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# Research regarding the establishment of effective efficiency for a new type of rotating volumetric pump

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**Abstract** - *The paper presents the constructive solution and the operating principle for a rotating volumetric pump with profiled rotors. The machine driving power was calculated for different speeds; a machine test stand is presented. Experimental researches were conducted on it. The real power absorbed by the machine was measured and subsequently the effective efficiency of the working machine was calculated.*

*Key Words: Rotating volumetric pump, Profiled rotors, Effective efficiency.*

## 1. Introduction

The rotating machines have the advantage that converts the torque received to the shaft in pressure potential energy with minimal losses.

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: $\vec{M} = \vec{F} \times \vec{b}$; $M = Fb\sin\alpha$ where the arm (b) of the force (F) is always perpendicular to the force, that is: $\sin\alpha = \sin 90^\circ = 1$.

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

The design presented in the paper is "reversible" because:

* - If the discharge pressure ($p_2$) must be higher than the suction pressure ($p_1$), the machine works as a pump.

** If $p_1 > p_2$ the machine works as hydrostatic motor.

This type of machine can be used in the following areas:

- in agricultural industry for irrigations,
- in energetics at hydroelectric power plants,
- in petrochemical industry at high viscosity fluid handling, etc.

## 2. THE CONSTRUCTIVE SOLUTION AND THE OPERATING PRINCIPLE

The machine (fig.1) has two identical profiled rotors (2, 5) of special shape which rotate in the opposite direction 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.

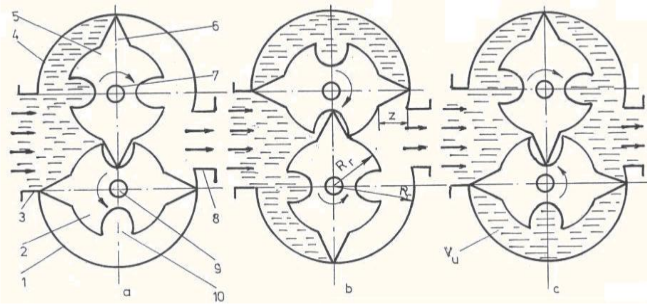


Fig -1: The rotors position after a 90° rotation

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.

### 2.1 The flow rate computation relations

After a 180° rotation the fluid contained in the useful volume $V_u$ (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]:

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

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

$$R_c = R_r + z \ \text{[m]} \tag{2}$$

it results:
$$\dot{V}_u = \pi z(z + 2R_r) \ \text{[m}^3\text{/rot]} \tag{3}$$

 

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

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

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

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

## 2.2 Driven power computation relations

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

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

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

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]; Δp-increase pressure achieved by the pump between the suction and discharge; it may be defined by [5]:

$$\Delta p = \rho\cdot g\cdot\Delta H\ [\mathrm{N/m^2}]$$

where: ρ - fluid density [kg/m³]; g - gravitational acceleration [m/s²]; ΔH - hydrostatic load [$mH_2O$]

## 3. THE COMPUTATION OF THE FLOW RATE CIRCULATED BY THE VOLUMETRIC ROTATING PUMP

In the flow rate computing relation the values of the constructed model are replaced:
- l = 0.05 m; z = 0.03 m; $R_r$ = 0.05 m
- the machine speed was chosen $n_r$: 100, 150, 200, 250, and 300 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 ($\dot{V}$) (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 [6]:

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

The calculation results are shown in Table 1.

Table -1 Flow rate and water velocity values

| $n_r$ [rpm] | 100 | 150 | 200 | 250 | 300 |
|---|---|---|---|---|---|
| $\dot{V}$ [m³/s] | 0.00204 | 0.00306 | 0.00408 | 0.00510 | 0.00612 |
| w [m/s] | 1.34138 | 2.01207 | 2.68276 | 3.35345 | 4.02414 |

## 4. THE COMPUTATION OF THE PRESSURE LOSS IN THE WATER CYCLE

In order to calculate the theoretical power necessary to drive the pump the fluid pressure losses in the circuit must be established.
The pump circulates water for which are known [7]: the dynamic viscosity (η), the kinematic viscosity (ν) and the density (ρ).

$$\eta = 10.4\cdot10^{-4}\ \frac{N\cdot s}{m^2};\ \nu = 10.4\cdot10^{-7}\ \frac{m^2}{s};\ \rho = 1000\ kg/m^3$$

The total pressure loss ($\Delta p_t$):

$$\Delta p_t = \Delta p_{lin} + \Delta p_{loc}\ [\mathrm{N/m^2}] \quad (8)$$

$$\Delta p_{lin} = \lambda\cdot\frac{l}{d}\cdot\rho\cdot\frac{w^2}{2}[\mathrm{N/m^2}] \quad (9)$$

$$\Delta p_{loc} = \sum\zeta_i\cdot\rho\cdot\frac{w^2}{2}[\mathrm{N/m^2}] \quad (10)$$

where:
λ - linear pressure loss coefficient [m]
l - pipe length [m]
d - inner diameter of the pipe [m]
ρ - fluid density [kg / m³]
w - fluid velocity [m / s]
ζ - local pressure loss coefficient

a) For n = 100 rot / min the power consumed to overcome the hydraulic resistance is determined ($\Delta p_H$).
The value of λ is determined from a chart [7] based on Re and d / ε:

$$\lambda = f\left(\mathrm{Re}, \frac{d}{\varepsilon}\right) \quad (11)$$

ε - absolute roughness of the pipe walls

$$\mathrm{Re} = \frac{wd}{\nu} = \frac{1.34138\cdot0.044}{10.04\cdot10^{-7}} = 5.87\cdot10^4 \quad (12)$$

$$\frac{d}{\varepsilon} = \frac{44}{0.03} = 1466 \quad (13)$$

$$\lambda = f\left(5.85\cdot10^4;1466\right) \Rightarrow \lambda = 0.023$$

$$\Delta p_{lin} = 0.023\cdot\frac{7.8}{0.044}\cdot1000\cdot\frac{1.34128^2}{2} = 3660.50\ [\mathrm{N/m^2}]$$

$$\sum\zeta_i = 3\zeta_{\mathrm{elbow}} + 2\zeta_{\mathrm{valve}} + \zeta_{debitm} \quad (14)$$

From [8] it results:

$$\sum\zeta_i = 3\cdot0.22 + 2\cdot0.05 + 0.2 = 0.96$$

$$\Delta p_{loc} = 0.96\cdot1000\cdot\frac{1.34128^2}{2} = 863.56[\mathrm{N/m^2}]$$

$$\Delta p_t = 3660.50 + 863.56 = 4524.06\ [\mathrm{N/m^2}]$$

$$\Delta P_{\Delta p_t} = \Delta p_t\cdot\dot{V} = 4524.06\cdot0.00204 = 9.229\ [\mathrm{W}]$$

Similarly, the calculation are made for $n_r$: 150, 200, 250, and 300 rot/min.
The calculation results are shown in Table 2.

Table -2 Values of $\Delta P_{\Delta p_t}$ [W]

| $n_r$ [rpm] | Re | λ | $\Delta p_{lin}$ [N/m²] | $\Delta p_{loc}$ [N/m²] | $\Delta p_t$ [N/m²] | $\Delta P_{\Delta p_t}$ [W] |
|---|---|---|---|---|---|---|
| 100 | $5.87 \cdot 10^4$ | 0.023 | 3660.50 | 863.56 | 4524.06 | 9.229 |
| 150 | $8.817 \cdot 10^4$ | 0.018 | 6459 | 1943.11 | 8402.11 | 25.71 |
| 200 | $1.175 \cdot 10^5$ | 0.016 | 10201.1 | 3452.67 | 13653.7 | 55.707 |
| 250 | $1.469 \cdot 10^5$ | 0.0152 | 15146.7 | 5396.45 | 20543.2 | 104.76 |
| 300 | $1.763 \cdot 10^5$ | 0.0147 | 21098.1 | 7772.43 | 28870.5 | 176.68 |

## 5. THE EXPERIMENTAL STAND FOR TESTING THE VOLUMETRIC PUMP

The installation is closed circuit and was built in the laboratory of Thermotechnics, Engines, Thermic and Refrigeration Plants Department. Before conceiving and designing the experimental installation specialty papers were consulted [9] [10] [11] [12]. Figure 2 presents the sketch of the experimental installation.
This installation was conceived, designed and constructed in order to validate the theoretical results of a PhD thesis.
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.

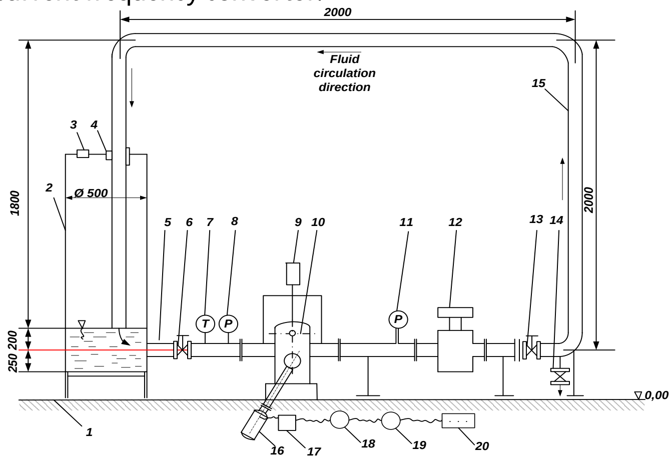


Fig -2: Sketch of the experimental installation
1-tank support; 2- tank for the fluids, V=0.1785 m³; 3- plug for aeration; 4-tank inlet pipe; 5-vent pipe Dn60 in the pump;6-valve Dn60,$p_n$ 2 bar;7-thermometer;8-manometer at the pump inlet;9-differential manometer;10- volumetric pump with profiled rotors; 11- manometer at the pump discharge; 12- electromagnetic flow meter; 13-valve for the flow rate adjustment; 14- fluid drain valve; 15- pipe Ø 50X3; 16- anti-explosive electrical motor; 17- frequency converter; 18-ampermeter; 19-voltmeter; 20- AC power source 380 V.

The experimental installation contains modern measuring devices with digital indication.

Fig -3: General overview of the installation
1- tank with fluid; 2- rotating volumetric pump; 3- electromagnetic flow meter; 4- transparent plexiglass pipe; 5- multimeter; 6- frequency converter; 7- fuse box; 8- differential manometer; 9- digital thermometer

Fig -4: Measuring instruments from the experimental installation
1- Bourdon manometer; 2- Barolli manometer; 3- electromagnetic flow meter; 4- differential manometer; 5- digital thermometer

 

## 6. EXPERIMENTAL RESEARCHES

In order to calculate the pump driven power at the coupling ($P_{c,m}$) first, the power absorbed by the electric motor ($P_{m,e}$) is calculated [13]:

$$P_{m,e} = \sqrt{3} \cdot U \cdot I \cdot \cos\varphi [\mathrm{W}] \quad (15)$$

U - voltage [V]; I - electrical current intensity [A]; cos φ - power factor.
U and I were measured with the devices (18) and (19) shown in Figure 2, for the three-phase electric current. From the electrical motors factory catalog [14] it results: $\eta_{m,e}$=0.747 and cos φ = 0.71.
As a result, the power at the machine couple will be:

$$P_{c,m} = P_{m,e} \cdot \eta_{m,e} [\mathrm{W}] \quad (16)$$

The circulated fluid was water with: ρ = 1000 kg/m$^3$ and t= 20 °C.
The results of the experimental measurements and calculation values of equations (15) and (16) are shown in Table 3.

Table -3 Values of $P_{c,m}$ [W]

| No. | $n_r$ [rpm] | 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 | 359.75 |
| 5 | 300 | 384.50 | 1.32 | 632.41 | 465.68 |

Based on the values in Table 3 to graph $P_{c,m}$ = f ($n_r$) in Chart 1 was plotted.

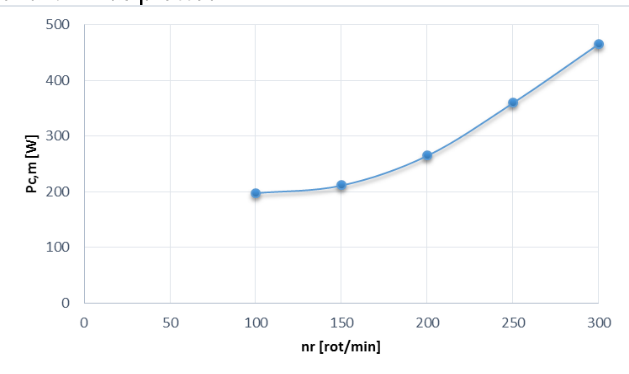


Chart -1: $P_{c,m}$ = f ($n_r$)

## 7. WORKING MACHINE EFECTIV EFFICIENCY COMPUTATION

The effective efficiency is given by [15] [16]:

$$\eta_e = \frac{P_t}{P_{c,m}} \quad (17)$$

The value of the power at the machine couple ($P_{c,m}$) resulted from the experimental measurements. The theoretical power of the machine ($P_t$) will be the sum of the consumed power to overcome the hydraulic resistance ($P_{\Delta p_t}$) and the hydrostatic load ($P_H$). For a speed of 100 rev / min, it results:

$$\eta_e = \frac{P_t}{P_{c,m}} = \frac{P_{\Delta p_t} + P_H}{P_{c,m}} = \frac{P_{\Delta p_t} + \rho \cdot g \cdot \Delta H \cdot \dot{V}}{P_{c,m}}$$

The discharge height is H = 2 m.

$$\eta_e = \frac{9.229 + 10^3 \cdot 9.81 \cdot 2 \cdot 0.00204}{197.66} = 0.25$$

Similarly, the calculation are made for $n_r$: 150, 200, 250, and 300 rot/min and the results are shown in Table 4.

Table -4 Values of $\eta_e$ for different machine speeds

| $n_r$ [rpm] | Pc,m [W] | $\Delta P_{\Delta p_t}$ [W] | $P_H$ [W] | Pt [W] | $\eta_e$ |
|---|---|---|---|---|---|
| 100 | 197.66 | 9.229 | 40.02 | 49.24 | 0.25 |
| 150 | 211.50 | 25.71 | 60.03 | 85.74 | 0.405 |
| 200 | 264.93 | 55.707 | 80.04 | 135.74 | 0.512 |
| 250 | 359.75 | 104.769 | 100.06 | 204.83 | 0.569 |
| 300 | 465.68 | 176.687 | 120.74 | 297.42 | 0.638 |

Based on the values in Table 4 to graph $\eta_e$ = f ($n_r$) in Chart 2 was plotted.

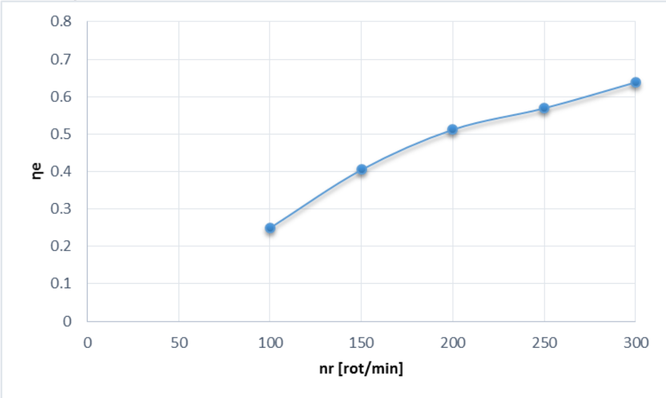


Chart -2: $\eta_e$ = f ($n_r$)

From Chart 2 one observes that the function $\eta_e$ = f ($n_r$) is an ascending curve.

## 8. CONCLUSIONS

1. The advantage of this rotating machine is that it can circulate both fluids (water, oil) and gases (air, oxygen).
2. For the conceived hydrostatic circuit the local pressure losses are about three times smaller than the linear pressure losses.
3. The consumed power to overcome the hydraulic resistance in the circuit is higher than that for the hydrostatic load.
4. At increased machine speed from 100 rot/min to 300 rot/min, the increase in the theoretical power of the

 

machine is faster than the increase in the power at the machine couple ($P_{c,m}$) which leads to an increase in the effective efficiency of the machine.
5. At increased speed, the volumetric efficiency of the machine increases, which leads to an increase in the effective efficiency of the machine.

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## BIOGRAPHIES

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