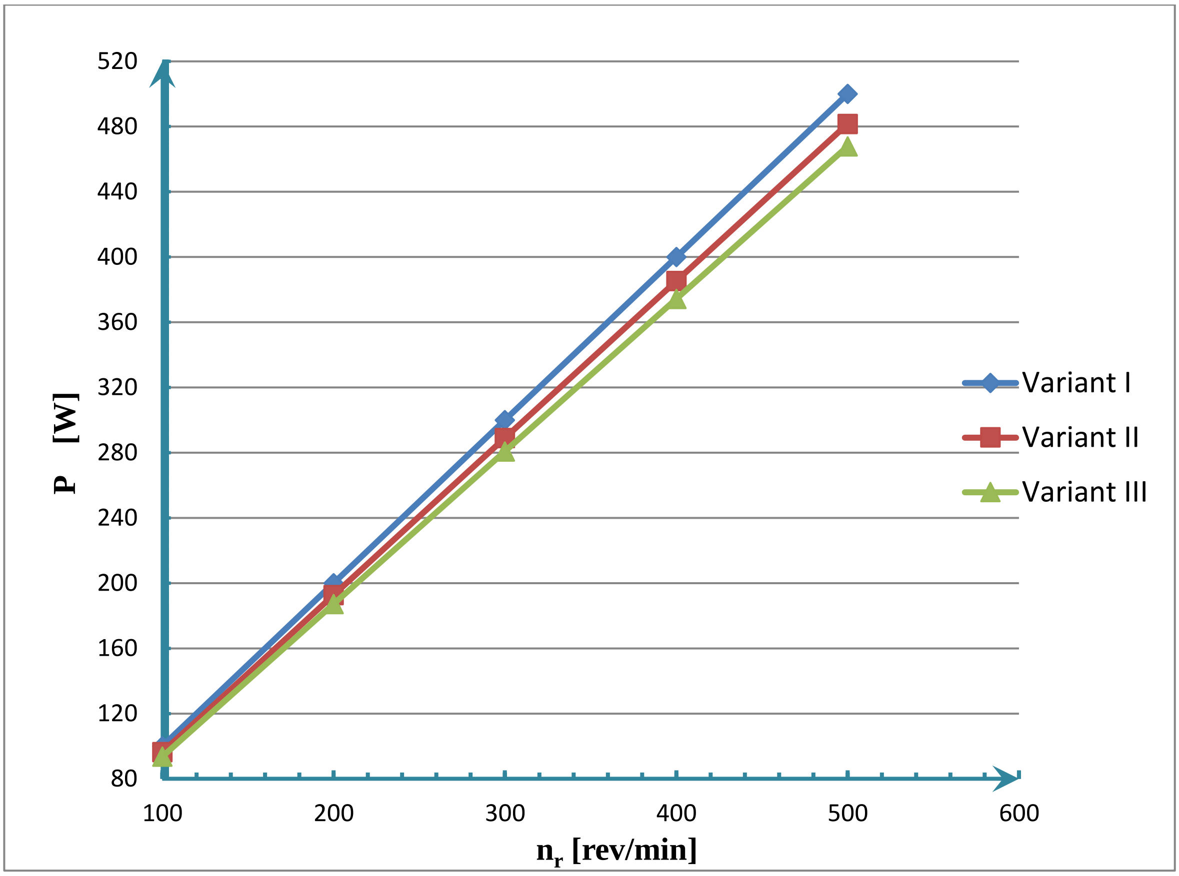

Fig. 6. Graphical representation of the function $P = f(n_r)$ for the three constructive variants
Variant I - rectangular blade shape piston, R_r = 50 [mm], z =30 [mm];
Variant II - piston in the form of an isosceles triangle, R_r = 50 [mm], z =30 [mm];
Variant III - curvilinear piston, R_r = 50 [mm], z =30 [mm].

From figure 6, a linear dependence is observed between the theoretical driving power and the speed of the rotating machine.
Obviously, if the flow rate for variant I is the highest, then the driving power will also be higher (variant I).

5. Conclusions

1. The flow rate transported by the rotating machine varies according to the following:
- the geometric parameters: l – rotor length [m]; R_r – rotor radius [m]; z – piston height [m];
- the functional parameters: n_r – machine speed [rev/min].
2. The driving power is influenced by the flow rate (that is, by the parameters mentioned above) by the increase in pressure (Δp) achieved by the rotating machine between suction and discharge, by the nature of the transported fluid. The pressure increase produced by the rotating machine must overcome the hydrostatic load and the pressure losses occurring on both the suction circuit and the discharge circuit of the pump.
3. In variant I (pistons in the form of rectangular blades) the flow rate transported by the rotating machine will be the highest compared to variant III.
This high flow rate will require a higher driving power of the machine: $P_I > P_{II} > P_{III}$ $[W]$.

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