THEORETIC AND EXPERIMENTAL RESEARCH ON THE CHARACTERISTIC DIAGRAMS OF A NEW TYPE OF ROTATING MACHINE WITH PROFILED ROTORS

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În lucrare se prezintă principiul de funcţionare şi soluţia constructivă a maşinii; se precizează relaţiile de calcul pe baza carora se construiesc curbele caracteristice teoretice ale maşinii.

Se prezintă standul de încercări pe care s-au efectuat măsurătorile pentru a stabili pe cale experimentală curbele caracteristice ale maşinii. Se compară curbele caracteristice obţinute pe cale teoretică cu cele obţinute pe cale experimentală..

The paper presents the functioning principle and the constructive solution of the machine; the computation relations that allow plotting the theoretical characteristic diagrams of the machine are given.

There is also presented the experimental setup where measurements were performed in order to establish the experimental characteristic diagrams of the machine. Theoretical and experimental characteristic diagrams are compared.

Keywords: rotating machine, profiled rotors, characteristic diagrams of the machine.

1. Introduction

The relations that establish the performances of a machine subjected to various working conditions, differing from the nominal conditions, are known as the characteristics of the specific machine.

This new type of rotating machine with profiled rotors can function as pump, fan or blower.

Such a machine has to be able to convert the motor torque received at the shaft level in other useful effect: increase of pressure, increase of speed etc.

The following sections will tackle only the characteristic diagrams of the rotating volumetric pumps.

Such a volumetric pump can be used for the transport of:

- polyphase fluids (water + ash, water + naphtha, water + sand);
- used waters from the water purification plants;

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- rheological fluids; - water in irrigation plants.

Accordingly, this type of working machine is useful in power industry, petrochemical industry, mining and agriculture.

2. The constructive solution and the functioning principle of the machine

The new type of rotating machine with profiled rotors functions in the following ways:
- as working machine (pump, fan, blower); in this case, the machine receives a torque motor at the level of the shaft (9); the discharge pressure of the fluid (p_r) will be higher than the intake pressure (p_a) [1] [2] [3] [4];
- as force machine (hydraulic motor, pneumatic motor, steam or gas motor); in this case $p_a > p_r$ and the machine delivers a torque motor through the shaft (9) [1] [2] [3] [4].

The present paper analyze only the machine functioning as a rotating volumetric pump with profiled rotors.

The machine consists (fig.1) of two identical rotors (2, 5) of special shape, that rotate with the same angular speed inside a casing (1, 4). The synchronous rotation of the two rotors is guaranteed by the use of a cylindrical gearing consisting of two helical gears mounted inside or outside the machine (as shown in chapter 5). The gears have the same pitch diameter and are mounted on the shafts 7 and 9; they rotate such as the rotating pistons (6) of the upper rotor would enter the cavities (10) of the lower rotor.

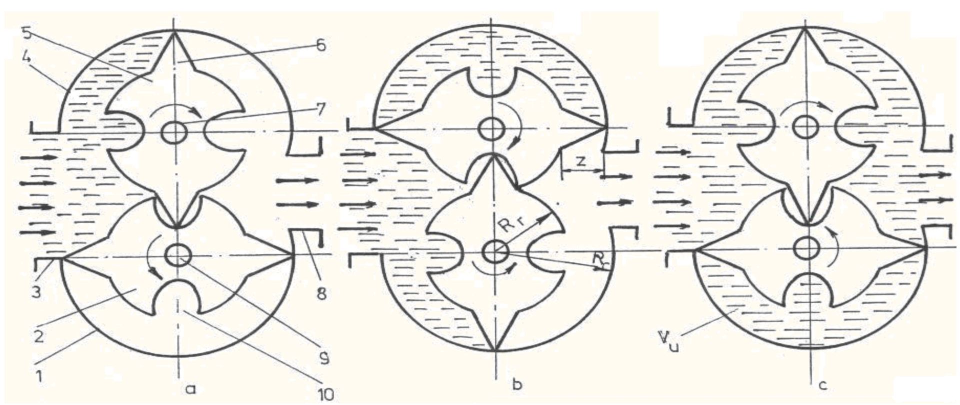

Fig.1. The functioning principle of the rotating volumetric machine. 1-lower casing ; 2-lower rotor; 3-intake chamber; 4-upper casing; 5-upper rotor ;6-rotating piston; 7-driven shaft; 8-discharge chamber; 9-driving shaft ; 10-cavity where the piston of the upper rotor enters

The suctioned fluid (fig.1a) is transported to the discharge and, after a 90° rotation of both rotors, the system arrives in the position shown in figure 1b and subsequently in figure 1c.

The fluid contained in the available volume V_u (fig.1c), that is the space between the pistons, the lower casing (1) and the lower rotor (2), will be transported to the discharge chamber after a 180° rotation. Two such volumes will be transported from intake to discharge during a complete rotation of the shaft (9):

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

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

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

(1) and (2) lead to:

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

3. Determining of the computation relations for the flow rate transported by the machine and for the theoretical driving power of the machine

*The volumetric flow rate discharged by a sole rotor of length l [m] and angular speed n [rpm] will be equal to:

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

Because the machine has two identical rotors, the fluid flow rate transported by the machine will be equal to:

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

It can be noticed from (5) that the machine flow rate depends on the following parameters:

- constructive parameters: l, R_r, z,
- functional parameters: n.

**The theoretical driving power o the machine is given by [4]:

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

where Δp denotes the increase of pressure achieved by the machine between intake and discharge.

4. Plot of the theoretical characteristic diagrams of the rotating working machine with profiled rotors

The following characteristic diagrams will be theoretically established onwards: a- $\dot{V}_t = f(n)$, b- $P_t=f(n)$, c- $P_t=f(\Delta p)$.

a - Establishment of the dependency $\dot{V}_t = f(n)$

The variation of the flow rate of the water transported by the rotating pump with profiled rotors will be onwards computed as a function of the machine speed. The computation results will be subsequently compared to the ones obtained by experimental research.

The computation formula of the flow rate transported by the machine is(5):

$$\dot{V}_m = \pi l z(z + 2R_r)\frac{n}{30}[m^3 / s]$$

The following values are specified for the solution built in the laboratory:

-rotor length: l =0.05 m;

-height of the rotating piston: z =0.03 m;

-rotor radius: R_r = 0.05 m.

$$\dot{V}_m = \pi \cdot 0.05 \cdot 0.03(0.03 + 2 \cdot 0.05)\frac{n}{30} = 0.00002041 \cdot n[m^3 / s] = 1.2246 \cdot n[l / \min] \quad (7)$$

The volumetric flow rate will be computed for various rotation speeds of the machine if the closing valve is completely open at the pump discharge ($\alpha = 90^o$) (Fig. 2):

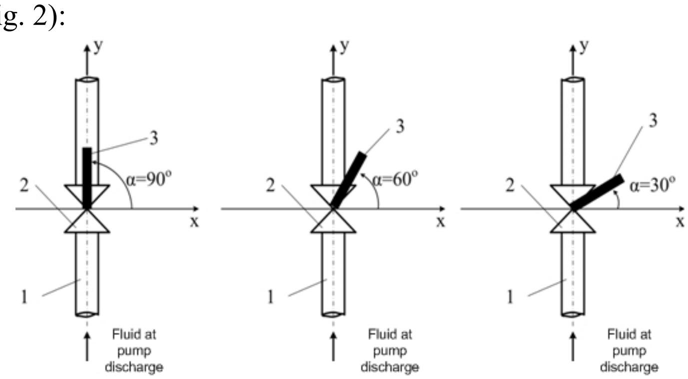

Fig. 2. Computation notations regarding the position of the closing valve lever mounted on the discharge pipe of the pump: 1- pipe Dn 50; 2 – valve; 3 – lever for the opening of the ball valve

The rotation speed of the machine was chosen in a range such as the speed of water at the pump intake would be of approximately 1m/s; values from table 1 are obtained if *n* is replaced in (7).

Table 1.

Values of the theoretical flow rate

n [rpm]	200	220	240	260	280	300
$\dot{V}_t$ [l/min]	244.92	269.41	293.90	318.39	342.88	367.38

Data from table 1 allowed plotting the function $\dot{V}_t = f(n)$ (fig.3).

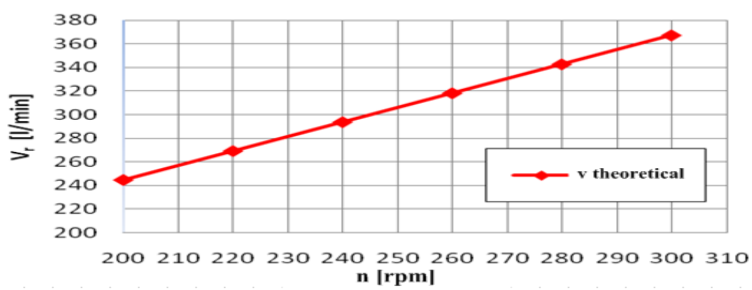

Fig.3 The characteristic diagram $\dot{V}_t = f(n)$

This graphical representation will be compared to the results obtained by experimental research.

b - Theoretical establishment of the characteristic diagram P_t=f(n) for the rotating working machine

The computation formula for the theoretical driving power of the machine was previously established as (6):

$$P_t = \pi l z(z + 2R_r)\frac{n}{30}\Delta p[W]$$

If the following replacements are made in (6): *l =0.05m, z =0.03m,* R_r *=0.05 m* and $\Delta p = 0.2 \cdot 10^5$ *Pa*, it results that:

$$P_t = 0.408 \cdot n \text{ [W]} \qquad (8)$$

In (8), *n* is replaced with the values presented in table 2.

Table 2.

The values of the theoretical power

n [rot/min]	200	220	240	260	280	300
P_t[W]	81.6	89.76	97.92	106.08	114.24	122.4

Data from table 2 allowed plotting the linear dependency $P_t = f(n)$. The result is shown in Fig. 4.

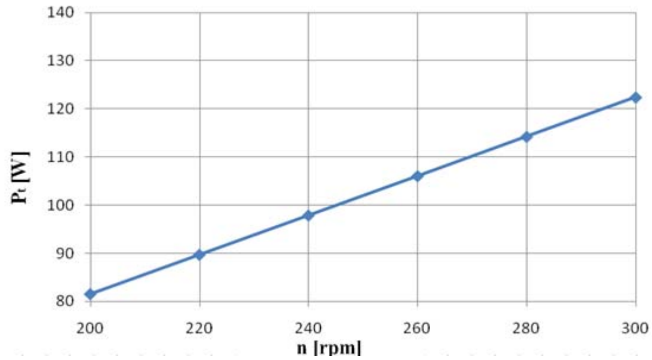

Fig.4. The characteristic diagram $P_t = f(n)$

c – *Theoretical establishment of the characteristic* P_t*=f(Δp) for the working rotating machine*

If the computation relation of the theoretical driving speed of the machine (6) is applied and the following parameters are considered: l *=0.05m, z =0.03m,* R_r *=0.05 m* and *n =220* rpm, it results that:

$$P_t=0.0052\,\Delta p \qquad (9)$$

Table 3.

Values of the theoretical power

n [rpm]	220	220	220	220	220
Δp [bar]	0.20	0.21	0.22	0.23	0.24
P_t[W]	104	109.2	114.4	119.6	124

The dependency $P_t=f(\Delta p)$ was plotted using the data presented in table 3.

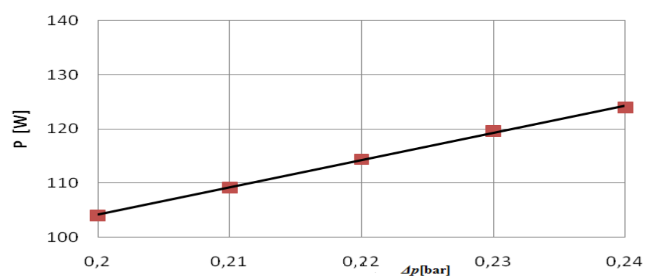

Fig.5. The characteristic diagram $P_t=f(\Delta p)$

Fig. 5 highlights the linear dependency between P_t and *Δp.*

5. The experimental setup for testing the rotating working machine

It can be noticed from figure 5 that the setup is a closed circuit type.

The setup was designed and built in the laboratory of the Chair of Thermotechnics, Thermic Machines and Refrigeration Plants.

The main components of the setup are:

- Cylindrical tank : $\phi =$ 1000 mm , $H = 2200$ mm, $\dot{V} = 2.2\,\mathrm{m}^3$;
- Volumetric rotating pump with the main dimensions: $R_r = 50mm$; R_c=*80mm* ; $z = 30mm$;
- Electric engine with device for speed control: *P*=1.1kW; *n*=940 rpm;
- Hydraulic control valve for controlling the pump load *Dn 50, Pn 6*;
- Measuring instrumentation: pressure gauge, thermometer, electromagnetic flow meter, electronic device for the control of the electric engine speed.

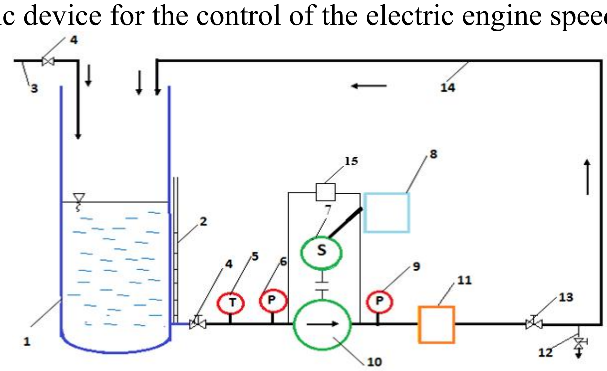

Fig.5.Sketch of the setup for testing the rotating machine
1-water tank; 2-level indicator; 3-filling pipe; 4-closing valve; 5-thermometer; 6-pressure gauge; 7-electric engine; 8-device for speed control ALTIVAR 58; 9-numeric pressure gauge; 10-volumetric pump; 11-electromagnetic flow meter; 12-drain pipe; 13-control valve; 14-discharge pipe; 15-differential pressure gauge

The tank (1) contains water from the supply network that is suctioned by the rotating volumetric pump (10).

The temperature of the water at the pump intake level is measured with the digital thermometer (5); intake and discharge pressures are measured using the pressure gauges (6) and (9); the setup was endowed with a differential pressure gauge (15) in order to detect the small values of the pressure increase achieved by the pump.

The measurements are performed at various constant speeds of the electric motor; the speed is measured and controlled using the electronic device ALTIVAR 58 (8). The electronic device allows also measuring the absorbed power.

6. Methodology of measurements

The design and building of the setup are presented in [5] and [6].

After the check of the instruments that measure the pressure, the temperature and the flow rate, the following work stages are performed:

a – The tank from fig.6 is filled with potable water from the supply network.
b – The plant is filled with water; the level of water in the tank is read using the level indicator.

Fig. 6 presents a lateral view of the experimental plant.

Fig. 6. Lateral view of the built experimental plant.

c – The speed regulator of the single phase electric engine is started: *P=1100W*; $\nu = 50 Hz$; in order to start at a speed of $n = 200$ rpm.
d – The circuit and the values indicated by the instruments are checked: temperature, speed, discharge pressure, flow rate, power.
e – Measurements are performed in order to establish experimentally the characteristics of a new type of volumetric working machine.

7. Experimental results

a - Plotting the characteristic diagram $\dot{V} = f(n)$

Table.4.

Discharge valve fully opened α=90°

n [rpm]	200	220	240	260	280	300
$\dot{V}_t$ [l/min]	244.92	269.41	293.90	318.39	342.88	367.38
$\dot{V}_r$ [l/min]	233.0	257.0	281.0	304.0	332.0	353.0

The characteristic diagrams $\dot{V}_t = f(n)$ $\dot{V}_r$ =*f(n)* (fig.7) were plotted using data presented in Fig. 4.

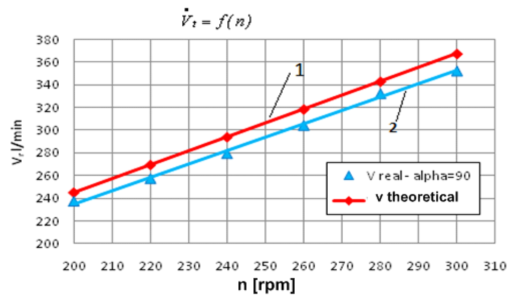

Fig.7. Graphical representation of the characteristic $\dot{V}_t = f(n)$;

1 – curve based on theoretical values; 2 – curve based on experimental values

b – Plot of the characteristic diagram $P_r = f(n)$

An efficiency of the electric engine of 95% is adopted and data of tabel 5 results.

Table 5.

Values of power in function of the speed

n [rpm]		200	220	240	260	280	300
P_r [W]	α = 90º	110	132	143	165	187	209
	α = 60º	99	121	143	165	187	209
	α = 30º	99	121	132	154	176	198

Data presented in table 5 allowed plotting the characteristic diagrams $P_r = f(n)$ for various positions of the valve mounted at the pump discharge (fig.8).

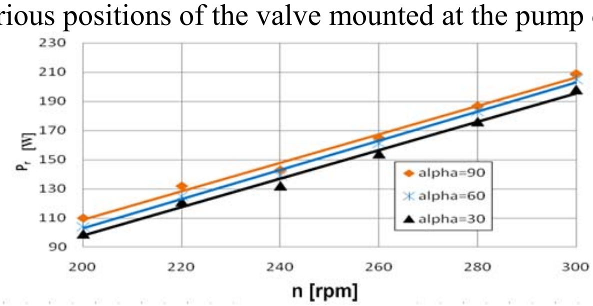

Fig. 8 Graphical representation of the characteristic diagram $P_r = f(n)$

c – *Plot of the characteristic diagram $P_r = f(\Delta p)$*

Tabel 6.

Values of the theoretical and of the real power

n [rpm]	220	220	220	220	220
Δp [bar]	0.20	0.21	0.22	0.23	0.24
P_t [W]	104	109.2	114.4	119.6	124
P_r [W]	127	130.9	133.3	137.5	140

Data presented in table 6 allowed plotting the characteristic diagrams $P_r=f(\Delta p)$ and $P_t=f(\Delta p)$.

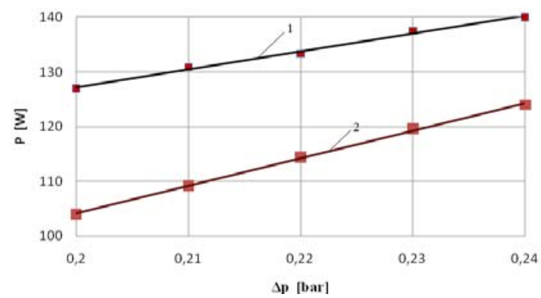

Fig.9. Graphical representation of the characteristic diagram $P_r = f(\Delta p)$
1 – curve based on experimental values; 2 – curve based on theoretical values

The graphical representation indicates an almost linear increase of the power absorbed by the working machine in function of the pressure increase achieved by the pump.

8. Conclusions

1.The comparison between the experimental and the theoretical data indicates a good agreement.

2.The experimentally established magnitudes fit in the range of values found in literature [6], [7].

3.The working machine used as volumetric pump is reliable; the constructive solution can be extended also as fan or blower.

4.The potential beneficiaries of this type of rotating working machine that transports any type of liquid, viscous or polyphase substance are the enterprises that work in the fields of power industry, chemical industry and metallurgy.

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