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Analysis of a rotary pump with two sectional impellers

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***Abstract*—The presented study shows aspects related to the fluid flow inside a rotary machine; this type of machine can be utilized as a ventilator, air pump or blower. Relations for computing the driving power of this pump as well as the fluid flow rate of transported are presented. The sealing between the impellers and between the impellers and the machine casing is studied and the advantages of different types of impeller shapes are specified.**

***Keywords*—rotary working machine, sectional impellers, volumetric pump**

I. INTRODUCTION

A pump's impellers profile is crucial to its performance because the impellers must be as tight as possible. The practicability of positive displacement pumps with sectional impellers is large: industry, household, etc.

For working machines with sectional impellers, the working principle is the same; they differ in working parameters. Considering the compression ratio (ε) there are distinguished [1, 2]: fans (ε <1.1), blowers (ε =1.1 - 2.5), compressors (ε > 2.5).

In conventional impeller profile design processes [3-6], the technical draftsman first designs the impellers profiles and then checks the contact points. Then, taking these into account, the performance of machines with two impellers can be evaluated.

Many studies are related to theoretical models that refer to determination of the mechanical losses, the physical behavior of such machines is studied [7], the total required power [8], the volumetric versus mechanical behavior [9] and the impellers of the impellers thickness and number [10].

To determine the influence of pressure drops in the development and design of variable displacement oil pumps, various mathematical models were proposed in [11] or to correlate the mass flow rate variations with pump design parameters [12-16].

A recent impeller solution from the basic Bach constructive solution was developed by the authors of [17] and [18]. Considering the optimal geometric parameters, in various studies [19] different types of impeller profiles have been developed to improve their performance.

By combining circular arcs in a number of five, the authors of [20], created another type of impeller. To increase the efficiency of the pumps the researchers [21] invented and patented an additional impeller solution.

Fang [22] patented a new impeller profile by introducing four circular springs to increase the efficiency of a vacuum pump. By using a single circular spring, the authors of [23] presented a two-lobed impeller with a new geometric design for the airfoil of it. By combining the conjugate epicyclical curve and circular arcs, a new impeller profile was developed [24].

What one can deduct from the analysis of the specialized literature above, is that the efficiency of the pump and the level of sealing are the key points in the design of a pump, which means that the subjects related to the geometric shape of the impeller profile, studying the amount of fluid transported and the drive power of the pump are important.

The rotary working machine presented in this paper can function with different fluids, more or less viscous and even solids.

II. THE DESIGN OF THE POSITIVE DISPLACEMENT PUMP

The rotary pump consists of two sectional impellers of the same type (3, 4); it rotates at the same speed in two casings (2, 5), Fig. 1. A cylindrical gear located outside the pump [25], consisting of two gears mounted on the spindles (7, 8), ensures the synchronous rotation of impellers.

Based on a computation program [25, 26], the shape of the contour of the two impellers is determined, and their construction is done on a numerically controlled center [27, 28].

The volume of the amount of fluid transported is carried to the exit and then, after a rotation of 90° of the two impellers, attains the second location in Figure 1, and finally, the third location in Figure 1.

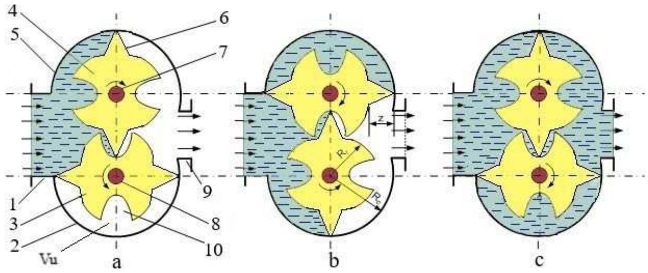

Fig. 1. The impellers location after a 180° rotation
1 - input; 2 - bottom casing; 3 - bottom impeller; 4 - top impeller; 5 - top casing; 6 - rotary piston of the top impeller; 7 - driven spindle; 8 - driving spindle; 9 - output; 10 - cavity into which the top rotor piston enters.

The rotary working machine, i.e., the positive displacement pump has two impellers with: piston height: z = 30 mm, piston length: l = 50 mm, impeller radius: R_r = 50 mm [29].

Case radius: $R_c = R_r + z = 50 + 30 = 80$ mm.

A speed of 300 rpm is chosen.

The machine volumetric flow is [2, 30]:

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

n_r = 200, 300, 400, 500 rpm.

$$\dot{V} = \pi\cdot 0.05\cdot 0.03\left(0.03 + 2\cdot 0.05\right)\cdot\frac{300}{30}\left[m^3/s\right]$$

$$\dot{V} = 0.00471\left(0.13\right)10 = 0.00612\ m^3/s \tag{2}$$

$$\dot{V} = 0.00612\cdot 3600 = 22.03\ m^3/h$$

Flow rate variation as pump speed changes.

Similarly, the amount of fluid transported by the positive displacement pump is determined for the speeds: n_r = 100, 200, 400, 500 rpm and the data from Fig. 2 results.

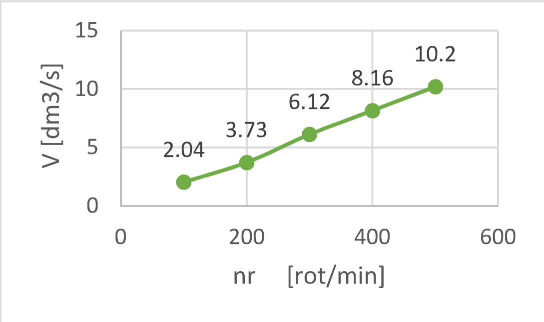

Fig. 2. The graph of the fucntion $\dot{V} = f(n_r)$.

Equation (1) shows that the amount of fluid transported by the rotary machine will multiply with the following variable changes:

l – the length of the impeller [m];
z – the height of the rotary piston [m];
R_r – impeller radius [m].
n_r – pump speed [rpm].

Therefore, it is necessary to establish a certain ratio amongst the impeller radius (R_r) and the height of the rotary piston (z).

The establishment of the computation equation for power.

The presented rotary machine is considered to be a positive displacement pump which must attain an increase in pressure equal to Δp [N/m²]. In this case, the theoretical driving power of the pump will be provided by the equation [31, 32]:

$$P = \Delta p\,\dot{V}\ \left[W\right] \tag{3}$$

Substituting the flow rate given by the relation (1), it results:

$$P = \pi l z\left(z + 2R_r\right)\Delta p\frac{n_r}{30}\ \left[W\right] \tag{4}$$

From (4) one can see that the power depends on the: impeller length; impeller radius; rotary piston height; machine speed; the pressure drop produced by the pump.

The positive displacement pump power will be bigger [33, 34]:

$$P_r = \frac{P}{\eta_e}\ \left[W\right] \tag{5}$$

wherein η_e is the actual efficiency of the machine:

$$\eta_e = \eta_v\cdot\eta_m\cdot\eta_h \tag{6}$$

wherein: η_v is the pump's volumetric efficiency, η_m is the pump's mechanical efficiency, η_h is the pump's hydraulic efficiency.

For the volumetric pump, the actual efficiency has been found to be η_{ef} = 0.8 in [32].

III. CONSTRUCTIVE ELEMENTS OF THE VOLUMETRIC PUMP

Fig. 3 shows the machine casing that contains the two impellers.

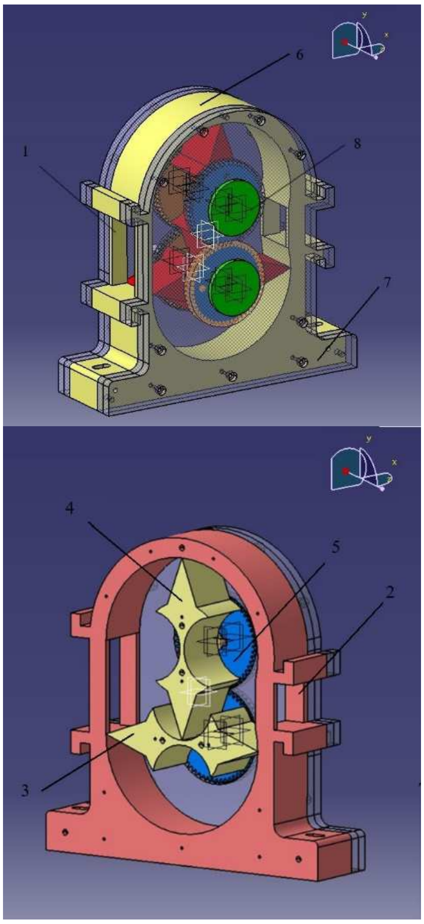

Fig. 3. Three-dimensional view of the machine. 1- input ; 2 - output; 3 - bottom impeller; 4 - top impeller; 5 - gearing; 6- casing; 7 – sidewalls; 8 – cap sealing.

Fig. 4 shows an axonometric view of the casing of the demonstration model of the designed rotary machine.

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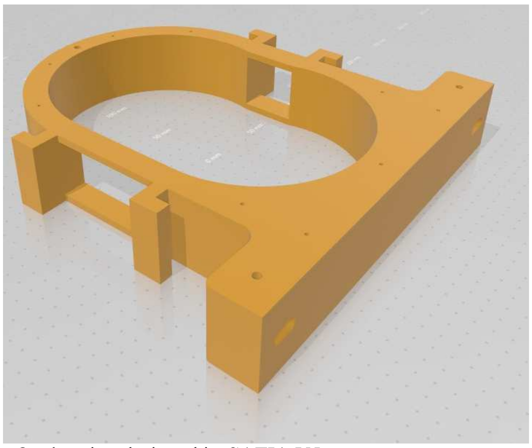

Fig. 4. Oval casing designed in CATIA V5.

The prototype components (Fig. 5) were constructed with a 3D printer.

Fig. 5. The demonstrative model of positive displacement pump.

The prototype of the positive displacement machine is shown in Fig. 6.

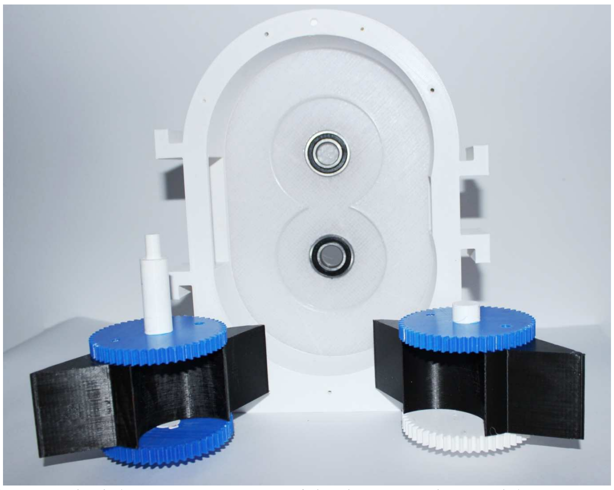

Fig. 6. Principle component parts of the demonstration model.

The prototype of the positive displacement pump with sectional impellers can be driven by an electric motor.

IV. Aspects regarding the sealing between the impellers and the casing and between the two impellers

In Fig. 7, one can observe that the sealing between suction and discharge is provided by the tip of the rotary piston and the casing.

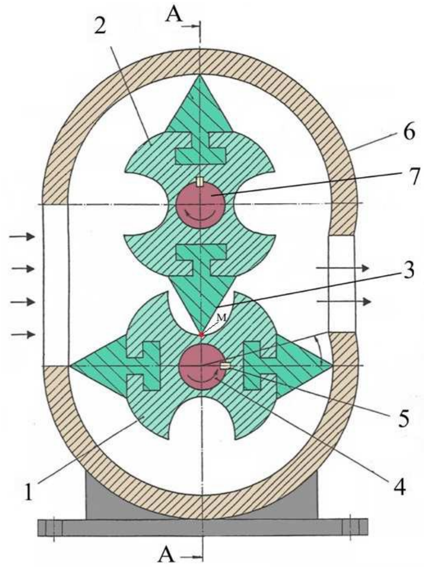

Fig. 7. Section through the positive displacement pump
1 - bottom impeller; 2- top impeller; 3- triangular piston; 4, 7 - spindles; 5 - cleat; 6 - top casing.

As a result, the relation $R_c = R_r + z$ must be fulfilled.

This was possible because the impellers and casing were designed and then developed on a CNC center.

In Fig. 8 it can be seen that between the two impellers there is contact generated only by the peak of the triangular piston and the bottom impeller.

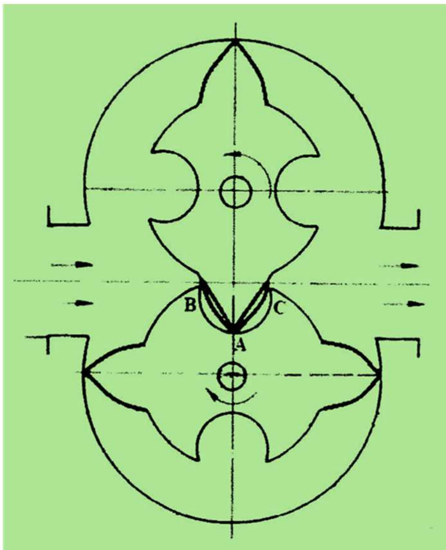

Fig. 8. Cross section through the rotary working pump.

The situation becomes more favorable if the rotary piston is curvilinear; in this case there are three points of contact between the two impellers, i.e. A, B, and C.

V. CONCLUSIONS

The benefit of solution is the fact that can convey any "fluid substance" that enters the input regardless of whether it has impurities, is corrosive or viscous.

From Fig. 8, two cases can be observed:

a) when the rotary piston has a triangular shape, between input and output there is only one sealing zone, that is between the peak of the top piston and the cavity of the bottom piston. As a result, this type of piston is recommended for volumetric pumps that transport incompressible fluids with low pressures.

b) when the rotary piston is oval, there are always contact points (A, B, C) between the two impellers, which ensures a better seal between the suction and discharge parts of the rotary machine. So, this solution can be used when the machine is used as a blower or compressor, in which case a better seal between suction and discharge is required.

The study presents a vast quantity of knowledge in the domain of working machines with sectional impellers, machines intended for transporting polyphase fluids.

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