U.P.B. Sci. Bull., Series D, Vol. 79, Iss. 1, 2017 ISSN 1454-2358

A NEW SYSTEM FOR MEASURING THE LIQUIDS FLOW RATES

Evelina DONISAN[1], Mihaela CONSTANTIN[2], Nicolae BARAN[3], Alexandru TOADER[4]

The paper presents the experimental model of a new type of volumetric flow meter used to measure the liquid volumetric flow rate. The volumetric flow meter constructive solution is presented and, for certain parameters, the liquid flow rate that passes through the flow meter is calculated. The flow meter is provided with two specially profiled rotors which rotate at the same speed but in opposite directions; each rotor is provided with two rotating pistons. The flow meter speed is measured with a tachometer with digital indication and the volumetric flow rate is read from the flow meter characteristic curve. Using the similarity theory and knowing certain parameters of the meter model, the volumetric flow meter prototype architecture is afterwards specified.

Keywords: Volumetric flow meter, profiled rotor, rotating piston, tachometer.

1. Introduction

For fluid flow rate measurement (liquid or gas) direct or indirect methods are used. Direct methods consist in measuring the volume of liquid flowing per unit of time. Among flow meters using the direct methods there can be distinguished: volumetric propeller flow meters and volumetric flow meters with profiled rotors. Indirect methods consist in measuring the fluid flow related effects, such as speed or pressure drop.

As an examples of flow meters functioning on this method we can specify: the diaphragm, the Venturi tube, Rotameters.

In the specialized literature, for the volumetric flow meters more constructive solutions are revealed; among those two of them stand out:

a) Lobe type flow meters [1] [2]; they measure high viscosity fluid flow rates: oil, milk, beer, wine, adhesives and paints.

[1] PhD Student, University POLITEHNICA of Bucharest, Romania, e-mail: evelina.donisan@yahoo.com

[2] As. Eng., Dept. of., Thermotechnics, University POLITEHNICA of Bucharest Romania, e-mail: i.mihaelaconstantin@gmail.com

[3] Prof., Dept. of., Thermotechnics, University POLITEHNICA of Bucharest Romania, e-mail: n_baran_fimm@yahoo.com

[4] PhD Student, University POLITEHNICA of Bucharest, Romania, e-mail: alexandru_toader90@yahoo.com

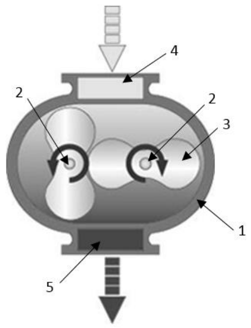

Fig. 1. Lobe type flowmeter
1 - case; 2 - shaft; 3 - lobe; 4 - suction connector; 5 - discharge connector
[http://www.lesker.com/newweb/vacuum_pumps/vacuumpumps_technicalnotes_1.cfm]

b) Brodie Birotor flow meters

The device comprises two units, one driver (1) and one driven (2) [3].
Figure 2 reveals the rotor's position after a 90° rotation (a, b, c).

a) b) c)

Fig. 2. Brodie Birotor Meter Operation Principle
[http://www.flo-vision.com.tw/ brodie/brodie-data/pdmeters/ birotor/Mechanical/dsmb04x.pdf]

The operating principle of this flow meter is the same as that of the screw pump. For a new type of volumetric flow meter that will be used to measure high liquid flow rates, it is recommended that the tests be performed on models.

These tests are required to be performed in the laboratory, aiming to determine the influence of two parameter categories on the studied flow meter performance. In this instance, a flow meter with two profiled rotors, each rotor having two rotating pistons is analyzed. The first category includes construction elements [4] [5]: rotor radius, rotor length, the height of the rotating piston, etc. The second category includes functional parameters [6] [7]: speed, fluid nature (viscosity, density, etc.).

The experimental research results that will be conducted in the laboratory on a model will underpin the building of the flow meter prototype and thereafter, a series of meters. The theory underlying the development of any machine is based on the results obtained on the model in the laboratory, results that can be applied to the machine itself then, using the mechanical similarity theory. The similarity theory specifies the conditions under which the model results can be applied to the original conception machine (the prototype).

In this case, the project of a volumetric flow meter model will be developed, at reduced scale and subsequently, the obtained results will be used for the construction of a flow meter in the "natural size" (the prototype). The term "natural size" refers to the fact that this type of volumetric flow meter will have larger dimensions and will be used at an industrial scale for measuring the flow rates of water, oil, gas oil, etc.

2. The volumetric flow meter model constructive solution presentation

For the tests performed in Thermotechnics, Engines, Thermal and Refrigeration Equipment's Department laboratory, the designing and building of the volumetric flow meter model in two stages is considered:

I) The instantaneous flow rate measurement passing through the flow meter by measuring the speed with a tachometer and the flow rate reading on the characteristic curve of the device.

II) The fluid volumetric flow rate registration from $\tau = 0$, ie from the start with an odometer [1] by recording the rotations number [1].

Considering the 3D printer type Maker Bot Replicator possibilities for building, in order to create the volumetric flow meter model, the following dimensions were chosen: $R_{r,m}$ – model rotor radius– 25 *mm*; l_m – model rotor length– 25 *mm*; z_m – rotating piston height – 15 *mm*; $R_{c,m}$ – case radius = $R_{r,m} + z_m$ = 40 *mm*

From previous researches [8], [9] it is necessary that $\frac{z_m}{R_{c,m}} < 0.42$. Verification: $\frac{z_m}{R_{c,m}} = \frac{15}{40} = 0.375 < 0.42$.

Figure 3 shows a cross section through the volumetric flow meter model. It consists of two identical rotors (2, 5), specially profiled; each rotor has two rotating pistons (4) and two cavities (6) in which, during the rotational movement, the adjacent rotor pistons enters.

The two rotors have a rotational movement in opposite directions but with the same speed; the equal speed is provided by two gear wheels (6) (Figure 4), with the same division diameter, mounted outside the flow meter on the shafts (7) and (9) from Figure 3, respectively (5) and (8) in Figure 4. In the suction chamber, the fluid passing through the flow meter has a high pressure, so as to ensure the rotation of the two rotors.

Fig. 4 shows a longitudinal section through the flow meter; the gear wheels (6) are located outside the flow meter.

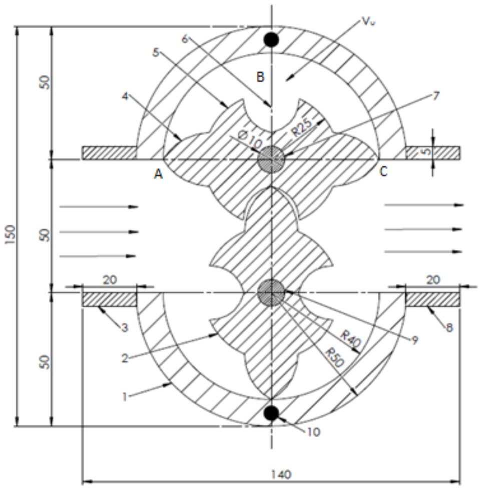

Fig. 3. Cross-section through the volumetric flow meter
1 - case; 2 - lower rotor; 3 - suction chamber; 4 - rotating piston; 5 - upper rotor; 6 - cavity into which the adjacent rotor piston enters; 7 - upper shaft; 8 - liquid discharge chamber; 9 - lower shaft; 10 – screw

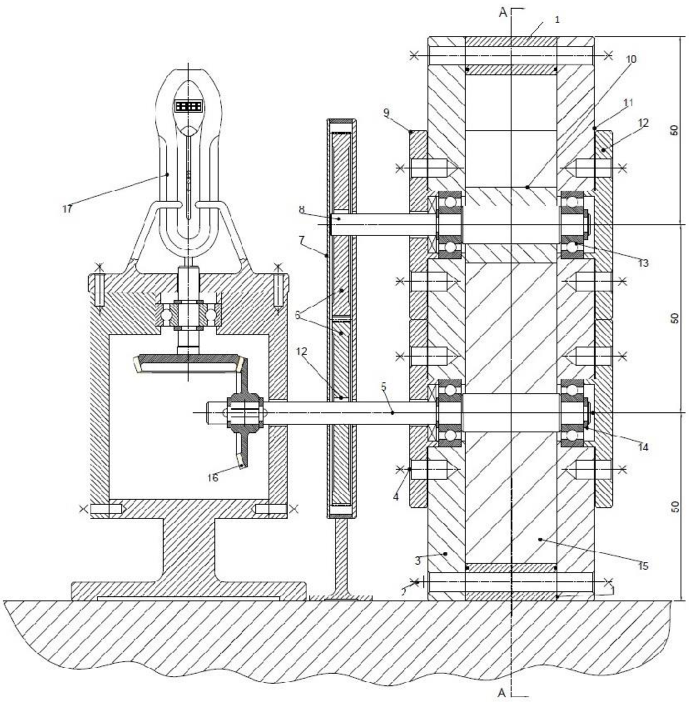

Fig. 4. Longitudinal through the volumetric flow meter
1 - case; 2 - screw M5x60; 3 - case left wall; 4 - screw M5x10; 5 - lower shaft; 6 - gear wheels D_0= 50 mm; 7 - lubricating oil box; 8 - upper shaft; 9 - bearing cap; 10 - upper rotor; 11 – case right wall; 12 - bearing cap; 13 - bearing Ø6 / Ø18; 14 - safety ring; 15 - lower rotor; 16 - bevel gears transmission; 17 - tachometer with digital indication

Through the shaft (5) the device speed is transmitted outside to a tachometer with digital indication.

3. Fluid volume indicating systems

For measuring the flow meter speed in a first phase, a tachometer with digital indication will be used [9]. The rotational movement of the lower shaft (position 5 in Figure 4) can be provided by the digital display system in two ways:

I) Through direct contact between the shaft and the tachometer shaft, measurement unit [rpm]

II) By counting the rotation in an optical way, measurement unit [rpm]

Knowing the flow meter speed, the instantaneous fluid flow rate passing through the flow meter can be read from the flow meter characteristic curve $\dot{V} = f(n_r)$ (Fig.5).

In this paper, the version I) will be adopted: from the shaft (5) via a bevel gear transmission the tachometer shaft will be driven (Fig. 4).

4. Computation of the fluid volume passing through the flow meter

From Figure 1, one can notice that, at a single shaft rotation (7) two volumes (V_u) will be transported from suction to the discharge, limited by the lateral surface of the rotor and the case (the ABC area). The volume occupied by the cavity (6) is ½ filled of the pistons volume (A) and (C). As a result:

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

, where: R_c - case radius [m]; R_r - rotor radius [m]; *l*- rotor length

If the piston height is noted with *z*:

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

By substituting equation (2) into (1) it is then obtained:

$$V_u = \pi l z \cdot \left(z + 2R_r\right) \left[m^3 / rot\right] \tag{3}$$

The volumetric flow rate circulated by one rotor will be:

$$\dot{V} = \pi l z \cdot \left(z + 2R_r\right) \cdot \frac{n}{60} \left[m^3 / rot\right] \tag{4}$$

, where: n – shaft rotation [rot/min]

The flow meter has two rotors, so, then it is obtained:

$$\dot{V}_c = 2\dot{V} = \pi l z \cdot \left(z + 2R_r\right) \cdot \frac{n}{30} \left[m^3 / s\right] \tag{5}$$

The speeds: n = 50, 100, 150, 200, 250, 300 [rot/ min] are selected.

By substituting: l = 0.025 m, z = 0.015 m, R_r = 0.025 m, n = 150 rot/ min, it is then obtained:

$$\dot{V}_c = \pi \cdot 0.025 \cdot 0.015 \cdot \left(0.015 + 2 \cdot 0.025\right) \cdot \frac{150}{30} = 0.0003826 \left[m^3 / s\right] \tag{6}$$

$$\dot{V}_c = 1.3776 \left[m^3 / h \right] \tag{7}$$

Calculating the values of the circulated volumetric flow rate by the two rotors for all the flow meter speeds, the data in Table 1 is obtained.

Table 1

Values of volumetric flow rate function of speed $\dot{V}_c = f(n_r)$

n_r *[rot/min]*	50	100	150	200	250	300
$V_c \cdot 10^{-4} [m^3/s]$	1.275	2.551	3.826	5.102	6.378	7.653

Based on the data in Table 1 diagram from Fig. 5 was constructed.

$V_c \cdot 10^{-4} [m^3/s]$

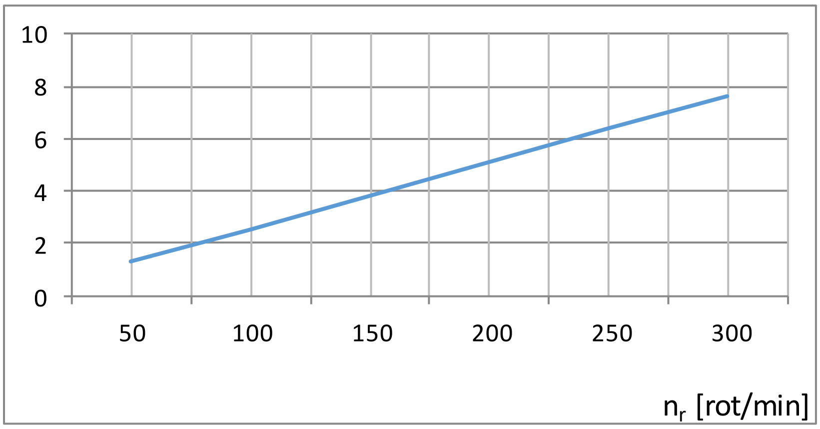

Fig. 5. The graph $\dot{V}_c = f(n_r)$

Measuring the flow meter speed with the tachometer, from this diagram the liquid flow rate passing through the volumetric flow meter can be read.

5. Similarity theory elements

Using the similarity theory and knowing some dimensions of the model, the main dimensions for the prototype will be determined.

Because in the studied field there is no thermal phenomena, the similarity will refer to the following [10]: A. Geometric similarity; B. Kinematic similarity; C. Dynamic similarity.

A mechanical similarity can be achieved between two phenomena if they are similar in nature and described by the same equations.

A) In the present case, for the model and the prototype, the fluid used is water, so the calculations are simplified seeing as: $C_\eta = 1$, $C_\rho = 1$.

, where C_η = kinematic viscosity scale factor, C_ρ = density scale factor.

If for the prototype, in the case of geometric similarity the value of C_l is considered 0.5, then the following dimensions are obtained: l=0.05 m, z =0.03 m, R_r =0.05 m. where C_l = length scale factor. The velocity is kept at n=150 rot/min.

The Flow rate passing through prototype will be:

$$\dot{V}_p = \pi \cdot 0.05 \cdot 0.03(0.03 + 2 \cdot 0.05) \cdot \frac{150}{30} = 30.615 \cdot 10^{-4} [m^3/s] \quad (8)$$

$$\dot{V}_p = 11.3814 \left[m^3/h \right]$$

This circulated volumetric flow rate is commonly found in the technical field.

B) For the kinematic similarity to exist, the fluid velocities ratio in homologous points of the model and of the prototype must be the same.

The fluid velocity in the suction chamber of the model w_{am} and the prototype w_a is calculated.

For the model [11]: $w_{am} = \dot{V}/A \, [m/s]$ (9)

A is the sectional area of the suction chamber:

A = 25·50 = 1250 mm^2 = 1.25·10^{-3} m^2; $w_{am} = \frac{3.82 \cdot 10^{-4}}{1.25 \cdot 10^{-3}} = 0.306 \, [m/s]$

For the prototype: $w_a = \dot{V}_p / A [m/s]$ (10)

A =50·100=5000mm^2=5000·10^{-6} m^2; $w_a = \frac{30.615 \cdot 10^{-4}}{5000 \cdot 10^{-6}} = 0.6123 \; [m/s]$

$$\frac{w_{am}}{w_a} = \frac{0.306}{0.612} = 0.5 \quad (11)$$

The velocity and the total flow rate at suction are determined; the flow meter has two circular channels, so, at velocity computation in the channel the total flow rate is divided by two: For the channel between the rotor and the case ($\dot{V} = \dot{V}_c / 2$): $w_{cm} = \dot{V} / A [m/s]$

A = 15 · 25· 10^{-6} = 375 · 10^{-6} m^2; $w_{cm} = \frac{3.82 \cdot 10^{-4}}{375 \cdot 10^{-6}} \cdot \frac{1}{2} = 0.510 \, [m/s]$

The fluid velocity at a point within the prototype will be [12]:

$$w_c = \dot{V} / A \, [m/s] \quad (12)$$

A = 30·50·10^{-6} = 1500·10^{-6} m^2; $w_c = \frac{30.615 \cdot 10^{-4}}{1500 \cdot 10^{-6}} \cdot \frac{1}{2} = 1.02 \, [m/s]$

$$\frac{w_{cm}}{w_c} = \frac{0.510}{1.020} = 0.5 \quad (13)$$

From the relations (11) and (13) one can notice the kinematic similarity conditions fulfillment: $\frac{w_{am}}{w_a} = \frac{w_{cm}}{w_c} = 0.5$

6. Conclusions

1. If on this new type of volumetric flow meter, on the driving shaft (the lower shaft) an electric motor is coupled, then, the machine, as a whole, can be used simultaneously as a pump and as a volumetric flow meter.

2. The fluid passing through the flow meter can be water, oil, diesel oil and other liquids that may have an increased viscosity.

3. Initially, the liquid flow rate evaluation will be performed by measuring the flow meter speed with a tachometer with digital indication and the flow rate will result from the characteristic curve $\dot{V} = f(n_r)$.

4. In the next stage, to record the rotation number, an "odometer" [1] will be used; a meter that records the flow rate passing through it from the start (τ=0).

5. Using the similarity theory, based on a model, the main constructive and functional parameters of the prototype are established.

R E F E R E N C E S

[1] *** Rotors Meters & Instruments Dresser, Inc. Houston, Texas, 77041-2654 USA, (www.dresser.com).

[2] *N. Băran, P. Răducanu, o.a.*, Bazele termodinamicii tehnice (Bases of Technical Thermodynamics), POLITEHNICA PRESS Publishing House, Bucharest, 2010.

[3] *** Brodie International (www.brodieintl.com).

[4] *A. Detzortzis*, "The influence of rotors architecture on the performance of an rotating volumetric compressor with profiled rotors", PhD Thesis, University "POLITEHNICA" of Bucharest, Faculty of Mechanical Engineering and Mechatronics, Bucharest, 2014.

[5] *A. Motorga*, The influence of constructive and functional parameters on the performance of a rotating machines with profiled rotors, PhD Thesis, University "POLITEHNICA" of Bucharest, Faculty of Mechanical Engineering and Mechatronics, Bucharest, 2011.

[6] *M. Hawas*, The influence of fluid viscosity on the performance of rotating machines with profiled rotors, PhD Thesis, University "POLITEHNICA" of Bucharest, Faculty of Mechanical Engineering and Mechatronics, Bucharest, 2015.

[7] *M. Hawas, N. Băran, A. Detzortzis*, Influence of the rotor architecture and of the speed on the volumetric efficiency of a new type of rotating volumetric machine, Advanced Materials Research, Trans Tech Publications, Switzerland, **vol. 905**, 2014, pp. 487 – 491.

[8] *N. Băran, Gh. Băran, O. Donțu*, Corelația dintre puterea de antrenare și înălțimea pistonului rotativ la un nou tip de compresor (The correlation between the driven power and the piston height of a new type of rotating compressor), Rev. Chimie, **vol. 55**, nr.1/2004, Bucharest, pp. 51 – 53.

[9] www.axiomet.eu

[10] *E. C-tin. Isbășoiu*, Tratat de Mecanica Fluidelor (Fluid Mechanics Treatise), AGIR Publishing House, București 2011.

[11] *Al. Dobrovicescu, N. Băran, Al. Chisacof*, Bazele termodinamicii tehnice, Elemente de Termodinamică Tehnică (Bases of Technical Thermodynamics, Technical Thermodynamics elements), POLITEHNICA PRESS Publishing House, 2009.

[12] *M. Marinescu, N. Băran, V. Radcenco*, Termodinamică și Transfer de Căldură, Îndrumar de laborator (Thermodynamics and Heat Transfer, Laboratory guide), Bucharest, 1996.