THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE XIV MECHANICHAL ENGINEERING, ISSN 1224-5615
2016

ASPECTS REGARDING THE CENTRIFUGAL PUMP OPERATION

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ABSTRACT

The centrifugal pumps are part of hydrodynamic units that enable the power transmission to the working fluid. These pump types are converting the mechanical energy taken from an external motor into kinetic energy characterized by fluid mass flow rate and flow velocity. A centrifugal pump assembly having three impeller models have been designed and analyzed with ANSYS CFX in order to highlight the fluid flow characteristics through the pump body and how the impeller geometry influences the centrifugal pump working process. The results are presented in terms of fluid flow velocity and pressure for each analyzed impeller model.

KEYWORDS: hydraulic unit, hydrodynamics, experimental modelling, CFD

1. INTRODUCTION

In the practice of hydraulic and pneumatic specific units are encountered, represented by hydrodynamic and hydrostatic pumps.

The hydrostatic or volumetric pumps are units intended for fluid circulation as volume and working pressure.

The hydrodynamic units are represented by the axial impeller pumps and centrifugal pumps that circulate the working fluid under the form of flow velocity and mass flow rate.

The basic parameters that characterize the centrifugal pumps operation are related to the flow rate of the fluid circulated per time unit, the aspiration pressure as a difference between the atmospheric pressure and the pressure at the aspirating column inlet and the discharge pressure which is the pressure created by pump action.

The centrifugal pump types are most widely used for applications that involve fluids handling at a certain height called the manometer height (H_m) ensuring a certain amount of flow rate (Q) for this transport.

The relationship between the fluid pressure difference and the manometer height can be written as follows: [3]

$$\Delta p = \rho g H_m \tag{1}$$

Where:

Δp - fluid pressure differences;

ρ - fluid density;

H_m - height.

2. CENTRIFUGAL PUMP PRINCIPLE OF OPERATION

The centrifugal pump converts mechanical energy into hydraulic energy because the hydraulic power is transferred to the working fluid: [3]

$$P_h = \rho \cdot g \cdot H_m \cdot Q = \Delta p \cdot Q \tag{2}$$

Where:

P_h - Hydraulic power;

Q - Fluid flow rate.

The working fluid enters the rotor zone from where it is taken through the rotational movement of the rotor blades. Thus, it is pushed towards the discharge area at full velocity.

The working fluid thus reaches the discharge region of the pump housing, where the flow area increases while the velocity of the liquid decreases. In this region it is achieved the transformation of kinetic energy into potential energy and this phenomenon can be described using one form of Bernoulli's equation: [3]

$$p + \rho g h + \frac{\rho v^2}{2} = C \quad (3)$$

Where:
p- fluid pressure;
v- fluid velocity;
C- constant.

The formula can be applied for a fluid particle circulation along a streamline.

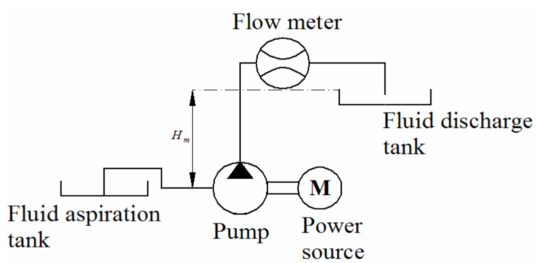


Figure 1. Schematic representation of pump operation

The centrifugal pump operation is defined by special parameters regarding fluid flow rate, head, power, and efficiency.

The fluid flow rate describes the rate at which the pump can circulate the working fluid through the installation.

The pressure value represents a measure of the force per surface that the pump can create and maintain during operation. At the centrifugal pumps, the pressure value is changing according to fluid specific gravity.

The head represents the height above the suction inlet at which a pump can lift a fluid during operation.

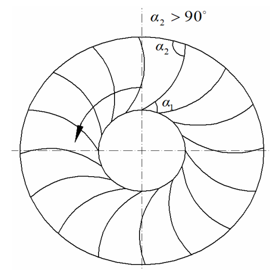
The centrifugal pump efficiency can be expressed as the ratio between the input and output power. This amount takes into consideration the energy losses inside the pump caused by friction and slip, in order to describe the total amount from the input power which performs useful work.

3. CENTRIFUGAL PUMP MODEL

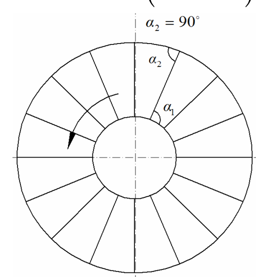
For a simple model of centrifugal pump, the main components are represented by the pump body and the impeller positioned at the interior. A number of blades with specific geometry are positioned on the rotor, which are able to retrieve fluid from the aspiration due to the rotor rotation and convey it to the discharge region.

The centrifugal pumps are used to circulate a particular fluid flow rate at a given pressure value by using the impeller rotation. Thus, the flow rate of circulated fluid is a basic parameter, together with the height at which the fluid can be transported as the difference between aspiration and the discharge region.

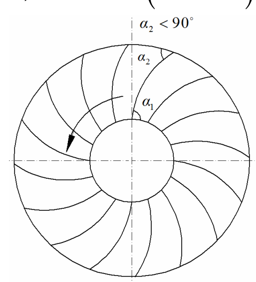
For the impeller are presented three different blade model arrangements shown in figure 2, depending on the inclination angle (α).



a) Model 1 $\left(\alpha > 90^\circ\right)$



b) Model 2 $\left(\alpha = 90^\circ\right)$



c) Model 3 $\left(\alpha < 90^\circ\right)$

Figure 2. Schematic representation of blade model arrangement for the centrifugal pump

A three-dimensional model of a centrifugal pump assembly was achieved using MICROSTATION V8i software from BENTLEY. Moreover, the three different impeller types have been modelled having different blades inclination.

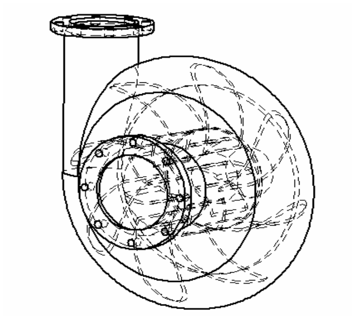


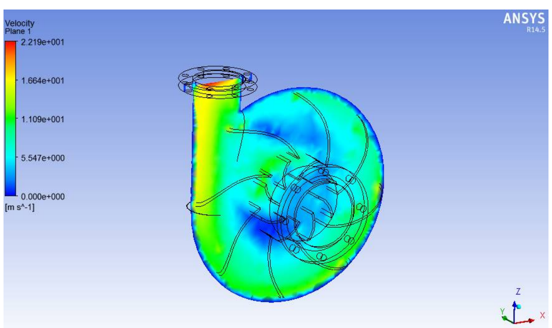
Figure 3. Three-dimensional model assembly for the centrifugal pump

4. NUMERICAL ANALISYS FOR THE CENTRIFUGAL PUMP MODEL

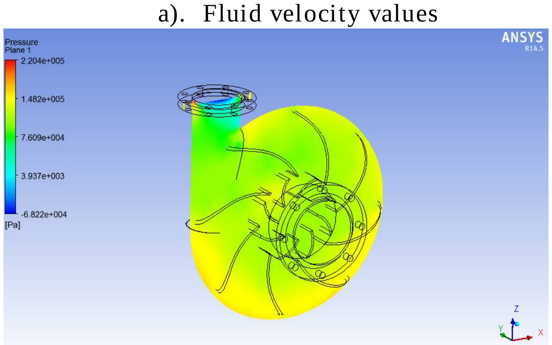
For the centrifugal pump model, a CFD analysis was carried out using ANSYS CFX program for all three impeller models in order to highlight the dynamics of the working fluid (water) inside the pump body.

The surface area at the aspiration inlet is of 28.27 and at the discharge outlet it is of 15.90 square centimetres.

The results are presented in terms of fluid velocity, flow rate and pressure values.

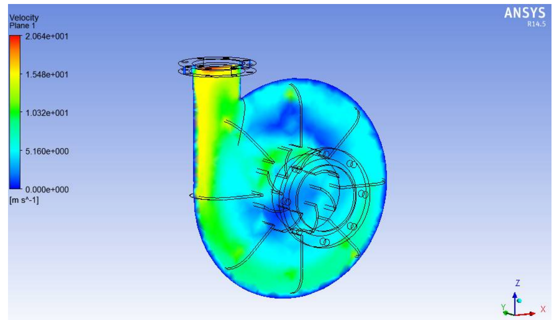


a). Fluid velocity values

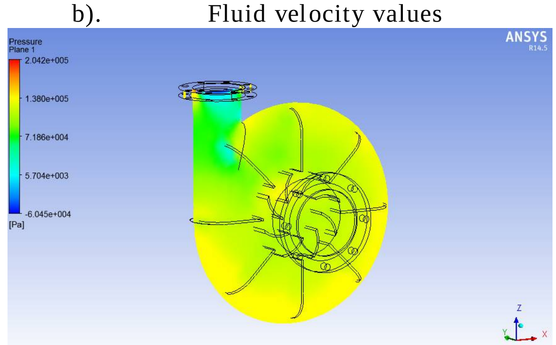


b). Pressure values

Figure 4. The results obtained for centrifugal pump analysis, model 1, $\left(\alpha > 90^{\circ}\right)$

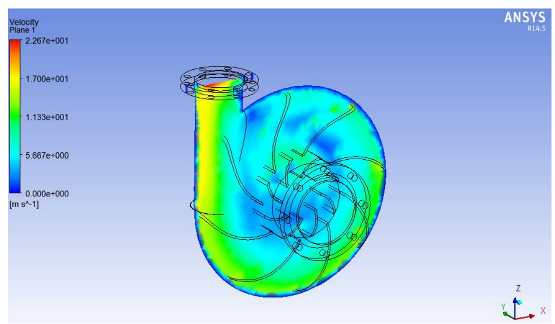


b). Fluid velocity values

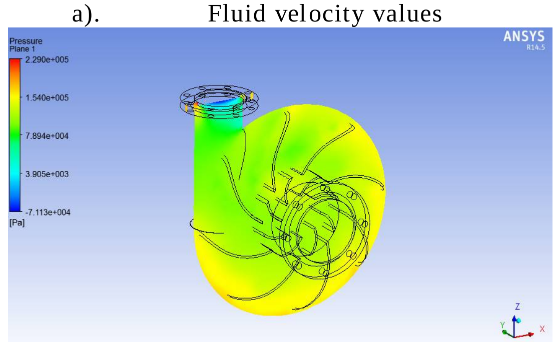


c). Pressure values

Figure 5. The results obtained for centrifugal pump analysis, model 2, $\left(\alpha = 90^{\circ}\right)$



a). Fluid velocity values



b). Pressure values

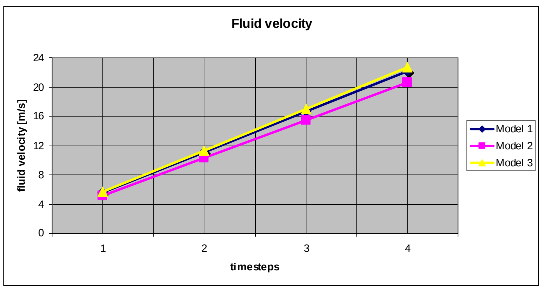
Figure 6. The results obtained for centrifugal pump analysis, model 3, $\left(\alpha < 90^{\circ}\right)$

For all three propeller models of the centrifugal pump, the impeller rotational motion had the same direction, the pressure value at the inlet was declared at 101325 Pa and the impeller rotational velocity value was set at 1500 rev / min.

The numerical results are presented in Table 1 and the corresponding diagrams for the fluid velocity and pressure are presented in figure 7.

Table 1. Numerical results obtained for fluid velocity and pressure

Model 1		Model 2		Model 3	
1500 rev / min					
[m/s]	[bar]	[m/s]	[bar]	[m/s]	[bar]
5.54	0.039	5.16	0.057	5.66	0.039
11.09	0.76	10.32	0.71	11.33	0.789
16.64	1.48	15.48	1.38	17	1.54
22.19	2.2	20.64	2.04	22.67	2.29



Fluid velocity results diagram for the three impeller models

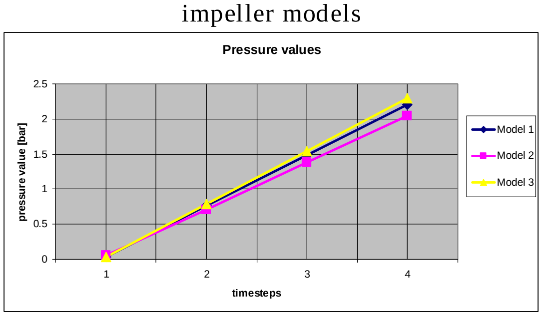


Figure 7. Pressure results diagram for the impeller models

The results obtained from the carried out analysis shows that model 3 of centrifugal pump impeller provides higher values of velocity and pressure for the working fluid at the pump outlet for the same impeller rotational velocity. Overall, the obtained results are close to similar for all the three analysed impeller models.

The centrifugal pump impeller is achieving the mechanical energy transfer to the working fluid, making use of rotational motion from the energy source, thus the rise of fluid pressure and velocity is obtained/ produced.

5. CONCLUSIONS

The centrifugal pumps are the most common form of hydrodynamic units generally used for transporting liquids.

The working principle for this unit is represented by the actuation of the impeller at a certain rotational velocity provided by an external energy source (thermal or electric motor). The impeller takes the mechanical energy from the motor shaft and transmits it forward to the working fluid under the form of fluid velocity and flow rate.

For each individual centrifugal pump unit, the general characteristics are related to the circulated fluid flow rate and height that can be raised as a result of the pump action.

The centrifugal pumps can operate by mounting in series for some applications that require higher value for the working fluid pressure.

Three distinct impeller models have been designed and mounted in a centrifugal pump assembly in order to be analysed with ANSYS CFX in terms of flow operation inside the pump body. The impeller rotational velocity was of 1500 rev/min, the working fluid was water, the pressure at the inlet was declared of 101325 Pa.

The obtained results from the conducted analysis have been presented under the form of fluid pressure and flow velocity values.

From the three analysed models, the numerical results are close to similar, but the model with the highest fluid velocity is stated by model 3 $(\alpha < 90^\circ)$, achieving also the highest pressure values at the pump body outlet.

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