EFFECTS OF IMPELLER SHAPES ON FLOW INDUCED VIBRATION OF CENTRIFUGAL PUMPS

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Pump vibration is partly caused by the fluid pressure pulsation inside the volute; different impeller shapes will cause the change of flow field inside the volute, which will affect vibration characteristics of the pump accordingly. A single-stage centrifugal pump was chosen as the experimental model, numbers of blades (5, 6, 7) and blade angles (22.5 °, 25 °, 27.5 °) were changed respectively in the same volute. The vibration of pumps with those different impellers was measured in the whole flow rate, and the pressure pulsation signals were recorded and processed as well. The results show that fewer blades (5 blades) have a better effect in the aspect of improving pump vibration. As the increase of blade angles, the amplitude of the tone at shaft frequency is gradually decreased, and the high harmonic of blade passing frequency is inhibited effectively. But too large blade angle could lead to instability of pressure pulsation at blade passing frequency, thus comprehensive consideration should be taken in the actual design.

1. Introduction

The impeller is the core component of centrifugal pump energy production and conversion, and its size and shape directly determines the characteristic parameters, such as pump flow, head, efficiency and cavitation performance. At the same time, the change in the form of impeller will also affect the unsteady pressure fluctuation, thus cause the change of The change of the sound field inside the pump and the vibration of the shell structure.

As early as 1998, Bi-peng Yan and Fang-ping Tang have research on the change of the number of blades of axial flow pump, and the influence of blade number on axial flow hydraulic performance was obtained, especially the cavitation performance. In 2012, Ming-gao Tan study on the vibration test of a centrifugal pump with different number of blades, the vibration of the pump was analysis with the blade number 4, 5, 6, 7. In the literature mentioned above, only the influence of blade number on the hydraulic performance of the pump was study, or the relationship between the vibration of the pump and the number of blades, but often only one of them, and did not study the fluid excitation.

Hydraulic optimization design is the basic method to reduce vibration and noise induced by fluid excitation, but the current research of this aspect is still imperfect, and there is no uniform effective low noise pump hydraulic design method. In this paper, a centrifugal pump is chose as the research object, through the experimental study on different blade number and different blade angle, and then get the influence on the vibration of the centrifugal pump, especially on its main characteristic frequency - BPF, and through the pressure pulsation test to get the original fluid pulse exciting force, in order to provide some reference for the establishing of low noise pump hydraulic design method.
2. Introduction of test model and system

2.1 Test system

In this paper, the test device is installed in the open circuit. Vertical centrifugal pump is installed on the base, DN125mm flexible pipes are used to connect pump import and export to lines, from line import to export, there are inlet control valve, the pump inlet pressure acquisition instrument, flexible pipe, centrifugal pump, pump outlet pressure acquisition instrument, flexible pipe, flow meter, export control valve and connecting lines, etc. Through the pump parameter collection device and the corresponding software to realize automatic control, collecting and reprocessing performance parameters, such as pressure, flow rate and outlet valve opening.

![Figure 1: Test system arrangement.](image1.png)

Figure 1: Test system arrangement.

Four pressure pulse sensors are arranged at the circumferential position of the pump volute, and each sensor is pointing to the center of the pitch circle. Through the test numerical analysis and comparison can be seen, the pressure pulsation of measurement point 1 (i.e. tongue position) is obviously higher than the other three measuring points, therefore, the pressure pulsation in point 1 (i.e. tongue position) is selected to compare and analysis.

![Figure 2: The pressure pulsation measurement points.](image2.png)

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2.2 Introduction of the impellers

There are three main methods for the hydraulic design of the impeller: 1) Similar conversion method. This method is mainly based on the similarity theory of pump; 2) Speed coefficient method. Actually it is also a kind of similar design method, and is essentially the same as the similar conversion method, the difference is that speed coefficient method is based on a series of similar pump design, namely according to the similarity principle, statistical coefficient (empirical formula) is used to calculate flow components size; 3) Theoretical calculation of the outer diameter of the im-
peller or the outlet angle of the blade. Theoretical calculation is based on the basic equation of pump, after using the velocity coefficient method to obtain the outer diameter of the impeller, on this basis, theoretical calculation is work out, and this method is more strict in theory, but the efficiency, limited blade number correction parameters, etc., which are used in the process of calculation, are also estimated by empirical formula.

In the design method introduced above, the similar conversion method is preferred. Because the similar conversion method is the most simple and reliable method compared with other methods, the practice is to choose a pump with the similar parameters (similar specific speed) as a model pump, after the appropriate model transformation, the size of the model pump flow component is enlarged or reduced by the size coefficient calculated. a proper model after transforming the model pump flow components all size according to the size coefficient calculated by the zoom in or out, get the geometric parameters of the pump design, and the geometric parameters of the pump are obtained. Because this method chooses a known performance model pump, so the performance of the designed pump can be guaranteed.

This project adopts model similar conversion method to all the five impellers’ hydraulic design.

![Figure 3: The impellers of different blade number.](image1)

![Figure 4: The impellers of different angle.](image2)

![Figure 5: Pictures of different impellers.](image3)

### 3. Effects of different blade number

To compare the effect of the changing blade number on the vibration of centrifugal pump, three impellers with different blade number are chosen, and the blade number are respectively 5, 6 and 7.
3.1 The influence on the pump body vibration

It can be seen from the figure above, shaft frequency vibration on pump body, pump inlet and outlet with different blade number shows almost the same trend, namely the shaft frequency vibration of 5-blade impeller is obviously better than that of 6-blade and 7-blade impeller, and the shaft frequency vibration of 6-blade and 7-blade impeller with the variation of the flow was alternate state. Under the small flow rate condition, 6-blade impeller does slightly better on shaft frequency vibration control than the 7-blade impeller, and under the large flow condition, the situation is the opposite.

3.2 The influence on the pressure pulsation

On the control of the blade passing frequency (BPF), 6-blade impeller is significantly worse than the other two impellers and the impeller ability on the BPF vibration suppression of 5-blade and 7-blade are alternating in different flow conditions.
The pressure pulsation at the volute tongue of 5-blade impeller under rated conditions is selected as an example, and it can be seen from the figure, in the numerical value of the dynamic pressure pulse sensor, the blade passing frequency (BPF) and the high order harmonics appear more prominent, and with the increase of the order, the amplitude of each step is decreased. The numerical value of the pressure pulsation at the fourth order is very small, so the numerical value of the pressure pulsation of the first three orders is compared.

![Figure 9: Pressure pulsation under different blade number.](image)

As can be seen from the figure above, with the change of flow condition, the frequency pressure fluctuation of the 6-blade impeller is more severe; by contrast, the pressure fluctuation of the 7 blade impeller is relatively gentle. From the overall flow conditions can be compared, suppression about the BPF pressure pulsation of 5-blade impeller is better than the other two impellers. Under small flow rate conditions, the suppression effects on double BPF pressure pulsation of 5-blade impeller is more apparent, and under the large flow rate conditions, double BPF pressure pulsation of 6-blade impeller substantial increases, while the other two impellers corresponding numerical values are lower. Under the small flow rate conditions, three times BPF pressure pulsation of 6-blade impeller has a higher value, and above 0.8 times rated flow conditions, the numerical values of three times BPF pressure pulsation of the three impellers are small. By comparison, the inhibitory effect of the 5-blade impeller is slightly better than the other two impellers.

4. Effects of different settling angle

To compare the effect of the changing blade angle on the vibration of centrifugal pump, three impellers with the same blade number are chosen, and the blade angle is 22.5°, 25° and 27.5° respectively.

4.1 The influence on the pump body vibration

![Figure 10: Shaft frequency vibration under different blade angles.](image)

As can be seen from the figure above, the shaft frequency vibration of the impeller with 22.5° blade angle is greater than the other two impellers with 25° and 27.5° blade angle, and the shaft frequency vibration value of the impeller with 25° blade angle is slightly less than that with 27.5° blade angle, it is concluded that the increase of the angle of the blade is helpful to restrain the vibration of the shaft frequency.
Figure 11: Blade passing frequency (BPF) vibration under different blade angles.

As can be seen from the figure above, the BPF vibration of the three impellers maintain a consistent trend with the change of flow rate, with the increase of flow rate, the BPF vibration decreases. The difference among the BPF vibration of three impellers is not obvious, and the BPF vibration of the impeller with 25° blade angle in the large flow condition area is slightly lower than the other two.

4.2 The influence on the pressure pulsation

In contrast to the blade angle change pressure fluctuations on the impact of fluctuating pressure, selects the various installation angle of the impeller corresponding measuring point 1 (i.e. the volute tongue position) numerical comparative analysis.

Figure 12: Pressure pulsation under different blade angles.

With the changes of the flow rate, the BPF pressure pulsation trend of 22.5° and 25° impellers is consistent, and that of 27.5° impeller varied greatly, especially between 0.8-1.1 times the rated condition, the BPF pressure pulsation of 27.5° is much higher than the other two impeller. Compared with the variation of BPF pressure pulsation, the double BPF pressure pulsation of 27.5° impeller reduces significantly and with the variation of the flow does not appear large fluctuations, while the trend of double BPF pressure pulsation of 22.5° and 25° impellers is still more consistent, which increases with the flow rate increases, and in the large flow rate condition area, double BPF pressure pulsation has increased sharply trend.

The triple BPF pressure pulsation of 27.5° impeller has maintained a lower values, and the triple BPF pressure pulsation of the other two impellers in small flow rate condition area is larger, but with the increase of flow rate, triple BPF pressure pulsation decreased rapidly.

5. Conclusion

Vibration test and pressure pulsation test were carried out by changing the number and the angle of the blade, and the following conclusions were obtained from the analysis of the test results:

In the inhibition of shaft frequency vibration, BPF vibration and the harmonic frequency pressure pulsation, the combined effect of 5-blade impeller is optimal in the three impellers; the adaptability of 6-blade impeller in partial operation condition is weaker, in some small flow rate and large flow conditions, vibration value or pressure pulsation values will appear obvious increase.
Increasing the blade angle of impeller will produce a beneficial effect on the shaft frequency vibration, and can effectively suppress the higher harmonics of the BPF pressure pulsation, but too large impeller blade angle will lead to the instability of the BPF pressure pulsation, and in terms of vibration control with characteristics frequency, the comprehensive performance of 25 ° angle impeller is more prominent, so in the design process, the angle should be appropriate to increase, and at the same time, according to the theoretical calculation results to make a reasonable choice.

REFERENCES


