EXPERIMENTAL RESEARCHES ON THE DETERMINATION OF THE EFFECTIVE EFFICIENCY OF A NEW TYPE OF VOLUMETRIC PUMP WITH PROFILED ROTORS

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Abstract The paper presents an experimental scheme performed in the laboratory of Thermotechnics, Engines, Thermic and Refrigeration Plants Department of Politehnica University of Bucharest. The purpose of the installation is to specify the effective efficiency of a new type of rotating positive displacement pump rotors profiled after the conducted experimental measurements.

Keywords: Rotating volumetric pump, profiled rotors, effective efficiency, anti-explosive electric motor, experimental installation.

1. Introduction

From rotating working machines class, the paper presents a new type of rotating volumetric pump that can convey any fluid substance: Pure liquids (clean); liquids with suspension; biphasic fluids (water + sand, water + ash); rheological fluids.

The aspirated fluid is circulated to the discharge with minimal loss of energy; thus, the torque is: where the arm (b) of the force (F) is always perpendicular to the force, that is: .

This leads to an advantage over the machines with piston and crank drive system.

In addition, the constructive solution does not contain elements that performs reciprocating movements; it presents a safe operation and an easy maintenance. At its construction an increased precision is required because, if there are big gaps between the rotor and the case, the volumetric efficiency of the pump will decrease. The design proposed in this paper was designed and constructed in the laboratory where a test stand was made. This type of machine can be used in the following areas: in agriculture for irrigation, in energetics at hydroelectric power plants, in the petrochemical industry at high viscosity fluid handling, etc.

The constructive solution and the operating principle

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 rotors is provided by two gearwheels attached to the shafts 7 and 9, which form a cylindrical gear mounted outside the machine.

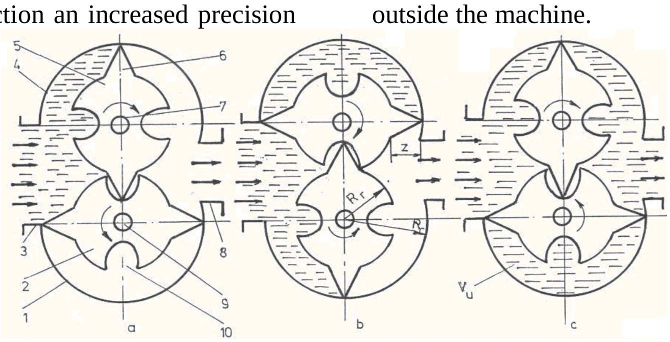

Figure 1: The rotors position after a 90° rotation
1- lower case; 2- lower rotor; 3-sucction chamber; 4- upper case; 5-upper rotor; 6- rotating piston; 7-driven shaft; 8-discharge chamber; 9-driving shaft; 10-cavity in which the upper rotor piston enters
The aspirated fluid (fig. 1. a) is transported to the discharge and after a 90° rotation of both rotors, the situation in Figure 1. b and thereafter in Figure 1. c is reached.

1.1. The flow rate computation relations

After a 180° rotation the fluid contained in the useful volume Vu (Fig. 1. c.), ie in the space between the pistons, the lower case (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 [1] [2] [3]:

$$\dot{V}_u = 2\left(\frac{\pi R_c^2}{2} - \frac{\pi R_r^2}{2}\right)\cdot l \text{ [m}^3\text{/rot]} \qquad (1)$$

The case radius (Rc) is the sum of the rotor radius (Rr) and the piston height (z):

$$R_c = R_r + z \text{ [m]} \qquad (2)$$

it results:

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

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

$$\dot{V}_u = \pi l z(z + 2R_r)\cdot \frac{n_r}{60} \text{ [m}^3\text{/s]} \qquad (4)$$

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

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

1.2. Driving power computation relations

The theoretical power of the machine is given by [4] [5]:

$$P = \dot{V}_m \cdot \Delta p \text{ [W]} \qquad (6)$$

$$P = \pi l z(z + 2R_r)\cdot \frac{n_r}{30}\cdot \Delta p \text{ [W]} \qquad (7)$$

From the relation (5) it is noted that the machine power varies according to the following parameters:
* Constructive parameters: l - rotor length [m]; Rr - rotor radius [m]; z - rotating piston height [m]
* Functional parameters: n-machine speed [rot/min]; Δp-increase pressure achieved by the pump between the suction and discharge.

2. The computation of the flow rate circulated by the volumetric rotating pump

In the flow rate computation relation the values of the constructed model are replaced:
- l = 0.05 m; z= 0.03 m; Rr = 0.05 m
- the machine speed was chosen nr: 100, 150, 200, 250 rot/min
- the fluid was water with the density ρ = 1000 [kg /m3]

It results the values of the water flow rate circulated by the pump ( ) (Table 1). The water circuit in the system takes place through an inlet pipe 50 x 3, so, the inner diameter is 44 mm. The water velocity in the circuit can be calculated [7] [8] [9]:

$$w = \frac{\dot{V}}{\frac{\pi d^2}{4}} = \frac{4\dot{V}}{\pi d^2} \text{ [m/s]}$$

The calculation results are shown in Table 1.

Table 1. Flow rate and water velocity values

n_r [rot/min] / Fluid (water)	100	150	200	250
$\dot{V}$ [m^3/s]	0.00204	0.00306	0.00408	0.00510
w [m/s]	1.34138	2.01207	2.68276	3.35345

3. The experimental stand scheme

Figure 2 shows the experimental installation scheme constructed in closed circuit.

The working fluid (air, water, oil) is absorbed from the tank (2) by the rotating pump with profiled rotors (5). This machine has the advantage that it can circulate both gas (air) as well as liquids (water, oil).

The pump is driven by an anti-explosive electrical motor (6) whose speed is controlled by a frequency converter (7).

At the pump discharge, the fluid passes through an electromagnetic flow meter (10) and a flow control valve (11). Thereafter, the fluid is pumped to h = 2 m and finally arrives in the tank (2).

In the tank, the fluid layer has a height of 0.5 m, height that provides the fact that the rotating pump with profiled rotors will always be "flooded" (fig. 2).

This type pump of circulates any fluid, but the electromagnetic flow meter puts the condition: the electrical conductivity of the fluid subjected to the measurement should be greater than 200 μS/m; as a result for the circulated flow rates and subject to the measurements it will refer only to water.

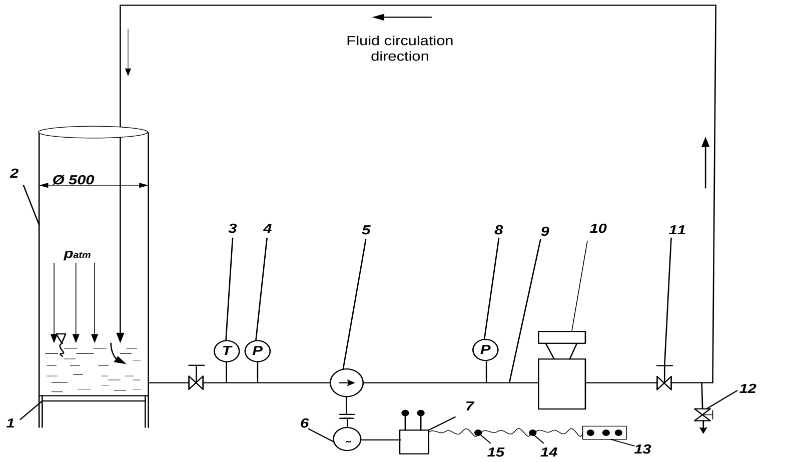

Figure 2: The scheme of the experimental installation

1- tank support; 2- water tank; 3-thermometer, 4- manometer; 5- rotating volumetric pump; 6- electric motor; 7-frequency converter, 8- manometer, 9- pipe Ø 50 x 3 mm; 10-electromagnetic flow meter; 11- regulating valve; 12- discharge valve; ; 13- AC power source 380 V.; 14- multimeter; 15- ampermeter

The pipeline route through which the fluid flows is made of transparent Plexiglas Ø 50x3 mm, which permit a good view of the flow. On the circulation pipeline route of the fluid, pressure gauges, thermometers, electromagnetic flowmeter are located; the pump speed can be changed with an electrical current frequency converter [10][11][12].

4. Experimental researches objectives

As a result of the voltage (U) and three-phase electric current intensity (I) measurement, the electrical power absorbed by the electric motor is determined:

$$P_{m.e} = \sqrt{3} \cdot U \cdot I \cdot \cos\varphi [\text{W}] \qquad (8)$$

From the electrical motors factory catalog, for the chosen motor, are given [10]:

- Electrical motor efficiency: $\eta_{m,e}$=0.747;
- Power factor: cos φ=0.71.

The power consumed by the electric motor is calculated (P_{me}) and by calculation, taking into account the electric motor efficiency, the power at the machine couple (P_{cm}) is determined.

$$P_{cm} = P_{me} \cdot \eta_{me} \; [\text{W}] \qquad (9)$$

Subsequently, from Pcm, the power consumed to overcome the hydrostatic pump load and the hydraulic linear and local resistance (PΔp) on the installation circuit is subtracted; the remaining value must be equal to the power consumed by viscous friction (Pt,f).

The effective efficiency of the pump will be:

$$\eta_e = \frac{P_H + P_{\Delta p}}{P_{cm}} \qquad (10)$$

With the equations (1) and (2), based on the experimental data (U, I), the data in Table 2 resulted, the working fluid was water.

Table 2. Values of Pme and Pcm for water

No.	n_r [rot/min]	U [V]	I [A]	P_{me} [W]	P_{cm} [W]
1	100	384.70	0.56	264.61	197.66
2	150	384.20	0.60	283.14	211.50
3	200	385.00	0.75	354.67	264.93
4	250	384.40	1.02	481.60	359.75

5. Computation of the power consumed to overcome the hydrostatic load and the hydraulic resistance

5.1. Computation of the power consumed to overcome the hydrostatic load [13] [14]

For exact calculations nr= 200 rot/min is chosen.

$$P_H = \dot{V} \cdot \Delta p_H \; [W] \qquad (11)$$

$\dot{V}$ - volumetric flow rate [m3/s]

ΔpH – pressure increase [N/m2]

ΔpH =ρgH= 103·9.81·1.5 =14715 N/m2 (12)

5.2. Computation of the power consumed to overcome the hydraulic resistance from the circuit

a) Linear pressure loss calculation

This calculation is performed when nr= 200 rot/min.

The following data are known:

- The fluid flow rate through the pipe φ 50 x3 mm: $\dot{V} = 4.08 \cdot 10^{-3} \, m^3/s$
- The fluid velocity (water) in the pipe: w = 2.68 m/s
- Dynamic and kinematic viscosity of water [7]: $\eta = 10.4 \cdot 10^{-4} \; \frac{N \cdot s}{m^2}; \nu = 1.04 \cdot 10^{-6} \; m^2/s$

- Absolute roughness of the transparent plexiglas pipe walls: $\varepsilon = 0.03$ mm

The linear pressure losses, are given by relation [7] [15]:

$$\Delta p_l = \lambda \frac{l}{d} \rho \frac{w^2}{2} \left[N/m^2\right] \qquad (13)$$

where:

$$\lambda = f\left(\mathrm{Re}, \frac{d}{\varepsilon}\right) \qquad (14)$$

$$\left.\begin{array}{l} \mathrm{Re} = \frac{wd}{\nu} = \frac{2.68 \cdot 0.044}{1.04 \cdot 10^{-6}} = 1.13 \cdot 10^5 \\ \frac{d}{\varepsilon} = \frac{44}{0.03} = 1466 \end{array}\right\} \text{From [16] it results}$$

λ= 0.021.

$$\Delta p_{lin} = 0{,}021 \frac{6}{0.044} 1000 \frac{2.68^2}{2} = 10283.89\, N/m^2$$

The power consumed to overcome the linear hydraulic resistance will be:

$$P_H = \dot{V} \cdot \Delta p_H = 4.08 \cdot 10^{-3} \cdot 10283.89 = 42 [W]$$

b) Local pressure loss calculation

From [7] it results:

$$\Delta p_{loc} = \sum_{i=1}^{n} \xi_i \rho \frac{w^2}{2} \left[N/m^2\right] \qquad (15)$$

$$\sum \xi_i = \xi_{pumpsuction} + 3\xi_{elbow 90^\circ} + \xi_{debitmeter} + 2\xi_{valve}$$

From [16] [17] it results:

$$\sum \xi_i = 1.6 + 3 \cdot 0.3 + 2.1 + 2 \cdot 1 = 6.6 \qquad (16)$$

$$\Delta p_{loc} = 6.6 \cdot 1000 \cdot \frac{2.68^2}{2} = 23701.92 \left[N/m^2\right]$$

The power consumed to overcome the local resistance will be:

$$P_H = \dot{V} \cdot \Delta p = 4.08 \cdot 10^{-3} \cdot 23701.92 = 96.7 [W] \qquad (17)$$

The total power consumed to overcome the hydraulic resistance (linear+local) will be:

$$P_{\Delta p} = P_{lin} + P_{loc} = 42 + 96.7 = 138.7 [W] \qquad (18)$$

6. The rotating volumetric pump with profiled rotors effective efficiency computation

The effective efficiency will be:

$$\eta_e = \frac{P_H + P_{\Delta p}}{P_{cm}} = \frac{60 + 138.7}{264.93} = 0.75 \qquad (19)$$

This is very good value compared with other data from the specialty literature [18] [19].

The energetic balance of the installation is the following:

$$P_{cm} = 264.93\, W \left| \begin{array}{l} \rightarrow P_H = 60 W \\ \rightarrow P_{\Delta p} = 138.7 W \\ \rightarrow P_f = 66.23 W \end{array} \right. \qquad (20)$$

Where P_f is the power consumed by viscous friction between the rotor and the case, calculated as the difference:

$$P_f = P_{cm} - \left(P_H + P_{\Delta p}\right) [W] \qquad (21)$$

Similarly, the calculation are made for n_r: 150,200,250 rot/min and the data in Table 3 results.

Table 3. Values of η_e for different machine speeds

n_r [rot/min]	P_{cm} [W]	$\Delta P_{\Delta p_t}$ [W]	P_H [W]	P_t [W]	η_e
100	197.66	17.57	30.01	47.58	0.24
150	211.50	57.11	45.02	102.53	0.48
200	264.93	138.7	60.03	198.74	0.75
250	359.75	255.2	75.04	258	0.719

Based on the values in Table 3 to graph $\eta_e = f(n_r)$ was plotted.

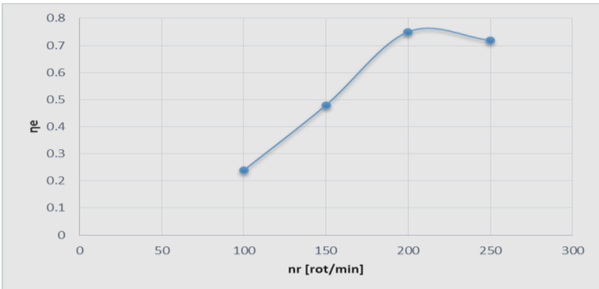

Figure 3: Graphical representation of the function $\eta_e = f(n_r)$

Figure 3 confirms that at the speed increase, i.e. of ω, the machine efficiency will increase up to a certain value then begins to decrease; this is because, at the speed increase, the flow rate increases, therefore, the pressure losses on the hydraulic circuit increases. The values obtained for ηe satisfactory coincides with literature data's [18] [20].

7. Conclusions

- The rotating machines have the advantage that converts the torque received to the shaft in pressure potential energy with minimal losses.
- The presented constructive solution can circulate both clean liquids or with suspensions and rheological fluids or gases.

- The effective efficiency of the machine is influenced by the fluid nature through the viscosity and through the machine speed.

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