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Research on Optimization of Splitter Blade of Centrifugal Pump Using CFD

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Abstract **Original Research Article**

In this paper, a method to determine the optimal design parameters of splitter blade of a centrifugal pump is proposed by using CFD (Computational Fluid Dynamics) simulation to raise the pump head. The pump performance is analyzed by CFD software and design parameter is optimized by MOGA (Multi Object Genetic Algorithm). The present paper aims to raise the pump head as high as possible. Throughout the simulation of the pump with splitter blades, it is found that the reverse-flow region near the suction side of the blade can be reduced by installing splitter blades and the pump head can be improved. We have analyzed possible design alternatives by CFD and implemented the design optimization by applying the MOGA. Thus, we obtained the reasonable design parameters of a centrifugal pump with only splitter blades so that we could increase the head by 20%.

Keywords: CFD, Centrifugal Pump, Splitter blade, Optimization.

Introduction

Centrifugal pumps are turbomachine, which is widely used in various fields, from heavy industry to home products. The pump needs to be modified due to the changing of operating conditions. Many studies were previously conducted for splitter design to improve the performance of centrifugal pumps. Ye Yuan et al. [1], numerical analysis was carried out to investigate the effect of the splitters on the performance of a high speed rotary centrifugal pump. As a result, the pump head was increased by about 10 m and the efficiency was increased by about 4%.

More recent research has occurred in the field of pump efficiency and cavitation. Kergourlay G et al.[13] predicted the performance of a centrifugal pump with splitters using the slip factor proposed by Wiesner. Gölcü et al. [14] used splitters to improve the efficiency of centrifugal pumps.The efficiency was increased by 1.14% for the centrifugal pump with five splitters, while the efficiency was decreased in 6 and 7. Kergourlay et al. [3] reported that the splitter blade installation had negative effect on pump efficiency, but the outlet pressure increased due to the increase in slip factor. Yuan et al. [4] reported that the splitter weakens the jet-wake flow pattern and reduces the flow separation from the main blade. The results showed that the efficiency of the pump was increased by 4%. Zhang et al. [5] argued that the secondary flows and flow circulation on the main blade pressure side are mitigated when the trailing edge of the splitter blades is closer to the main blade suction side. Yuan et al. [6] presented the relationship between the outlet diameter of the splitter in a low-specific-speed pump and the inlet and outlet diameter of the impeller. Zhang et al. [7] developed an artificial neural network model with 85 groups of experimental data to predict the efficiency and head coefficient of a centrifugal pump with splitter blades. Le et al. [8] reported a flattened head-flow curve with an increment between 2% and 12%

in head rise due to the addition of splitters to centrifugal pumps. Cavazzini et al. [9] suggested that the splitter blades enlarges the anti-cavitation working region of the pump in the high flow rates but decreases the suction performance in the low flow rates. Yang et al.[10] showed that the required suction pressure is reduced because the blade loading is distributed between the main and splitter blades, which increases the pump’s efficiency notably at high flow rates.

The flow behaviors inside the centrifugal pump with complex impeller were investigated by numerical simulation and inner flow test. Obvious jet-wake structure was observed in the outlet of the blade passage, and this structure was improved using splitter blades in the impeller [10,11]. In [12], the experiment and response surface method were used to optimize the head and efficiency of centrifugal pump by changing the impeller blade width and the splitter blade leading edge position. Compared with the initial splitter blade geometry, an increase in head rise of 4.4% is achieved during the optimization process. Approximately 15% increase in head risies is observed compared to the base impeller without splitter blades.

CFD simulation have been extensively applied to the study of the efficiency of centrifugal pump. Most studies have only focused the pump efficiency. However, little research has focused on the head of centrifugal pump head.

We optimize the design dimensions of the centrifugal pump splitter blade based on CFD and multi-objective genetic algorithm (MOGA). The design model of the splitter blade is obtained from different parameters such as splitter blade deflection angle, blade outlet width, splitter blade length, and splitter blade profile. Based on the simulation results, the surrogate model constructed and the splitter blade design parameter optimization carried out to effectively raise the head of centrifugal pump.

The aim of the present work is to optimize the splitter blade to enhance the centrifugal pump head as much as possible. This optimization method will be able to help the raising the centrifugal pump head.

This paper is divided into three sections. The first section gives a brief overview of splitter blades. The second section simulate the centrifugal pump with splitter blades by CFD. In the third section optimization of impeller is presented.

2. CFD simulation of centrifugal pump with splitter blades

2.1 Parameter determination of analytical model

The centrifugal pump to install the splitter blade was designed for use at 60 Hz industrial frequency. The pump is driven by a mobile motor generator. But the power frequency of generator is 50Hz, so there is a need to improve the centrifugal pump dimensions. In order to raise the pump head, we install the splitter blades. The original pump is low specific speed pump with an impeller outlet diameter of 310 mm and the impeller outlet width of 36 mm.

Taking into account the previous research and installation conditions, we set the parameters necessary for the analysis as follows:

X1-splitter blade deflection angle

X2-blade outlet width

X3-splitter blade length

X4, X5-splitter blade profile position (t, m) of intermediate control point and range of values of parameters are presented in Table 1.

Table 1. The range of parameters

Splitter deflection angle/main blade angle (%)	Splitter length/hub length (%)	Outlet width (mm)	control point coordinate t (%)	control point coordinate t m (%)
20~80	60~90	30~40	26~95	15~66

CFturbo 2022.1.1 were used for the design of the centrifugal pump with splitter blade. The blade was defined as a two-dimensional blade considering computational resources. The intermediate control point was used to form the profile of the splitter blade.

Three control points based on the Bezier curve were used for blade profile formation, where the first and the end points are fixed according to the value of the inlet and outlet angles as they control the inlet and outlet angles of the blades.

Therefore, the controllable point is the central control point. In Fig.1, the possible variation range of the central control point is shown.

The distribution of the outlet angle along the blade length is shown in Fig. 2.

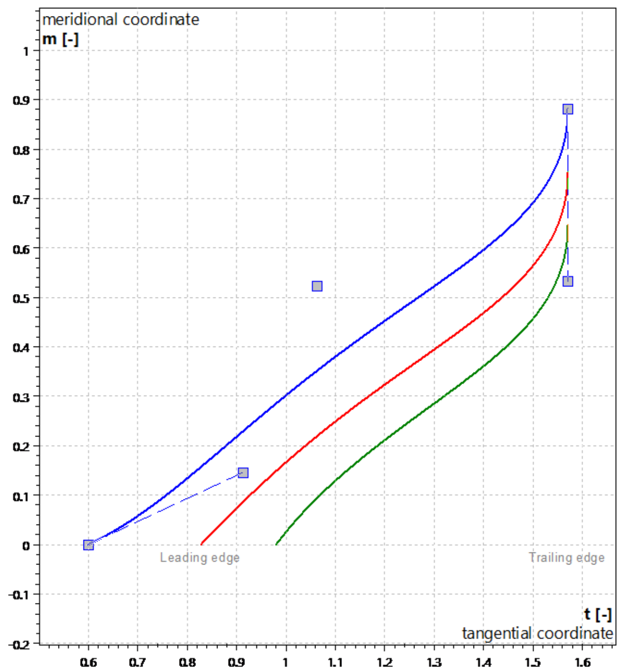


Fig. 1 Variation region of aileron profile mid-control point

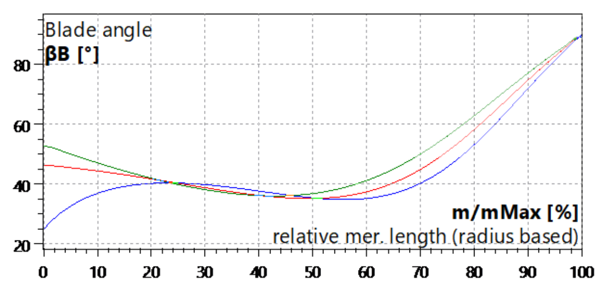


Fig. 2 The blade outlet angle distribution curve for the blade length.

As shown in the figure, since the inlet angle is as small as 26°, and the outlet angle is set to 90° to maximize the head. It can be seen that the blade shape takes the S shape. The length of the splitter blade in the Meridian section was defined. The length of the splitter blade can be expressed as the ratio of the total Meridian section length.

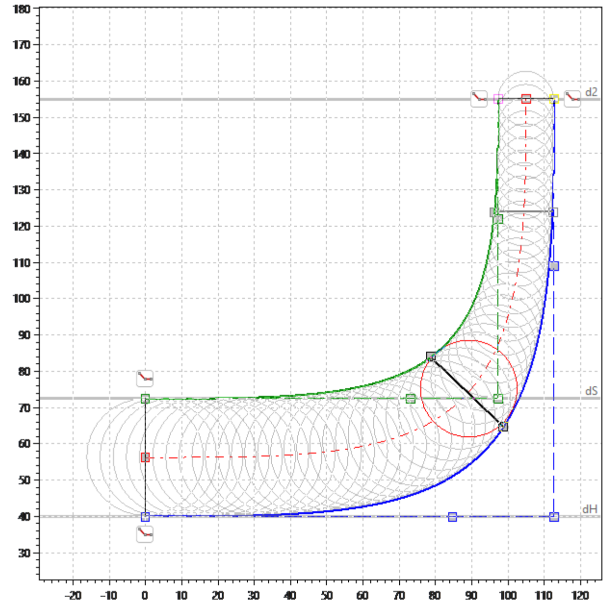


Fig. 3. Length of splitter blade

2.2 Meshing and CFD setup

Depending on the computational grid, the accuracy of the CFD results will be different. Increasing the number of computational meshes can increase the accuracy, but the computational resources will increase. Therefore, we constructed the structured mesh to increase the analysis accuracy and reduce the computational time. The ICEM CFD 19.2 were used as a computational meshing tool. The C and H-type topologies around the blades were chosen to be meshed. The mesh dependency tests were carried out by changing the number of meshes from one to three million to satisfy Y+<2 on the blade surface. At 2.1 million meshes, the rate of change of pump head was relatively constant, about 1%.

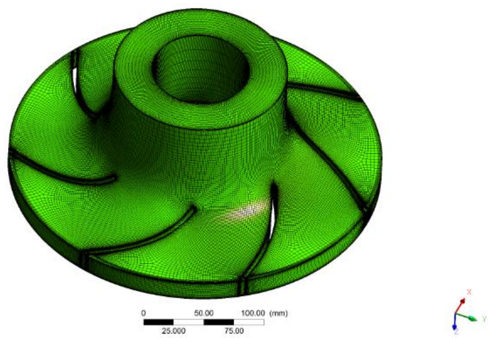
The CFX of Ansys 19.2 were used as CFD analysis tool. The working fluid was defined as water. The boundary conditions were set as follows:

Inlet : Pressure = 1 atm

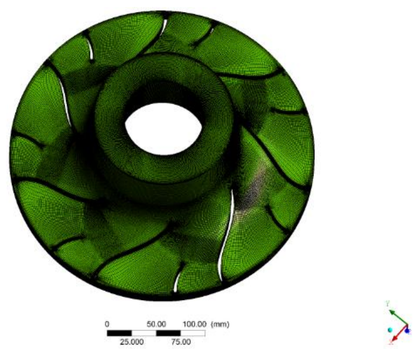
Outlet: mass flowrate = 100 t/h

SST k-w model

Interface: Frozen-Rotor



a)



b)

Fig.4. The constructed computational mesh (a. Original impeller, b. Improved impeller)

3. Optimization of impeller with splitter blades

3.1 Design of Experiment method

In the process of optimal design, more than hundreds of iterations are needed to converge to the optimal point.

Numerical analysis for all processes is almost impossible in practice because it takes a considerable amount of time and computational resources.

To solve this problem, the optimal design uses a surrogate model that reflects the approximate relationship between the design variables and the objective function.

Optimization using surrogate models is an approach to find approximate optimal point by reducing the cost of analysis, making only the minimum analysis for surrogate model construction and using optimization.

Most CFD analyses have been studied using this type of experimental design (DOE) and response surface approximation (RSM)[15].

That is, after performing the experiment using the experimental design method based on the corresponding experimental point configuration with the chosen design variables, the regression model function, which is the correlation of the input and output, is estimated by the response surface, and is applied to the optimization algorithm to obtain the optimized design.

In this paper, the response surface optimization method, an optimization approach, is used to approximate the effects of design variables as response surfaces, taking into account the effects of different design variables simultaneously.

Response surface optimization can be divided into least squares, variable selection, regression analysis, analysis of variance, and experimental design.

To construct the response surface, CFD analysis with different values of parameters was carried out.

We obtained the experimental points using the optimal space filling method.

In many literatures, experiments such as CFD analysis, the small amount of random error, OSF (Optimal Space Filling) with a fixed number of experiments and evenly placing the experimental points in the design domain is found to be the most suitable.

The sampling method used as central composite design (CCD). This method has the advantage of obtaining a lot of information with minimal numerical experiments.

Thus, the total number of experiments was y=2^(k-f)+2k+n and five design variables were used in this study and the total number of experiments was 28.

3.2 Response surface model

The RMSE, which is the mean value of the error of the calculated values at the experimental points and at the response surface, was used to evaluate the fit of the obtained response surface model.

The Non-parametric regression method was used. This method, unlike other response surface methods, estimates the results of the design points that we want to know from the data without going beyond the experimental values.

This regression analysis has the advantage of being able to remove and reduce noise from the characteristics of the given data and to find a regression model approaching the practical data in the data analysis.

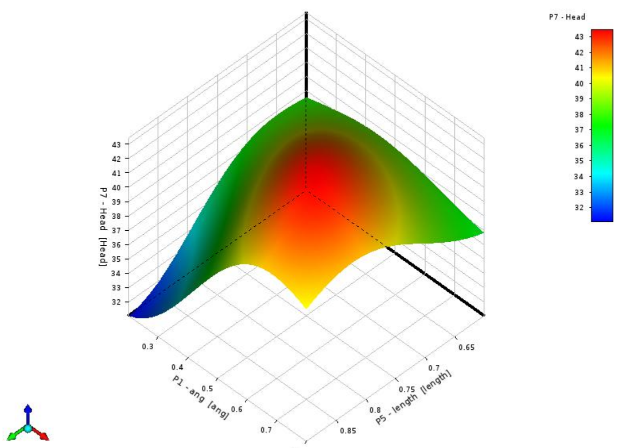


Fig 5. Response surface between head and t, m of splitter blade profile control point

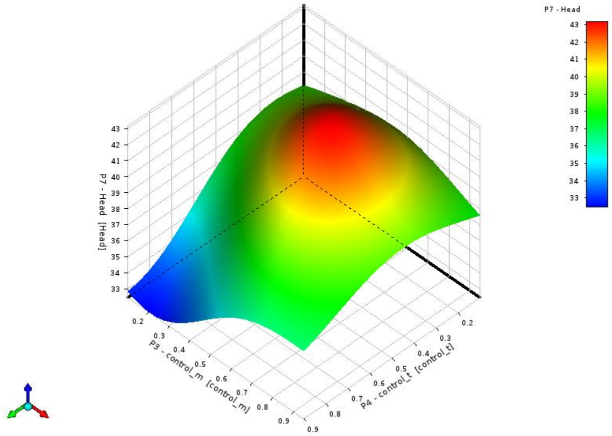


Fig6. Response surface between head and deflection angle, length of splitter blade

3.3 Optimization algorithm

The objective function of the optimization is to maximize the head and efficiency. Then the power consumption is given as a constraint.

MOGA were used as the optimization algorithm.

The surrogate model values expressed as RMSE and the relative error of the CFD results were generated within 0.002%. The head is 3.8 %, efficiency 0.6 % and power 0.08 %. Thus, the goodness of fit of the surrogate model can be estimated as high.

4. Result and Discussion

After splitter blades installation, the flow conditions were improved and head increased. The obtained optimal points are shown in Table 2.

Table 2. Optimal design points

X1 - ang	X2 - b2_	X3 - (control_m)	X4 - (control_t)	X5 - length)	
0.425	38.2	0.406	0.353	0.751	

The head was 48 m and the efficiency was about 30%, which increased by about 20% and decreased by 0.9%.

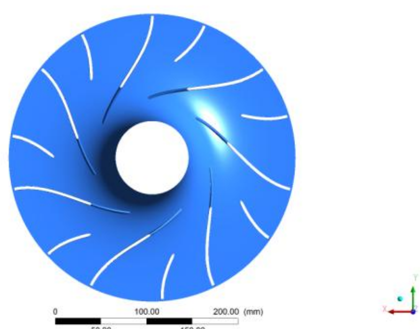
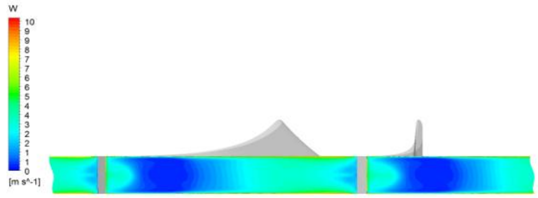
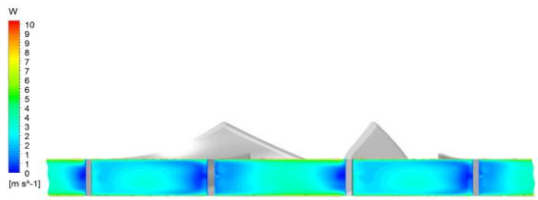


Fig.7 Optimized impeller model



a)



b)

Fig.8 Impeller outlet velocity distribution

(a. original impeller, b. improved impeller)

It can be seen from Fig. 8 that the jet-wake flow improved significantly after the modification of the impeller. The relationship between the flap dimensions of the runner and the head is expressed by a spline-fitted plot as follows:

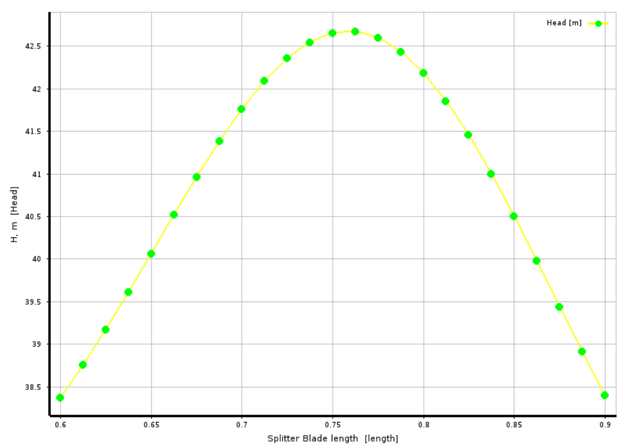


Fig. 9 Relationship between head and blade length

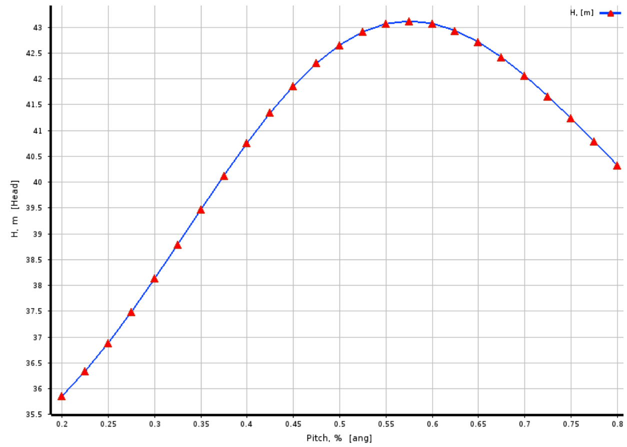
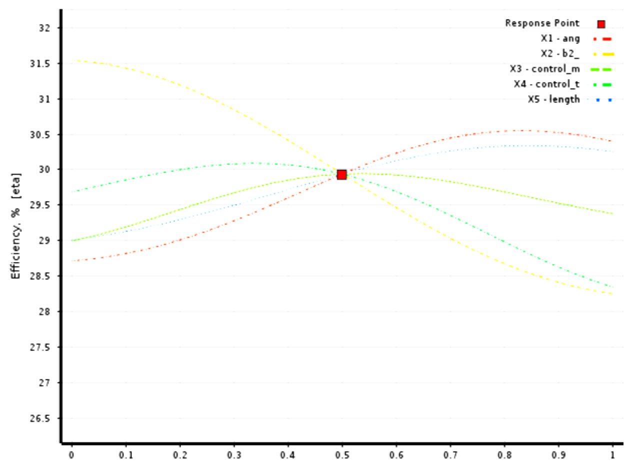
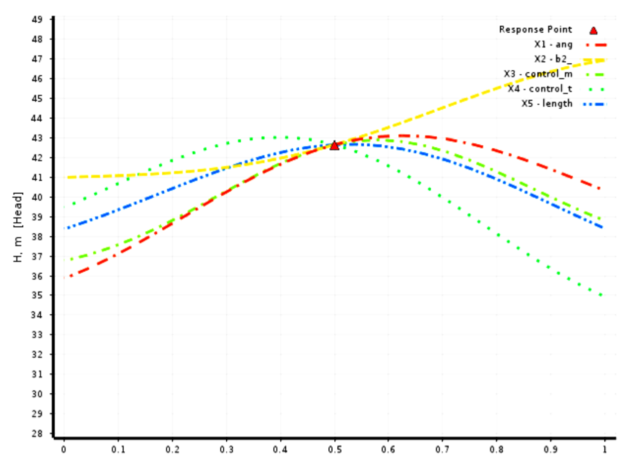


Fig. 10 Relationship between head and splitter blade deflection angle



a) Efficiency



b) Head

Fig. 11 Relationship between parameters

From Fig. 9, it can be seen that the head decreases from the 75% of the splitter blade length. Beyond the splitter blade deflection angle of 58%, the head decreases. This is because the splitter blade does not reduce the jet-wake flow region.

From an efficiency point of view, it is not only expected that the splitter is less efficient. The installation of the splitter blade effectively prevents jet-wake flow, thus increasing efficiency in some cases.

However, we should to pay more attention to the head increase.

The relationship between the parameters of the splitter blade X1~X5 and the head and efficiency are shown in Fig. 11. The blade outlet width strongly affected head rises, but the power consumption can be increased very much.

Therefore, when only the impeller was modified, especially when the splitter blades were installed, the desirable head rises can be achieved considering the effect of the parameters on the head.

5. Conclusions

We have here descried optimal design of centrifugal pump impeller with splitter blades.

With the aim of increasing the head of the centrifugal pump, impeller with splitter blades was parameterized and optimized.

The parameters of the impeller geometry were chosen: X1-splitter blade deflection angle, X2-blade outlet width, X3-splitter blade length, X4, X5-splitter blade profile control point position (t, m) and optimized by a genetic algorithm based on the response surface approximation.

As a result, the optimum point was obtained when the splitter blade deflection angle was 42.4%, the blade exit width was 38 mm, the position of splitter blade profile control point was 40.6% and t-coordinate was 35.3%, respectively.

The head was increased by 20% and the efficiency was decreased by about 0.9%. The method presented in this paper can help to obtain an optimal design when installing the splitter blade for the purpose of raising the head.

The results of this paper are encouraging and show that the modification only the impeller leads to a significant head rises.

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Conflict of interests

The author declares no conflict of interest.

Disclosure statement

No potential conflict of interest was reported by the authors.

Data Availability

The data that support the findings of this study are available within the article.

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