Analysis research on tenth level pump impeller symmetry model

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Abstract. The simplified model of the ten-stage pump was established with UG and then was input into the ANSYS Workbench for its dynamic and modal analyses. Considering the potential axial thrust caused by unparallel-arranged impeller would have a adverse effect on the device, we decided to adopt the impeller symmetrical as its layout. Through the analysis on the modal with the improved impeller a conclusion was drawn as there was little difference between the improved impeller arrangement and the unimproved one on their natural frequencies of each stage. The control mode and strategy we adopted here can be still in use lately, which also offers theoretical references for the subsequent improvement and analyses.

1 Introduction
Feed water pump system is used in mine drainage, power plants, chemical plants and other places for its advantages of simple structure, economical, and widely-used. Its mechanical characteristics and work performance has important influence on the whole plant stably[1-6]. There is the most important reason that feed water pump impeller shaft to the thrust of feed water pump instability; especially the multistage pump makes the overlapped axial thrust unstable to the whole water supply system. And the forces bring hidden trouble to the factory normal production. Thrust bearing, balancing the slider were usually used to eliminate the influence of the axial thrust, but its effect is limited. This paper discusses the using of symmetrical arrangement to eliminate ten stage impeller pump axial thrust method, and modal analysis is carried out on the improvement after impeller mechanism[7,8].

2 Ten pump impeller dynamics method
2.1 Ten pump impeller improvement method
Install the impeller symmetrically in pairs on the same axis. Impeller of axial force balance each other at all levels, this balance method can significantly reduce the effects of axial thrust for water supply system. Its main drawback is the flow length between levels and overlaps each other, so the pump shells have to cross to decorate. It makes the pump shell casting more complex, and the cost high. But we can be the impeller around the overall arrangement for the two parts. The left half impeller inlet to the left; the right part of the impeller inlet to the right. Both the left and right sides is symmetrical layout. This way will greatly simplify the design of the feed water pump flow channel. And this way can reduce the kinds of unstable factors for the axial force. And it has simple structure. So this arrangement has high research value[9,10].
2.2 The geometric model
Based on a water pump factory production plan of the pump impeller design data and actual measurement data, we use UG NX establish the geometric model of the pump impeller \(^{[11,12]}\). As shown in figure 1.

![Figure 1: The dissymmetric geometric model](image1)

The model includes ten impellers and the pump shaft. Because the model analysis of impeller is the research focus, we have simplified the impeller system. We omit the supporting parts. For example, the balance pipes on the impeller, the keys that stable between the impellers and the axles and some other secondary parts. The effect of the simplified modal simulation of impeller is small. Using UG itself provided interfaces, we output the model. As shown in figure 2.

![Figure 2: The symmetry geometric model](image2)

3 Modal analyses
3.1 Basis of modal analysis
The finite element analysis of the structural modal analysis is that disperse some objects into a limited number of unit cell.

In solving structural free vibration natural frequency and vibration mode, damping has less affected to the results. So we can ignore the influence of damping force to the system. And the free vibration equation can be gotten:

\[
[M][x"] + [K][x] = 0
\] (1)

Make the following harmonic vibration of the structure:

\[
(X) = \{x\} \cos(\omega t)
\] (2)

Put (2) in (1) getting the homogeneous equation:

\[
([K] - \omega^2 [M])(X) = 0
\] (3)

When the system makes free vibration, the amplitude of every node of the structure is not all 0. So we can get the frequency equation of free vibration:

\[
([K] - \omega^2 [M]) = 0
\] (4)

Where, [M] , [K] is the third order square, its node number of degrees is three. So (4) is the 3 algebraic equation about \(\omega^2\). The solve problem of the inherent frequency and the vibration mode of
the system is solve the problem of the matrix eigenvalues $\omega$ and eigenvectors (x). Solve the (3) we can get the rotor free vibration frequencies and mode shapes.

3.2 Mesh
This article in view of the centrifugal pump impeller structure model is more complicated, the automatic mesh method is adopted: firstly, we solid modelling of centrifugal pumps impeller by UG NX. Secondly, impeller model import in ANSYS Workbench entities and definition the boundary by the connector between UG and ANSYS. Grid cell number: 42304, total number of nodes: 85241. As shown in figure 3.

![Figure 3: The automatic mesh method](image)

3.3 The modal analysis results
Below we will impeller asymmetric arrangement and symmetrical arrangement modal analysis by ANSYS, then we get the first ten order modal vibration mode figure, the results are as follows.

| stage | $f_{\text{dis}}$/Hz | $f$/Hz | value ( $f_{\text{dis}}$ - $f$) |
|-------|---------------------|--------|---------------------------------|
| 1     | 19.987              | 20.102 | 0.115                           |
| 2     | 20.071              | 20.224 | 0.153                           |
| 3     | 54.636              | 54.526 | 0.11                            |
| 4     | 54.765              | 54.784 | 0.019                           |
| 5     | 95.774              | 95.50  | -0.274                          |
| 6     | 106.03              | 106.52 | 0.49                            |
| 7     | 106.12              | 107.13 | 1.01                            |
| 8     | 172.80              | 172.58 | -0.22                           |
| 9     | 173.13              | 173.32 | 0.19                            |
| 10    | 188.36              | 187.71 | -0.65                           |

By comparing we know that impeller in asymmetric arrangement and the symmetrical arrangement of the modal vibration mode are basically the same, there is some difference of natural frequency. Impellers in the two states of each order natural frequency of vibration type figure are shown in figure 5. The basic equal between two order natural frequencies is actually the same order vibration in two mutually perpendicular directions. By contrast can be found that the impeller asymmetric arrangement and symmetrical arrangement each order modal frequency difference is very small, maximum is about 1 Hz.

Below is the impeller under the asymmetric arrangement and the symmetrical arrangement of each order modal graph (for asymmetric arrangement on the left, for symmetrical layout on the right):
The first order mode

The second order mode

The third order mode

The forth order mode

The fifth order mode
Figure 4: Ten order modal analysis of asymmetric arrangement and symmetrical arrangement of impeller
3.4 The results of simulation analysis

Observe each order modal vibration mode we can get some results. The first order modal vibration mode and the second order modal vibration mode of two impeller arrangement is the motion of the shaft deformation. The largest amplitude is the middle of the mode. The amplitude is diminishing on both sides. Maximum amplitude is on the forth and the fifth wheel. The first order modal deformation mainly is for the y direction. And the second order modal deformation mainly for the z direction. The third order modal vibration mode and fourth-order modal vibration mode both impeller arrangements for the motion of the shaft deformation. There are two maximum amplitude points, one is located in the third and the forth levels of impeller, the other is located in the eighth level of impeller. The third order modal deformation mainly for the y direction. And the forth order modal deformation mainly for the z direction.

The fifth order modal vibration mode mainly tensile deformation of the impeller. The maximum deformation in the middle level of impeller is namely the fifth and the sixth level of impeller. And the closer the impeller outer end deformation is larger.

The deformation of the sixth and the seventh order modal vibration mode is mainly for the motion of the shaft, and a small amount bending deformation in the impeller. Pump shaft bending is wavy. The biggest deformation is on the third, sixth and ninth wheels. The sixth order modal deformation mainly for the y direction. And the seventh order modal deformation mainly for the z direction. The deformation of the eighth and the ninth order modal vibration mode is also mainly for the motion of the shaft, and a small amount bending deformation in the impeller. Pump shaft bending is wavy. But the difference is the biggest deformation under two kinds of modal more frequently. It is appear in the second, fifth, seventh and ninth impellers. The eighth order modal deformation mainly for the y direction. And the ninth order modal deformation mainly for the z direction.

The tenth modal is similar with the fifth modal vibration mode. The main deformation is tensile deformation. But the biggest mode of vibration appears twice, in the third and the eighth impeller.

Observation wheel vibration mode, we found that there is swing deformation on each parties and tensile deformation in the impeller. The biggest swing deformation is about 0.28mm. And the tensile deformation is much bigger about 0.5mm. The deformation is not increased with the rotational speed, but with the increase of impeller speed, impeller deformation maximum points will increase, the present wave deformation will be more intense. Therefore, we should be considered when working in design impeller speed, and then reasonable arrangement of the impeller rotating speed range. Deformation, maximum deformation, natural frequency of the two ways to decorate the difference is very small. Therefore, after the tenth level pump impeller by asymmetric parallel arrangement instead of symmetrical arrangement, when over the natural frequency we can use the method is similar with the original.

4. Conclusion
This paper uses UG NX to establish the model of the impeller of the ten-stage pump. And then make model simulation in ANSYS; discusses the tenth level pump impeller layout from asymmetric parallel arrangement to the symmetrical; reduces the influence by axial thrust of unstable on feed water system, and find the change of natural frequency is very small. Therefore, we can reserve the old control strategy, or modified the old slightly. After changing, the axial thrust of the water pump can be greatly reduced by the symmetrical structure. The pump work is more stable. And the construction is relatively simple.

Acknowledgements
This work is partially supported by key research and development plan (general) in Shanxi Province (No.201603D321021). The authors also sincerely acknowledge the constructive comments and suggestions given by the reviewers, which have improved the presentation.

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