# Design Details and Fluid Flow Analysis for the Centrifugal Pump with Special Rotor Pattern

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***Abstract:*** *The operating principle of a pump is represented by the conversion of mechanical energy taken from an energy source such an electric or thermal engine in hydraulic energy of the circulated fluid. By means of a pump, an energy amount is generated being uniformly distributed within the fluid mass that can defeat the hydraulic resistances and reaching a maximum height to which the fluid can be lifted by the pump. The centrifugal pumps are considered as hydrodynamic units that can perform the circulation of a fluid flow rate at a certain height. The primary functional sub-assembly found in the composition of a centrifugal pump is represented by the impeller which through the rotational movement inside the pump body performs the fluid transport from the aspiration region to the pump discharge region. Between the rotor blades and the working fluid some interaction forces are arising due to which the mechanical rotational energy is converted into flow energy of the fluid. In this paper the general considerations regarding centrifugal pump are presented and analyzed in terms of the functioning of a constructive type. Thus, a three-dimensional assembly of centrifugal pump was built having an impeller inside and analyzed with the ANSYS CFX program for emphasizing of fluid flow parameters. The results are presented in terms of pressure and flow velocity of the fluid regions.*

***Keywords****: centrifugal pump, impeller model, fluid flow, 3D modelling, computational fluid dynamics (CFD)*

## 1. Introduction

The operation principle of centrifugal pumps is based on the fact that the working fluid is conveyed and delivered to a certain difference level ensured through the pump.
In the composition of a centrifugal pump enters the fixed part or pump casing having a specific design and the mobile part or rotor being positioned inside the casing.
In order to circulate the fluid the rotor has several blades through which the fluid can be driven from the pump aspiration area to the discharge area.
Centrifugal pump operation is represented by the conversion of mechanical energy taken from the power source represented by a thermal or electric engine in energy in hydraulic energy of the driven fluid.
The centrifugal pumps are considered as part of hydrodynamic or kinetic units capable of providing kinetic energy to the transported liquid characterized by mass flow rate and flow velocity.

## 2. General considerations regarding the centrifugal pumps

The operation of the centrifugal pump is ensured by the rotational movement of the rotor within the casing. As a result of this movement, the fluid particles are entrained from the aspiration region where a depression is created and sent to the peripheral region of the casing, by means of centrifugal force field that arises at the high velocity rotational motion of the rotor.
The fluid is continuously aspirated due to the continuous rotational motion of the drive shaft being conveyed through the discharge pipe. In the outlet region it has a high velocity, which means a high kinetic energy, but as it moves into the discharge pipe the motion velocity value gradually decreases and the kinetic energy is converted into pressure energy.
The rotor construction involves a number of angled shape blades being mounted on a shaft within the pump casing. The rotational movement of the impeller inside the pump casing is forming a field of centrifugal forces whose action causes fluid transport in a vortex-type movement depending on the blades profile.
By continuously rotational motion ensured by the rotor inside the pump casing the energy is generated within the fluid region which allows overcoming the hydraulic resistances and ensuring a height value at which the fluid is circulated.

The energy generated is uniformly distributed in the fluid mass within the pump and his specific increase describes a linear evolution represented by the load of the pump or the pump head, which can be calculated by the relationships: [5]

$$H_{pc} = \left( \frac{p_1}{\gamma_f} + \theta_1 \frac{v_1^2}{2g} \right) - \left( \frac{p_0}{\gamma_f} + \theta_0 \frac{v_0^2}{2g} \right) \quad (1)$$

$$H_{pc} = \frac{p_1 - p_0}{\gamma_f} + \frac{\theta_1 v_1^2 - \theta_0 v_0^2}{2g} \quad (2)$$

where:

- $\gamma_f$ - fluid specific weight;
- $g$ - gravitational acceleration;
- $v$ - fluid velocity.

The pump head can be presented as a sum of total increases regarding pressure (static) and kinetic energy (dynamic).

The functioning of centrifugal pumps within an fluid pumping installation presents a dependency relationship between functional parameters represented by the fluid flow rate, pumping height, power consumption, pump efficiency and rotor velocity: [7]

$$f\left(Q_p, H, P_a, \eta_p, n\right) = 0 \quad (3)$$

where:

$Q_p$ - fluid flow rate;

$H$ - pump head;

$P_a$ - absorbed power;

$\eta_p$ - pump yield;

$n$ - rotor rotational velocity.

$$Q_p = \frac{dV}{dt} \quad (4)$$

In order to determine the pumping height is applied the first principle of thermodynamics to the fluid unit mass circulated inside the pump casing: [7]

$$L = \Delta E_c + \Delta E_p + \Delta F_f \quad (5)$$

where:

$\Delta E_c$ - kinetic energy variation;

$\Delta E_p$ - potential energy change of position and pressure;

$\Delta F_f$ - energy amount dissipated and transformed into heat.

$$\Delta E_c = d\left( \frac{v^2}{2} \right) \quad (6)$$

$$\Delta E_p = gdz + \int Vdp = gdz + \int \frac{dp}{\rho} = gdz + \frac{p_1 - p_0}{\rho} \quad (7)$$

For both values sets at the pump inlet and outlet can be written: [7]

$$L = \frac{v_1^2 - v_0^2}{2} + g\left(z_1 - z_0\right) + \frac{p_1 - p_0}{\rho} + F_f \tag{8}$$

Thus, the useful work done is described by the relation: [7]

$$L_0 = \frac{v_1^2 - v_0^2}{2} + g\left(z_1 - z_0\right) + \frac{p_1 - p_0}{\rho} \tag{9}$$

Dividing the useful work relationship with the gravitational acceleration can be achieved the pumping height (*H)*: [7]

$$H = \frac{v_1^2 - v_0^2}{2g} + z_1 - z_0 + \frac{p_1 - p_0}{\rho g} \tag{10}$$

The useful power can be defined as the total strength transferred to the working fluid that is transported through the centrifugal pump casing:

$$P_u = \rho g H Q \tag{11}$$

The absorbed power represents the power applied to the motor shaft in order to achieve impeller rotary motion within the pump casing and entrainment of the working fluid:

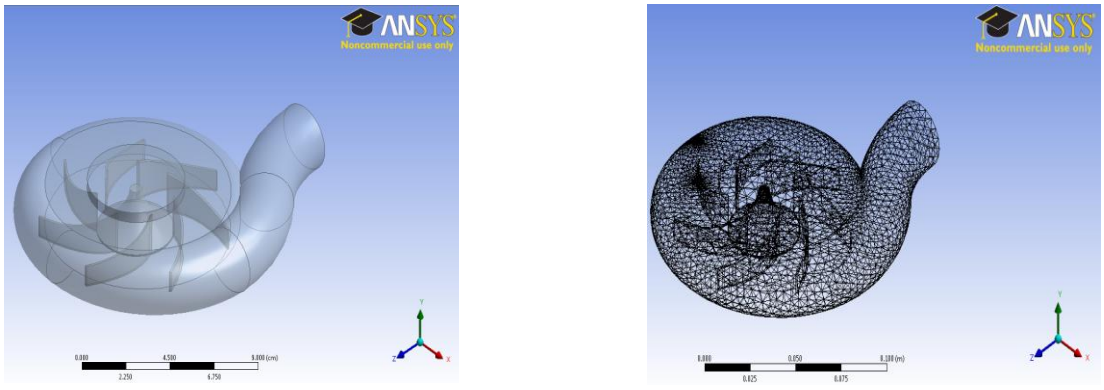
$$P_a = EI \tag{12}$$

Thus the pump efficiency can be calculated as the ratio between the useful power and the absorbed power:

$$\eta_{pc} = \frac{P_u}{P_a} \tag{13}$$

### 3. CFD analysis for the centrifugal pump with impeller model

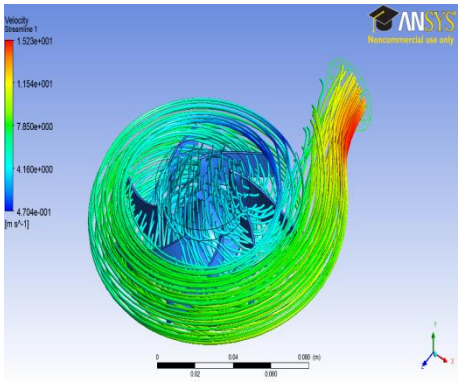
Two three-dimensional assembly models are constructed for the centrifugal pump assembly model and analyzed using ANSYS CFX in order to emphasize the fluid flow parameters represented by water velocity and pressure. In figure 1 and 3 are presented the analized models having the inlet diameter of 50 and 30 mm, while the outlet diameter is mantained at constant value of 30 mm. The working fluid is declared as water. There have been declared a rotational velocity of 1500 rot/min at the rotor and velocity at the inlet of 4 m/s. The pump impeller have a special design with seven angled blades capable of taking over the fluid, conduct it along the outer walls of the pump housing and then send it to the output region with a particular velocity.



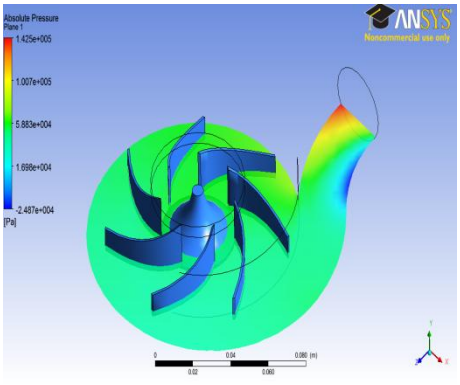

**a)** centrifugal pump model assembly **b)** mesh model of 11931 nodes and 58880 elements of triangle surface

**Fig. 1.** The centrifugal pump assembly model (D1=50 mm) imported in Design Modeler (ANSYS CFX) and mesh details

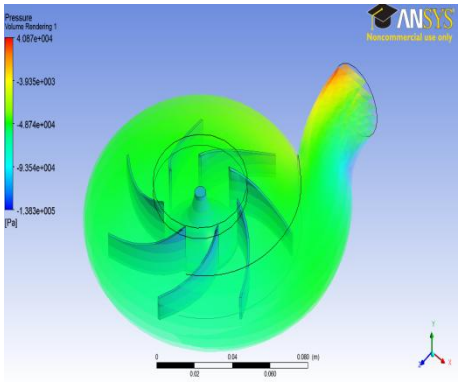
The obtained results from the analysis are presented in figure 2 and 4, showing the fluid streamlines and pressure values in the fluid region.



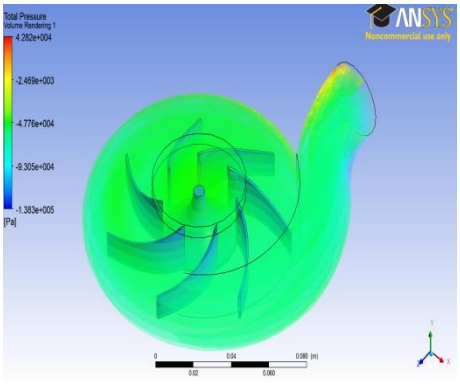

**a)** Fluid velocity [m/s] as fluid streamlines




**b)** Absolute pressure [Pa] in ZX plane

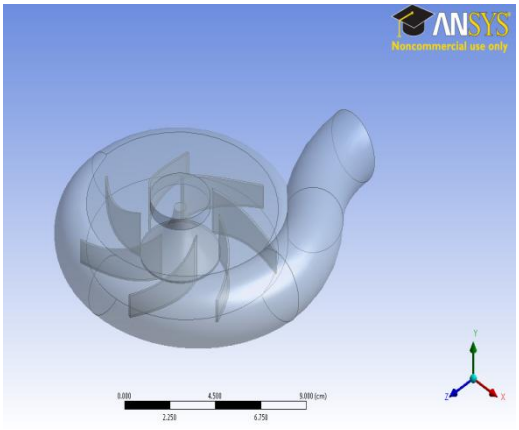



**c)** Static pressure [Pa]
(fluid volume rendering)

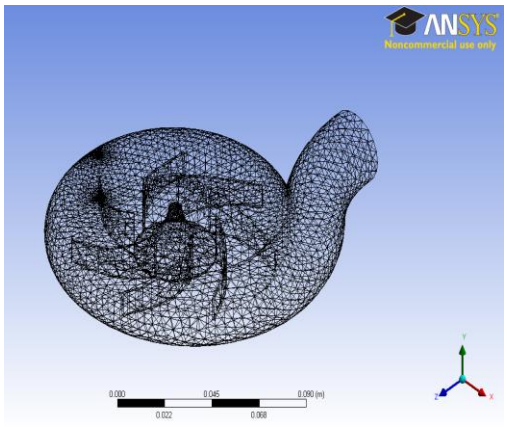



**d)** Total pressure [Pa]
(fluid volume rendering)

**Fig. 2.** The CFD analysis obtained results for model with inlet of D1=50 mm

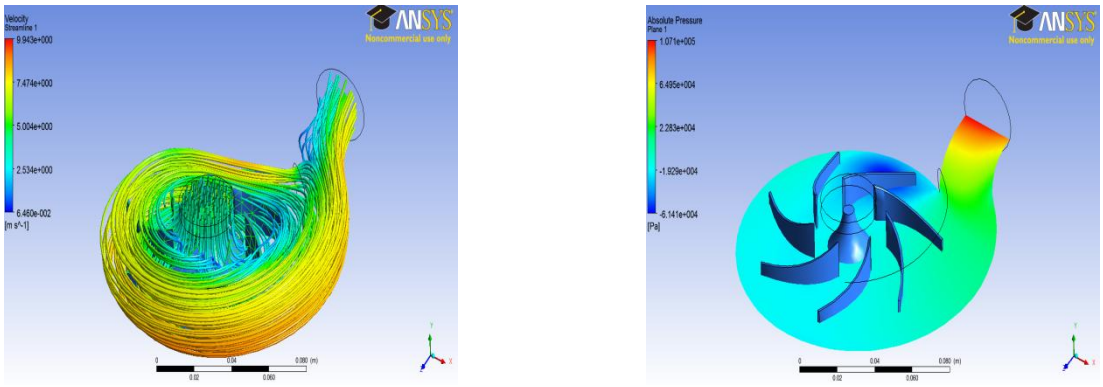



**a)** the centrifugal pump model (D=30 mm)




**b)** mesh model of 12183 nodes and 60280 elements of triangle surface

**Fig. 3.** The centrifugal pump assembly model (D2=30 mm) imported in Design Modeler (ANSYS CFX) and mesh details



**a)** Fluid velocity results [m/s] as fluid streamlines

**b)** Absolute pressure [Pa] in ZX plane

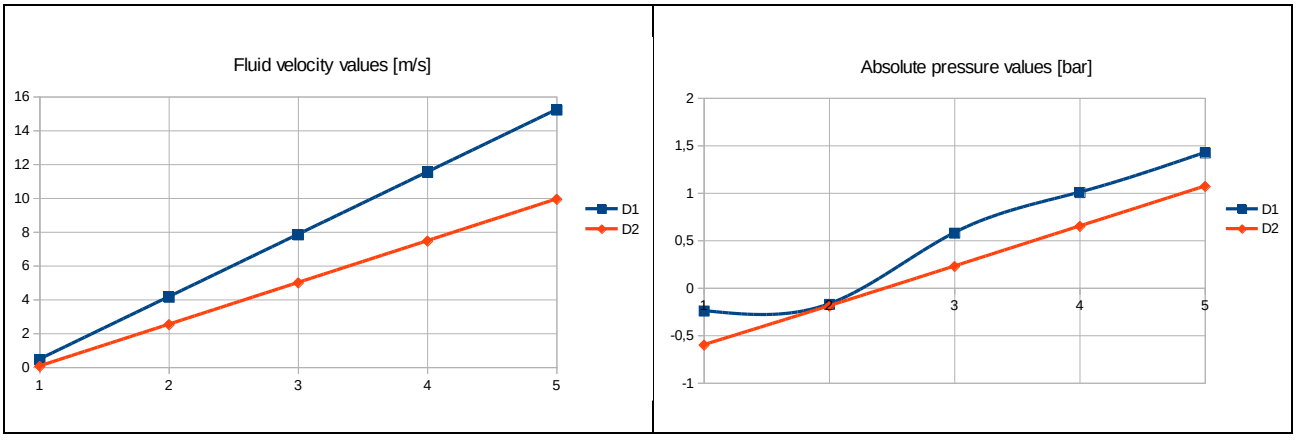
**c)** Static pressure [Pa] (fluid volume rendering)

**d)** Total pressure [Pa] (fluid volume rendering)

**Fig. 4.** The CFD analysis obtained results for model with inlet of D2=30 mm

The centrifugal pump model working principle was analyzed of fluid flow for the two values of inlet diameter (D1 = 50 mm, D2 = 30 mm). It was declared the fluid region having considered the impeller as inner solid rotating after OY axis. The reference pressure of the fluid in the region of 1 atm.

**Table 1:** The diagrams for fluid velocity and absolute pressure values for the two analyzed models




In Table 1 are presented the results diagrams for the theoretical fluid velocity values according with the inlet diameter of the centrifugal pump casing model. Also are presented the diagrams regarding the absolute pressure values for the two analyzed cases.

## 4. Conclusions

In this paper it was presented and analyzed in terms of the functioning a centrifugal pump model. The assembly consists of the fixed part - pump housing and the mobile part represented by impeller, located inside the pump casing.
The pump housing has been special designed having variable geometry at the outlet region. The casing was modelled for the two inlet diameter values of 30 and 50 mm, while the diameter of the fluid outlet was kept constant at 30 mm.
The numerical analysis performed using the ANSYS CFX program aimed mainly to emphasize the operating characteristics of centrifugal pump assembly when the impeller is performing a rotational motion within the casing with a velocity of 1500 rev/min. The results obtained from carried out analyzes shows the Eigen values for the working fluid velocity and fluid pressure created in the considered fluid region and specific fluid particles trajectory carried from the inlet region, along the pump casing walls inside and finally to the output region. For the carried on analyses the declared working fluid was water.
Such types of centrifugal pumps are used in particular for the construction of specialized circuits intended of water conveying or other types of fluids to a certain specific height depending on the pump construction type and dimensions.

### References

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