Design Details of a Turbine Model Used for Energy Conversion in Low Flow Rate Water Streams

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Abstract: *The potential of water flows has been used since ancient times. Today more than ever, the water streams are used for energy production. Depending on the three essential parameters of water flow represented by flow velocity, flow rate and level difference, the optimal design solutions for choosing the turbine type used to generate energy in a hydroelectric power plant are usually adopted. Over time, special turbine models have been built that have been fitted with hydro-electric power plants such as the Pelton, Francis or Kaplan turbines. The Pelton turbine model was built for use on water courses with a low flow rate but with a considerable difference level.*

A three-dimensional model for the Pelton turbine was built and analyzed in terms of operation in this work. The results obtained from the analysis are presented as values for the flow velocity and pressure of the water in the considered fluid area.

Keywords*: Hydro power plant, PELTON turbine, fluid flow, three-dimensional modeling, CFD*

1. Introduction

The construction of some hydroelectric power plants along the rivers is considered a solution to be used in order to obtain energy over a long period of time, leaving aside the disadvantages of local damage to the flora and fauna habitat. However, the advantages represented by the amount of energy that is produced have made the difference in favor of the continuous construction of energy units along the rivers, whose energy potential is under-exploited at present. With the continuous increase in energy requirements, the methods of obtaining electricity have to be taken into account using the water flow rate of the rivers with enough flow rates to operate the turbine of an energy system, in this case the Pelton model turbine.

2. Theoretical aspects and operation principle

The overall model of the power system based on the rivers water flow consists of a turbine with cups (Pelton turbine model), which has the possibility to rotate around its own axle on the basis of the pressing force exercised by the water stream to which it is exposed.

The operating principle of the turbines can be described as being related to the mechanical energy transformation of the fluid in rotation motion at the turbine shaft. 00

To ensure the operation, a level difference is needed between which the water has the possibility to flow. The static level difference for the turbine model, measured between the water level upstream and downstream, is given by: 0

$$Z_{st} = Z_{am} - Z_{av} \tag{1}$$

The net difference level at the turbine that can provide a net loss of water is obtained by the expression: 0

$$Z = Z_{st} - z_r + \Delta z_0 \tag{2}$$

where:

z_r - total hydraulic load losses;

Δz_0 - the restoration fall.

The value of Δz_0 is dependent on the type of turbine connection to the water flow and the turbine operating mode.
The relation defining the power value at the turbine shaft can be written as: 0

$$N_T = \frac{\gamma_a \cdot Q_a \cdot Z \cdot \eta}{102} \ [kW] \tag{3}$$

where:

γ_a - the water specific weight;

Q_a - water flow rate crossing the turbine enclosure;

Z - the net water loss;

η - yield.

The turbine with cups (Pelton model) is the most common turbine type used in hydro power plants for the production of hydraulic force based on the water flow. The principle of operation is presented schematically in figure 1.

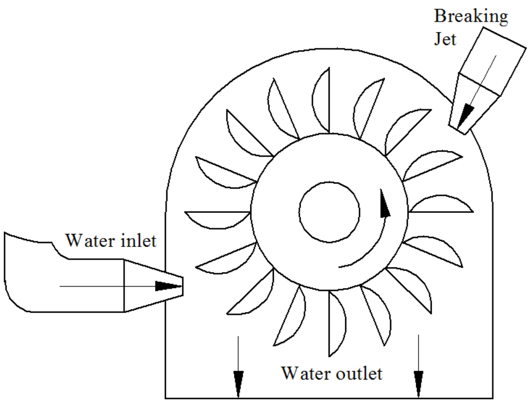
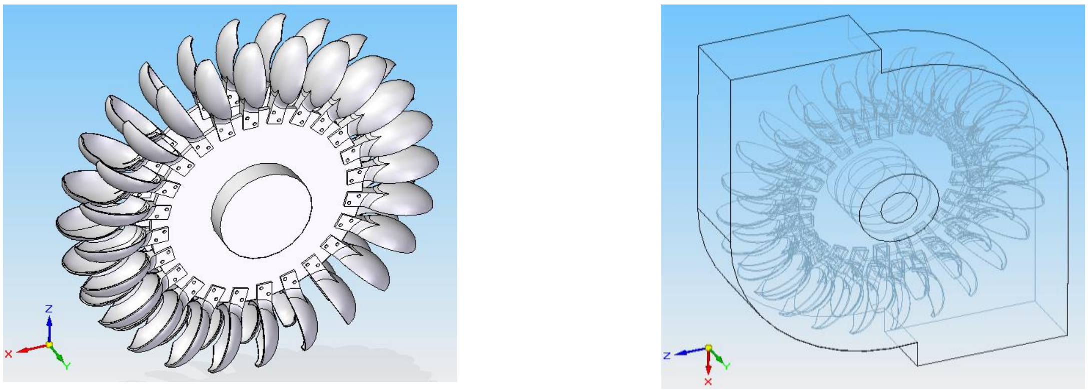


Fig. 1. Turbine assembly schematic representation

It is a model that uses an injector nozzle to which water is drawn through a pressure pipe.
The injector is provided with an adjusting needle through which the nozzle opening and water flow can be modified by simply axial displacement of the needle.
On the turbine rotor are mounted the cups, which ensure the successive take-off of the water from the injector and its transport to the exhaust area.
The positioning of the turbine shaft can be both horizontal and vertical.
Water injectors acting to direct water onto cups can be one or more (up to 6 injectors).
The turbine model can also have one or two rotors with cups.
It should be noted that the Pelton turbine rotor rotates freely, being positioned outside the flooded area (no drowning).
The Pelton turbine model is usually located above the maximum downstream water level, which means a reduction in the level difference (fall) with the required value for the installation.

3. Turbine assembly model

A three-dimensional model for the turbine rotor (Pelton) was built using the Solid Edge V20 program. It is a double-rotor model with an outside diameter of 5 m, (figure 2).



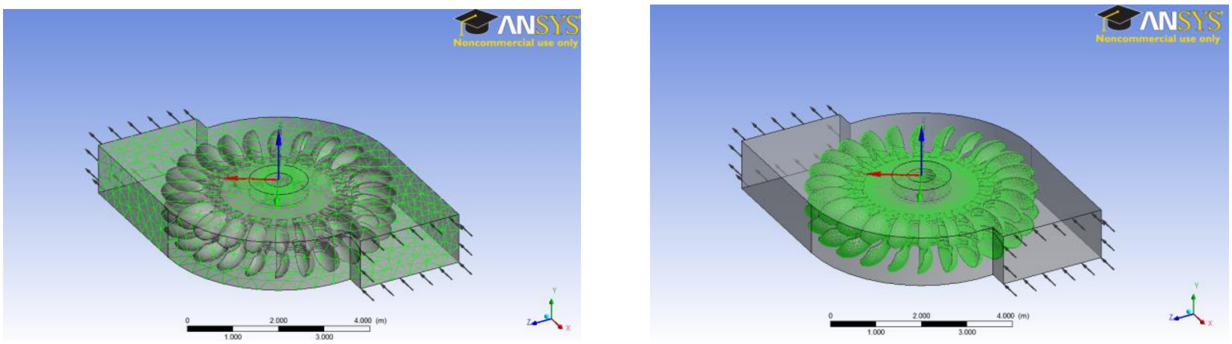
a) turbine double rotor b) enclosure model

Fig. 2. Turbine enclosure assembly model

The turbine model includes a number of cups (Pelton model) being by design a solution for converting the water flow rate energy into mechanical rotation energy at the turbine shaft. The water flow is metered through the injectors which action is to direct of the water flow directly onto the cups so that an impulsive force is formed in the normal direction which acts successively on the cups ensuring the initial movement and a continuous rotation of the turbine.
A considerable amount of energy based on water strength is thus obtained.

4. CFD analysis for turbine model

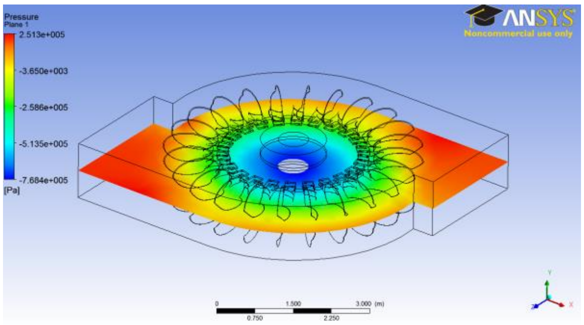
Based on the turbine virtual model a water flow analysis was carried out on the enclosure containing the turbine.
By the performed analysis are presented the results describing the water flow regime when is declared a value for the water velocity at the enclosure inlet for the analyzed fluid region.
The analysis is carried out using the ANSYS CFX Academic program.
The fluid region is using water as the working fluid, with a flow velocity of 1 m/s at the inlet, which causes a forced rotation movement on the turbine shaft by the direct action of water on the turbine cups. The water inlet was declared on the rectangular area built on the fluid area containing the turbine rotor, having the input area on one side and the exit area opposite.
Figure 3 shows the analysis main domains containing the turbine double rotor assembly model and the enclosure flow region.



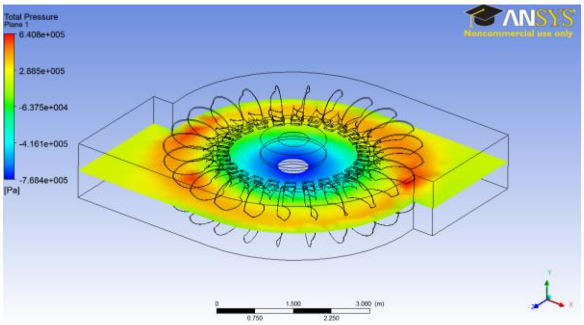
a) Fluid region b) Immersed solid (turbine)

Fig. 3. Flow analysis main domains

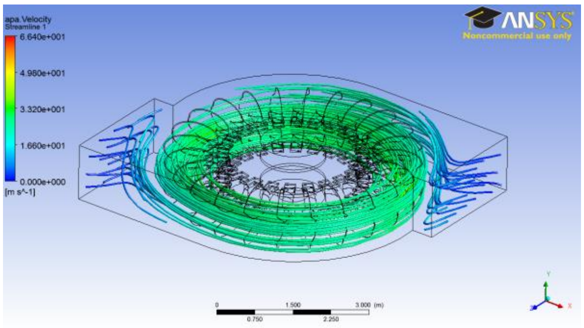
The meshing network was made with triangular shape elements, having 334725 nodes and 1612461 elements.
The results are presented in terms of the pressure and fluid velocity, (figure 4).



a) pressure values



b) total pressure values



c) water velocity values

Fig. 4. The flow analysis obtained result values

The results indicate specific values calculated for the flow parameters as flow velocity and pressure, on the main analysis domains represented by the fluid region and the turbine with cups considered as immersed solid.
The calculated specific values are presented for the fluid domain containing 34.59 cubic meters of water. The turbine pressure range is between 128754 and 219337 Pa, the inlet section area is 2.93 m2, while the mass flow rate is 2935.72 kg/s. On the inlet, the minimum value of the total pressure is 157308 Pa. The water flow velocity values range from 16-33 m/s for the case when the turbine double rotor has a rotational velocity of 1 revolution per second.

5. Conclusions

Pelton turbine model is one of the most used in hydroelectric power plants due to the advantages it offers. These relate to the low water flow rates required by these turbines, but considerable level differences necessary for optimal operation. A three-dimensional turbine model with double rotor was designed and analyzed in terms of water flow inside the enclosure in order to highlight the specific pressure and flow velocity values. The results are presented in static and total pressure limits but also in the fluid velocity on the turbine's rotor action zone.

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