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The Advantages of Using Rotating Machines with Profiled Rotors

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Abstract

In order to achieve a lower consumed energy, the performance of a new type of rotating volumetric pump with two profiled rotors (variant I) which is compared with a centrifugal pump (variant II) is presented. The analysis regarding the same flow rate of transported liquid and the same pressure increases points out the conduct of the system at the variation of the key operating parameters. The actual driving power of the rotating volumetric pump is higher stating that is more advantageous in operation. The effective efficiency of the system is improved due to the original constructive solution.

Keywords

Rotating Machine, Volumetric Pump, Profiled Rotors, Centrifugal Pump, Energy Performances

1. Introduction

Conventional technologies for the construction of rotating pumps are based on the use of maximum mechanical power [1]. However, if the pump is operating at low speed, providing low flow rates and heads, the pump efficiency can be 15% - 20% or even lower. Rotating volumetric pumps, on the other hand, do not have such low efficiencies and present additional advantages related to reliability, their geometry, weight, capacity and compactness [2]. The physical behaviors of rotating machines have been studied based on representative theoretical models to determine the total power required [3], the reduction of mechanical losses [4], the mechanical behavior compared to the volumetric one [5], the effect of the number and thickness of the rotors [6].

Considering the problems that existing profiled rotors of rotating pumps have, a new rotating working machine with profiled rotors was proposed in this paper.

A special problem consists in performing a rotating working machine that will transform the energy received at the coupling into potential pressure energy with minimal losses. There are two main criteria for classifying pumps [7] [8]:

1) According to the principle of operation: volumetric pumps and non-volumetric pumps.

2) According to the driving mode: electric pumps, motor pumps and turbo pumps.

In this paper, a comparative analysis between two pumps will be presented, namely, as variants:

1) A rotating volumetric pump with two profiled rotors designed and made by the University Politehnica of Bucharest [9] [10].

2) A centrifugal pump made by WILO [11].

As part of a research topic, the performances of the two types of pumps were compared and the results are presented below.

2. Methodology and Materials

The parameters relevant for the study are the flow rate transported by the machine and the driving power for both variants studied in the paper. In this section, the two studied versions are presented.

2.1. Design Methodology of Arotating Pump with Profiled Rotors

For the concept proposed for analysis in this paper (variant I), the rotating piston has the shape of a triangle due to the materials strength (**Figure 1**) [8]. For the specified values for Rr, z, the base of the piston triangle (*i.e.*, the piston section) was dimensioned.

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

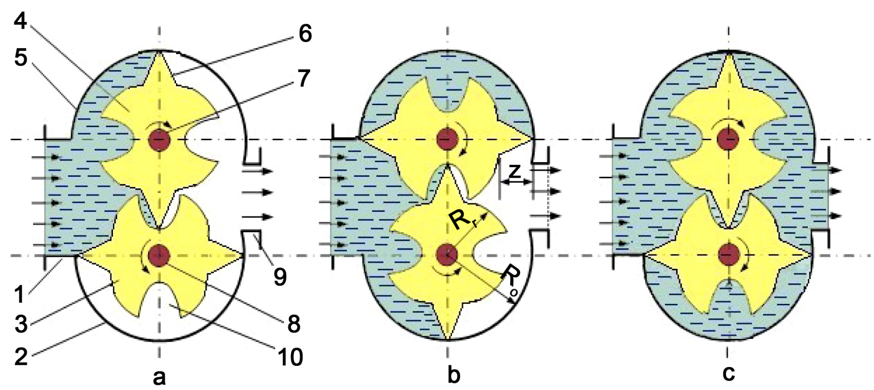

Figure 1. The operating principle of the rotating volumetric machine. 1: suction chamber; 2: lower casing; 3: lower rotor; 4: upper rotor; 5: upper casing; 6: rotating piston; 7: driven shaft; 8: driving shaft; 9: discharge chamber; 10: cavity into which the piston of the upper rotor enters.

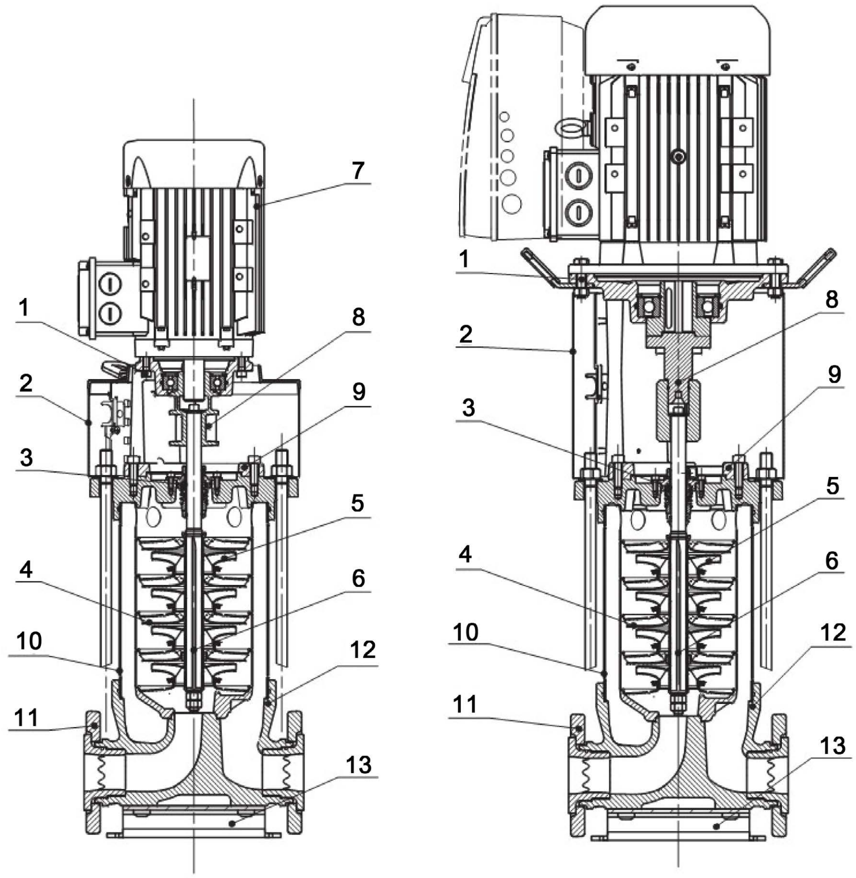

Figure 2. Centrifugal pump WILO type. 1: engine fixing bolts; 2: coupling protection; 3: mechanical seal with cartridges; 4: stages; 5: rotors; 6: pump shaft; 7: engine; 8: coupling; 9: pump column; 10: downspout with mantle; 11: flange; 12: pump casing; 13: motherboard.

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.

Because the machining cost is high, ordinary CNC machine tools are used by some manufacturers instead of the five-axis CNC machine tools that have very high costs. Therefore, it is necessary to analyze the relationship and transform the corresponding profile of the rotor in different cross-sections [12] [13] [14] [15] [16].

2.2. Design Methodology of Atraditional Centrifugal the Pump

The outline of the WILO type centrifugal pump (variant II) is presented in **Figure 2** [11]:

From the pump documentation [11], the following data were extracted:

- pump type: HELIX VE 606 RBI;
- flow rate: 5 $m^3/h = 1.38 \times 10^{-3}$ m^3/s;
- pumping height at 0.75 mH_2O;
- temperature of the pumped agent: $t = 10^{\circ}C$;
- maximum pressure: $p = 16$ bar.

1) for variant I: building with height S + P + 2E + floors 3, 4 removed from Muzeul Zambaccian street, number 15, sector 1, Bucharest, the pump has the characteristics: $\dot{V} = 1.38\times10^{-3}\ \text{m}^3/\text{s}$, H = 60 mH_2O, the driving power will be:

$$P = \frac{\dot{V}\cdot\Delta p}{\eta_I} = \frac{\dot{V}_I\cdot\rho g H_I}{\eta_I}\left[\text{W}\right]. \tag{1}$$

2) for variant II, the WILO-Helix VE type pump is replaced with a rotating volumetric pump with profiled rotors that must pump cold water at the same parameters:

$$P_{II} = \frac{\dot{V}_I\cdot\rho g H_I}{\eta_{II}}\left[\text{W}\right]. \tag{2}$$

2.3. Computation of the Flow Rate Transported by the Machine

After a 180˚ rotation the fluid contained in the useful volume V_u, *i.e.*, in the space between the pistons, the lower casing (1) and lower rotor (2), will be sent to the discharge chamber. On a full rotation of the shaft (9), two such volumes will be transported from the suction to the discharge [7] [8] [9]:

$$\dot{V}_u = 2\left(\frac{\pi R_c^2}{2} - \frac{\pi R_r^2}{2}\right)\cdot l\left[\text{m}^3/\text{rot}\right]. \tag{3}$$

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

$$R_c = R_r + z\left[\text{m}\right]. \tag{4}$$

it results:

$$\dot{V}_u = \pi l z\left(z + 2R_r\right)\left[\text{m}^3/\text{rot}\right]. \tag{5}$$

The fluid volumetric flow rate discharged by a single rotor of length l [m] and speed nr [rot/ min] will be:

$$\dot{V}_u = \pi l z\left(z + 2R_r\right)\cdot\frac{n_r}{60}\left[\text{m}^3/\text{s}\right]. \tag{6}$$

Because the machine has two identical rotors, the fluid flow rate circulated by machine will be:

$$\dot{V}_m = 2\dot{V}_u = \pi l z\left(z + 2R_r\right)\cdot\frac{n_r}{30}\left[\text{m}^3/\text{s}\right]. \tag{7}$$

From Relation (5) it can be seen that the flow rate transported by the rotating machine will increase proportionally to the change of the following parameters: l: length of the rotor [m]; z: piston height [m]; R_r: rotor radius [m]; n_r: the machine speed [rot/min]. Obviously, a certain ratio must be established between the rotor radius (R_r) and the piston height (z).

2.4. Establishing the Computation Relation of the Driving Power of the Rotating Machine

It is considered that the rotating machine presented is a volumetric pump that must achieve a pressure increase equal to Δp [N/m²].

In this case, the theoretical driving power of the machine will be given by the relation [9]:

$$P = \dot{V}_m \cdot \Delta p \; [\mathrm{W}]. \tag{8}$$

Replacing $\dot{V}_m$ from Equation (7), one can obtain:

$$P = \pi l z \left(z + 2R_r \right) \cdot \frac{n_r}{30} \cdot \Delta p \; [\mathrm{W}]. \tag{9}$$

From Equation (7) one can see that the power of the machine varies according to the following parameters:

*Constructive parameters: l: rotor length [m]; R_r: rotor radius [m]; z: the height of the rotating piston [m].

*Functional parameters: n_r: machine speed [rpm]; Δp: the increase in pressure achieved by the pump between suction and discharge.

The actual driving power of the rotating volumetric pump will be higher:

$$P_r = \frac{P}{\eta_e} \; [\mathrm{W}]. \tag{10}$$

where η_e is the effective efficiency of the pump [9]:

$$\eta_e = \eta_v \cdot \eta_m \cdot \eta_h. \tag{11}$$

where:

- η_v is the volumetric efficiency of the pump;
- η_m is the mechanical efficiency of the pump;
- η_h is the hydraulic efficiency of the pump.

3. Research Results and Discussions

For the volumetric pump (variant I), in the paper [9] the effective efficiency of the pump was determined, n = 0.8; this value was determined by tests in the Department of Thermotechnics, Engines, Thermal and Refrigerating Equipment of the Faculty of Mechanical and Mechatronics Engineering. For the centrifugal pump (variant II), from the pump brochure [11], the following were extracted: the overall efficiency of the pump is given by the relation [9]:

$$\eta_e = \eta_v \cdot \eta_m \cdot \eta_h. \tag{12}$$

where:

- η_v is the volumetric efficiency of the pump(η_v = 0.9);
- η_m is the mechanical efficiency of the pump (η_m = 0.8);
- η_h is the hydraulic efficiency of the pump (η_h = 0.72).

So, for the volumetric pump η = 0.8, and for the centrifugal pump η = 0.51 [17] [18]. For the same volumetric flow rate ($\dot{V}$) and the same pressure increase (Δp), it follows that the energy consumed for pumping will be:

$$\frac{E_{II}}{E_I} = \frac{\dot{V}_I \cdot \Delta p}{\eta_{II}} \cdot \frac{\eta_I}{\dot{V}_I \cdot \Delta p} = \frac{\eta_I}{\eta_{II}} = \frac{0.8}{0.51} = 1.56. \tag{13}$$

It can be concluded that the volumetric pump with profiled rotors used will be more advantageous because it leads to an energy saving for its driving.

4. Conclusions

The influence of the rotor profile on the performance of an original new rotating pump was studied in comparison with a centrifugal pump, highlighting the increase in flow rate achievable using the triangular shape of the rotors. The aspirated fluid is circulated to discharge with minimal energy loss; thus, the motor torque is: $M = F \cdot b \cdot \sin\alpha \left[\mathrm{N \cdot m}\right]$, where F is the force which presses on the rotating piston, b is the force arm: $b = R_r + \frac{z}{2}\left[\mathrm{m}\right]$.

The force F will always be perpendicular to the arm, so the angle between the force (F) and the arm (b) is always equal to 90˚. This fact leads to an advantage over piston machines which are variable during 360. As a result, neglecting the friction between the rotor and the casing, the entire engine torque is used to drive the fluid.

The constructive solution presented in the paper has parts only in rotational movement, it has a safe operation and easy maintenance.

The investment for building a pumping installation is not high; this is because, for the rotor's construction, a computation program is available and their constructions can be made on a computer center with numerical control.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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