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Numerical and experimental studies of hydraulic noise induced by surface dipole sources in a centrifugal pump*

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Abstract: The influences of the four different surface dipole sources in a centrifugal pump on the acoustic calculating accuracy are studied in this paper, by using the CFD combined with the Lighthill acoustic analogy methods. Firstly, the unsteady flow in the pump is solved based on the large eddy simulation method and the pressure pulsations on the four different surfaces are obtained. The four surfaces include the volute surface, the discharge pipe surface, the inner surface of the pump cavity, and the interfaces between the impeller and the stationary parts as well as the outer surface of the impeller. Then, the software Sysnoise is employed to interpolate the pressure fluctuations onto the corresponding surfaces of the acoustic model. The Fast Fourier Transform with a Hanning window is used to analyze the pressure fluctuations and transform them into the surface dipole sources. The direct boundary element method is applied to calculate the noise radiated from the dipole sources. And the predicted sound pressure level is compared with the experimental data. The results show that the pressure fluctuations on the discharge pipe surface and the outer surface of the impeller have little effect on the acoustic simulation results. The pressure pulsations on the inner surface of the pump cavity play an important role in the internal flow and the acoustic simulation. The acoustic calculating error can be reduced by about 7% through considering the effect of the pump cavity. The sound pressure distributions show that the sound pressure level increases with the growing flow rate, with the largest magnitude at the tongue zone.

Key words: centrifugal pump, noise, large eddy simulation (LES), dipole source, experiment

Introduction

The quality of the environmental noise and sound in cities of China has been attracting more and more attentions in resent years. The pump, as is most frequently used for power transmission, generates a lot of noise, which becomes one of the key factors which affect the sound quality in cities. Therefore, the study of noise radiated by centrifugal pumps is important. The noise of centrifugal pumps is mainly induced by both mechanical problems and hydraulic unsteadiness. The mechanical noise is mainly caused by misalignment of the rotors and the mass imbalance. However, with the rapid developments of online dynamic balancing technology recently, the mechanical problems can be solved easily. Comparing with the mechanical causes, the turbulence and the fluid-structure interaction inside a pump can not be easily removed. The noise generated by unsteady flow in centrifugal pumps is unavoidable, therefore, the hydraulic noise is an important research issue. The experiments of noise in a centrifugal pump conducted by Langthjem and Olhoff[1] show that the dipole source is the main cause of noise. The dipole source is an unsteady fluid force acting on the wall surface, induced by the dynamic interaction between the rotor and the stator. The dipole can be represented by a sound source model composed of two monopoles in a close proximity to each other[2]. The pressure pulsations in centrifugal pumps studied by Choi et al.[3] show the same results as obtained by Langthjem and

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Olhoff[1]. Timouchev and Tourret[4] investigated the sound pressure level at the blade passing frequency of centrifugal pumps and the relationship between the pressure pulsation in pumps and the sound pressure was summed up. Srivastav et al.[5] examined the influence of the radial gap between the impeller and the stator on the vibration and the noise, and it was revealed that the overall level of the vibration and the noise would be reduced by decreasing the radial gap. The flow rate is one of the main factors affecting the radiated noise according to the experimental research by Yuan et al.[6]. Also, the effects of the blade number and the impeller outlet width on the hydraulically generated vibration and noise in centrifugal pumps were studied by experiments and simulations[7,8].

Currently, the CFD combined with the Lighthill acoustic analogy method was widely used for the sound computation[9]. For the noise calculation in centrifugal pumps, this hybrid method was proven feasible and was an important means for complementing the lack of the experiment[7,10-13]. In the acoustic calculations, the first step is the CFD simulation, which makes the CFD method a very important factor affecting the acoustic calculating accuracy. The noise simulation conducted by Wagner et al.[14] was carried out by using the Reynolds turbulence model and the large eddy simulation (LES) turbulence model. The results show that the LES model is more accurate when solving the noise source of the acoustic wave propagation equation. Several authors used the LES turbulence model in the noise calculations for centrifugal pumps[7,10-13]. However, though the unsteady flow field can be predicted accurately, the unsteady force on the appropriate surfaces should be considered in order to improve the acoustic calculating accuracy. Most previous studies considered the forces on the volute and blade surfaces. The unsteady force acting on the pump leakage paths was rarely included in the acoustic simulation. The experiment conducted by Hsu and Brennen[15] indicated that leakage flow from the impeller outlet to the front sidewall gap between the shroud and the casing can produce a great hydraulic force, about 70 percent of the total radial force and 30 percent of the total tangential force. These alternating hydraulic forces can induce a great deal of vibration and noise. Therefore, it is necessary to study the influence of the leakage flow in the pump cavity on the acoustic simulation accuracy.

The main goal of this paper is to study the influences of four different surface dipole sources in a centrifugal pump on the noise calculating accuracy. For this purpose, a single stage and single suction type centrifugal pump with a shrouded impeller is chosen for both experimental and numerical studies. Firstly, the internal transient flow field of the pump is solved based on the large eddy simulation method. The pressure pulsations on the four different surfaces are obtained during two impeller revolutions. The four surfaces include the volute surface, the discharge pipe surface, the inner surface of the pump cavity, and the interfaces between the impeller and the stationary parts as well as the outer surface of the impeller. Then, the Fast Fourier Transform with a Hanning window is used to analyze the pressure fluctuations and transform them into the surface dipole sources. On basis of the Lighthill acoustic analogy theory, the direct boundary element method is applied to calculate the noise radiated by different surface dipole sources. Lastly, the predicted results at three different flow rates are compared with the experimental data.

1. Internal unsteady flow simulation

The focus of the present investigation is a single stage and single suction centrifugal pump with a shrouded impeller. The impeller is designed to operate at 2 900 rpm. The designed flow rate is $Q_{\text{opt}} = 50\ \text{m}^3/\text{h}$ and the designed head is $H_{\text{opt}} = 30\ \text{m}$, with the specific speed $n_s = 97$. The main geometric parameters of the test pump are summarized in Table 1.

Table 1 Main parameters of the test pump

Parameter	Value
Inlet diameter of impeller, d_1/m	0.036
Outlet diameter of impeller d_2/m	0.168
Number of blades, z	5
Outlet blade angle, β_2/°	33
Total blade wrap angle, γ/°	115
Outlet width of impeller b_2/m	0.01
Blade passing frequency, f_{BP}/Hz	242
Radius to cutwater d_3/ m	0.184
Volute width, b_3/m	0.02
Discharge nozzle diameter, d_4/m	0.05

A CAD model is generated first as shown in Fig.1. The computing model includes (1) the pump cavity, (2) the impeller, (3) the volute and (4) the discharge pipe. As the impeller (2) has a relative rotation with respect to the three other parts, six surfaces are created as the interfaces between (1)-(2), (1)-(3) and (3)-(4). Figure 1 shows the details of the computing model and the interfaces. In Fig.1, the surface A serves as the interface between the volute and the discharge pipe. The surface B is the interface between the pump cavity and the volute. The surface C, D, E and F are used as the interfaces between the pump cavity