Investigation on vibration of Centrifugal Pump by Bearing supported position

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Abstract. Vibration is one of the main problems which should be considered seriously in designing and operating a marine centrifugal pump to decrease vibration for the reliability of equipment and safety of ship. The reduction for vibration also can provide a guarantee for enhancing concealment, which will be benefit for military ships with higher requirements for concealment to improve combat effectiveness. A numerical calculation model of whole centrifugal pump was established in this paper. The emphasis of this article is that influence of bearing supported position on vibration of centrifugal pump. And conclusion was obtained that vibration peak can be reduced through adjust supported position of bearing reasonably. The simulation results was proved by experiment which was carried out in the Shaking Table Test.

1. Introduction

Centrifugal pump is one of the important auxiliary devices on a ship, which plays an important role in its operation. While vibration and noise will be generated when the pumps work at various rotating speeds. And noise and vibration generated by the pump are harmful to the acoustic stealth performance of the ships as pump is running and even affect safety of ship and people’s health.

Extensive research on vibration of centrifugal pump was conducted by scholars at home and abroad. Studies have been carried out on vibration of pumps in terms of structure by scholars. Zhang et al. [1] proposed a special slope volute to reduce vibration level of pump and vibration characteristics of model pump were measured, which were compared with conventional spiral volute pump. And result was presented that vibration energy of conventional spiral volute pump is much large than slope pump at different working conditions in their works. And the influence of inlet guide of inlet guide vanes on unsteady flow in centrifugal pump is slight when the inlet guide vanes angles are regulated in a suitable
region is numerically studied by Wang et al. [2].

Vibration generated by unsteady fluid flow is also unavoidable in pumps. Choi et al. [3] designed an experiment on the generation mechanism of pump noise with a simplified model and found that the pressure and vibration produced by the interaction between the impeller and volute was much higher than the others. The vibration characteristics of the pump caused by different excitation sources that including fluid excitation was analyzed with modal superposition method[4]. And order of contribution of different excitation sources to vibration in pumps was obtained. Mele et al. [5] found that flow-induced vibration in general increases with pump speed and was clearly linked to pump efficiency can be obtained.

It is well known that bearing plays a pivotal role in the stability and safety of the rotor system. Therefore, the influence of bearing parameters on rotor system has been investigated extensively. Zhang et al. [6] proposed a radial clearance adjustable bearing for investigating the dynamics characteristics with the change of radial clearance. Conclusion was obtained that when the rotational speed does not reach the critical speed, reducing the radial clearance can effectively reduce the vibration of the rotor system and when the rotational speed approaches the critical speed, increasing the radial clearance can significantly reduce the resonance amplitude of the rotor system in their works. The unstable periodic solution of a balanced rotor bearing system can be avoided when the applied axial preload is sufficient was presented by Bai et al.[7].

Centrifugal pump is a rotating fluid machinery. Bearing-rotor system is also plays an indispensable role for stability of pump when running. The purpose of this paper is to study influence of bearing supported position on vibration of whole centrifugal pump. A numerical calculation model of whole electric centrifugal pump was developed. The numerical calculation model of whole electric centrifugal pump can show the dynamic characteristics of physical object much better, which compare with the models with only several components considered in previous studies. Results were obtained that vibration of pumps changes with supported position of bearing is not linear. And vibration peak of pump can be reduced by adjusting supported position reasonably.

2. Establishment of numerical calculation Model

The research object of this paper is a marine single-stage vertical electric centrifugal pump. A three-dimensional models were developed in SolidWorks as shown in Figure 1 according to physical object. And main performance parameters of the pump are shown in Table 1. Some less important details of the model are neglected to facilitate the division of finite element mesh in simulation software and improve computational efficiency.

![Figure 1. The numerical model and key parts of centrifugal pump: A is the motor case; B is the bracket; C is the pump case; D is the suction cover; E is the shaft of pump; F is the stator winding; G is the mechanical seal ring; H is the impeller; I is the seal ring.](image)
Table 1. Main performance parameters of pump

| Type    | Power(kw) | Discharge(m³/h) | Lift(m) | Speed(r/min) |
|---------|-----------|-----------------|---------|--------------|
| 50CL-24.5T | 3         | 18              | 24.5    | 2950         |

2.1. *Fluid Excitation*

It is well-known that vibration caused by unsteady flow is inevitable during running of pumps. Therefore, Fluid Excitation should be considered when modeling in order to ensure the reliability of subsequent study. The Flow Passage Model was established, which mainly includes inlet pipeline, outlet pipeline, volute, and impeller. And Flow passage model will be meshed in finite element software subsequently as shown in Figure 2. The fluid excitation will be calculated based on the basin model. The residual values calculated by the flow passage model of centrifugal pump in this paper are all lower than 10⁻³, which means that the calculation has a good convergence result. And data of the resultant radial force of the fluid will be fitted, which applied to numerical calculation model established in software Adams as a fluid excitation.

![Figure 2. The finite element mesh of flow passage model](image)

2.2. *Establishment of numerical calculation model*

Main characteristics of materials such as density, Young’s modulus and Poisson’s ratio are defined and given to the parts during the process of modeling. The material properties of key parts are shown in Table 2. And constraints also need to be imposed on model in software Adams before analysis. Simulation calculations will be carried out after model was developed.

Table 2. Material properties of key parts

| Part       | Material            | Density(g/cm³) | Young’s modulus (E/G pa) | Poisson’s ratio |
|------------|---------------------|----------------|--------------------------|----------------|
| Impeller   | QA19-2              | 7.5            | 110                      | 0.33           |
| Bracket    | QT450-10            | 7.1            | 169                      | 0.28           |
| Shaft      | 14Cr17Ni2           | 7.75           | 210                      | 0.34           |
| Pump case  | ZCuAl8Mn13Fe3Ni2    | 7.5            | 103                      | 0.30           |
| Seal ring  | ZCuZn16Si4          | 8.2            | 137                      | 0.37           |

3. *Influence of bearing supported position on vibration characteristics*

Marine electric centrifugal pump is a kind of rotating fluid machinery. Bearings as a key part, which parameters can directly affect vibration peaks of pumps. The overall structure of centrifugal pump will be directly affected by bearing supported position. Therefore, it is necessary to investigate the relationship between the bearing support position and the characteristic vibration of electric centrifugal pumps by adjusting supported position of single bearing with a small size.

The modeling of bearing through Adams/Machinery Bearing module in software Adams. And bearing stiffness, bearing preload, bearing support position and other parameters can also be set in Adams to develop a bearing model with real performance parameters. Vibration acceleration response of pump in different supported position of bearing can be obtained by ensuring that other parameters of bearing remain unchanged.
3.1. Variable scheme of bearing supported position

A right angle coordinate system with the center of the lower end face of the pump shaft of the model pump as the reference point was established as shown in Figure 3. The coordinates of the lower bearing mounting point are (0,0,-200) and the point coordinates of the upper bearing are (0,0,-433). The unit of coordinates is millimeter. The vibration response of pump obtained through adjust supported position of the lower bearing in this paper and the scheme is shown in Table 3.

![Figure 3. Diagram of bearing supported position](image)

**Table 3. Variable scheme of bearing supported position**

| Serial No. | 1   | 2   | 3   | 4   | 5   |
|-----------|-----|-----|-----|-----|-----|
| Dimensions of lower bearing | -195 | -198 | -200 | -202 | -205 |

3.2. Analysis of simulation results

Bracket as a key part as shown in Figure 1 to connect centrifugal pump and ship hull, its vibration characteristics can reflect effectively the vibration characteristics of pump and even ship hull. Therefore, vibration response of bracket are mainly tested and analyzed when analyzing relationship between vibration characteristics of pump and bearing supported position. And results are shown in Figure 4.

![Figure 4. Vibration response of different supported position](image)
The rated speed of the centrifugal pump is 2880 r/min. Shaft-frequency $f_s = 49.17\, Hz$ and semi-frequency $f_a = 24.58\, Hz$ can be obtained consequently. It can be shown in Figure 4 that obvious peaks appeared nearly semi-frequency, shaft-frequency and double-frequency. And the maximum value occurs at shaft-frequency. The following order from smallest to largest of vibration acceleration of pump can be obtained is: -200, -202, -205, -195, -198.

The results indicates that variation of vibration on pumps with the change of bearing support position is not linear in one direction. And the trend of vibration acceleration of pump will not be change with small adjustment of bearing supported position while it has a certain impact on size of vibration peaks. And vibration peaks of centrifugal pump can be reduced through adjust bearing supported position reasonably.

4. Experimental Verification

A Shaking Table Test of centrifugal pump is carried out. The centrifugal pump is mounted on the vibration test table by bolts as shown in Figure 5. And vibration signals from the pump were obtained with the accelerometers, which were positioned beside the bolts of bracket. Vibration amplitudes at the semi-frequency, shaft-frequency and double-frequency were extracted from experimental results as shown in Figure 6.

Figure 6 shows that the experimental data have a good agreement with simulation results. Some small errors may exist while can be acceptable when considering the complexity of the actual experimental conditions.

5. Conclusion

Bearing supported position is discussed to investigate its influence on vibration of centrifugal pump in this paper. And some conclusions were drawn are as following:

1) Vibration peaks of centrifugal pump appeared mainly in semi-frequency, shaft-frequency and double-frequency.

2) Vibration on pumps with the change of bearing support position is not linear in one direction. And vibration peaks of centrifugal pump can be reduced through adjust bearing supported position reasonably.

The model will be optimized in the future. And focus of further study is how to accurately determine the bearing supported position with minimum vibration response.

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