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# A solution for the volumetric flow rate increasing of a rotating volumetric pump

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**Abstract**
The paper presents a rotating machine with two profiled rotors that was designed and built in the laboratory of the Faculty of Mechanical and Mechanical Engineering, Department of Thermotechnics, Engines, Thermal Equipment and Fridge at the Polytechnic University of Bucharest.A mathematical relation between the radius of the rotor and the height of the rotating piston is established; by deriving this relation, a relevant conclusion is obtained, namely: the flow rate increases until the height of the rotating piston becomes equal to the rotor radius. A calculation programme shall be developed to determine the flow rate by changing the height of the rotating piston and the radius of the rotor.
***Keywords:*** *profiled rotor, rotating piston*.

## 1. Introduction

This paper is part of the category of scientific paper that addresses the research field of rotating machines that transports fluids.
A type of rotating working machine with profiled rotors is presented; it can work as [1], [2]:
- a fan, for driving different gas mixtures with or without suspensions;
- a low pressure compressor;
- a rotating volumetric pump for the conveyance of any type of liquid or gas fluid

Rotating machines with profiled rotors are meet in the technique both as force machines and as working machines. A classification of rotating machines with profiled rotors is presented in table 1.

**Table 1:** Classification of rotating machines with profiled rotors

| Classification by purpose | Classification in terms of construction |
|---|---|
| Working machines | Pumps for driving fluids or with suspensions |
| | Fans for transporting gases or vapors |
| | Blowers for gas and vapor compression |
| Force machines | Hydraulic motor |
| | Pneumatic motor |
| | Steam engine or combustion gases |

A more difficult problem is to make a rotating machine that can be used as a working machine or a force machine, that is theoretically a "reversible" machine.
Such a machine must provide:
- transforming the useful moment with minimal losses when it works as a working machine.
- maximum use of the energy of the working agent for shaft actuation when it is working as a force machine.

For the transport of some incompressible fluids, pumps are used, which in the case of the present paper takes the form of a rotating volumetric pump with two profiled rotors.
The main advantages of this volumetric pump with profiled rotors are the following [3]:
a) The pump can carry any type of single-phase or multiphase fluid.
• water, oil, diesel;
• water + ash, water + sand;
• food liquids, rheological fluids.
b) In the composition of the machine there are no alternating rectilinear moving parts;
c) Mechanical frictions are reduced;
d) The motor torque received at the pump shaft is used almost entirely to increase the potential energy of the fluid;
e) The machine has a high reliability and no materials or special technologies are required for its construction;
f) Essential is the construction of the rotors, for which a computation program is available and can be adapted to a computer center with numerical control (C.N.C.)

For the analyzed constructive solution, depending on the required flow rate, the length of the rotor, its radius and the height of the piston are chosen, resulting in the rotor architecture.

## 2. The operating and the constructive solution of the rotating machine with profiled rotors

The fluid sucked into the chamber (1) (figure 2) is transported to the discharge chamber (2) (figure 2) by the rotating pistons.
The machine has two profiled rotors that rotate counterclockwise inside some casings (figure 1). Each rotor has two rotating pistons that enters into the cavities of the adjacent rotor.
The synchronous rotation of the two rotors (3, 7) is ensured by means of two gear wheels (5) (figure 2) which form a cylindrical gear with straight teeth.

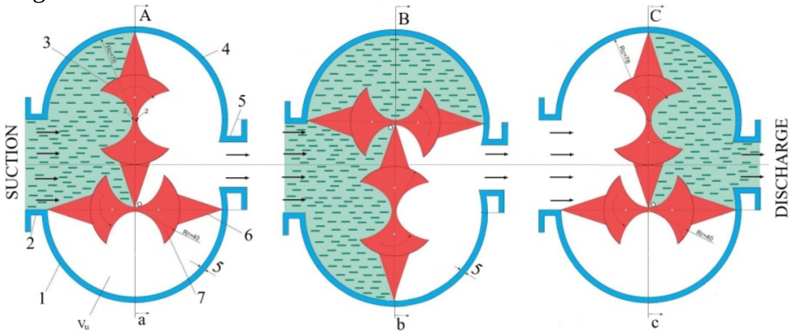


Fig. 1.Operating principle of the rotating volumetric machine
1 - lower case; 2 - fluid suction connection; 3 - upper rotor;
4 - upper case; 5 - fluid discharge connection; 6 - rotating piston; 7 - lower rotor.

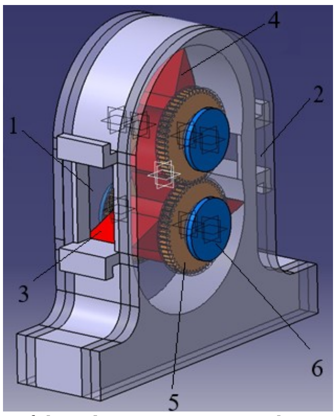


Fig. 2. Axonometric view of the volumetric rotating machine model with profiled rotors
1- suction chamber; 2 - discharge chamber; 3 - lower rotor; 4 - upper rotor; 5 – gear wheels; 6 - sealing caps.

The shape of the rotor contour was established in the work [4], and the manufacturing technology in the work [5].
As a working model, such a rotating machine with profiled rotors was designed and built in the laboratory of the Department of Thermotechnics, Engines, Thermal and Refrigeration Equipment of the Polytechnic University of Bucharest.
In figure 1.a was noted with $V_u$ the fluid volume between two rotating pistons and the carcase. At a complete rotation, two such volumes will be transported by the rotating pistons, from the suction to the discharge: [6]

$$V_u = 2\left(\frac{\pi R_c^{\ 2}}{2} - \frac{\pi Rr^2}{2}\right)\cdot l \quad \left[m^3 / rot\right] \tag{1}$$

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

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

Replacing the relation (2) in the relation (1) the volume flow of fluid transported by the pump will be:

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

where: l – the length of the rotor [m]

$n_r$ – the speed of the rotating machine [rot/min].

## 3. Establishing the mathematical relation between the rotor radius, the height of the rotating piston and the radius of the rotating machine carcase

It is considered one piston (5) fixed to the lower rotor(1) (figure 3).

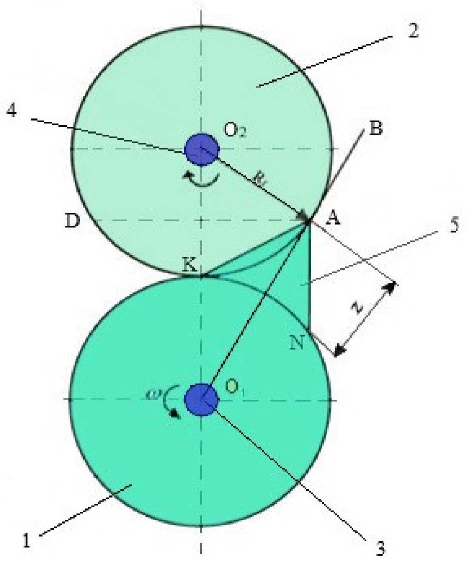


Fig. 3. Calculation notations
1 – lower rotor; 2 – upper rotor; 3 – driving shaft;
4 – driven shaft; 5 – rotating piston of triangular shape.

The rotor radius (1) is extended by a length (z) and thus the line $O_1B$ reaches the rotor (2) at point A. Theoretically, when point K reaches point D, point A reaches K, respectively point N reaches K, because the length of the circle arcs AK, KD and KN is the same. When the piston (5) exits the gap created in the rotor (2), points A and N reach point K; the sealing between the two rotors being ensured by the direct contact between the lateral surfaces of the rotors.
From the right triangle $O_1O_2A$ results [7]:

$$O_1O_2^2 = AO_2^2 + AO_1^2 \qquad (4)$$

$$(2R_r)^2 = R_r^2 + (R_r + z)^2 \qquad (5)$$

relation that becomes:

$$z^2 + 2R_r z - 2R_r^2 = 0 \qquad (6)$$

If in the relation (6) the derivative is performed according to z, $z = R_r$ is obtained; this means that the flow rate of the machine is maximum when the height of the piston is equal to the rotor radius.

## 4. Determination of flow rate, when changing the piston height (z) and rotor radius ($R_r$)

For the laboratory constructive solution, are known:
l – rotor length: l = 50 [mm] = 0,05 [m];
z – rotating piston height: z = 30 [mm] = 0,03 [m];
$R_r$ – rotor radius: $R_r$ = 50 [mm] = 0.05 [m];
$R_c$ –case radius: $R_c$ = 80 [mm] = 0,08 [m].
The piston height (z) is changed from 0,03 [m] to 0,04 [m], so that we obtain $z = R_r$, but with the conditions:

- $R_c = R_r + z$
- $R_r \geq$
- n = ct; n = 300 [rot/min].

The volumetric flow rate is calculated with (z) between 30÷40 [mm]: z = 31, 32, 33... 40 [mm] = $40 \times 10^{-3}$ [m].
respectively: $R_r$ = 50÷40 [mm] : $R_r$ = 49, 48, 47... 40 [mm] = $40 \times 10^{-3}$ [m].
In figure 4 the graphical function $R_r = f(z)$ was plotted.

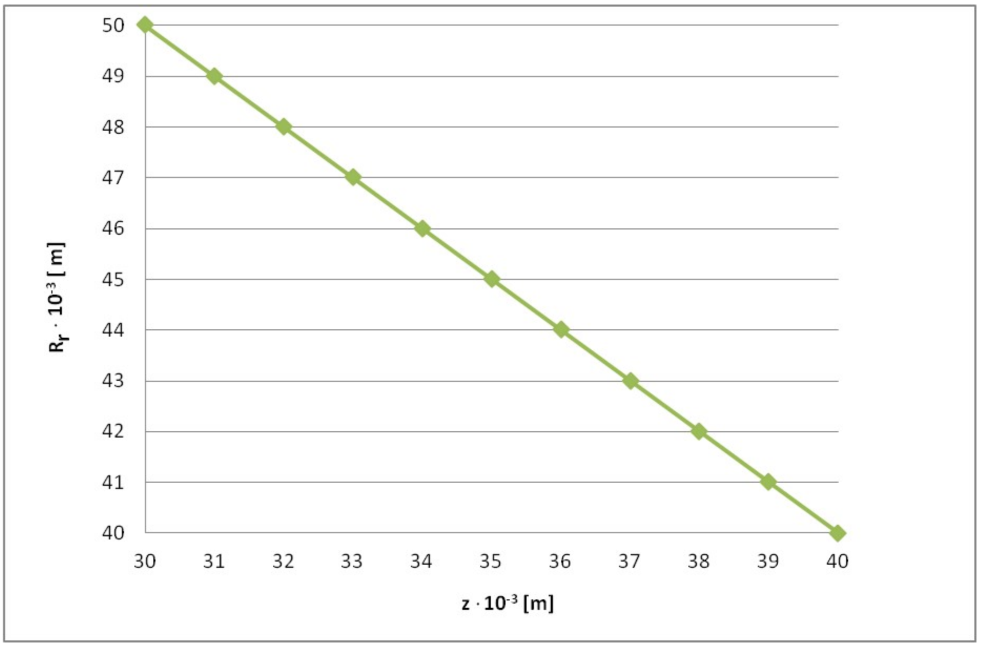


Fig. 4. Graphical representation of the function $R_r$ = f(z)

**Calculation variants:**

**I.** $R_r$ = 50 [mm]; z = 30 [mm]; l = 50 [mm]; $R_c$ = 80 [mm]; $n_r$ = 300 [rot/min]; $O_1O_2$ = 100 [mm]

$$\dot{V} = \pi \cdot l \cdot z\left(z + 2R_r\right) \cdot \frac{n_r}{30} = 3{,}14 \cdot 0{,}05 \cdot 0{,}03(0{,}03 + 2 \cdot 0{,}05)\frac{300}{30} = 0{,}006123[m^3/s] = 6{,}123 \cdot 10^{-3}[m^3/s]$$

**II.** $R_r$ = 40 [mm]; z = 40 [mm]; l = 50 [mm]; $R_c$ = 80 [mm]; $n_r$ = 300 [rot/min]; $O_1O_2$ = 80 [mm]

$$\dot{V} = \pi \cdot l \cdot z\left(z + 2R_r\right) \cdot \frac{n_r}{30} = 3{,}14 \cdot 0{,}05 \cdot 0{,}04(0{,}04 + 2 \cdot 0{,}04)\frac{300}{30} = 0{,}007536[m^3/s] = 7{,}536 \cdot 10^{-3}[m^3/s]$$

One can observe that the flow rate of the machine in variant II is higher than in variant I, because in variant II z = Rr.
It is calculating the values of volumetric flow rate, with relation (3) for:
$R_r$ = 0,04÷0,05 [m]; z = 0,03÷0,04 [m]; l =0,05 [m]; $n_r$ = 300 [rot/min] and the data in Table 2 are obtained.

**Table 2.** Variation volumetric flow rate when $n_r$ = ct.

| $R_r[m]$ | $z[m]$ | $l[m]$ | $R_c[m]$ | $n_r[rot/min]$ | $\dot{V}[m^3/s]$ | $\dot{V}[m^3/s \cdot 10^{-3}]$ |
|---|---|---|---|---|---|---|
| 0,05 | 0,030 | 0,050 | 0,080 | 300 | 0,006123 | 6,123 |
| 0,049 | 0,031 | 0,050 | 0,080 | 300 | 0,006278 | 6,27843 |
| 0,048 | 0,032 | 0,050 | 0,080 | 300 | 0,006431 | 6,43072 |
| 0,047 | 0,033 | 0,050 | 0,080 | 300 | 0,00658 | 6,57987 |
| 0,046 | 0,034 | 0,050 | 0,080 | 300 | 0,006726 | 6,72588 |
| 0,045 | 0,035 | 0,050 | 0,080 | 300 | 0,006869 | 6,86875 |
| 0,044 | 0,036 | 0,050 | 0,080 | 300 | 0,007008 | 7,00848 |
| 0,043 | 0,037 | 0,050 | 0,080 | 300 | 0,007145 | 7,14507 |
| 0,042 | 0,038 | 0,050 | 0,080 | 300 | 0,007279 | 7,27852 |
| 0,041 | 0,039 | 0,050 | 0,080 | 300 | 0,007409 | 7,40883 |
| 0,040 | 0,040 | 0,050 | 0,080 | 300 | 0,007536 | 7,536 |

Performing the calculations, but varying the speeds ($n_r$), rotor radius ($R_r$) and rotating piston height (z), the data in Table 3 are obtained.

**Table 3.** Variation of volumetric flow rate according to $n_r$, $R_r$ and z

| $n_r$ | [rot/min] | 100 | 200 | 300 | 400 | 500 |
|---|---|---|---|---|---|---|
| $R_r$ [m] | z [m] | $\dot{V}\left[m^3/s\cdot 10^{-3}\right]$ | | | | |
| *0,05* | *0,03* | *2,041* | *4,082* | *6,123* | *8,164* | *10,205* |
| *0,049* | *0,031* | *2,09281* | *4,18562* | *6,27843* | *8,37124* | *10,46405* |
| *0,048* | *0,032* | *2,143573333* | *4,287147* | *6,43072* | *8,574293* | *10,71787* |
| *0,047* | *0,033* | *2,19329* | *4,38658* | *6,57987* | *8,77316* | *10,96645* |
| *0,046* | *0,034* | *2,24196* | *4,48392* | *6,72588* | *8,96784* | *11,2098* |
| *0,045* | *0,035* | *2,289583333* | *4,579167* | *6,86875* | *9,158333* | *11,44792* |
| *0,044* | *0,036* | *2,33616* | *4,67232* | *7,00848* | *9,34464* | *11,6808* |
| *0,043* | *0,037* | *2,38169* | *4,76338* | *7,14507* | *9,52676* | *11,90845* |
| *0,042* | *0,038* | *2,426173333* | *4,852347* | *7,27852* | *9,704693* | *12,13087* |
| *0,041* | *0,039* | *2,46961* | *4,93922* | *7,40883* | *9,87844* | *12,34805* |
| *0,04* | *0,04* | *2,512* | *5,024* | *7,536* | *10,048* | *12,56* |

One can observe that the volumetric flow rate ($\dot{V}$) of the rotating pump with profiled rotors is maximum when the rotor radius is equal to the rotating piston hight ($R_r$ = z).
Previous experimental researches confirms the accuracy of the performed calculations [8].
Based on the data in Table 3, the graphs in figure 5 were drawn.

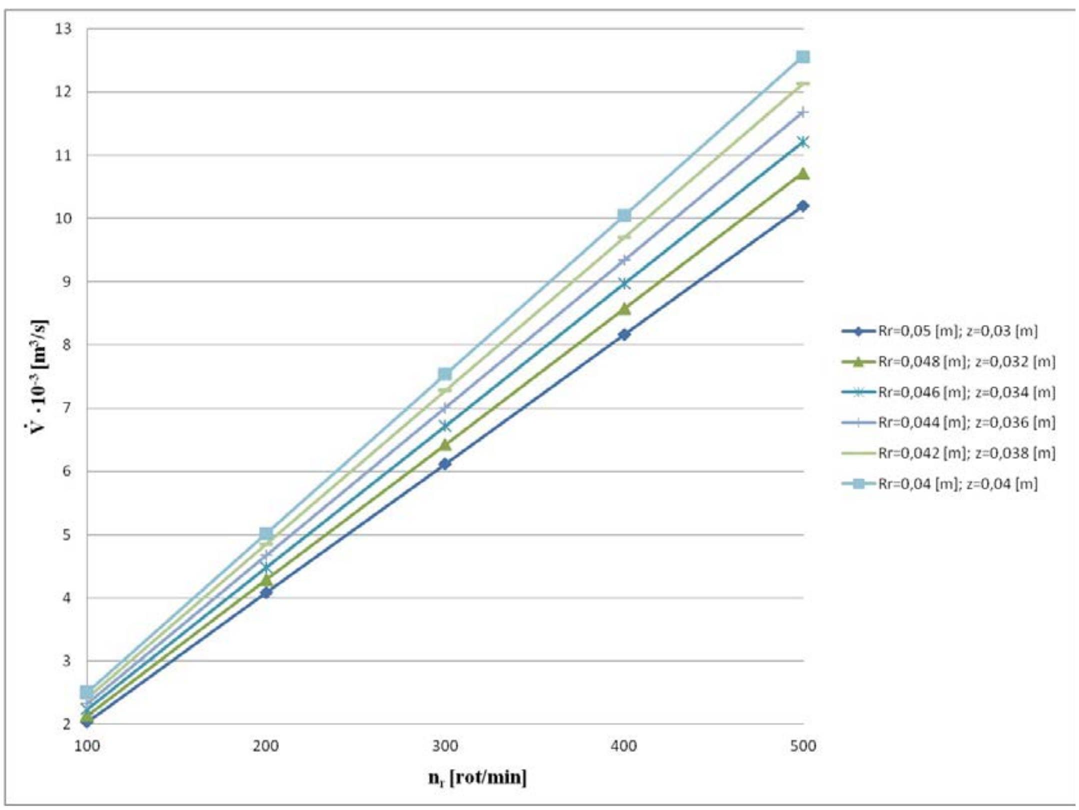


Fig. 5. Variation of volumetric flow rate according to $n_r$, $R_r$ and z

## 5. Presentation of the constructive solution when the rotors are not crossed by the shafts

In figure 6 the constructive solution of the rotating machine with profiled rotors, when the rotors are not crossed by the shafts is presented. It has the following particularities:

a) The shaft for each rotor does not penetrate inside the rotor, thus $z \rightarrow R_r$;

b) The shaft drives the lower rotor through a flange fixed with rotor screws; the flange rotates inside the side wall of the case;

c) In the figure 6 the side wall of the case on the right side is not drawn, which is similar to the wall on the left side; in this way, in view (a) the two rotors are observed.

The elaboration of this constructive solution aims to validate the previously established conclusion, namely that the value of (z) must tend to ($R_r$).

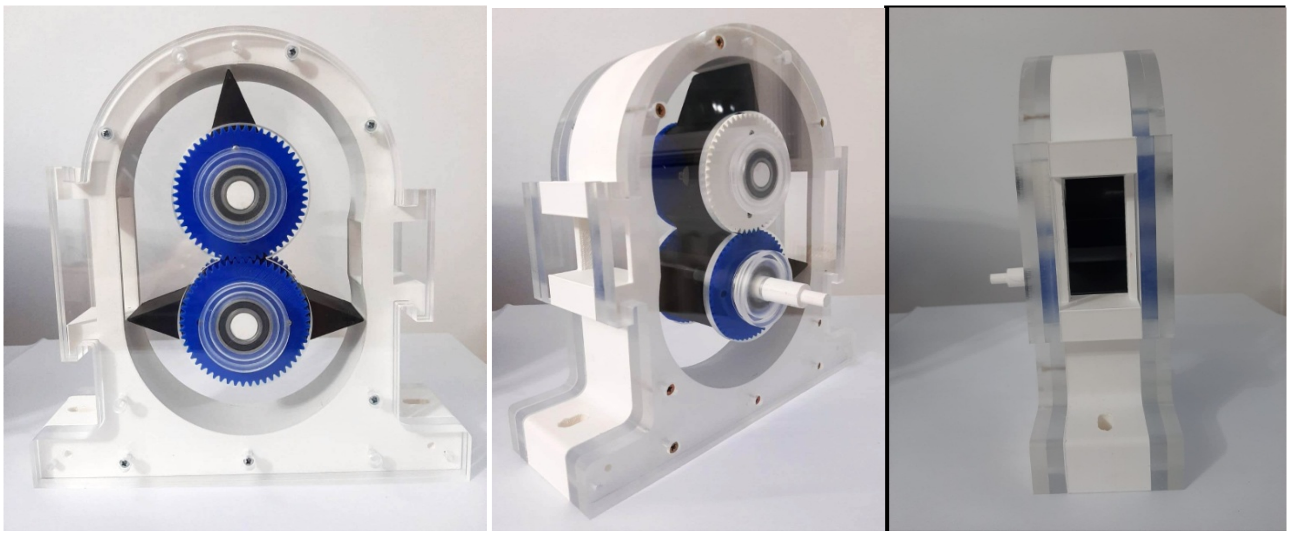

Fig. 6.. Longitudinal end transversal view of the model of the working machine

Previous researches in the field of rotating machines [9], [10] continue with this new constructive solution where the value of (z) tends towards ($R_r$).

## 6. Conclusions

1) By deriving the power formula of the machine it resulted:

- If the rotating machine acts as a working machine (pump, compressor) the required drive power from the outside is maximum if $z = R_r$; of course, and the flow rate transported by the machines is maximum.
- If the rotating machine acts as a motor machine (steam engine, pneumatic motor), the power developed by it is maximum when $z \rightarrow R_r$.

2) In figure 6 a constructive solution of the machine was presented, a solution that allows z to tends towards $R_r$.

3) The original relation for which the derivative is carried out and it follows that $z = R_r$ leads to a maximum flow rate for a speed of 500 [rot/min].

4) By changing the piston height (z) from 0,03 [m] to 0,04 [m] $z = R_r$ was obtained, thus the conditions were met:

- $R_c = R_r + z$
- $R_r \geq z$
- n = ct; n = 300 [rot/min].

5) One can observe that the volumetric flow rate increases linearly with length (l), rotor radius ($R_r$), piston height (z) and speed ($n_r$).

## References

[1] N. Băran, P. Răducanu, et. al. „*Bases of Technical Thermodynamics*", Politehnica Press Publishing House, Bucharest, 2010.

[2] M. Exarhu, „*Pneumatic and hydraulic machine and installations* ", (in Romanian), SC. ANDOR SRL, Bucharest, 2011.

[3] N. Băran, D. Besnea, A. Motorga, „*Elements of computing the architecture and manufacturing technology for a new type of profiled rotor*", Proceedings International Conference, 6th Workshop on European Scientific and Industrial Collaboration on promoting Advanced Technologies in Manufacturing, WESIC'08, Bucharest, 2008, pp. 233-241.

[4] A.Costache, N. Băran, „Computation method for establishing the contour of a new type of profiled rotor", University Politehnica of Bucharest, Scientific Bulletin Series D: Mechanical Engineering vol. 70, nr.3, 2008, pp. 93 – 102.

[5] N. Băran, D. Besnea, T. Sima, A. Detzortzis, C. Cărnaru, „Manufacturing Technology for a New Type of Profiled Rotor", Advanced Materials Research, Trans Tech Publications, Switzerland, vol. 655-657, 2013, pp. 235-240.

[6] A. Motorga, „*Influence of constructive and functional parameters on the performances of rotating machines with profiled rotors*", PhD Thesis, Faculty of Mechanical Engineering and Mechatronics, Politehnica University of Bucharest, 2011.

[7] Ioan Goleț, Ciprian Herdea, Camelia Petrișor, „*Analiză matematică. Sinteze teoretice și aplicații*", Politehnica PressPublishing House, Bucharest, 2014.

[8] N. Băran, I. Căluşaru, A. Detzortzis, „*Research Regarding the Testing of a New Type of Rotating Machine with Profiled Rotors*", Journal of Materials Science and Engineering A 2 (3) 372-376, 2012, pp. 372-376.

[9] M. Hawas, PhD Thesis, „*The influence of fluid viscosity on the performance of rotating machine with profiled rotors* ", Universitatea Politehnica din București 2015, Romania.

[10] M. Hawas, „*Research regarding the establishment of efficiency for a new type of rotating volumetric pump*", International Research Journal of Engineering and Technology (IRJET), Vol. 02. Issue, 02, 2015, pp. 796-800.