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EXPERIMENTAL STUDY ON THE PUMP ACOUSTIC SOURCE CHARACTERIZATION BASED ON THE TWO PORT MODEL

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The centrifugal pump is one of the main noise sources with independent acoustic characteristics in the water pipeline system. Research on the acoustic source characteristics has significant importance in the design of the low noise pipeline system. In this paper, the two port model is adopted to describe the acoustic source characteristics of the centrifugal pump. Both the multi-load method and the two location source method are employed to obtain the source characteristics. Effects of the random turbulent fluctuation pressure and the vibration on the water noise measurement are eliminated. The obtained results of the source strength from both methods agree well with each other. It is shown that the water muffler can change the acoustic load of the pipe effectively in the multi-load method and the scattering matrix of the working mode can be approximately substituted by that of the non-working mode in the source method.

Keywords: source characteristics； two port model； multi-load method； two position of sound source method

1. Introduction

The pipeline system is widely used in various industries. In recent years, the noise of pipeline system has attracted more and more attention. The hydrodynamic noise in the pipeline system is mainly caused by fluid motion instability (turbulence, cavitation and so on) induced by pump, valve, etc. Among those hydrodynamic noise sources, the pump is the dominant one. Research on the acoustic source characteristics has important significance for the quantitative design of the low noise pipeline system.

The popular mathematical models for the acoustic source characteristics include the one port model [1] and the two port model [2], where the pump is regarded as a "black box". The one port model is directly applicable to the pumps that there is limited acoustic transmission between the two ports, and the test process of the one port model is easy to be accomplished. The two-port model represents a more general description of centrifugal pumps, allowing the acoustic interaction between pump ports. Therefore, its application is not restricted by the pump geometry and size, and the acoustic wavelength. But the test process of the two port model is more complex. Rzentkowski et al. [3] employed the two port model to research the acoustic source characteristics of a single-stage, double-volute pump, and investigated the source characteristics at the blade-passing frequency by an experimental method. Ye et al. [4] discussed the multi-load method and the sound source method. Zhang et al. [5] predicted the source characteristics of a plate using the multi-load method based on the commercial code Sysnoise. Zhong et al. [6] measured the source characteristics of a valve by the sound source method. Liu [7] applied the multi-load method to examine the source characteristics of a butterfly valve. Bardeleben [8] examined the centrifugal pump acoustic characteristics based on the scattering matrix model.

In this paper, the acoustic source characteristics of the centrifugal pump are described using the two port model. The multi-load method and the two position source method have been used to obtain the needed acoustic signals. The obtained results are verified by comparison.

2. Formulation of Experimental Technique

2.1 Two port model

The two port model accounts for the acoustic coupling between the pump suction and discharge ports (see Figure 1). The scattering matrix form can be expressed as

$$\begin{pmatrix} p_{o+} \\ p_{i+} \end{pmatrix} = \begin{pmatrix} r_o & \tau_i \\ \tau_o & r_i \end{pmatrix} \begin{pmatrix} p_{o-} \\ p_{i-} \end{pmatrix} + \begin{pmatrix} p_{so+} \\ p_{si+} \end{pmatrix} = [S] \begin{pmatrix} p_{o-} \\ p_{i-} \end{pmatrix} + \begin{pmatrix} p_{so+} \\ p_{si+} \end{pmatrix} \tag{1}$$

where p_{o+} and p_{o-} denote acoustic waves travelling along the positive and negative direction of the pump discharge, p_{i+} and p_{i-} denote acoustic waves travelling along the positive and negative direction of the pump suction, p_{so+} and p_{si+} denote the source strengths at the pump suction and discharge ports, and [S] is the scattering matrix.

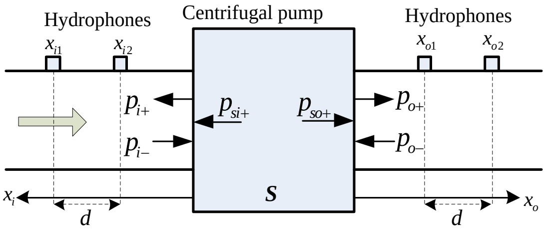


Figure 1: Schematic diagram of the two port model

The present paper employs both the multi-load method and the two location source method to obtain the acoustic characteristic parameters used in the two port model.

2.2 Multi-load method

In the multi-load method, the impedance boundary condition is changed by altering the acoustic loads of the pump suction and discharge ports. The acoustic waves are obtained by the wave decomposition method based on the experimental data. Instituting the calculated p_{o+}, p_{o-}, p_{i+} and p_{i-} into Eq. (1), then

$$\begin{gathered} \begin{pmatrix} p_{o+}^{(1)} \\ p_{o+}^{(2)} \\ \vdots \\ p_{o+}^{(n)} \end{pmatrix} = \begin{pmatrix} p_{o-}^{(1)} & p_{i-}^{(1)} & 1 \\ p_{o-}^{(2)} & p_{i-}^{(2)} & 1 \\ \vdots & \vdots & \vdots \\ p_{o-}^{(n)} & p_{i-}^{(n)} & 1 \end{pmatrix} \begin{pmatrix} r_o \\ \tau_i \\ p_{so+} \end{pmatrix} \\ \begin{pmatrix} p_{i+}^{(1)} \\ p_{i+}^{(2)} \\ \vdots \\ p_{i+}^{(n)} \end{pmatrix} = \begin{pmatrix} p_{o-}^{(1)} & p_{i-}^{(1)} & 1 \\ p_{o-}^{(2)} & p_{i-}^{(2)} & 1 \\ \vdots & \vdots & \vdots \\ p_{o-}^{(n)} & p_{i-}^{(n)} & 1 \end{pmatrix} \begin{pmatrix} \tau_o \\ r_i \\ p_{si+} \end{pmatrix} \end{gathered} \tag{2}$$

According to Eq. (2), it needs at least three sets of experimental data to determine the source characteristics.

2.3 Two position of sound source method

The two position of sound source method obtains the acoustic characteristics by three steps. Step 1: The external strengthening sound source is applied at the pump suction port. Step 2: The sound source at the suction port is closed while the external strengthening sound source at the discharge port is open. The scattering matrix [S] can be obtained by the following equation.

$$\begin{pmatrix} p_{o+}^{(1)} \\ p_{o+}^{(2)} \end{pmatrix} = \begin{pmatrix} p_{o-}^{(1)} & p_{i-}^{(1)} \\ p_{o-}^{(2)} & p_{i-}^{(2)} \end{pmatrix} \begin{pmatrix} r_o \\ \tau_i \end{pmatrix}$$
$$\begin{pmatrix} p_{i+}^{(1)} \\ p_{i+}^{(2)} \end{pmatrix} = \begin{pmatrix} p_{o-}^{(1)} & p_{i-}^{(1)} \\ p_{o-}^{(2)} & p_{i-}^{(2)} \end{pmatrix} \begin{pmatrix} \tau_o \\ r_i \end{pmatrix} \tag{3}$$

Step 3: The sound sources at the pump suction and discharge ports are all closed. Then, the source strength can be obtained by the following equation.

$$\begin{pmatrix} p_{so+} \\ p_{si+} \end{pmatrix} = \begin{pmatrix} p_{o+}^{(3)} \\ p_{i+}^{(3)} \end{pmatrix} - \begin{pmatrix} r_o & \tau_i \\ \tau_o & r_i \end{pmatrix} \begin{pmatrix} p_{o-}^{(3)} \\ p_{i-}^{(3)} \end{pmatrix} \tag{4}$$

3. Experimental validation

3.1 Test rig

The acoustic characteristics of the centrifugal pump were measured on the open circulating water pipeline system, which mainly consists of the pump, the test tube section and the rigid support. The schematic diagram of the test rig is shown in Figure 2. The test was conducted on a 100-CLG-30 type centrifugal pump with rated flow equal to 80t/h and rated speed equal to 2930r/min. The pump is directly connected with the test tube section. The length, inner diameter and wall thickness of the inlet and outlet pipes are 2200mm, 100mm and 7mm respectively. Each test tube section is equipped with 3 hydrophones with the same distance 0.5 m. The 4314 type acceleration transducer is arranged around the 8103 type hydrophone to monitor the vibration of the pipe wall. The rigid support is used to reduce the pipe vibration effect on the water acoustic measurement.

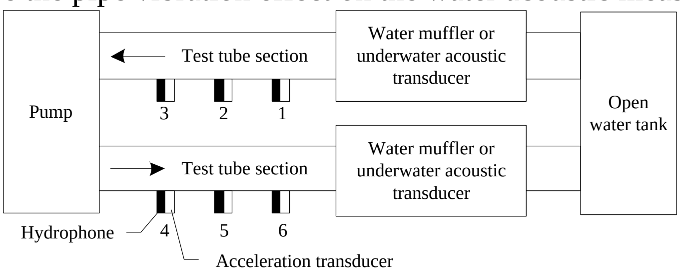


Figure 2: Schematic diagram of the test rig

3.1.1 *Multi-load method*

For experimental study with the multi-load method, two water mufflers shown in Figure 3 are used to alter the acoustic load of the pump suction and discharge ports. Four cases are employed to test the pump source variables. In case 1, the pump suction port is connected with the water muffler but the pump discharge port is not connected with the water muffler. In case 2, the pump suction port is not connected with the water muffler but the pump discharge port is connected with the water muffler. In case 3, both the pump suction and discharge ports are not connected with the water muffler. In case 4, both the pump suction and discharge ports are connected with the water muffler.

Figure 3: Water mufflers used in the experiment

3.1.2 Two position of sound source method

For the experimental study on the pump source characteristics with the two position of sound source method, an underwater acoustic transducer with ultra-low frequency and high power is connectedwith the test tube section as shown in Figure 4. The operating frequency range of the transducer is from 5Hz to 1.6kHz. The maximum sound source level is up to 158dB, but it is still lower than the sound level of the running pump. Therefore, the scattering matrix of the working mode is approximated by that of the non-working mode.

Figure 4: Underwater acoustic transducer used in the experiment

3.2 Results and discussion

The three hydrophones method in Ref. [9] is employed to eliminate the effects of the random pulsating pressure. The hammering method is employed to estimate the effect of the pipe wall vibration on the water acoustic measurement. Figure 5 shows the comparison of the hydrophone signal, the random pulsating pressure and the vibration disturbance of 1/3 octave band. Since both the random pulsating pressure and the vibration disturbance are at least 10dB lower than the hydrophone signal, the hydrophone signal can be used to calculate the acoustic source characteristics directly. It demonstrates that the test equipments fixed on the test tube section have little influence on the flow field and can effectively avoid the influence of the random pulsation pressure. It also demonstrates that the test tube section has good damping measures which can effectively avoid the influence of the pipe wall vibration on the water acoustic measurement.

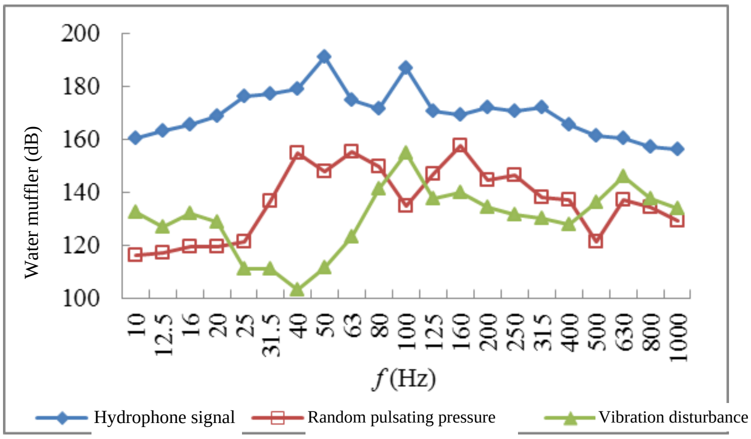
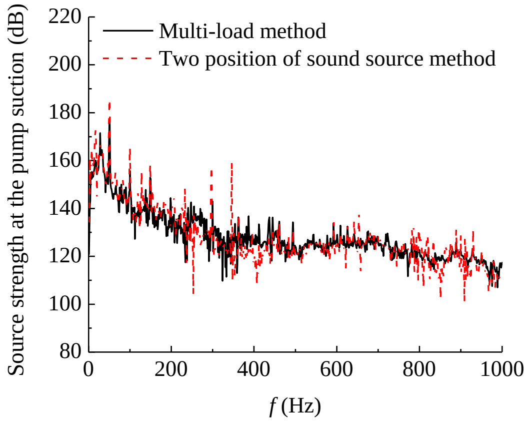
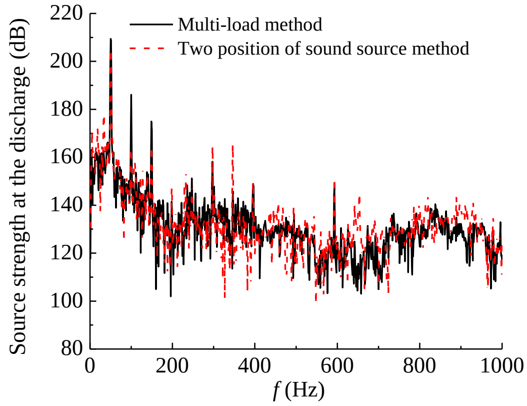


Figure 5: Comparison of the hydrophone signal, the random pulsating pressure and the vibration disturbance of 1/3 octave band

Figure 6 shows the acoustic source characteristics intensity of the centrifugal pump obtained by the multi-load method and the two position of sound source method. The experiment results agree well with each other, which demonstrate the water mufflers employed can effectively change the acoustic load of the pipe and the scattering matrix of the working mode can be approximately replaced by that of the non-working mode.



(a) pump suction



(b) pump discharge

Figure 6: Acoustic source characteristics intensity of the centrifugal pump

4. Conclusions

In the present open circulating water pipeline system, both the multi-load method and the two location source method are employed to obtain the source characteristics. Both the random pulsating pressure and the vibration disturbance are at least 10dB lower than the hydrophone signal which can be used to calculate the acoustic source characteristics directly. The acoustic source characteristics obtained by the multi-load method and the two position of sound source method agree well with each other. The water mufflers employed can effectively change the acoustic load of the pipe and the scattering matrix of the working mode can be approximately replaced by that of the non-working mode.

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