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# THE RELATION BETWEEN THE POWER REQUIRED TO DRIVE A ROTATING VOLUMETRIC PUMP AND THE IRRIGATED AGRICULTURAL AREA

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***Abstract***

*The constructive solution of a rotating volumetric pump with two profiled rotors is presented; each rotor is provided with two triangular-shaped rotating pistons. The calculation relation of the driving power of the volumetric pump is established and the graph* $P = f(n_r)$ *is drawn. Subsequently, the pump is placed in an "in situ" hydraulic network and the pump load and the water transport distance are specified; linear and local pressure losses are calculated, resulting in total pressure loss. The driving power of the pump is determined and* $V = f(n_r)$ *and* $P=f(n_r)$ *is plotted.*

***Key words***: *rotating volumetric pump, profiled rotors.*

## INTRODUCTION

This paper belongs to the category of scientific papers that address the field of land reclamation for rotating machines that transports fluids.
There is a type of rotating working machine with profiled rotors that can operate (Dobrovicescu et al., 2009; Băran et al., 2010):
- As a fan, for the circulation of different gas mixtures with or without suspensions;
- As a low-pressure compressor;
- As a rotating volumetric pump for transporting any type of fluid, liquid or gas, namely:
- general fluids: water, air, steam, etc.;
- polyphase fluids: water + air, water + sand, water + ash, etc.;
- viscous fluids: oil, diesel, oil, etc.

The advantage of the rotating working machine is that the entire motor torque received from the driving motor is used to transport the fluid.
Table 1 presents a classification of rotating machines (Dobrovicescu et al., 2009; Băran et al., 2010).
The construction of rotating working machines (pumps, fans, blowers) with high performance is topical.
The researches aim to build machines that ensure the transformation of the motor torque received from the shaft into useful effects, but with energy losses as small as possible.

Table 1. A general classification of rotating machines

| According to the pursued purpose | Depending on the constructive solution | According to the working parameters |
|---|---|---|
| Working machines | With profiled rotors | a) Fans, blowers, pumps |
| | With pallets | b) Fans, blowers |
| Force machines | With profiled rotors | c) Internal combustion engines, steam or gas engines, pneumatic engines |
| | With pallets | d) Steam turbines, gas turbines |

The construction of rotating working machines (pumps, fans, blowers) with high performance is topical.
The researches aim to build machines that ensure the transformation of the motor torque received from the shaft into useful effects, but with energy losses as small as possible.
Table 2 presents the classification of rotating machines with profiled rotors according to the intended purpose and the adopted constructive solution (Dobrovicescu et al., 2009).
A more difficult problem is to make a rotating machine that can be used as a working machine or as force machine, i.e., theoretically to be a "reversible" machine (Motorga, 2011; Băran et al., 2012).
Such a type of machine must ensure:

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- transforming the useful moment with minimal losses, when it operates as a working machine;
- full use of the working agent's energy to drive the shaft when it is working as a power machine.

Table 2. Classification of rotating machines with profiled rotors

| According to the pursued purpose | Depending on the constructive solution |
|---|---|
| Working machines | Fans for the circulation of gases or vapors |
| | Blowers for gas and vapor compression |
| Force machines | Hydraulic motors |
| | Pneumatic motors |
| | Steam or flue gas engines |

**Volumetric pump architecture and the operating principle**

Figure 1 shows the sketch of the demonstration model of the rotating machine with two profiled rotors, a constructive solution that allows the height of the rotating piston (z) to aim at the rotor radius ($R_r$). It is noted that, in order to prevent "reverse flow", a central portion of 4 mm thick of the rotor was left.

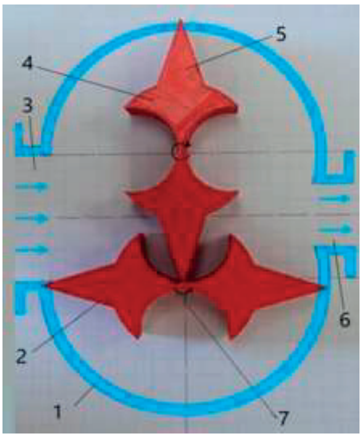


Figure 1. Cross section through the demonstration model of the rotating machine with two profiled rotors: 1- machine case; 2- lower rotor; 3- fluid suction connection; 4- upper rotor; 5- rotating piston; 6 - fluid discharge connection; 7- cavity into which the piston of the upper rotor enters

In (Stoican Prisecaru et al., 2021), the relation between the rotor radius of the and the height of the rotating piston was established, where the maximum value of the height of the rotating piston should be equal to the rotor radius ($z = R_r$).

Basically, this condition can be partially fulfilled because:
- if $z = R_r$, then the fluid can flow in the "reverse direction" from discharge to suction between the gaps between the two rotors; $z < R_r$ is chosen;
- the shafts on which the rotors are fixed must disappear.

This is possible by attaching the rotors to the gearwheels (Figure 2).

The gears fixed to the rotors by screws, ensure the synchronous rotation of the rotors.

A single gearwheel attached to the lower rotor has a driving shaft that takes power from the outside from an electric motor.

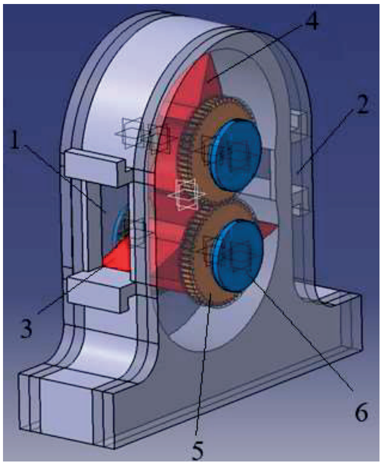


Figure 2. Axonometric view of the volumetric rotating machine model with profiled rotors: 1 - suction chamber; 2 - discharge chamber; 3 - lower rotor; 4 - upper rotor; 5 - gearwheels; 6 - sealing caps

Figure 3 shows the operation of the rotating volumetric pump with profiled rotors. One can observe that after a 180° rotation, the useful volume of the transported fluid ($V_u$) is discharged into the discharge chamber.

The useful volume is the volume between two pistons and the case (Figure 3.a).

When operating as a rotating volumetric pump with profiled rotors, two volumes ($V_u$) will be transported from the suction to the discharge at a complete rotation of the shaft.

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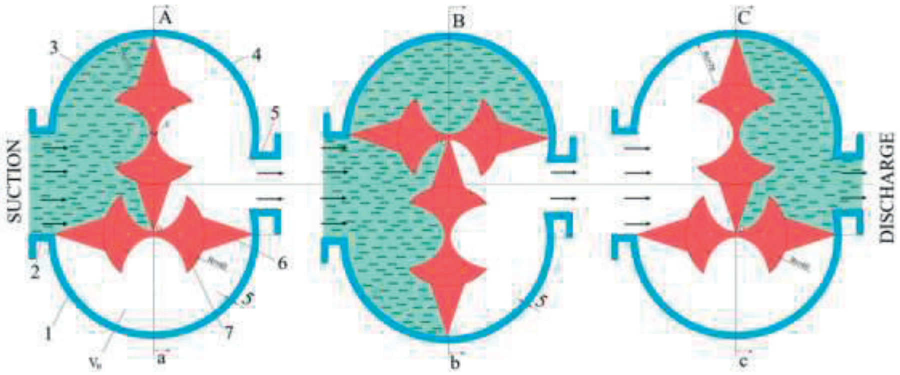


Figure 3. Operating principle of the rotating volumetric machine
1 - lower case; 2 - fluid suction connection; 3 - upper rotor;
4 - upper case; 5 - fluid discharge connection; 6 - rotating piston; 7 - lower rotor.

**Determination of the driving power of the rotating volumetric pump with two profiled rotors**

The theoretical driving power of the rotating pump for the three constructive solutions can be calculated as follows (Bansal, 2005; Băran et al., 2008):

$$P = \dot{V} \cdot \Delta p \ [W] \quad (1)$$

The increase in total pressure achieved by the rotating pump (*Δ*p) changes as the pump speed increases; the hydrostatic load and pressure losses that occur on the hydraulic circuit of the pump are evaluated at about 4 $mH_2O$ (Isbăşoiu, 2011):

$$\Delta p = \rho_{H_2O} \cdot g \cdot H = 10^3 \cdot 9.81 \cdot 4 = 0.3924 \cdot 10^5 \ [Pa] \quad (2)$$

where:

* $\dot{V}$ - volumetric flow rate [$m^3$ / s];
* Δp - pressure increase [N /$m^2$];
* ΔH - pumping height [m];
* $\rho_l$ - density of the circulated fluid [kg /$m^3$].

In [9], the calculation relation of the volumetric flow rate of the fluid transported by the pump was established:

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

where $n_r$ is the rotating machine speed [rpm].
Substituting relation (3) and (2) in relation (1) one can obtain:

$$P = \dot{V} \cdot \Delta p = \left[\pi \cdot l \cdot z \cdot (z + 2R_r) \cdot \frac{n_r}{30} - \dot{V}_p\right] \cdot \Delta p \ [W] \quad (4)$$

Substituting l = 0.05 [m], $R_r$ = 0.04 [m], z = 0.038 [m], $n_r$ = 100… 500 [rpm] and $\Delta p = 0.3924 \cdot 10^5 \ [Pa]$, the values of the flow rate and the theoretical driving power of the rotating pump are presented in Table 3.

Table 3. The values of the flow rate and the theoretical driving power of the rotating pump depending on the speed

| **$n_r$ [rpm]** | **100** | **200** | **300** | **400** | **500** |
|---|---|---|---|---|---|
| $\dot{V}$ [$m^3$/h] | 8.1058 | 16.211 | 24.317 | 32.423 | 40.529 |
| P [W] | 88.353 | 176.70 | 265.06 | 353.41 | 441.76 |

One can observe that $P_m = f(l, z, R_r, n_r, \rho l, \Delta H)$.
Based on the data in Table 3, the graphs in Figures 4 and 5 were constructed.

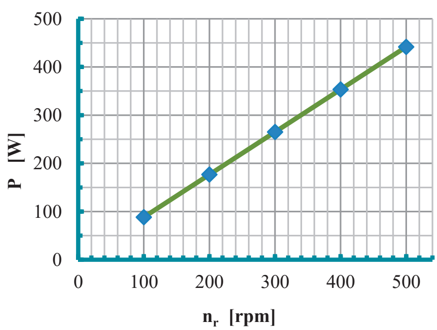


Figure 4. Variation of the theoretical driving power of the pump depending on the speed

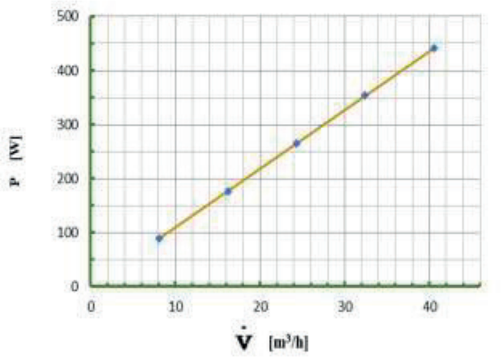


Figure 5. Variation of the theoretical driving power of the pump depending on the flow rate

Figures 4 and 5 show a linear dependence of the theoretical driving power of the pump depending on the speed and the flow rate.

**Establishing the connection between the theoretical driving power of the rotating volumetric pump and the irrigated agricultural area**

For a certain geometry of the irrigation system, it is necessary to know:

1. The flow rate required for a single watering;
2. Irrigation network architecture:

- The length of the straight pipe sections for which, the following are calculated:

*linear pressure losses are calculated with the relation (1):

$$\Delta p_{lin} = \lambda \frac{\sum l_i}{d} \rho \frac{w^2}{2} \left[ N/m^2 \right] \quad (5)$$

*local pressure losses (elbows, tee-joints, changes in water flow section) are calculated by the relation:

$$\Delta p_{loc} = \sum_{i=1}^{n} \xi_i \rho \frac{w^2}{2} \quad \left[ N/m^2 \right] \quad (6)$$

*the total pressure loss will be:

$$\Delta p_{tot} = \Delta p_{lin} + \Delta p_{loc} \quad \left[ N/m^2 \right] \quad (7)$$

The pump load will be: $\rho g H_{AB} + \Delta p_{tot}$.

Figure 6 shows the technological scheme of an irrigation system.

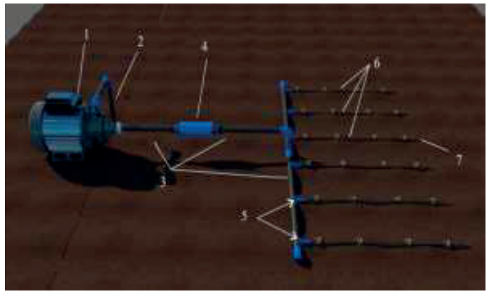


Figure 6. Technological scheme of an irrigation system: 1 - water pump; 2 - water source; 3 - distribution pipe; 4 - filtration-fertilization unit; 5 - connectors; 6 - drip tube; 7 - plugs

**Calculation of the water flow rate required for watering and the driving power of the pump**

It is considered an agricultural land area of 1 hectare. Watering is once a day with 10 l/m$^2$. So, $10^4 \cdot 0.010 = 100 \ \left[ m^3/day \right]$ are needed.

Watering time per square meter - 5 minutes.

The volumetric flow rate will be:

$$\dot{V} = \frac{100 \ m^3}{300 \ s} = 0.33 \ [m^3/s] \quad (8)$$

The main water distribution pipe (3) will have a diameter (d). The speed of the water in the pipe is $w = 1.5 \left[ m/s \right]$.

$$\dot{V} = A \cdot w = \frac{\pi d^2}{4} w \quad (9)$$

$$d = \sqrt{\frac{4\dot{V}}{\pi w}} = \sqrt{\frac{4 \cdot 0.33}{\pi \cdot 1.5}} = 0.28 \left[ m \right] \quad (10)$$

The pipe is made of steel for which the roughness is [1]: $\varepsilon = 0.2 \left[ mm \right]$; $\frac{d}{\varepsilon} = \frac{0.28}{0.2 \cdot 10^{-3}} = 1400$

$$\mathrm{Re} = \frac{wd}{\nu} = \frac{1.5 \cdot 0.28}{1 \cdot 10^{-6}} = 420000 \quad (11)$$

From the diagram (9): $\lambda = f\left( \mathrm{Re} \frac{d}{\varepsilon} \right) = 0.01$.

Linear pressure losses with l = 2 km = 2000 m, transport length.

$$\Delta p_{lin} = \lambda \frac{l}{d} \rho \frac{w^2}{2} \left[ N/m^2 \right] \quad (12)$$

$$\Delta p_{lin} = 0.01 \cdot \frac{2000}{0.28} \cdot 10^3 \cdot \frac{1.5^2}{2} = 80.357 \cdot 10^3 \left[ N/m^2 \right]$$

$$(13)$$

$$\Delta p = 80357 \left[ N/m^2 \right] = 0.8 \left[ bar \right]$$

Local pressure losses plus the suction = 0.8 + 0.2 = 1 bar are also added.
Local losses are due to elbows, changes in flow section, valves, etc. It is estimated that these losses plus the pressure drop for suction (H = 10 m) are of the order of 0.2 bar = 20 $mH_2O$.
The theoretical power of the pump will be:

$$P = \dot{V} \cdot \Delta p = 0.33 \cdot 1 \cdot 10^5 = 33000\ [W] = 33\ [kW] \quad (14)$$

To transport 0.33 $m^3$ /s: l = 0.2 m, $R_r$ = 0.15 m, z = 0.1 m are chosen:

$$\dot{V} = \pi l z (z + 2R_r) \cdot \frac{n_r}{30} = 0.000837 \cdot n_r\ [m^3/s] \quad (15)$$

$$0.333 = 0.000837 \cdot n_r \Rightarrow n_r = 397.8 \approx 400 [rpm]$$

So, for l = 0.2 m, $R_r$ = 0.15 m, z = 0.1 [m] and $n_r$ = 400 [rpm]:

$$\dot{V} = 0.000837 \cdot n_r = 0.334 \left[m^3/s\right] \quad (16)$$

In relation (14) and (16) the number $n_r$ = 100-500 rpm is replaced and the values of the flow rate and the driving power of the rotating pump are presented in Table 4.

Table 4. The values of the flow rate and the driving power of the rotating pump depending on the speed

| $n_r$ [rpm] | 100 | 200 | 300 | 400 | 500 |
|---|---|---|---|---|---|
| $\dot{V}$ [$m^3$/s] | *0.0837* | *0.1674* | *0.2511* | *0.3348* | *0.4185* |
| P [W] | 8370 | 16740 | 25110 | 33480 | 41850 |

Based on the data in Table 4, the functions $\dot{V} = f(n_r)$ and $P = f(n_r)$ from Figures 7 and 8 were plotted.

Figures 7 and 8 show a linear dependence of the theoretical driving power of the pump depending on the speed and on the transported flow rate.

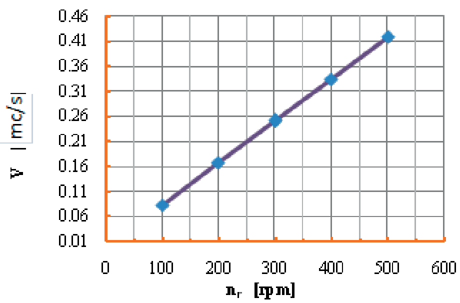


Figure 7. Graphical representation of the function $\dot{V} = f(n_r)$ for different pump speeds

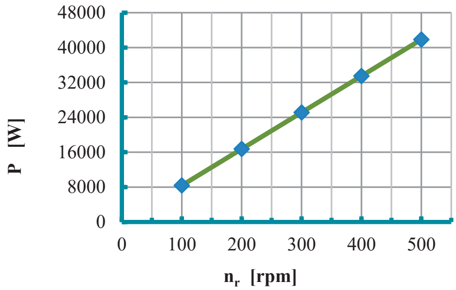


Figure 8. Graphical representation of the function $P = f(n_r)$ for different pump speeds

## CONCLUSIONS

Compared to working machines with reciprocating pistons used for transporting the same fluid flow rate, the energy consumption is lower in the case of rotating machines with profiled rotors, because the motor torque at the shaft level is almost entirely transmitted to the transported fluid.

Because $P = \dot{V} \cdot \Delta p$, the power required to drive the rotating machine will also increase.
When the rotational speed of the machine increases, the fluid flow rate increases linearly accordingly.
The volumetric pump with profiled rotors has an increased reliability and can be used in the field of land reclamation, in wastewater treatment plants, in: mining, energy, petrochemical industry.

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