Hydro Power Solution with Radial Turbine Based on Medium Flow Rate Water Streams

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Abstract: *It is evident the continuous increase of the energy needs, proportionate to the increase of the number of inhabitants, but also due to the increase of the living standards of the human communities. For providing the necessary energy, the fossil fuels are used in the majority proportion, which bring changes to the environment. In order to avoid this disadvantage, energy obtaining methods based on natural renewable resources that are practically unlimited and most importantly do not bring negative changes to the environment are increasingly taken into account. Thus, besides solar energy, wind power, tidal energy and hydro power are solutions that are currently used all over the world, but which need to be further developed in the future. A turbine model working within a hydro power system is described in this paper aiming to highlight the main working parameters. A CFD analysis is conducted on the virtual model and presented the obtained results regarding fluid velocity, absolute pressure, turbine shaft torque and the total power amount calculated values.*

Keywords*: hydro power, hydraulic energy, water resource, turbine model, fluid flow, 3D modelling, computational fluid dynamics (CFD)*

1. Introduction

There are multiple power solutions available today that can use the renewable resources available, in order to avoid burning fossil fuels and environmental degradation. Renewable resources include solar energy, wind power, tidal and wave strength, as well as the potential of water flows. There are currently areas where these energy-efficient methods are being implemented with good results but must be developed and exploited to the real potential. The water-based energy was considered an environmentally friendly alternative, and has been used since ancient times in mills located directly on a water course before electricity has been discovered. For obtaining a good efficiency in the energy production based on water streams, there must be favourable conditions related to the water flow rate and the difference level. Where these essential conditions are met, hydropower plants have been established in operation. There are countries where a considerable percentage of total energy is produced on the basis of water flow in hydropower plants, such as Norway producing 99% of its energy from hydro power plants, New Zealand 75%, Canada 57%, Switzerland 55%, Sweden 40%, USA 10%. Around 20% of the world's electricity is produced in hydropower plants, but the potential is much higher, especially in countries with a predominantly mountainous relief or major water courses.

2. Construction types of hydraulic turbines

Today's hydropower plants have in use several turbine types, including PELTON, KAPLAN, or Francis models. All these models are using the water flow in order to convert the hydraulic energy into mechanical rotational energy.

PELTON'S turbine model was one of the most efficient types of hydraulic turbine, invented by Lester Allan PELTON in 1870, operating on the basis of the mechanical pulse generated by falling water pressure. These hydraulic turbines are recommended and used for relatively low water flows and high level differences.

The water drop capture unit built for the PELTON turbine model contains the drainage channel made at a considerable level, the turbine mounted in the housing and the downstream water outlet channel, (figure 1). The solution of this hydropower plant can be used both on a large scale and on a small scale as a micro-hydropower having a low water flow rate, but at an optimal level difference.

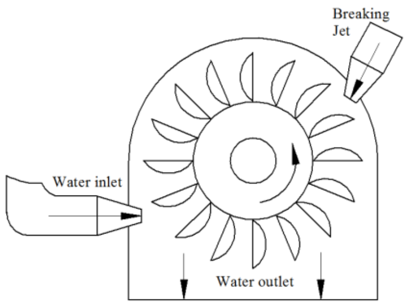


Fig. 1. Schematically representation of PELTON turbine

In ROMANIA, at the LOTRU Hydro Power Plant, PELTON turbines with vertical axis were installed, as well as the DOBREŞTI Hydro Power Plant, built within 1928-1930, equipped with PELTON turbines, which at the moment of commissioning was the highest hydroelectric power plant in Romania. [6]
FRANCIS and KAPLAN turbine models are also in use. The difference between the two constructive types lies in the fact that the water goes differently to the turbine blades: the Francis turbine has water in the radial direction, while the KAPLAN turbine benefits from the inlet of the water in the axial direction, (figure 2).
At the FRANCIS turbine, the blades are fixed, while the KAPLAN turbine blades benefit from angular adjustment in order to modify the rotational speed of the turbine shaft, depending on the intensity of the water flow.
The two types of turbines can operate at a medium water fall difference level and an medium water flow rate for the FRANCIS turbine and a low height but considerable flow rate for the KAPLAN turbine.
Rotational speed is ranging from 50-250 rpm for the FRANCIS turbine, and for the KAPLAN turbine between 200-550 rpm.

a) KAPLAN model b) FRANCIS model

Fig. 2. Schematically representation of KAPLAN and FRANCIS turbine models

Hydro power system IRON GATES I, built between 1964-1972, use vertical KAPLAN turbines operating on a 20 to 30 meter difference level, depending on the Danube level. [7]

3. Theoretical model of water flow through the hydraulic turbine

Water courses appropriate to geographical differences level are presenting particular importance since it can be used to obtain energy. Each water course can be appreciated after flow rate and drop height. Based on these parameters, the available power can be approximated, considering the flow rate, water density, drop height and gravitational acceleration: [5]

$$P = \rho \cdot g \cdot h \cdot \eta \cdot Q \quad (1)$$

The operation of the water turbine of a power plant depends on the fluid momentum on the turbine which causes the rotational movement of the turbine shaft which is connected to the power generator.

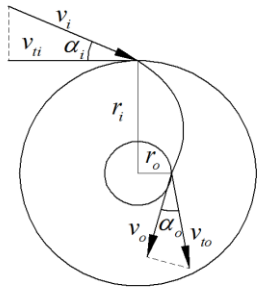


Fig. 3. Turbine blade model

The turbine shaft torque can thus be approximated based on input and output data of the water flow, (figure 3): [9]

$$T = \rho Q_w (r_i v_i - r_0 v_0) \quad (2)$$

The power at the turbine shaft can be approximated on the basis of the difference between the inlet and the outlet angle of the turbine blades: [9]

$$P_t = wT = w\rho Q_w (r_i v_i \cos\alpha_i - r_0 v_0 \cos\alpha_0) \quad (3)$$

4. CFD analysis of water flow through the turbine type system

A tri-dimensional model with a blade turbine is analyzed using the ANSYS CFX program. The system benefits from 4 radial-directional circular inputs that provide direct drive action on the turbine blades. For each entry an input flow rate of 50-100 kg/s was declared. The working fluid is chosen as water. The overall virtual hydro power model is shown in Figure 4.

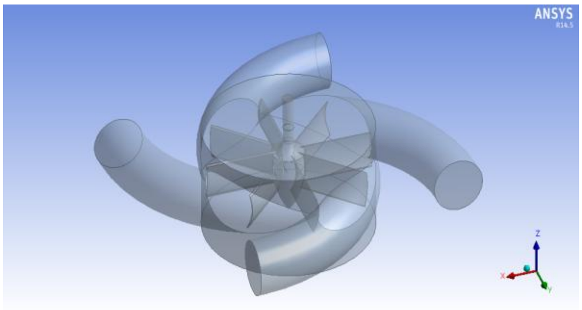
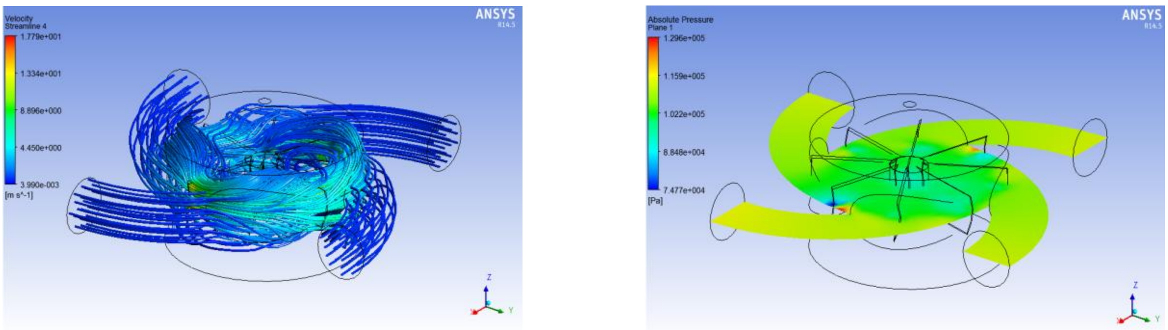


Fig. 4. Adduction channel and turbine model



a) water velocity streamlines b) absolute pressure values

Fig. 5. The result obtained from the flow analysis

Figure 5, shows the fluid velocity and absolute pressure. The results obtained show the direct action of the fluid on the turbine blades. Also, the calculated values for the maximum torque and total power amount that can be obtained using this turbine type are presented in table 1.
The values of the turbine shaft torque and total power were calculated using the values of the input and output velocity of the working fluid obtained from the performed analysis. The volumetric flow rate of the fluid was 0.2 m^3/s and a rotational speed of the turbine shaft of 60 rpm.

Table 1: The values for fluid velocity, torque and power

v_i (m/s)	v_0 (m/s)	T (Nm)	P(W)
10	2.5	1420	8917.6
10.5	3	1479	9288.12
11	3.5	1538	9658.64
11.5	4	1597	10029.16
12	4.5	1656	10399.68
12.5	5	1715	10770.2
13	5.5	1774	11140.72
13.5	6	1833	11511.24
14	6.5	1892	11881.76
14.5	7	1951	12252.28
15	7.5	2010	12622.8

This water-based energy generation system is a small-scaled model that shows the theoretical possibility of obtaining energy by using a low-flow rate water course.

5. Conclusions

This paper shows a hydro power system model with turbine intended for the production of energy using water streams. It is a simple, small-scaled model for which a CFD analysis was performed. Based on the result values obtained from the analysis the turbine shaft torque and the power amount productivity were calculated based on water flow rate.
This model can be a solution to apply in the case of water flows with medium water flow rate and an optimum fall height.

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