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Aspects regarding the Operation of PELTON Turbine Model Used in Energy Recovery from Water Streams

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Abstract: *It is highlighted the major potential of natural water flows that can supply large amounts of electric energy when the necessary conditions are met regarding the water flow rate and height. In order to achieve this goal, different models of hydraulic turbines have been developed over time that are capable of taking over and using the nature provided water flow rates for the energy production. The constructive PELTON turbine type represents a special model having fixed or variable blades which can ensure an axial rotation mode when there is a low water flow rate and high drop height values. The theoretical aspects are presented in this paper, characteristic for the turbine type and a fluid flow analysis is made on a PELTON turbine virtual model emphasizing the flow parameters when the operation conditions are simulated. The virtual model describes a scaled turbine type which can be used on a low height water stream and specific flow rate values.*

Keywords: *Water flow, energy recovery, three-dimensional modelling, CFD*

1. Introduction

The continuous increase in energy demands is the challenge that human communities must face in the near future. That is why the opportunities that lead to the objectives achievement of producing energy from renewable sources which also avoids environmental damage must be considered. One of these opportunities is the use of the water flow force on level differences that can ensure a necessary potential energy in order to obtain rotational motion at a turbine shaft, mounted directly on the water stream.
Several solutions for water energy recovery are presented in producers offer presently worldwide comprising the main components needed for energy production represented by turbine and generator in compact mode. The turbine can achieve the take over of water energy and conversion into the mechanical energy described by rotational motion and shaft torque, while the generator is the component which converts the mechanical energy into electric energy according with the rotation velocity received.
The energy obtaining principle based on water flow is the traditional method but it is the provided power value that makes the difference based on water flow rate and height.
For the PELTON turbine type the water fall height is of major importance in comparison with water flow rate. A solution for energy recovery based on water flow using a PELTON turbine type is presented. It represents a model that can be used for capturing water source flow energy of reduced flow rate values ensuring the energy generation possibilities. 00

2. Water stream recovery energy concept based on PELTON turbine model

For water streams that have a low flow rate but high drop height, it is preferable to use the water capture solution through a PELTON turbine type. In order to achieve this, the initial design of the basic turbine model must be considered in order to perform an optimal energy conversion function. The used PELTON turbine model under optimum conditions has a quite high efficiency in operation with values slightly exceeding 90% depending on provided water flow rate and the height of fall. The main parameters related to the operation of the turbine are the power at the turbine shaft, the maximum torque, the rotation velocity, as well as the specific values for sizing the model of water dosing at the entrance to the turbine enclosure. 000

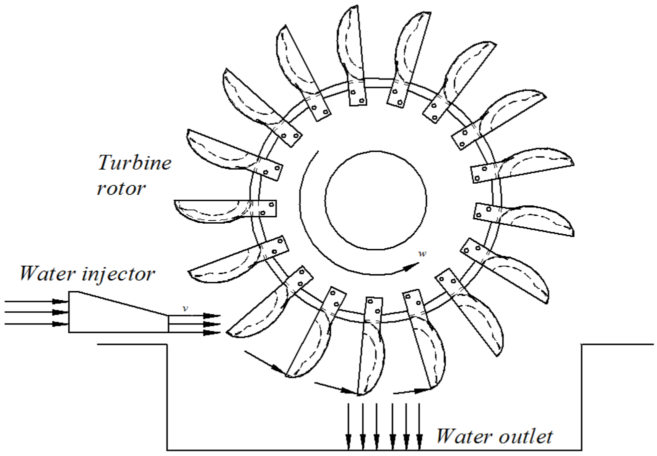


Fig. 1. Schematical representation of PELTON turbine operation

By means of this constructive turbine model it is possible to convert the water mechanical energy into shaft rotational energy. Shaft power is a proportionality relation between turbine drop height, water flow and turbine output:00

$$P_T = 9.81 Q H \eta \tag{1}$$

The fundamental equation that underlies the turbine operation is represented by Euler's equation and expresses the relationship between the specific energy transmitted to the rotor by each mass unit of water that is driven through the turbine enclosure and the mediated velocities parallelograms at the inlet and outlet sections of the turbine rotor. 00

$$E_T = H\eta_h = \frac{v_{r1} v_1 \cos a_1 - v_{r2} v_2 \cos a_2}{g} \tag{2}$$

where:
E_T - the specific energy transmitted to the turbine;
H - the height of fall;
η_h - hydraulic efficiency.

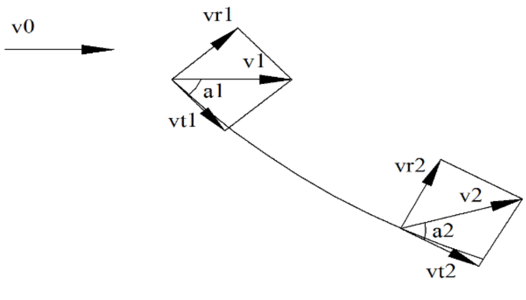


Fig. 2. Velocity components description for turbine rotor

Considering the velocity dimension which for the axial-symmetrical water flow type is described by the relation: 00

$$\mathrm{K} = \pi D v \cos a \tag{3}$$

The Euler equation can be rewritten based on the angular velocity of the turbine rotor , (w) and the turbine circulation velocity before and after the turbine (K_1, K_2) as follows: 00

$$H\eta_h = \frac{w}{2\pi g}(K_1 - K_2) \tag{4}$$

The optimal operating regime of the turbine (maximum efficiency) can be defined based on the fulfillment of the following conditions:

- The water entry into the rotor enclosure should be made without shocks (the relative velocity to the entry edge being tangent to the rotor blade);
- The outlet water stream direction from the rotor is so positioned as to ensure minimal load losses.

The calculation relations for the change case in fall height and turbine diameter under the similarity conditions of the operating regimes are the following: 00

$$\frac{n_1}{n_2} = \frac{D_2}{D_1} \frac{\sqrt{H_1 \eta_{h1}}}{\sqrt{H_2 \eta_{h2}}}$$
$$\frac{Q_1}{Q_2} = \left(\frac{D_1}{D_2}\right)^2 \frac{\sqrt{H_1 \eta_{h1}}}{\sqrt{H_2 \eta_{h2}}} \qquad (5)$$
$$\frac{N_1}{N_2} = \left(\frac{D_1}{D_2}\right)^2 \frac{H_1 \eta_1}{H_2 \eta_2} \frac{\sqrt{H_1 \eta_{h1}}}{\sqrt{H_2 \eta_{h2}}}$$

The total yields (η_1, η_2) and hydraulic yields (η_{h1}, η_{h2}) are taken into account. If the variation of the yield value is neglected, the relations can be written as follows: 00

$$\frac{n_1}{n_2} = \frac{D_2}{D_1} \frac{\sqrt{H_1}}{\sqrt{H_2}}$$
$$\frac{Q_1}{Q_2} = \frac{D_1^2}{D_2^2} \frac{\sqrt{H_1}}{\sqrt{H_2}} \qquad (6)$$

The turbine-specific parameters can only be recalculated if the principle of geometrical similarity of the turbine component elements in direct contact with water is respected. The unit values for the calculation parameters describing a diameter rotor of 1m operating at a drop height of 1m are thus introduced. The parameter equations become: 00

$$n = n_1^* \frac{\sqrt{H}}{D}$$
$$Q = Q_1^* D^2 \sqrt{H} \qquad (7)$$

In order to describe the specific velocity regime of the turbine rotor for which the velocity values, water drop height and shaft power are known, the following relation can be written: 00

$$n_{sp} = \frac{n}{H} \sqrt{\frac{1.36 N}{\sqrt{H}}} \qquad (8)$$

If the values for the unit parameters $\left(n_1^*, Q_1^*\right)$ are known, the following relation can be used to calculate the specific velocity at the turbine shaft: 00

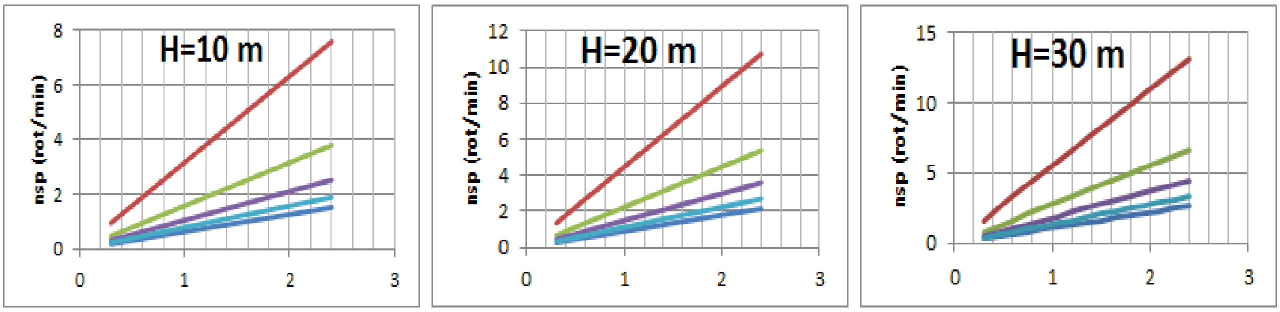
$$n_{sp} = 3.65 n_1^* \sqrt{Q_1^* \eta} \qquad (9)$$

Different values for the specific velocity regime for PELTON type turbines with one or more nozzles are shown in table 1.

Table 1: Specific PELTON turbine rotor velocity function of mounted nozzle number 0

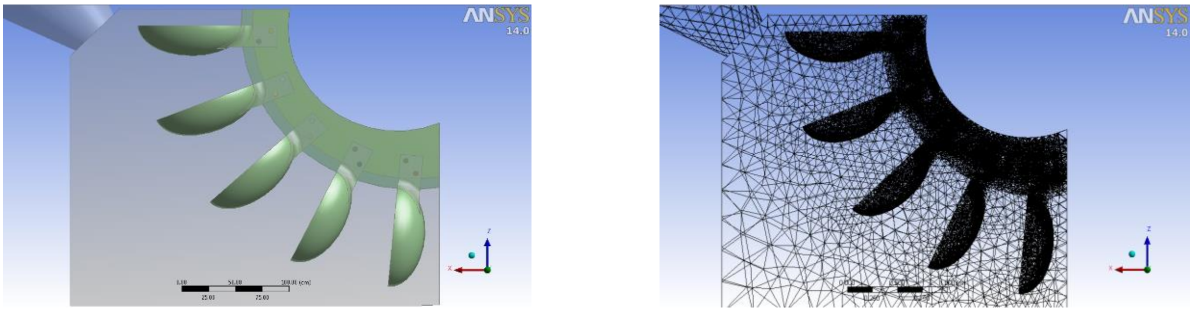
Number of turbine rotor nozzles	Specific rotor velocity $\left(n_{sp}\right)\left[rot/\min\right]$
1	3-24
2	20-34
4	32-47
6	38-58

Table 2: Velocity values for PELTON turbine rotor type with one nozzle based on $\left(n_1^*\right)$



3. Water flow analysis on turbine rotor model

A three-dimensional turbine rotor model is constructed with a number of 17 double blades and a 5.135 m in diameter.
The model is placed in a closed enclosure having an VENTURI injector model with an outlet of 0.5 m diameter for water discharge.
The assembly represents the basic model for a PELTON turbine type and the surrounding fluid region of 10.29 cubic meters in volume.
A water flow analysis is made on the virtual rotor model using ANSYS CFX software, in order to highlight the flow parameters at the level of the blades operated by water gravitational motion.

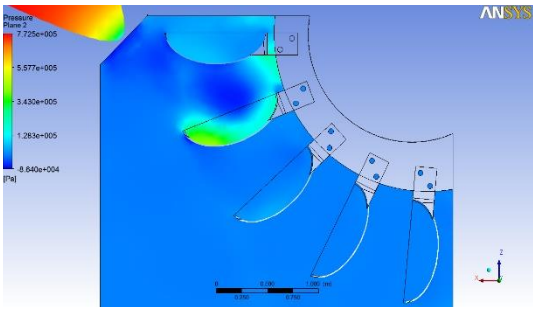


a) Analysis assembly model

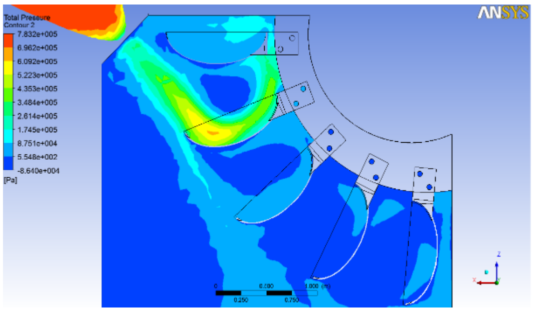
b) Mesh network (192573 nodes, 969475 elements)

Fig. 3. Turbine model used for flow analysis and mesh network

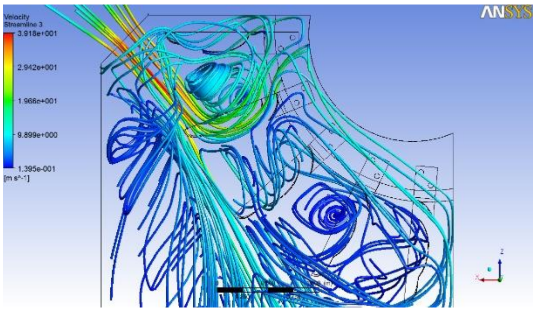
Based on the analysis initial values declared for the turbine enclosure inlet and outlet regions the specific flow values at the analyzed fluid region level are calculated. The water values are used as the working fluid.
The assumed water inlet velocity value is of max 5 m/s, while for the output region the reference pressure of zero value is declared.
The results are presented as pressure and velocity distribution inside the fluid domain emphasizing the active contact region where the water is directed mainly on the rotor blade, having the role of motion entrainment basing on the values obtained, tending to move the blade through the direct action of hydrostatic forces.



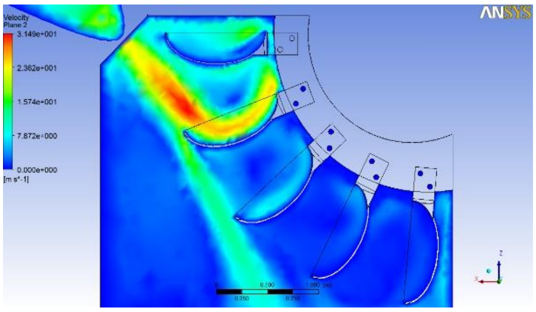
a) Pressure values on XZ cutting plane



b) Total pressure values on XZ cutting plane



a) Velocity path-lines on fluid domain

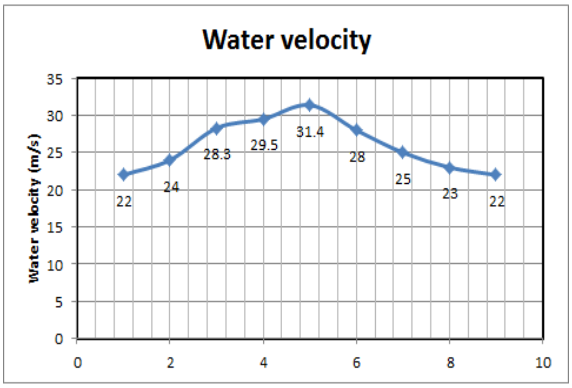


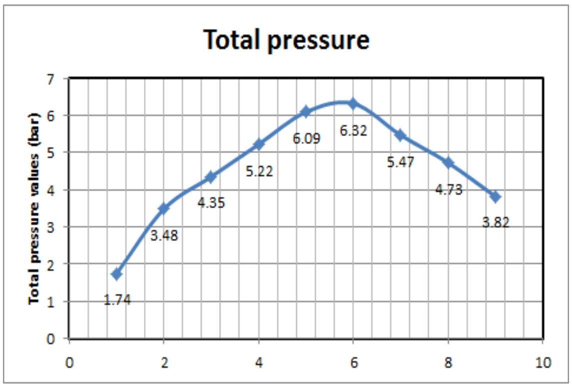
b) Velocity distribution on XZ plane

Fig. 4. Results obtained from water flow analysis on virtual model

Based on the obtained results, the main fluid stream flowing through the turbine enclosure can be identified.
Are highlighted the recorded values for water pressure and velocity starting from the fluid region inlet area and up to the contact with the turbine blade, determining the appearance of the hydrostatic forces at the level of the blade surface.
The resultant hydrostatic forces are acting for the blade forced displacement enabling the rotational movement of the turbine rotor.
The continuous water circulation ensured through the optimum dosage realized by the injector have results in a continuous action on the rotor blades which by successive modification of the position provide the possibility of taking over the hydraulic flow in a continuous cycle thus ensuring the rotor rotational movement with a certain velocity.

Table 3: The result values recorded at the fluid region for velocity and total pressure





The specific values recorded at the fluid region level for water velocity and total pressure are presented in table 3.
Water velocity and total pressure are increasing from the inlet region up to rotor propeller at maximum values.
The specific values recorded determine the occurrence of the hydrostatic pressure forces whose tangential result has the role of pressing the blade in the downward vertical direction so that the movement conditions of the turbine rotor are fulfilled.

4. Conclusion

The methods of capturing the water courses energy have been developed and improved over time, so that at present it represents a significant percentage in the total energy produced in the favorable areas that benefit from water courses with significant flow rate values and an optimum flow difference level.
Several turbine constructive types have been designed and used over time in water-flow plants all being able to retrieve and transform the flowing water energy into mechanical energy of the rotating shaft.
A constructive version of PELTON turbine has been presented in this paper. Represents a turbine model with large diameter rotor with blades for which an overall virtual model assembly was developed and analyzed from the water flow point of view in order to highlight the flow pattern inside the rotor enclosure and the values obtained for water velocity, pressure and water stream path-lines. Thus, specific values are obtained for the water velocity and pressure characteristic for the flow energy required for the rotational movement of the turbine rotor, with a certain speed value.
It should be emphasized that the PELTON turbine types are used mainly in the case of low water flow rates and high fall heights ensuring a high operating efficiency of over 90%.
An optimum rotor operation efficiency can be obtained by adjusting the constructive parameters of the rotor blades so that the radial component of the water velocity is acquired at minimum values.

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