Advanced and Sustainable Technologies (ASET)
Volume 1, No 1, June 2022 [10-16]

Parametric Investigation on Centrifugal Pump Impeller via Finite Element Analysis

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Received 14 February 2022, Revised 1 April 2022, Accepted 20 May 2022

ABSTRACT

The centrifugal pump impeller is very important in the industry since its widely used functions. However, the impeller performance of centrifugal pumps varies since centrifugal pump impellers come in various designs. This study presents the parametric investigation of the centrifugal pump impeller to understand its mechanical aspects under various impeller parameters. The finite element analysis method was used in this study to simulate the loading acting on the impeller. The physical parameters of the impeller were considered based on the existing design of the centrifugal pump impeller. The simulation analysis revealed that the changes in physical parameters significantly influenced the mechanical aspects. It is believed that the simulation results can increase the understanding of centrifugal pump impeller design for engineers in the pump industry.

Keywords: Centrifugal pump, Impeller, Design optimization, Finite element analysis

1. INTRODUCTION

In the centrifugal pump, the impeller is the main component that determines the performance of the pumps. There are various kinds of designs for centrifugal pumps on the market. The design needs to be capable of withstanding the increasing fluid pressure from the pump inlet to its outlet during the centrifugal pump operation [1]. The fluid pressure for the centrifugal pump increases because it will change the pressure by transferring the mechanical energy from the rotating impeller of the motor to the fluid. The centrifugal pumps have various functions. They have been used in sizeable liquid transfer tasks such as fluid control, dewatering, irrigation, and power station cooling systems [2]. The usage of the centrifugal pump as a turbine is beneficial for maintaining the sustainable development of human beings and reducing carbon dioxide emissions. Compared with the normal hydro-turbines, a centrifugal pump as a turbine is cheaper and more feasible [3]. Besides, one of the parameters is the blade exit angle. If it is not appropriately designed, it will affect the hydraulic efficiency and the head of the pump seriously. So, it is crucial to select the design parameters wisely [4].

During the rotation of the centrifugal pump impeller, the fluid moves from the inner radius to the outer radius. In this situation, the suction is created at the eye of the impeller. Therefore, the kinetic energy is converted into pressure energy when continuous lifting of the fluid is carried out from the sump to the pump [5]. By modifying the centrifugal pump impeller, different specifications of pumps will be created, and the impeller accounts for 17.5% of energy losses [6]. For the hydraulic design of centrifugal pump impeller, much experience has been collected, and its efficiency has been satisfactory. However, the design and optimal processes of the centrifugal pump impeller are still challenging. This is because of the design's significant amount of free

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geometric parameters. Choosing and evaluating the possible geometrical variations for a design depends on the engineer's experience [7].

The impeller consists of a rotating disc known as the hub. It is the part where the blades are attached. The impeller is always placed directly onto the motor's shafts to ensure the maximum speed of the spin. However, the maximum spin speed will cause a constant vibration on the pump [8]. The performance of the pump can be tested via simulation technique. The performance of the centrifugal pump impeller was simulated with different conditions using the ABAQUS software [9]. Then, the mean streamline theory was applied to design the blade section of the mixed flow pump impeller blade. The design was carried out using solid modelling software [2]. Besides, different methods are being developed to enhance centrifugal pump performance. These methods trim the impeller, vary the blade angles, and add the diffuser and splitter blades [10].

The significant problems of the impeller are crack and cavitation, which lead to the failure of the impeller and influence the performance of the centrifugal pump. The physical design of the impeller, such as the number of the blades, blade thickness, and blade angle, may affect the effectiveness of the pump. Different blade thicknesses may lead to different effects on stress and displacement. Besides, the material properties used to fabricate the impeller may also be considered as one of the factors in determining the impeller's strength. Thus, this study used finite element analysis to study the physical design factors, such as the thickness of the hub plate, the diameter of the hub plate, and the blades' thickness.

2. MATERIAL AND METHODS

The 3D centrifugal pump impeller with six blades was created using modelling software, as shown in Figure 1. The 3D model was exported to finite element software using the IGES file format. Twenty-five thousand tetrahedral elements were generated to mesh the 3D model, and the interior element growth size used is 1.05. The sizing control of the global seed used is 1.5. In this study, the Inconel alloy was selected as the material for the impeller. The material properties are summarized in Table 1.

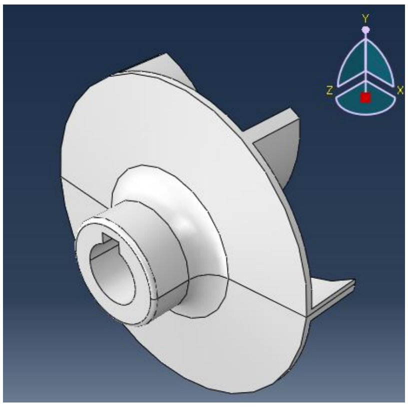


Figure 1: 3D model of the centrifugal pump impeller.

Table 1: Material Properties of Inconel Alloy 740 [11].

Density	7860 kg/m^3	Yield strength	1034 MPa
Poisson's Ratio	0.285	Elongation	15%
Elastic modulus	200 GPa	Reduction in area	53%
Tensile strength	1158 MPa	Hardness	335 HB

Several assumptions were made in the simulation analysis: (1) the impeller is assumed as solid, (2) the material is homogeneous, (3) the impeller is static and (4) water pressure is acting on the surface of the impeller. In the current study, three independent parameters are the thickness of the hub plate, the diameter of the hub plate, and the blades' thickness. However, the Von Mises stress and displacement are the dependent parameters. The fixed boundary condition was applied to the driver shaft area, and the pressure boundary (160 kPa) was applied on the surface of the impeller.

Moreover, the grid sensitivity test was carried out to ensure the grid size is converged and predicts reliable results [12]. The grid sensitivity test considered various grid sizes (1.1-1.6). The simulation results revealed that 1.5 and 1.6 grid sizes yielded converged results, as depicted in Figure 2. Thus, a 1.5 mesh size was selected regarding the computing time and the number of elements for the 3D model.

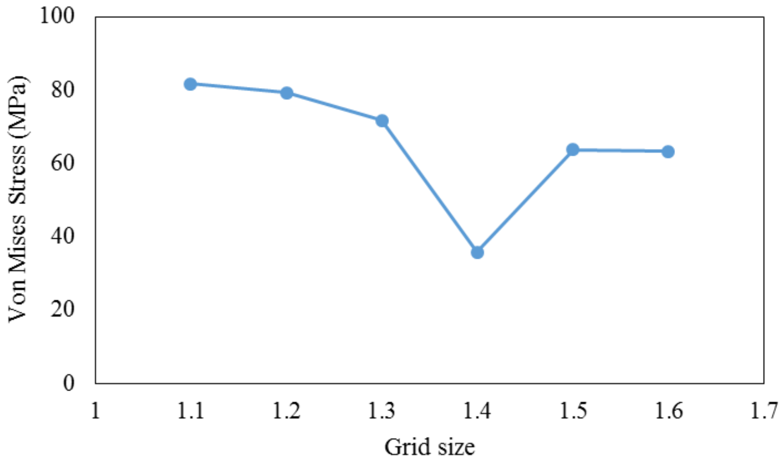
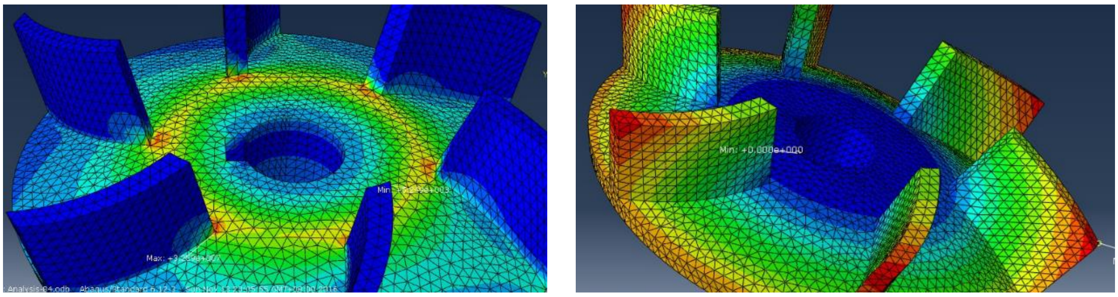


Figure 2: Grid sensitivity test on different mesh sizes.

3. RESULTS AND DISCUSSION

Figure 3 shows the result of the Von Mises stress and displacement for the thickness of the hub plate. The simulation results revealed that the maximum stress occurred around the hub plate and blade intersection (Figure 3). The displacement was found concentrated on the blade corner. The stress concentration at the blade intersection region might cause the failure of the blade in long term operation. Besides, the cavitation phenomenon in the operating pump induces an unintended effect on the impeller blade. Thus, this situation indicated that the impeller blade's optimal design is significant and could counter the blade failure. The influence of the hub plate thickness was analyzed in the current study (Figure 4). The increase in the thickness up to 3 mm significantly reduced the von Mises stress by 50.5%. The decreasing trend of von Mises stress shows a polynomial behaviour. Similarly, the maximum displacement on the blade also demonstrates a decreasing trend. The displacement decreases up to 15% when the thickness of the hub plate increase by 200 % (from 1 mm to 3 mm). The displacement plot shows a linear correlation to the thickness of the hub plate.

The simulation study was extended to investigate the effect of the hub plate diameter of the impeller. The diameter of the hub plate was increased from 60 mm to 100 mm. The increase of hub plate diameter crucially raised the Von Mises stress and displacement on the impeller, as clearly shown in Figure 5. The results show the Von Mises stress increase in polynomial and displacement rise in exponential behaviour. The increase in diameter (from 70 mm - 90 mm) is about 28.5%, which has resulted in the upsurge of Von Mises stress of 272%. Moreover, the displacement increases up to 234%, from 13.1 mm to 43.8 mm. This observation can be attributed to the increase in surface area of the impeller that experiences the uniform pressure acting on the surface. Thus, the Von Mises stress and displacement rise as expected.



(a) (b)

Figure 3: (a) Von Mises stress on the blade intersection and (b) displacement on the blade.

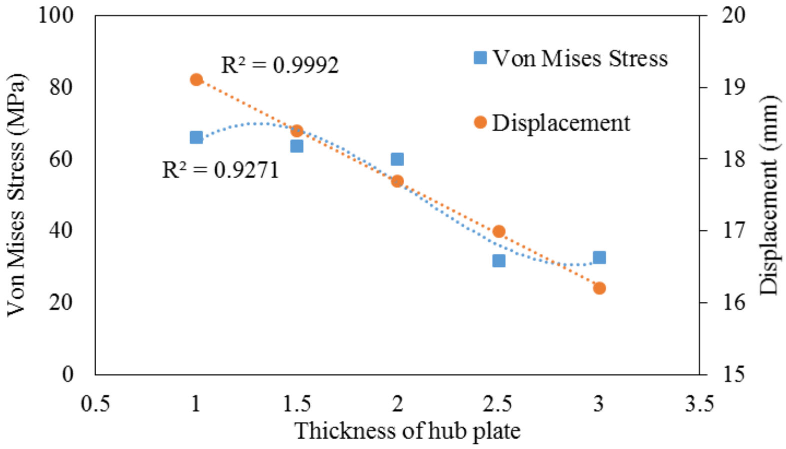


Figure 4: Effect of hub plate thickness (mm) on the maximum Von Mises stress and maximum displacement.

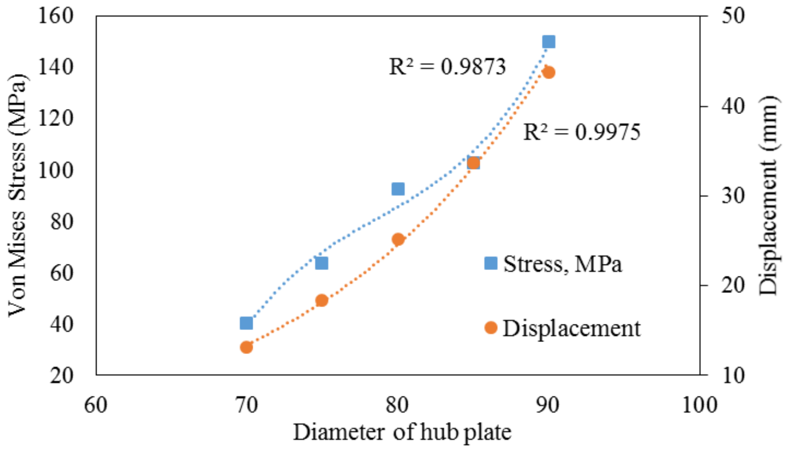
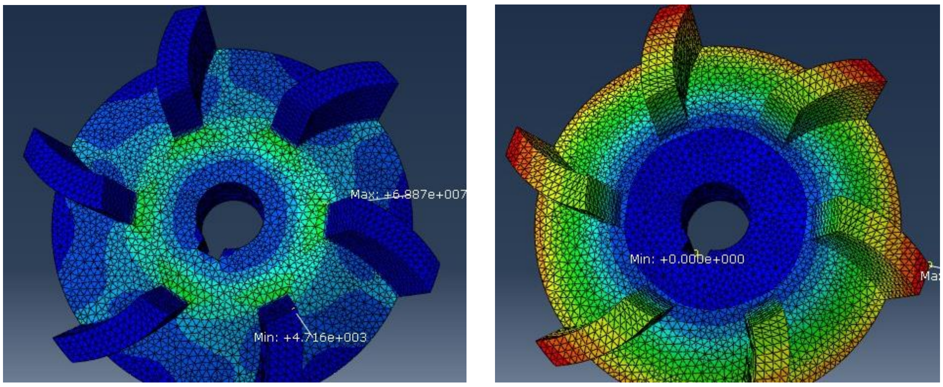


Figure 5: Effect of hub plate's diameter (mm) on the maximum Von Mises stress and maximum displacement.

Furthermore, the blade thickness was studied in the simulation analysis. The blade thickness is varied from 2 mm to 6 mm. The maximum stress and displacement location were found almost identical to the earlier investigation. Similarly, considerable stress was also observed near the hub side and trailing edge [13]. Figure 6 shows the distribution of the von Mises stress and displacement of the impeller when the blade thickness increases. The simulation results revealed that the von Mises stress increased irregularly in the polynomial behaviour, as depicted in Figure 7. However, the displacement increased linearly. The maximum displacement was found at the corner of the blade. The von Mises stress increased at 2 mm to 4mm of blade thickness. However, the stress drops until 36.6 MPa at 5 mm and continuously increases at 6 mm of blade thickness. The percentage of increment for the displacement is only 2.2%, which indicates that the increase in blade thickness only slightly influences the displacement. Besides, the performance of the centrifugal pump can be improved by using various optimization methods [14], including machine learning and hybrid algorithm [15], response surface methodology [16] and the Taguchi method [17]. The current simulation results contribute to understanding the mechanical aspects of the centrifugal pump impeller.



(a) (b)

Figure 6: (a) Von Mises stress and (b) impeller displacement.

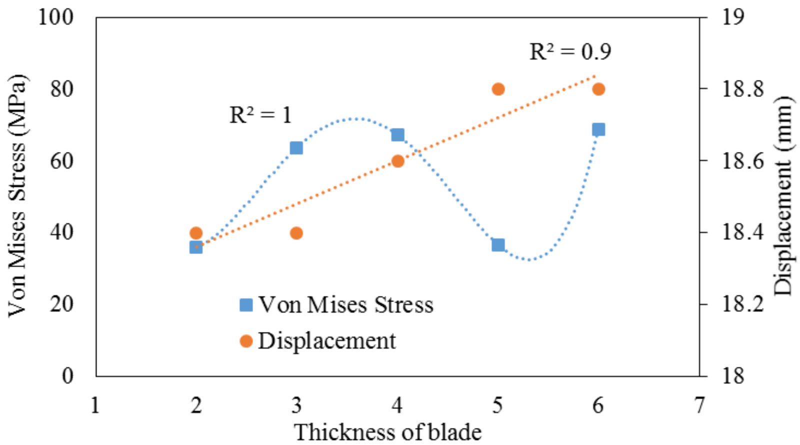


Figure 7: Blade thickness (mm) affects the maximum Von Mises stress and maximum displacement.

4. CONCLUSION

The influence of the impeller's physical parameters on the mechanical aspects was successfully studied via the finite element simulation analysis. The simulation results revealed that the variations in the impeller parameters significantly affect the Von Mises stress and displacement. The increase in thickness of the hub plate and blade resulted in the polynomial and linear variations on the von Mises stress and displacement, respectively. Polynomial and exponential behaviour was observed on von Mises stress and displacement when the hub plate diameter increased from 70 mm to 90mm. The results indicated that the optimal design is required to obtain the optimized impeller to withstand the high stress and displacement. This study will be extended to the optimization study of the impeller for the centrifugal pump.

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