Study of the volute inlet width effect on structural strength of hot water circulating pump

To cite this article: F Xue et al 2018 IOP Conf. Ser.: Earth Environ. Sci. 163 012109

View the article online for updates and enhancements.

Related content
- Study of volute cutwater diameter on the structural strength of pump rotor
  S L Sun, B H Fu, C Q Chao et al.
- Numerical analysis of head degrade law under cavitation condition of contra-rotating axial flow waterjet pump
  D Huang and Z Y Pan
- Analysis of Internal Flow in Boiler Water Circulating Pump
  Tong Kai, Feng Zizheng, Kong Fanyu et al.
Study of the volute inlet width effect on structural strength of hot water circulating pump

F Xue¹, Y L Zhang¹, C Q Chao¹ and D Liu¹

¹ School of Energy and Power Engineering, Jiangsu University, Zhenjiang, China

Corresponding author: liudong@ujs.edu.cn

Abstract. Based on the ANSYS CFX software and Workbench platform, steady-state thermal analysis and static analysis of hot water circulating pump body structure are carried out when medium in the pump is 150°C. The effect of the different volute inlet width on the strength of pump body is compared. Temperature distribution, equivalent stress and total deformation of the pump body are emphatically studied when the volute inlet width is 18mm, 20mm and 22mm. The numerical simulation result shows that the change of volute inlet width affects the flow field of the hot water in the pump. With the increasing of the volute inlet width, the minimum temperature of the pump body increases firstly and then decreases. However, the maximum deformation and the equivalent stress of the pump body decreases with the increasing of the width of the volute inlet.

1. Introduction

During the operation of the hot water circulating pump, because of its unique structure and the harsh operating conditions, problems of the stress concentration and the changes of hydraulic performance caused by heating deformation of solid structure often appear. It will affect the stability and reliability of the pump operation or even possibly lead to serious accidents [1]. Therefore, the study on the strength of the pump body structure, which can provide a theoretical basis for the reliability design of the hot water pump, is essential.

The pump body structure of the hot water circulating pump needs to meet the pressure load of the conveying medium, and it also needs to bear certain temperature load as well. Normal strength checking method can not meet the requirements. However, the study of fluid mechanical structure strength initially confined to normal temperature. For example, Shouqi Yuan [2] compared the distribution of internal flow field in a screw centrifugal pump. They found that pressure fluctuations in pump inlet intensified with the effect of FSI. Houlin Liu [3] took the two-way fluid-structure interaction method to analyze the external characteristics and the internal flow field of the diffuser centrifugal pump. The amplitude of pressure pulsation at the impeller outlet with fluid-structure interaction effect is larger than that in normal condition. In order to optimize the matching of impeller with extra-thick blades and volute in a centrifugal pump, the structure displacement, equivalent stress and modes of different volutes were simulated by Haiyu Wang [4]. Thermal-fluid-structure coupling [5] has been a focus in the field of engine, environmental geologic formation and so on. Based on the fluid-thermal coupling and fluid-structure interaction, the stress-strain on the pump body and impeller were analyzed by Fanyu Kong [6, 7]. The deformation and distribution of stress-strain were obtained, and the pump structure strength was checked at the same time. The stress distribution of rotatable and stationary parts at high
temperature and pressure conditions were contrasted with normal conditions by Liang Dong [8]. He also analyzed the stress distribution characteristics of the structure. Comparisons of pressure and velocity distributions at impeller and volute were conducted by Yunjiao Li [9] between two different pumps under different flow rate conditions. Result shows that the radial forces exerted on the impeller and volute reached minimum values respectively under large flow rate conditions.

The variety of the volute inlet width may change the flow of hot water in the pump, thus affecting the strength of the pump body. In this paper, the temperature, deformation and equivalent stress distribution of three pump models with different volute inlet width are studied and the influence of inlet width on the pump strength is acquired.

2. Pump and its related parameters
In this paper, the designed flow rate of this pump is \( Q = 23.6 \text{m}^3/\text{h} \). What is more, the head and rotational speed is \( H = 14 \text{m} \) and \( n = 1450 \text{r/min} \) respectively. Related properties of the pump material is shown in table 1. The diagram is shown in figure 1. (a) and figure 1. (b).

| The pump material | Poisson’s ratio | Young’s modulus (GPa) | Density (kg/m3) | Coefficient of thermal expansion | Specific heat capacity (J/(kg·K)) | Coefficient of thermal conductivity (W/(m·K)) |
|-------------------|----------------|-----------------------|-----------------|--------------------------------|---------------------------------|---------------------------------------------|
| ZG230-450         | 0.3            | 204                   | 7830            | 1.232\times10^3                | 477                             | 49.65                                       |

3. Modeling methods and process
The pump body structural strength is emphatically studied in this paper when the volute inlet width is 18mm, 20mm and 22mm. Modeling for pump body structure and fluid area of the high temperature hot water circulating pump is carried out by software Pro/E. Fluid area is meshed by ICEM and numerical simulation for the internal flow field of the pump is carried out by software CFX, as shown in figure 1.(c). In the thermal-fluid-structure coupling, the flow field is calculated first. For more accurate calculating results, the fluid domain is imported into Fluent with the solid domain to calculate the pressure and temperature distribution of the fluid. The results are then imported into the Workbench. Also, the temperature loads, pressure loads and related boundary conditions are applied to the solid domain. The different working fluid temperature and the corresponding parameters are shown in table 2. The pump structure is meshed by the ANSYS15.0 Workbench module, as shown in figure 1.(d). The ANSYS Workbench module with a grid partition function provides six different meshing methods including 4 types of units.

![Coupling interface](image)

**Figure 1.** (a) Diagram of fluid area, (b) diagram of solid area, (c) mesh distribution of fluid area, (d) mesh distribution of solid area
Table 2. Related parameters of working fluid.

| Temperature(℃) | Saturated vapor pressure (KPa) | Density (kg/m³) | Isobaric specific heat(J/(kg·℃)) | Heat conduction coefficient (W/(m·℃)) | Dynamic viscosity (Pa·s) |
|----------------|--------------------------------|----------------|-----------------------------------|----------------------------------------|------------------------|
| 0              | 0.61                           | 999            | 4212                              | 55.13                                  | 179.21                 |
| 25             | 3.29                           | 997            | 4181                              | 60.69                                  | 88.99                  |
| 50             | 12.31                          | 988            | 4174                              | 64.78                                  | 54.94                  |
| 100            | 101.33                         | 958            | 4220                              | 68.04                                  | 28.38                  |
| 150            | 476.24                         | 917            | 4312                              | 68.38                                  | 18.63                  |
| 200            | 1554.77                        | 863            | 4505                              | 66.29                                  | 13.63                  |

4. Verification of the accuracy of numerical method
For high temperature hot water circulating pump, only the verification experiment about the external characteristic at normal temperature was carried out because it was difficult to carry out the performance test at high temperature. In figure 2, numerical simulation results of \( b_f = 20 \text{mm} \) pump are compared with the experimental results when the temperature of working fluid is 25℃. It can be seen that the simulation results agree well with the experimental results. Thus, the CFD numerical simulation method is reliable. At the same time, further simulation about the pump lift and efficiency under different flow rate was carried out when the medium temperature is 150℃. It is acquired that the viscosity of the hot water in the pump gradually decreases when the medium temperature increases.

Figure 2. External characteristic curve of pump.

5. Numerical simulation results and analysis
The figure. 3 shows the temperature and heat flux density distribution of pump body when \( b_f = 20 \text{mm} \). The pump body has a low temperature on both sides of the bracket while there is obvious temperature gradient at the inlet and outlet flanges. What is more, the heat flux density value of the corresponding position is relatively large. In table 3, the maximum and minimum temperature of pump body and heat flux density of pumps with different volute inlet width under design condition are listed. The minimum temperature of the pump body increases when volute inlet width increases, while the minimum temperature decreases when it continues to increase. What is more, the change rule of maximum heat flux density is the opposite.
Figure 3. (a) Temperature distribution and (b) heat flux density distribution of pump body.

Table 3. Results of steady state thermal analysis for different pump bodies

| Model | \( b_3 = 18\)mm | \( b_3 = 20\)mm | \( b_3 = 22\)mm |
|-------|-----------------|-----------------|-----------------|
| Parameter | Temperature (°C) | Heat flux density (W/mm²) | Temperature (°C) | Heat flux density (W/mm²) | Temperature (°C) | Heat flux density (W/mm²) |
| Min    | 119.8           | 7.62e⁻⁶         | 120.55          | 6.5355e⁻⁸         | 120.35           | 2.31e⁻⁶         |
| Max    | 150.0           | 0.0366          | 150.00          | 0.036293          | 150.00           | 0.0377          |

Static analysis of the pump body structure is carried out. Figure 4 shows the deformation and equivalent stress distribution of \( b_3 = 20\)mm pump body. The biggest deformations of three pumps are respectively studied under three different loads. They are pressure and gravity loads, only temperature load and three loads at the same time, being respectively represented by S/F, S/T and S in table 4. Due to the small structure of the pump, medium within the pump has relatively small effect on the pump body structure. Compared with the pressure and gravity loads, temperature load has obvious effect on the pump body deformation because the temperature of medium in the pump is relatively high. The maximum deformation of the pump decreases with the increase of volute inlet width. The temperature load plays a leading role in the deformation of the pump body. The maximum deformation of the pump decreases as the inlet width increases under three loads at the same time. The maximum equivalent stress value of the pump body under these three different loads is shown in table 5. From the value, we know that the maximum equivalent stress value decreases as inlet width increases from 18mm to 20mm under pressure and gravity loads, but the maximum equivalent stress value increases when inlet width continues to increase. The \( b_3 = 20\)mm model pump has the maximum equivalent stress, while the \( b_3 = 22\)mm model has the minimum one under temperature load. What is more, the pressure load of the medium in pump and its own gravity have stronger effects on the pump body than temperature load. The change rule of the maximum equivalent stress is the same with that of the maximum deformation under these three loads. With the increase of inlet width, the maximum equivalent stress value of pump body gradually decreases. The maximum equivalent stress value does not vary too much when inlet width \( b_3 \) increases from 18mm to 20mm, but it decreases sharply when \( b_3 \) continues to increase.
Table 4. The maximum deformation of pump body for different working conditions.

| Deformation | $b_3=18\text{mm}$ | $b_3=20\text{mm}$ | $b_3=22\text{mm}$ |
|-------------|-------------------|-------------------|-------------------|
| S/F (mm)    | 0.0050            | 0.00446           | 0.00478           |
| S/T(mm)     | 0.0812            | 0.07914           | 0.07342           |
| S(mm)       | 0.1696            | 0.16792           | 0.16327           |

Table 5. The maximum equivalent stress of pump body for different working conditions.

| The maximum equivalent stress | $b_3=18\text{mm}$ | $b_3=20\text{mm}$ | $b_3=22\text{mm}$ |
|------------------------------|-------------------|-------------------|-------------------|
| $\sigma/F$ (MPa)             | 6.7               | 6.06              | 7.7               |
| $\sigma/T$ (MPa)             | 5.0               | 5.10              | 4.9               |
| $\sigma$ (MPa)               | 172.5             | 172.34            | 157.4             |

In order to further analyze the stress concentration at the pump body bracket, the stress value of the point A-1 to A-2 and B-1 to B-2 was extracted from figure 5. (a), as shown in figure 5. (b) and 5.(c). There is obvious stress concentration at the points A-1 and B-1 on both sides of the brackets. For $b_3=18\text{mm}$ and $b_3=20\text{mm}$ pumps, equivalent stress are not much different and the maximum equivalent stress value of the brackets on both sides of the $b_3=20\text{mm}$ pump are basically the same. With the increase of volute inlet width, the point of the minimum equivalent stress on the left side of the bracket gradually gets close to the center of the bracket, while the point of the minimum equivalent stress on the right side gradually departs from the center of the bracket to point B-2. At the same time, the right side of the $b_3=22\text{mm}$ pump bracket has the minimum equivalent stress value.

Figure 4. (a) Deformation distribution and (b) equivalent stress distribution of $b_3=20\text{mm}$ pump body.

Figure 5. The change rule of the equivalent stress of the bracket. (a) Pump body, (b) stress distribution from A-1 to A-2, (c) stress distribution from B-1 to B-2
6. Conclusion

- The minimum temperature of the pump body increases gradually when the volute inlet width increases from \( b_1=18\) mm to \( 20\) mm, while the minimum temperature decreases when it continues to increase to \( b_1=22\) mm. With the increase of volute inlet width, the lowest temperature of the pump body first increases and then decreases while the maximum deformation and the equivalent stress of pump body decrease.

- Compared with the pressure and gravity loads, temperature load has obvious effect on the pump body deformation because the temperature of medium in the pump is relatively high. The temperature load plays a leading role in the deformation of the pump body. The maximum deformation of the pump decreases as the inlet width increases under three loads at the same time.

- Pressure and gravity loads have relatively huge influence on the pump body equivalent stress, compared with temperature load. The maximum equivalent stress of pump body gradually decreases with the increase of volute inlet width, especially when \( b_1=20\) mm to \( 22\) mm.

Acknowledgments

This study is supported by the National Natural Science Foundations of China (51676086), Natural Science Foundation of Jiangsu Province (BK20161351), China Postdoctoral Science Foundation (2017M610305), and A Project Funded by the Priority Academic Program Development of Jiangsu Higher Education Institutions.

References

[1] Z D Cai, X F Zhang and W C Xing 2014 Design research and application of high temperature hot water circulating pump[J]. General Machinery issue2 pp64-65.

[2] S Q Yuan, Y P Xu, J F Zhang 2013 Numerical analysis for effect of fluid-structure interaction on flow field in screw centrifugal pump[J]. Transactions of The Chinese Society of Agricultural Machinery volume44 issue1 pp38-42.

[3] H L Liu, H Xu, X F Wu 2012 Effect of fluid-structure interaction on internal and external characteristics of centrifugal pump[J]. Transactions of the Chinese Society of Agricultural Engineering volume28 issue13 pp82－87.

[4] H Y Wang, D S Zhang; W D Shi; L Zhang 2014 Analysis and optimization of structure in centrifugal pump based on fluid-structure interaction[J]. Journal of Drainage and Irrigation Machinery Engineering volume32 issue6 pp472-476.

[5] C H Wei 2012 Damage model for coal and rock under coupled thermal-hydraulic-mechanical conditions and its application[D]. Northeastern University.

[6] F Y Kong, T Wang, W T Wang 2012 Finite element analysis of high temperature pump impeller stress based on fluid-solid coupling[J]. Journal of Jiangsu University volume33 issue3 pp269-273.

[7] F Y Kong, W M Jiang, W T Wang 2012 Cavitation performance analysis for cryogenic high-speed canned pump based on coupled flow[J]. Journal of Huazhong University of Science and Technology volume40 issue5 pp24-28.

[8] L Dong, Y Bai, H L Liu 2015 Effect of high temperature and pressure on structural strength of metallurgical hot water circulating pump[J]. Journal of Huazhong University of Science and Technology volume43 issue3 pp28-31.

[9] Y J Li, C Kang, Y C Zhu 2013 Influence of volute structure on performance of vertically-installed high-temperature molten-salt pump[J]. CIESC Journal volume64 issue8 pp2853-2859.