The Influence of Fluid Viscosity on the Driving Power of a Rotating Working Machine

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Abstract— The paper presents the constructive solution of a machine that can function as a blower or as a pump. For three different fluids: air, water, oil, the power consumed to overcome the viscous friction between the rotors and the machine case, is calculated. The benefits of the rotating machines that can circulatepure fluids or with suspensions, fluids with high viscosity, are highlighted.

Keywords—Rotating machine, profiled rotors, driving power, fluid viscosity, blower, pump

I. INTRODUCTION

In real fluid flow the viscosity propertyhas special importance. This property has been highlighted by Isaac Newton (1642-1727) and it interferes in the computing relation of the tangential friction effort that occurs in laminar flow processes.

At fluid flow between the rotors and the machine case, due to the fluid viscosity, hydraulic resistance appears which causes a certain loss of energy, finally increasing the driving power of the machine.The paper presents a rotating machine which serves the fluidcirculation.

The "rotating machine" term relates to the fact that the presented constructive solution can be used as a blower or as a pump.

The rotating machines have the following advantages:

- Eliminates the valves;
- Eliminates the crank drive mechanism.

The absence of admission and discharge valves, the crank drive mechanism, leads to an increase in the internal and mechanical efficiency of the rotating machine.

The power supplied to the machine shaft is almost entirely transferred to the fluidto increase the potential pressure energy of the fluid.The paper presents the constructive solution and the working principle for a new type of rotating machine which is used in fluids circulation (air, water, oil).

The computing relations for the power consumed due to viscous friction between the rotors and the case to drive the rotors are presented.

The calculations are performed for three fluids: air, water, oil.

The paper concludes with a selective list of references that reflects the current state of research in rotating machines with profiled rotors.

The experimental research will be conducted in the laboratory of the Department Thermotechnics, Engines, Thermic and Refrigeration Plants, University Politehnica of Bucharest. This paper is a contribution to theoretical and experimental research in the field of rotating machines with application in the study of those with profiled rotors.

II. THE CONSTRUCTIVE SOLUTION AND THE OPERATING PRINCIPLE

The machine has two profiled rotors which rotate in the opposite direction within a case (Fig. 1).

The synchronous rotation of the rotors (3, 8) is provided by two gearwheels, which form a cylindrical gear with straight teeth's.The gear wheels are mounted on the shafts (5) and (9) outside of the machine; during the rotational movement, the rotary pistons (4) enter into the cavities of the adjacent rotor.

The rotor profile shape has been established in [1,2] and the manufacturing technology in [3,4].

With the notations from Fig. 1, the flow rate and the driving power of the machine calculation relations are [5,6,7]:

$$\dot{V} = \pi l z \left(2 \cdot r_r + z\right) \cdot \frac{n}{30} \left[m^3 / s\right] \tag{1}$$

$$P_m = \dot{V}_m \Delta p = \pi \cdot l \cdot z \cdot \left(2 \cdot r_r + z\right) \frac{n}{30} \cdot \Delta p \ \left[W\right] \tag{2}$$

where n-the machine rotation, Δp- the increase in pressure between suction and discharge [N/m^2].

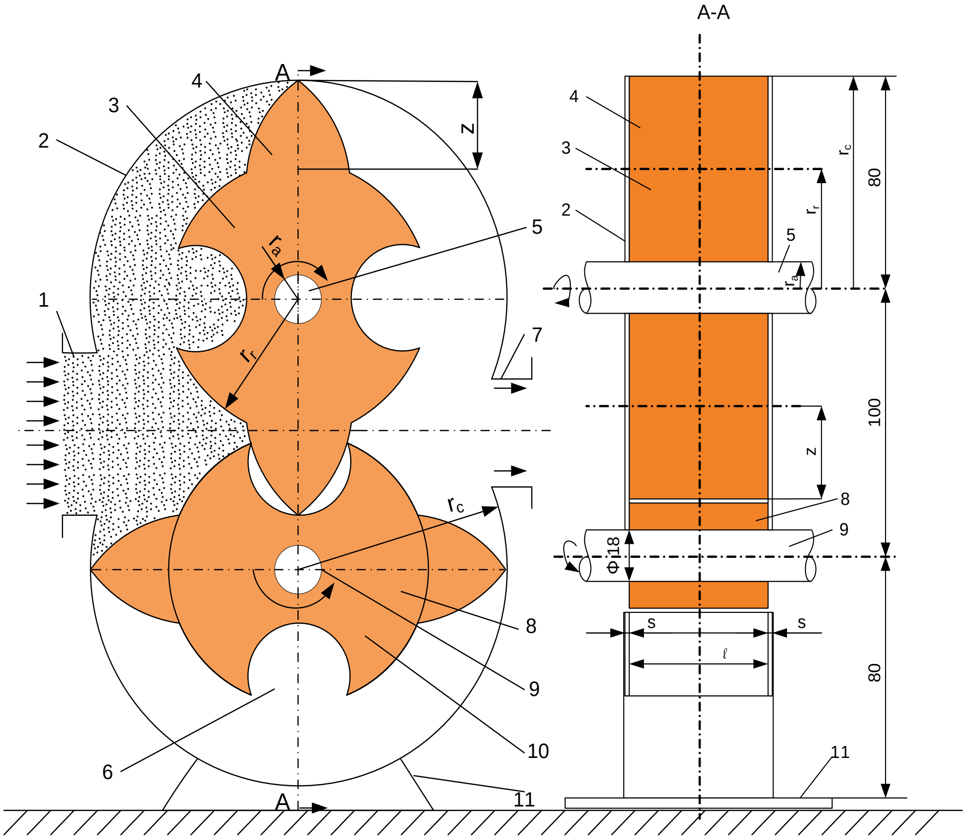

Fig. 1 Cross section (a) and longitudinal section (b) through the blower
1-gas suction connection; 2-upper case; 3-upper rotor; 4- rotating piston; 5-driven shaft; 6-cavity; 7-gas discharge connection; 8-lower rotor; 9-driving shaft; 10-contact surface between the rotor and the case wall; 11-support
r_a- shaft radius; r_r- rotor radius; z- piston height
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III. THE DETERMINATION OF THE POWER CONSUMED BY VISCOUS FRICTION BETWEEN THE ROTORS AND THE CASE SIDE WALLS

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Calculation hypotheses:

- The friction between the top of the piston and the case is neglected.

- The front surface of the piston completes the cavities created in the rotor, so the calculation area is from r_a to r_r (fig. 1).

-The fluid velocity at each point on the front surface of the rotor is equal to the rotor velocity.

- The velocity at a point on the surface of the disk will be in the range of:

$$w_a = \omega \cdot r_a \text{ and } w_r = \omega \cdot r_r \quad [m/s] \tag{3}$$

It is required to establish the power consumed by viscous friction between the front surfaces of the rotors and the case walls.

As initial data are known:

- The shaft radius on which the rotor is mounted: $r_a = 9 \cdot 10^{-3}$ m; the rotor exterior radius: $r_r = 50 \cdot 10^{-3}$ m;

-The angular velocity for a given rpm of the disk;

- The dynamic viscosity of the fluid at t = 20 °C is found from [8,9]:

$$\eta_{air} = 18.5 \cdot 10^{-6} \frac{Ns}{m^2}; \quad \eta_{water} = 10,04 \cdot 10^{-4} \frac{Ns}{m^2}; \quad \eta_{oil} = 130,5 \cdot 10^{-4} \frac{Ns}{m^2}$$

-The gap between the disk and the case walls is chosen equal to a numerical controlled centerprecision processing [10]: s= $0.01 \cdot 10^{-3}$ m.

The calculation is made for one rotor. From mechanics is known that the torque is the product between the force and the force arm. The elementary resistant torque due to viscous friction between the rotor and the two walls of the case will be [11]:

$$dM_r = 2rdF_f \tag{4}$$

where F_f is the viscos friction force.

$$dF_f = \tau dA \tag{5}$$

τ- tangential effort; dA – elementary surface area (Fig.2).

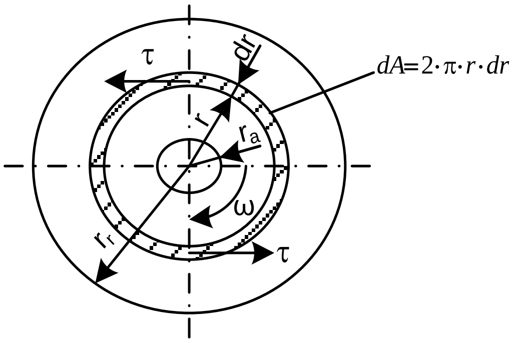

Fig. 2 Plan view of a portion of the rotor

The tangential tension (shear stress) due to fluid viscosity is calculated with Newton formula [12,13]:

$$\tau = \eta \frac{dw}{dy} \tag{7}$$

where the coordinate y is measured perpendicularly to the disk surface (Fig. 3).

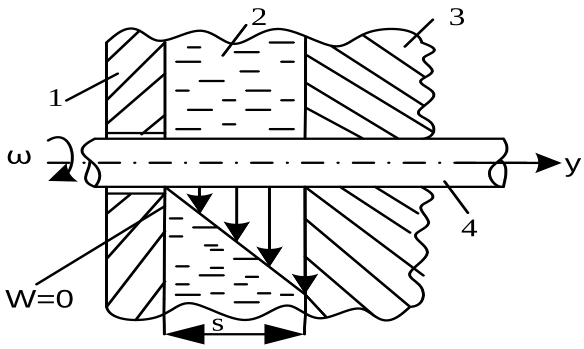

Fig. 1 Computing section

1- case; 2- thin layer of fluid; 3- rotor disk; 4-shaft

The velocity gradient for the boundary layer with "s" thickness, assuming a linear variation, has the expression:

$$\frac{dw}{dy} = \frac{\omega r}{s} \tag{8}$$

Equation (7) becomes:

$$\tau = \eta \cdot \frac{\omega r}{s} \tag{9}$$

Equation (5), taking into account equation (6) and (9) becomes:

$$dF_f = \eta \cdot \frac{\omega \cdot r}{s} \cdot 2\pi r dr = 2\pi r^2 \eta \frac{\omega}{s} dr \tag{10}$$

A more exactly calculation for dF_fcan be performed using the dynamic boundary layer theory [14,15].
Form equation (4) and (10) is obtained:

$$dM_r = 2r \cdot 2\pi r^2 \eta \frac{\omega}{s} dr \tag{11}$$

$$\int_0^M dM_r = \int_{r_a}^{r_r} \frac{4 \cdot \pi \cdot \omega \cdot \eta \cdot r^3}{s} dr \tag{12}$$

$$M_r = \frac{\pi \cdot \eta \cdot \omega}{s} [r_r^4 - r_a^4] \;\; [N \cdot m] \tag{13}$$

From mechanics is known the computing relation of the power consumed to overcome the viscous friction for one rotor [11]:

$$P_{1r} = M_r \cdot \omega \;\; [W] \tag{14}$$

For the entire machine, the power consumed by viscous friction (P_m) will be:

$$P_m = 2 \cdot P_{1r} \;\; [W] \tag{15}$$

Introducing the relations (13) and (14) into (15) it results:

$$P_m = 2\frac{\pi \cdot \eta \cdot \omega^2}{s} \cdot (r_r^4 - r_a^4)[W] \quad (16)$$

From equation (16) is observed that for a given constructive solution the value of P_m is influenced by η and ω^2.

IV. CALCULATING RESULTS REGARDING THE MACHINE POWER CONSUMED BY VISCOUS FRICTION

The power consumedby viscous friction between the rotors and the case walls for certain machine rpm is successively calculated.

The viscous friction for three fluids, air, water, oil is studied.

A.The working fluid is the air

In this case is assumed thatthe rotating machine with profiled rotors operates as a blower.

The power consumed by viscous friction between the frontal surfaces of the rotors and the case walls, with values of ω and η for air given by n_r = 200, 400, 600, 800, 1000 rpm, is calculated:

$$\omega_1 = \frac{2 \cdot \pi \cdot n_r}{60} = \frac{\pi}{30} 200 = 20.93 \ rad/s \quad (17)$$

$$P_m = 2 \cdot \frac{3.14 \cdot 18.5 \cdot 10^{-6} \cdot (20.93)^2}{0.01 \cdot 10^{-3}} \left[\left(50 \cdot 10^{-3}\right)^4 - \left(9 \cdot 10^{-3}\right)^4 \right] = 0.031 \ W \quad (18)$$

Similarly, the calculations for other values of n_r are made, resulting the data in Table 1.

TABLE 1
VALUES OF P_m=f(n_r) FOR AIR

n_r [rot/min]	200	400	600	800	1000
ω [rad/s]	20.933	41.866	62.799	83.680	104.660
P_m [W]	0.031	0.127	0.286	0.508	0.791

Based on the results in Table 1, the curve P_m = f (n_r) is plotted in Fig. 4.

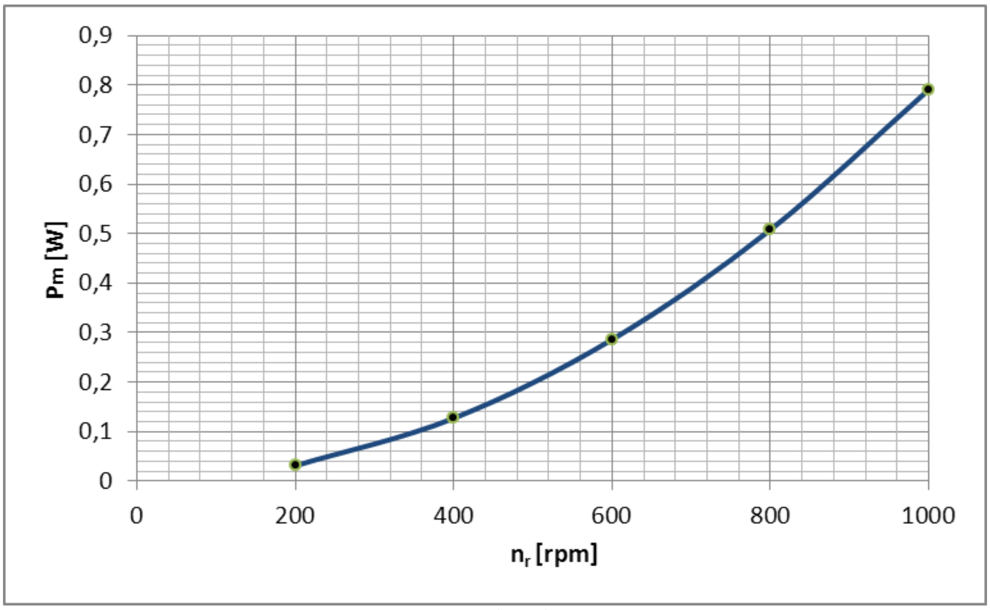

Fig.4 P_m = f (n_r) for air

From Fig.4 it is found that with the machine rpm increase, the power consumed by viscous friction between the machine rotors and the case the will increase; thenecessary driving power of the machine will increase.

B.The working fluid is the water

In this case the machine will work as a pump.

$$\omega_1 = \frac{2 \cdot \pi \cdot n_r}{60} = \frac{\pi}{30} 200 = 20.93 \ rad/s \quad (19)$$

$$P_m = 2 \cdot \frac{3.14 \cdot 10.04 \cdot 10^{-4} \cdot (20.93)^2}{0.01 \cdot 10^{-3}} \left[\left(50 \cdot 10^{-3}\right)^4 - \left(9 \cdot 10^{-3}\right)^4 \right] = 1.722 \ W \quad (20)$$

be Similarly, the calculations of $P_m$for other values of n_r are made, resulting the data in Table 2.

TABLE 2
VALUES OF $P_m=f(n_r)$ FOR WATER

n_r [rot/min]	200	400	600	800	1000
ω [rad/s]	20.933	41.866	62.799	83.680	104.660
P_m [W]	1.722	6.888	15.498	27.519	43.048

Based on the results in Table 2, the curve $P_m = f(n_r)$ is plotted in Fig. 5.

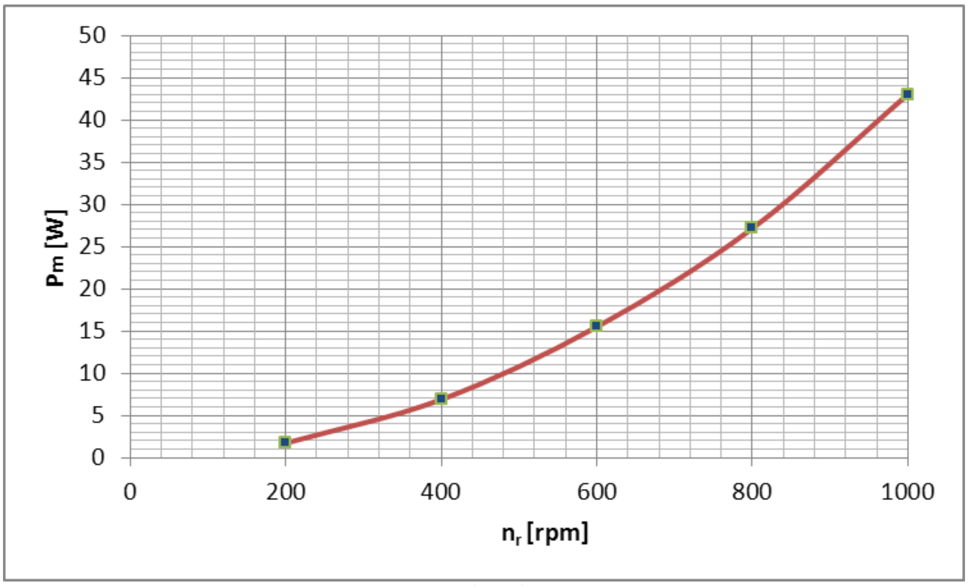

Fig.5 $P_m = f(n_r)$ for water

C.The working fluid is oil
In this case the machine will function as rotating pump.

$$\omega_1 = \frac{2\cdot\pi\cdot n_r}{60} = \frac{\pi}{30}200 = 20.93 \ \ rad/s \quad (21)$$

$$P_m = 2\cdot\frac{3.14\cdot130.5\cdot10^{-4}\cdot(20.93)^2}{0.01\cdot10^{-3}}\left[\left(50\cdot10^{-3}\right)^4-\left(9\cdot10^{-3}\right)^4\right] = 22.417\ W \quad (22)$$

Similarly, the calculations of P_m for other values of n_r are made, resulting the data in Table 3.

TABLE 3
VALUES OF $P_m=f(n_r)$ FOR OIL

n_r [rot/min]	200	400	600	800	1000
ω [rad/s]	20.933	41.866	62.799	83.680	104.660
P_m [W]	22.417	89.671	201.760	358.23	560.392

Based on the results in Table 3, the curve $P_m = f(n_r)$ is plotted in Fig. 6.

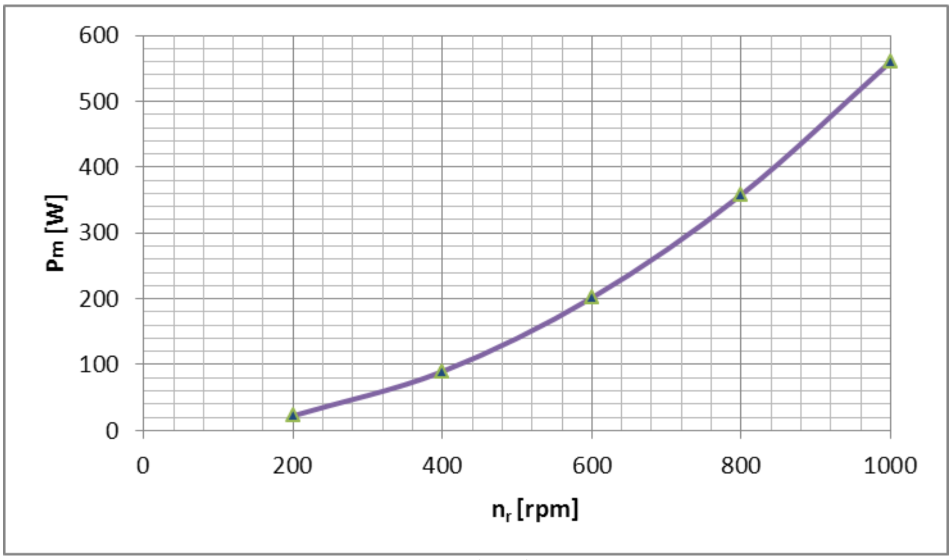

Fig.6 $P_m = f(n_r)$ for oil

In Fig. 7 were plotted the three curves P_m = f (nr) for the three fluids.

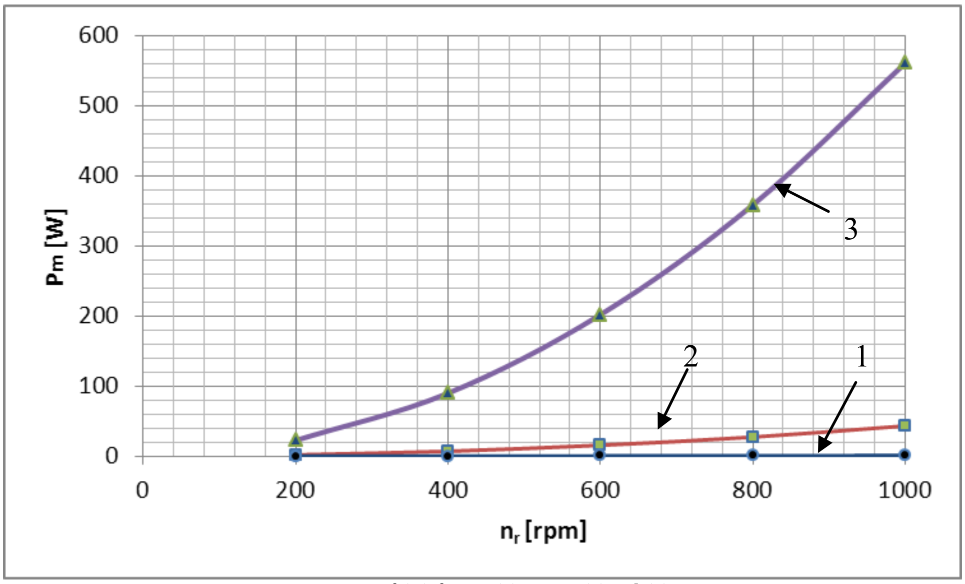

Fig.7 P_m = f (n_r) for air (1), water (2), oil (3)

From Figure 7 is noted that, if the fluid viscosity increases, the necessary power to overcome the viscous friction between the rotors and the case will increase.

As a result, the rotating machine driving power will increase; it depends on the fluid nature.

The theoretical results obtained above will be validated in experimental researches that will be conducted to develop a PhD thesis.

V. Conclusions

- For the machines with rotors profiled the essential problem is the frontal and the radial seal between the rotors and the case.
- Obviously, the space remaining between the movable rotors and fixed case depends on the execution accuracy of the rotors and the case.
- This problem can be solved by executing the rotors and the case in a CNC that provides an accuracy of 0.01 mm.
- The fluid nature (air + liquid) influences the power consumed by viscous friction for this type of rotating machine.
- The necessary power to drive the machine will be according to the fluid nature: air, water, oil.

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