Numerical study of the influence of changing impeller geometry on improving the performance of a centrifugal pump as turbine

Salman Saremian, Mohammad Hassan Shojaeefard*

Department of of Mechanical Engineering, Iran University of Science and Technology, Tehran, Iran

ABSTRACT

Implementation of pump as turbine rather than traditional turbines in the soft pressure regulation system reduces the initial costs and construction time of the power plant. But the significant losses occur under off-design conditions because the pump was not built to work in reverse mode. In this study, the design and simulation of the centrifugal pump as turbine as the most important part of the power plant have been done by CFturbo and CFX software. The discretization of governing equations was done with the help of the finite volume method, and regarding the turbulent nature of flow in the pump as turbine from k-ω SST model was used. The changing trend of the pump as turbine simulation results is basically in acceptable agreement with the experimental results. The impact of changing the parameters of blade thickness, blade inlet width, and splitter blades was numerically investigated in the operating range. Since increasing the efficiency and production capacity of the power plant is considered, the selection of the optimal mode of changes in the geometrical parameters of the impeller was investigated based on the statistical analysis of the flow rate. The results indicated that by simultaneously modifying the parameters, the operating range with high efficiency and electricity production is increased compared to the original impeller. The optimal impeller is better performing in the range of $0.77Q_{BEP}$ to $1.2Q_{BEP}$, and efficiency at the design point has increased by 1.92%.

KEYWORDS

Pump as Turbine, Blade thickness, Splitter Blades, Blade inlet width, CFD.

* Corresponding Author: Email: shojaeefard@iust.ac.ir

1. Introduction

In mountainous regions of our country, there is often a significant elevation difference between treatment plants and consumption sites, making it possible to generate electricity from excess pressure using pressure-reducing power plants [1]. Despite their lower efficiency compared to traditional turbines, the use of pump as turbine (PAT) has become widespread since the third decade of the 20th century. Based on the results of their work, various researchers have recommended the use of single-stage centrifugal pumps in the operating range with low flow rates from a technical and economic point of view [3, 2].

Due to the unavailability of the pump catalog in the reverse cycle and the reduction of their efficiency compared to the pumping cycle, researchers have made many efforts to provide solutions to increase efficiency, as well as provide relationships according to experimental studies to obtain the performance curves of the PAT. However, each of these relationships is suitable for pumps with specific speed and hydraulic and geometric characteristics [4]. Researchers have paid greater attention in recent years to increasing the efficiency of computational fluid dynamics and experimental research to evaluate and improve the PAT performance.

Extensive research has been conducted in the past to improve the hydraulic parameters and efficiency of PATs by modifying their geometric parameters in the water supply systems. The present study aims to enhance the operating range with high efficiency of a PAT installed in an urban water distribution network. The absence of a mechanical device to properly guide the input fluid to the impeller causes a significant reduction in the efficiency of PAT power plants by moving away from the design point. In this article, the effect of modifying the blade inlet width and thickness parameters, as well as adding separator blades to the impeller, on the PAT performance has been investigated. To determine the optimal geometric parameters, the flow rate changes in one working day are evaluated statistically. Finally, the effect of the optimized impeller with the simultaneous change of the geometric parameters of the impeller on increasing the operating range with high efficiency of the PAT was investigated.

2. Numerical Simulation

2-1- Geometric modeling

In this study, the geometry of centrifugal pump 100-250 was employed for numerical and experimental investigations. According to the geometric specifications, impeller and volute modeling have been done using CF Turbo software, and a view of the impeller and screw is shown in Figure 1.

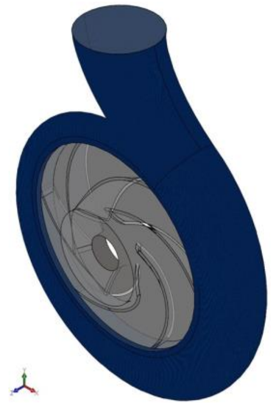

Figure 1. Designed pump with CFturbo software

2-2- Meshing

The pump geometry consists of two parts: a rotating impeller and a stationary volute. A structured mesh is generated for the impeller using TurboGrid software, while an unstructured mesh is generated for the volute using ANSYS Mesh.

Figure 2. The grid generated for the impeller and volute

3. Extended Abstract Preparation

Numerical simulation was conducted using CFX software to investigate the PAT performance within the operational range. Figure 5 presents a comparison between the experimental and simulated performance curves of the PAT. Analysis of the figure reveals that the trend of the simulated performance curve of the PAT is essentially consistent with the experimental results. The maximum discrepancies between the numerical results and the experimental data at the design point for head, power, and efficiency are 10.2%, 7.4%, and 5.3%, respectively. Therefore, the utilization of the generated computational mesh and the presented numerical approach in this study appears to be reasonable, considering the validation and verification provided in this section.

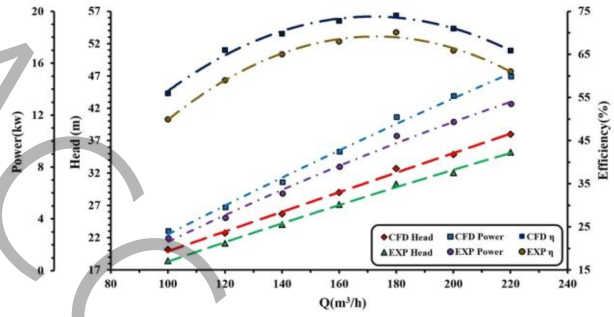

Figure 3. Comparison of the performance curve between the simulation and the experiment

4. Results and Discussion

Numerical analysis shows that adding splitter blades, reducing the vane diameter to 3 mm, and increasing the blade inlet width to 21 mm have the greatest effect on increasing the PAT performance in the operation range. The results of the numerical simulation show that the simultaneous change of the geometrical parameters reduces the hydraulic losses and improves the PAT efficiency.

Generally, the efficiency of PATs significantly declines at flow rates lower than the design point. Simultaneous changes in the geometric parameters of the impeller exacerbate this condition. Typically, PAT power plants are scheduled to be taken off the circuit at these flow rates. As depicted in Figure 4, with an increase in flow rate reaching the design condition, changes in parameters play a significant role in reducing losses and increasing PAT efficiency. the most substantial impact occurs at a flow rate of $1.2Q_{BEP}$, which shows a 3.76% increase in efficiency. If the PAT operates within this flow rate range, efficiency will increase significantly.

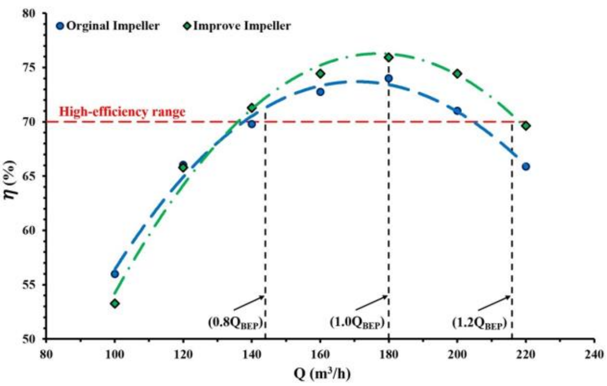

Figure 4. Comparison of efficiency between the optimal and original impellers

In Figure 5, the velocity contours of the original and optimized impellers at the operational point are compared. In the optimized impeller, the velocity gradient is reduced, resulting in diminished losses. After the fluid enters the impeller, the vortex level on both the suction and pressure sides of the blade gradually decreases, with the vortices dissipating at a higher rate.

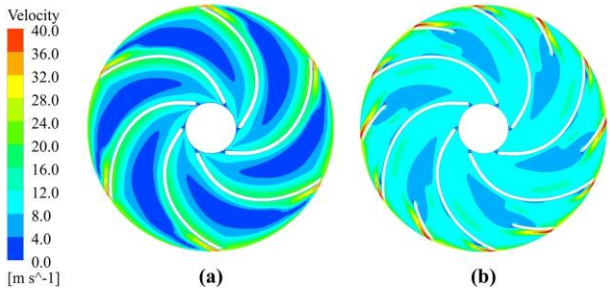

Figure 5. Comparison of velocity contour between a) original b) optimal impellers

5. Conclusions

The impact of impeller geometric parameters on the performance enhancement of Pumps as Turbines (PAT) was numerically analyzed.

Reducing the blade thickness alters the internal flow field within the impeller, decreasing turbulence intensity. Consequently, the flow in the PAT becomes more stable, and flow losses are reduced with thinner blades.

Increasing the blade inlet width reduces flow path blockage and frictional losses within the impeller, significantly lowering the required head under these conditions and increasing the efficiency of the PAT within this operational range.

Adding splitter blades enhances fluid compliance with the blade profile, reducing flow separation and vortices at the blade inlets, thereby minimizing energy losses within the impeller.

The simultaneous implementation of splitter blades, increased blade inlet width, and reduced blade thickness enhance performance at flow rates above $0.77Q_{BEP}$. These modifications significantly reduce losses due to decreased velocity gradients, vortices, and flow separation within the impeller, thereby extending the high-efficiency operating range of the PAT.

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