Research of the optimal design of a jet pump for regulating a Pelton hydro turbine

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Abstract. Hydroelectric power plants (HPP) contribute a significant share to electricity generation in Russia. Considering the prospects for the development of this sector and using the hydropower potential, it is necessary to explore methods for the modernization of hydroelectric power plants. This article explores a new method of regulating active turbines (Pelton) based on altering the nozzle flow rate by using a jet pump that operates with used fluid from the runner. The relevance of this solution lies in the potential to increase the operational lifespan of high-head pumped storage hydroelectric power plants (PSHPP) and enhance reliability by eliminating or reducing the intensity of the regulatory needle's operation in the guide vane mechanism. Based on the hydraulic scheme incorporating the jet pump into the hydroelectric power plants penstock upstream of the guide apparatus, several geometric configurations of the jet pump were evaluated using CFD modeling to assess the energy losses associated with the proposed regulation method.

1 Introduction

The methodology described in [1] for regulating the generated power of a Pelton hydro turbine involves integrating a jet pump directly in front of the guide apparatus (Fig. 1 To implement this regulation method, it is necessary to determine the design of the jet pump, which will serve as the regulating element. Several designs of jet pumps have been developed for this purpose. Further refinement of the parameters of the obtained models through the CFD method will provide insight into the geometric parameters and energy characteristics of the designed jet pump. This, in turn, will facilitate the development of a detailed plan for refining the regulation method.

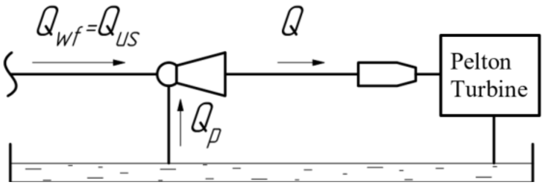

Fig. 1. Connection scheme.

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Here: Q – flow through the guide apparatus [m^3/s]; Q_{wf} – workflow [m^3/s]; Q_{p} – passive flow [m^3/s].

2 Materials and methods

2.1 Research Problem

Due to the low energy efficiency of the jet pump, a crucial task is selecting its optimal configuration to ensure regulation with minimal losses. When examining the operation of the jet pump in the hydroelectric power plant penstock system, it is essential to initially define the desired parameters that the injector, acting as the regulating element, should possess [2].

The key parameters of jet pumps are the ejection coefficient q and the relative head h, describing the nature of flow changes before and after the jet pump [3-4]. High values of q correspond to large passive fluid flow Q_{p} relative to active flow Q_{wf} resulting in a greater decrease in head at the outlet, and vice versa [5]. Given that the power generated by Pelton turbines is largely influenced by high heads and low flows, the design of the jet pump must ensure minimal head losses. This corresponds to low q values and high h values. As a starting point, a jet pump design with a central circular nozzle was chosen, for which preliminary energy characteristics are known for various q values. Based on the above, initial parameters for the jet pump were selected with $q = 0.3$ and $h = 0.5$, as these values maintain relatively high efficiency $\eta = 0.3$.

As noted in [6], jet pumps with a design featuring a annular nozzle inducing a twist in active and passive flows may exhibit a positive impact on energy efficiency under certain circumstances compared to jet pumps with a circular nozzle. Thus, its geometric parameters were calculated for further hydrodynamic analyses. The geometric parameters were computed using an established calculation methodology, which includes the calculation of the annular nozzle, throat, clearance gaps, and other components.

Figure 2 presents to-scale sketches of the jet pumps with a central circular nozzle and with annular nozzles.

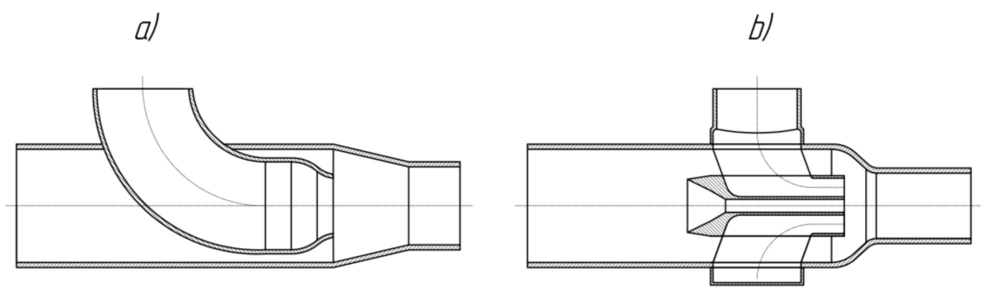

Fig. 2. Jet pumps designs: with a central circular nozzle – *a)*; with a central annular nozzle – *b).*

2.2 Numerical Experiment

For the presented models, numerical experiments were conducted. In order to obtain more accurate results, the same type of control volumes – tetrahedrons and a similar number of prismatic boundary layers were used for each model. Mesh convergence studies were conducted, and the values of the wall function *Y+* were checked to meet the requirements of the *k-ε* turbulence model. The boundary conditions were also identical for both models.

The configuration included setting a constant mass flow rate at the outlet, corresponding to the flow rate Q through the hydro turbine At the inlet of the active flow, excess total pressure was set, determined by the hydroelectric power station considered as an example At the inlet of the passive flow, static pressure equal to the relative (atmospheric) pressure was set. Thus, the ejection coefficients and relative heads were obtained as a result of the calculations.

Subsequent numerical experiments were conducted for two models of jet pumps, and to further refine the impact of flow twisting on the jet pump's performance, an additional numerical experiment was carried out for another model. The third model represents the same jet pump with a central circular nozzle, as shown in Figure 2 *a)*, but the inlet of the active flow has a twist, which can be set using a boundary condition or by placing guiding walls inside the pipe. In the numerical experiment, the flow twist was introduced by adding internal walls.

3 Results

As a result of the calculations, the following outcomes were obtained, presented in Table 1. The jet pump with a central circular nozzle without twisting exhibited the highest efficiency, calculated using the expression below.

$$\eta = qh/(1-h). \quad (1)$$

The twisting of the active flow in the jet pump with a central circular nozzle resulted in an increase in the ejection coefficient q along with a decrease in the relative head h. The jet pump with a central annular nozzle exhibited an even greater tendency to increase q and decrease h, as it induces even more significant flow twisting.

Table 1. Calculation results.

Parameter\ Pump	With a central circular nozzle, Figure 3. – *a)*	With a central circular nozzle and twist, Figure 3 – *b)*	With a central annular nozzle and twist, Figure 3 – *c)*
q	0.22	0.27	0.35
h	0.62	0.54	0.43
η	0.36	0.32	0.26

In Figure 3, color contours of total pressures are shown in the average section of the calculated models. Colors correspond to different pressures in such a way that red indicates maximum pressure, while blue represents minimum pressure.

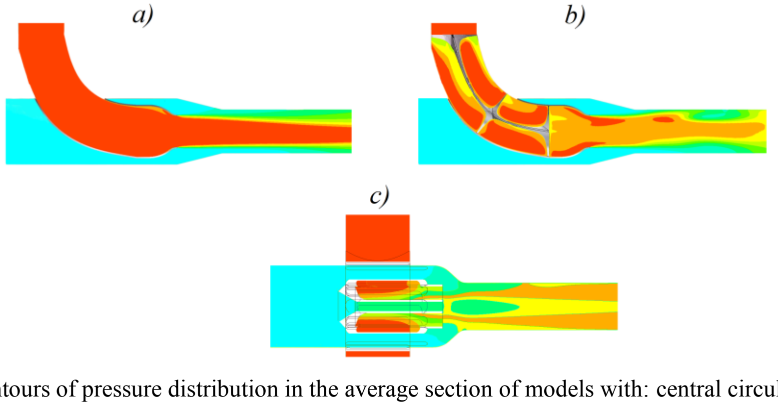

Fig. 3. Contours of pressure distribution in the average section of models with: central circular nozzle without twist– *a)*; central circular nozzle with twist – *b)* central annular nozzle – *c)*.

From the images in Figure 3 and the data in Table 1, it is evident that the models with flow twisting – *b)* and *c)* in these conditions perform somewhat worse than the classical desing.

4 Conclusions

For the purpose of investigating the feasibility of an alternative regulation method for a Pelton turbine using the ejection of used fluid after the turbine wheel with a jet pump, several models were designed, which were expected to exhibit the highest efficiency within the set task.

Subsequent CFD analysis showed that the most optimal configuration for the jet pump is the model with a central circular nozzle without flow twisting, as it maintains the highest efficiency. However, it is worth noting that the jet pump with a central annular nozzle has a greater number of geometric parameters affecting the fluid flow. Therefore, for better performance, it may be beneficial to conduct a parametric optimization task.

Acknowledgement

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