Influence of Parameters on vibrations for Centrifugal Pump Based on the Modal Dynamics Method

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Abstract. The influence of the parameters on the vibrations for a centrifugal pump is investigated under the consideration of the fluid excitation force in this paper. The responses of the centrifugal pump during the operation were mostly generated by the fluid excitation force. It is difficult to simulate accurately and make prediction of this coupling vibration in a rigorous analytical method. The finite element model was established in this article with consideration of the effect of the fluid excitation. Based on the modal dynamics method, the analysis is carried out to study on the effect of the parameters such as the flow rate, the blade number, the exit installation angle and the outside diameter of impeller on the frequency-response curves. The results show that there exists an optimal blade number value for a better effect of vibration reduction; the design of the outside diameter should consider the response to get a better damping. The research work is meaningful for the parametric designation and the safe check for the centrifugal pumps.

Introduction

The centrifugal pump is a kind of rotating fluid machinery. The working fluid obtains the energy of the rotating blade during the operation; then the working fluid exerts an unsteady excitation pressure on the body of pump and the shaft of rotation. This excitation pressure produces a coupled vibration of sound field within the pump body and structural responses. The vibration and noise propagate outward along the pipeline. The mechanical noise is directly associated with the pump, for example from the bearings and from the sealing elements. However the mechanical noise is not notable unless there exists mechanical fault. The fluid dynamic noise mainly derives from the interior of the centrifugal pump shell and it is directly associated with the unsteady pulsating flow within the pump body. This type of vibration and noise have an effect on the performance of the machinery system. Accordingly, the research on the vibrational characteristic for the centrifugal pump is significant for the engineering application.

During the last decades, much progress has been made about the vibration of the centrifugal pump. C.G.Rodriguez [1] et. al carries out a theoretical analysis to predict and explain in a qualitative way the frequencies and amplitudes for the rotor stator interaction in a centrifugal pump turbine. A successful corrective action is proposed as a consequence of this new interpretation. Y.Y. Jiang et al [2] reports on reports on a full-scale structural simulation of flow-induced mechanical vibrations and noise in a 5-stage centrifugal pump. They clarified the mechanisms of the resonant vibration and the noise generation and propagation, which can then be used for noise reduction. Andreas Lucius et al [3] researched on the velocity fluctuations during rotating stall of a centrifugal pump in order to determine their importance for excitation of structural vibrations. Lohasz, M et. al [4] and Byskov, R et.al [5] applied the large eddy simulation in the field of turbomachinery to solve more details of the flow field and restricted to low Reynolds numbers. In addition, the hybrid methods [6-9] like detached eddy simulation are used increasingly. Many researchers [10-14] studied the fault diagnoses of the centrifugal pump or rotational machinery. Zhou Yunlong and Zhao Peng [15] proposed a new fault diagnose method for the nonlinear and non-stationary characteristics of the vibration signals of centrifugal pump based on complexity feature of Empirical Mode Decomposition (EMD). While V. Muralidharana et al [16] carried out an investigation of fault diagnose for the monoblock centrifugal pump using the support vector machine (SVM) and artificial neural networks were employed for continuous monitoring and fault diagnosis. Even though the mass unbalance is not be eliminated completely, the dynamic balance technology is applied to decrease the influence of the mass unbalance for a minor excitation force. For the rotor misalignment, the periodic excitation force can be effectively decreased if the flexible connections are applied to the junctions of the two rotors. However, the unsteady fluid excitation is the main causation of the vibration and noise and it has not been eliminated effectively at present. Therefore, the construction of the centrifugal pump model and the study of the vibrational characteristics are essential for the theory and engineering application. Dynamic characteristics of centrifugal pump Induced by the fluid excitation force have been studied rarely in the published articles, this research will be reported in this paper.

Modelling and calculation

Importing the geometry model into the *Abaqus* and then meshing the components by using the type of C3D4 lead to the analytical model. The different types of element and dimension are used for the different parts in order to obtain the fine geometry features. The meshing quality of the elements is checked to get a good quality and the parts will be remeshed if their quality does not meet the requirements until the quality is good enough for calculation. The parameters used are as follows: Modulus of elasticity E=210GPa, densityρ=7850Kg/m^3, Poisson ratioμ=0.3. After calculating the free modal of the components and comparing the results with that of experiments and they agree well.The connection between the two components in centrifugal pump mainly includes the bolting, the shaft coupling and so on. The springs with the different stiffness values are applied to simulate the connections in this paper. The absorber on the frame, the connectors between the inlet/outlet pipes with the exterior are also simulated to be the springs with a specific stiffness values, and the type of springs is *connect point to ground.* The spring are built with the different types and stiffness with consideration of the stiffness in three components in order to be closer to reality.

The modal dynamics method is adopted in this paper to calculate the responses. This method applies the modal superposition method to solve the transient responses of the linear system. The characteristic modes should be extracted before this method based on the characteristic modes is applied. The method is applied to make the time-domain analysis of a linear system, where the excitation is a function of time and there is an assumption that the amplitude in every incremental time step is linear under the determined excitation. In this paper, the excitation force is the fluid excition force which was obtained by the numerical simulation. This excitation force is exerted on the analytical model to submit calculation.

Results and analysis

The response on the volute under the fluid excitation will be investigated in this section. The constrained modes of the centrifugal pump which are connected with the inlet/outlet pipe are calculated before the responses are calculated. Appling the Spring（*connect point to ground*）, the feet of the machine, the inlet and the outlet are joined by Springs to the ground. The constrained modes are calculated by using the *Lanczos* Method; the results are seen in Table 1. The analytical point on the volute A is selected as the analytical point of the centrifugal pump, as seen in Figure 1.

In order to study the effect of the blade number, the impeller outside diameter, the exit installation angle on the response of the analytical point, the number of the impeller is selected as: 4 blades, 5 blades, 6 blades, 7 blades and 8 blades, respectively; the outside diameter of the impeller is selected as: 170 mm, 171mm, 172mm, 173mm and 174mm, respectively; the exit installation angle is 20°, 23°, 27° and 35°, respectively. Then, the response of the analytical point is extracted for analysis. The influence of the flow rate, the blade number, the exit installation angle and the outside diameter on the vibrations will be reported in the next sections.

Table 1 The main constrained modes (constrained on the inlet/outlet and the feet of the machine)

Order	Frequency (Hz)
1	128.18
2	154.28
3	184.43
4	282.95
5	301.85
6	343.89
7	363.71
8	384.88

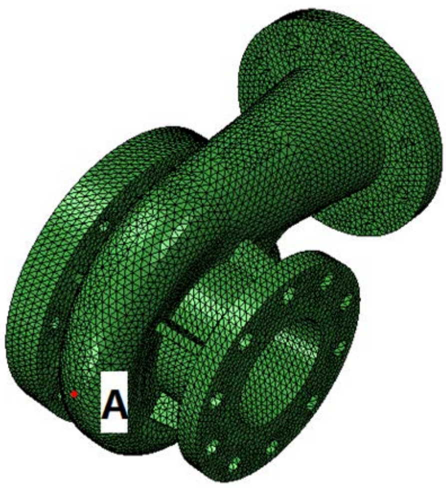

Fig. 1 The analytical model and the analytical point A of the centrifugal pump

The flow rate

The flow rate is the liquid quantity delivered in unit time; it is the fundamental parameter of the performance for the centrifugal pump. The influence of the flow rate on the vibration is investigated in this section. Figure 2 shows the FR (Frequency Response) curves for the analytical point A with the different flow rate 0.6Q, 0.8Q, 1.2Q and 1.4Q. It can be seen from Figure 2 that the acceleration responses of the analytical point for the centrifugal pump decreases with the increasing of the flow rate; the different flow rates excite the same resonant frequency 291Hz.

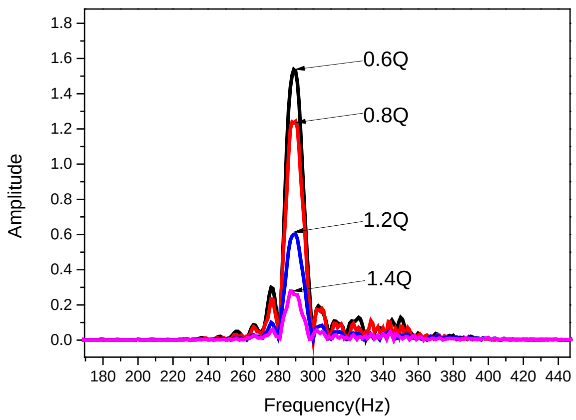

Fig. 2 The influence of the flow rate on the FR curves

The blade number

The blade number is the important parameter of the centrifugal pump. Figure 3 shows the FR curves for the analytical point with the different blade number 4-blade, 5-blade, 6-blade and 7-blade. It can be seen from Figure 3 that the max acceleration responses of the analytical point is for the 5-blade, while the minimal acceleration response is for the 6-blade; the frequency multiplication 193Hz, 242Hz, 290Hz and 338Hz, which are the multiplications of the shaft frequency 48.3Hz (rotating speed is 2900r/min), appear for the blade number 4-blade, 5-blade, 6-blade and 7-blade, respectively; the frequency of the response peak is 386Hz, 296Hz, 290Hz, 340Hz for the 4-blade, 5-blade, 6-blade and 7-blade, respectively. Therefore, the optimal number of the blade is 5-blade only under the consideration of the vibration reduction. The resonant frequency and the reducing vibration should be considered comprehensively in selecting the blade number.

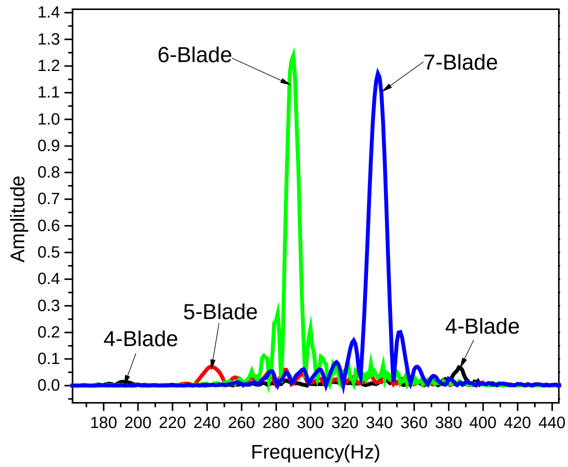

Fig. 3 The influence of the blade number on the FR curves

The exit installation angle

The exit installation angle is an essential parameter of the centrifugal pump. The exit installation angles are selected as 20°, 23°, 27°, 30° and 35°. The influence of them on the vibrations is shown in Figure 4. It can be seen from Figure 4 that the different angles have the same resonant frequency 290Hz; and the maximal amplitude is for the 30° which is nearly equal to the amplitude for 35°; while the minimal amplitude is for 20°.

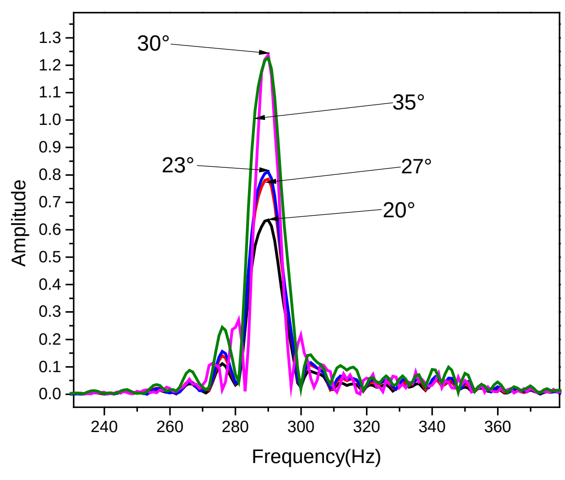

Fig. 4 The influence of the exit installation angle on the FR curves

The outside diameter

The outside diameter of the impeller for the centrifugal pump has effect on the dynamic characteristics of the system. The outside diameters of the impeller are selected as 170mm, 171mm, 172mm, 173mm and 174mm. The influence of them on the vibrations is shown in Figure 5. It can be seen from Figure 5 that the different outside diameters have the same resonant frequency 290Hz; and the maximal amplitude of the response is for the 174mm while the minimal amplitude is for 170mm. Accordingly, the design of the outside diameter should consider the response to get a better damping; in this calculation example, the 170mm is the better selection only from the vibration reduction.

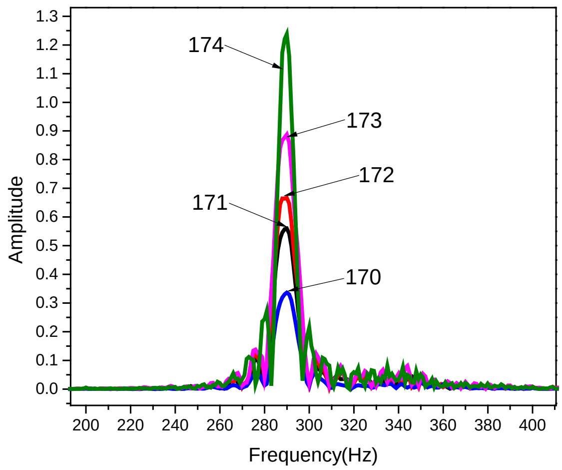

Fig. 5 The influence of the outside diameter on the FR curves

Summary

The numerial model of a centrifugal pump was established under the consideration of the fluid excitation force in this paper. Based on the modal dynamics method, the analysis was carried out to study the effect of the parameters such as the flow rate, the blade number, the exit installation angle and the impeller outside diameter on the dynamic characteristics. The main conclusions are as follows:

- The responses of the centrifugal pump under the fluid excitation force decreases with the increasing of the flow rate; the different flow rates excite the same resonant frequency 291Hz. The optimal number of the blade is 5-blade from the perspective of the vibration reduction. The resonant frequency and the reducing vibration should be considered comprehensively in selecting the blade number.
- The different exit installation angles have the same resonant frequency 290Hz; and the maximal amplitude is for the 30° while the minimal amplitude is for 20°. The design of the outside diameter should consider the response to get a better damping; and in this calculation example, the 170mm is the better selection only from the vibration reduction. It is prudent and comprehensive to design the parameters of the centrifugal pump.

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