EXPERIMENTAL RESEARCH CONCERNING THE ENERGY PERFORMANCE DETERMINATION OF A NEW TYPE OF ROTATING WORKING MACHINE

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ABSTRACT

The paper presents a rotating machine that consists of two profiled rotors placed in a case. The machine was designed and built in the laboratories of the Politehnica University of Bucharest and it can circulate both liquids and gas. The driving power and the flow rate computation relations of the machine are exposed. An experimental stand was conceived, designed and built where the rotating machine was tested performing with an effective efficiency of 77%. This constructive solution can be used in energetic industry, in agriculture and petrochemical industry.

Keywords: Volumetric pump, Profiled rotors, Effective efficiency, Rotating machine, Constructive solution, Flow rate computation, Theoretical power.

1. INTRODUCTION

At the presented rotating machine with profiled rotors, the torque received by the machine shaft is almost entirely used for increasing the potential pressure energy of the fluid; this provides advantage and also the fact that at rotating machines the pieces moving with reciprocating motion are missing, thus leading to greater opportunities for the spread usage of these machines.

At piston machines, the reciprocating motion of the piston is converted to rotation motion through a crank-rod mechanism, transformation that is accompanied by a number of frictions between the parts that perform this mechanism. Currently, the researcher's attention is directed towards eliminating this mechanism by constructing rotating machines that ensure the transformation of the torque received by the shaft in a useful effect with minimal losses.

At the rotating machine with profiled rotors the torque: $\vec{M} = \vec{F} \, x \, \vec{b}; \; M = Fb\sin\alpha$ is maximum during a complete rotation, because the angle α between the force (F) and the force arm (b) is 90º [1].

Rotating machines with profiled rotors cover both working machines and force field machines [1]; [2]; [3]; [4].

In terms of working machines the following solutions are found:

- gear pumps and paddle pumps;

- Roots and Lysholm compressors.

A Wankel type motor force machine was build.

By its content, the paper aims to present a new type of rotating machine with profiled rotors that can be practically used in several versions:

- As a working machine (pump, fan and blower); in this case the fluid pressure at discharge (p_2) is higher than at suction (p_1).

- As a force machine (steam engine or combustion gases, hydrostatic motor); in this case $p_1 > p_2$.

The machine (fig.1) has two identical profiled rotors (2, 5) of a special shape which rotate with the same speed within a case (1, 4).
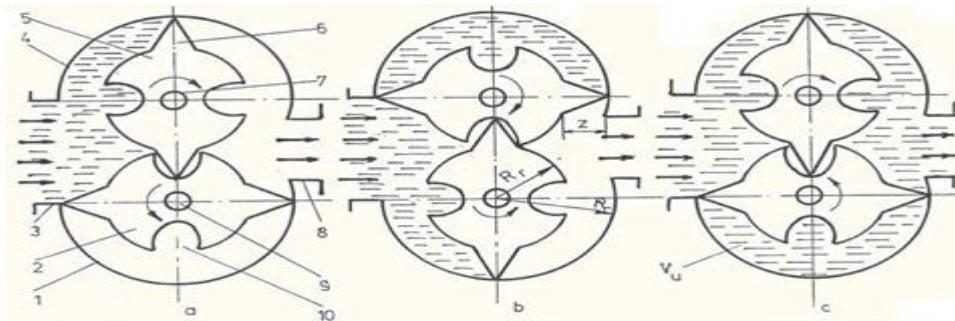
Fig-1. The rotors position after a 90° rotation

1- lower case; 2- lower rotor; 3- suction 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 in Figure 1. c is reached.

Researches in the field of rotating machines extend in the sense that these machines convert one form of energy into another form of energy with minimal losses; in this type of machine there is no reciprocation motion, there are no valves.

This paper reveals an example that includes original elements on both constructive solution, as well as computing relations on its functioning.

The paper reveals new theoretical aspects on fluid handling with a new type of rotating machine with profiled rotors; its performances will be validated through experimental researches.

2. CONSTRUCTIVE SOLUTION DESCRIPTION

2.1. The Flow Rate Computation Relations

The pump conveyed flow rate is established as follows:

After a 180° rotation the fluid contained in the useful volume V_u (Fig. 1. c.), i.e. 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:

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

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

$$R_c = R_r + z \left[m\right] \qquad (2)$$

it results:

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

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

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

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

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

From the relation (5) it is noted that the machine power varies according to the following parameters:

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

* **Functional parameters**: n - machine speed [rot/min].

If the relation 5 is written as:

$$\dot{V}_m = \left(\pi l z^2 + 2\pi l z R_r\right) \cdot \frac{n}{30} \qquad (6)$$

It is noted that the volumetric flow rate $\dot{V} = f(z^2)$, therefore on the flow rate, the piston height has the strongest influence.

2.2. Determination of the Working Machine Theoretical Power Based on the Machine Diagram in *P-V* Coordinates

The machine power driving is determined by using the working diagram in p−V coordinates, figure 2 [5].
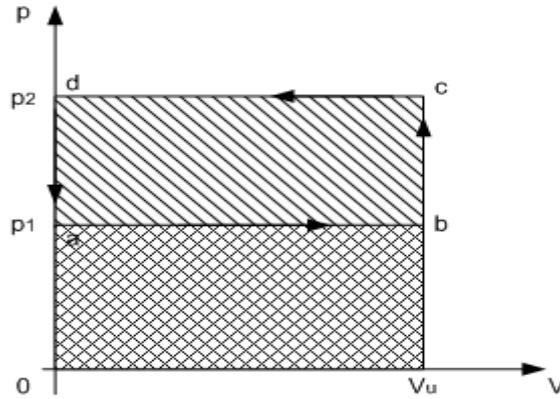
Fig-2. Functional diagram of the working machine

The diagram consists of the following transformations: two isobaric processes (a → b and c → d) and two isochoric processes (b → c and d → a);

a → b – gas suction in the useful volume (V_u) (fig. 2)

b → c –gas compressing in the volume V_u which is performed through high pressure gas flow p_2 in the volume V_u (the propagation of a pressure wave).

c → d –compressed gas discharge from the volume V_u

d → a – theoretical transformation (V = ct), the diagram closure

In order to establish the needed driven work it is proceeded as follows:

For one rotor:

$$L_{d,I} = L_{a-b} + L_{b-c} + L_{c-d} = p_1(V_b - V_a) + o + p_2(V_d - V_c) \qquad (7)$$

$$L_{d,I} = p_1 V_u - p_2 V_c = V_u(p_1 - p_2) \qquad (8)$$

At one shaft rotation two equal volumes are aspirated V_u and with $R_c = R_r + z$:

$$2\frac{\pi(R_c^2 - R_r^2) \cdot l}{2} = \pi l z(z + 2R_r) \cdot l[W]$$

$$L_{d,I} = \pi l z(z + 2R_r)(p_1 - p_2)[J / rot] \qquad (9)$$

The machine has two identical rotors, so the total outside work will be:

$$L_d = 2\pi l z(z + 2R_r)(p_1 - p_2)[J / rot] \qquad (10)$$

The theoretical required power to drive the machine is:

$$P_m = \frac{|L_d| \cdot n_r}{60}[W] \qquad (11)$$

Where: n_r – the machine speed [rot/min]

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To remove the module, $(p_2 - p_1)$ will be written instead of $(p_1 - p_2)$:

$$P_m = \frac{2\pi l z(z + 2R_r)(p_2 - p_1)n}{60} = 2\pi l z(z + 2R_r)\Delta p \cdot \upsilon \qquad (12)$$

Where: $\nu = n_r/60$ the rotation frequency [rot/s]
Or:

$$P_m = \pi l z(z + 2R_r)(p_2 - p_1)\frac{n}{30}[W] \qquad (13)$$

Considering the relation (4) can be written:

$$P_m = \overset{\bullet}{V} \cdot \Delta p\,[W] \qquad (14)$$

Where: Δp- pressure increase between suction (p_1) and discharge (p_2).
From equation (12) it is noted that the value of P_m is a function of:

$$P_m = f\left(R_r, l, z, \Delta p, n_r\right) \qquad (15)$$

3. THE EXPERIMENTAL STAND SCHEME FOR THE VOLUMETRIC PUMP

The experimental researches have been performed in the laboratory of Thermotechnics, Engines, Thermic and Refrigeration Plants Department from Politehnica University of Bucharest.

It was conceived, designed and built as a closed circuit stand in order to establish the energetic performances (flow rate, power, efficiency) of this new type of machine that can convey both liquid (pure or suspension) and gases.

Figure 3 show the experimental installation sketch constructed in closed circuit.

The working fluid (air, water, oil) is absorbed from the tank (2) by the rotating pump with profiled rotors (5).

The pump is driven by an anti-explosive electrical motor (15) 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. 3).

This type of pump circulates any fluid, but the electromagnetic flow meter sets 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.
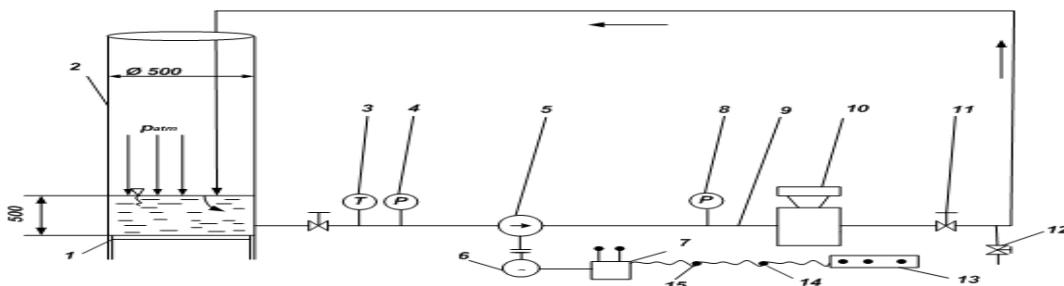
Fig-3. The scheme of the experimental installation

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

Some devices from this scheme have been used in other research papers [6].

4. EXPERIMENTAL RESEARCHES

The working fluid is water, with the characteristics: ρ=1000 kg/m³; $\eta = 10.4 \cdot 10^{-4}$ Ns/m².

From the electrical motors factory catalog, for the chosen motor, the characteristics are provided [7]: electrical motor efficiency: $\eta_{m,e}$=0.747; power factor: cos φ=0.71.

The active power absorbed by the electric motor ($P_{m,e}$) is determined with Ghiță [8]:

$$P_{m,e} = \sqrt{3} \cdot U \cdot I \cdot \cos \varphi \ [W] \qquad (16)$$

U- electrical voltage [V]; I- electric current intensity [A].

With the devices (14) and (15) from Figure 3 U and I were measured; the active power with (16) and the electric motor power given to the machine couple ($P_{c,m}$) was subsequently calculated:

$$P_{c,m} = P_{m,e} \cdot \eta_{m,e} \left[W\right] \qquad (17)$$

Measuring U and I, with the relations (16) and (17) the values of $P_{m,e}$ and $P_{c,m}$ resulted in table 1.

Table-1. Values of $P_{m,e}$ and $P_{c,m}$ for water

No.	n_r [rot/min]	U [V]	I [A]	$P_{m,e}$ [W]	$P_{c,m}$ [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	356.75

Based on the values in Table 1 to graph in Figure 4 was plotted.
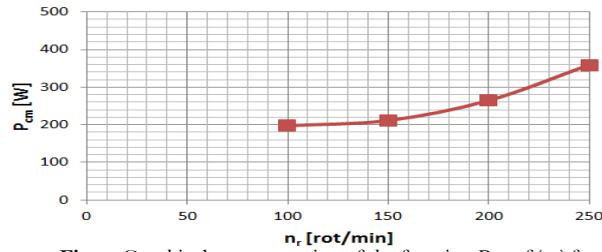
Fig–4. Graphical representation of the function $P_{c,m}=f(n_r)$ for water

From Figure 4 is noted that at the speed increase, the power at the machine couple increases.

This fact is explained as follows: at the speed increase, the fluid speed in the circuit increases and therefore the pressure losses and the viscous friction losses between the rotors and the casing increases.

5. THE ENERGY BALANCE OF THE EXPERIMENTAL INSTALLATION ELABORATION

If from $P_{c,m}$, the power consumed to overcome the hydrostatic load (P_H) and the power consumed to overcome the hydraulic linear and locale resistance from the circuit ($P_{\Delta p}$) are deducted; the remained value must be equal with the power consumed by viscous friction (P_f).

$$P_f = P_{c,m} - P_H - P_{\Delta p}\left[W\right] \tag{18}$$

The value of P_H is determined with Exarhu [9]; Bar-Meir [10]:

$$P_H = \overset{\bullet}{V}\cdot\Delta p = \overset{\bullet}{V}\cdot\rho_{H_2O}\cdot g\cdot H\left[W\right] \tag{19}$$

For a machine speed of 200 rot/min, a flow rate of $4.05\cdot 10^{-3}$ m³/s results.

$$P_H = 4.08\cdot 10^{-3}\cdot 1000\cdot 9.81\cdot 1.5 = 60\left[W\right] \tag{20}$$

$$P_{\Delta p} = P_{lin} + P_{loc} = \overset{\bullet}{V}\left(\Delta p_{lin} + \Delta p_{loc}\right)\left[W\right] \tag{21}$$

The linear pressure losses [2] are:

$$\Delta p_{lin} = \lambda\frac{l}{d}\rho\frac{w^2}{2}\left[N/m^2\right] \tag{22}$$

The linear pressure loss coefficient is chosen from Kiselev [11]; Idelcik [12];

l – pipe length, 6 m.

For a diameter of 0.044 m and the chosen flow rate $\overset{\bullet}{V}$ results a water circulation speed of 2.68 m / s.

$$\Delta p_{lin} = 0.026\frac{6}{0.044}1000\frac{2.68^2}{2}12732\,N/m^2$$

The local pressure losses are Al Dobrovicescu and Băran [2]:

$$\Delta p_{loc} = \sum_{i=1}^{n} \xi_i \rho \frac{w^2}{2} \left[N / m^2 \right] \qquad (23)$$

On the fluid circuit the following local resistance can be found [12]:

- The change at pump inlet section, $\xi_{asp} = 1.6$;

- Three elbows at 90°, $\xi_{cot} = 0.3$;

- An electromagnetic flowmeter, $\xi_{debitm} = 2.1$;

- Two taps Dn 50, $\xi_{rob} = 1$.

It results: $\sum_{i=1}^{7} \xi_i = 6.6$

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

$$P_{\Delta p} = 4.08 \cdot 10^{-3} \cdot (12734 + 23701) = 146.23 \left[W \right]$$

With the equation (19), results:

$$P_f = 264.9 - 60 - 146.23 = 158.67 \left[W \right] \qquad (24)$$

With the above values the effective efficiency of the rotating machine (η_e) can be calculated:

$$\eta_e = \frac{P_H + P_{\Delta p}}{P_{c,m}} = \frac{60 + 146.23}{264.93} = 0.77 \qquad (25)$$

The effective efficiency of the volumetric pump, calculated for a speed of 200 rot / min, indicates a value of 77%, which is superior to other pumps types [13]; [14].

From the received power at the machine couple (264.93 W) one part (60W), about 22% is consumed to overcome the hydrostatic load, a part (146.23 W), about 55% is consumed to overcome the hydraulic resistances in the pump circuit and the rest to overcome the viscous friction between the rotors and the case (58.67 W), ie 22%, and 1% are other losses, such as the friction in the machine bearings.

6. CONCLUSIONS

1. The machine circulated flow rate is influenced by the constructive elements (R_r, z, l) and the machine speed. (n_r).

2. The driving power depends on machine architecture (R_r, z, l), the machine speed (n_r) and the pressure increase (Δp) between the machine suction and discharge.

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

4. The presented constructive solution can circulate clean liquids, rheological fluids or polyphasic fluids (water + sand, water + vapor, water + ashes).

5. We are concerned with finding some beneficiaries for this new type of working machine with profiled rotors.

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