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Study on Numerical Model of Vortex Shedding for Three-way Pipe

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ABSTRACT
The three-way pipe vortex shedding phenomenon is the main excitation source for pipe vibration, which can lead to the generation of acoustic resonance. The existing researches mainly focus on air and wet steam, however the researches on water medium is rare. In this paper, the formation mechanism of vortex shedding for three-way pipe under water medium is studied, and the influence of turbulence model, water compressibility, boundary layer and model size is discussed. A more accurate simulation model is established, The suggestions for the establishment of the three-way pipe vortex shedding simulation model are given according to the simulation results.

Keywords: Three-way pipe, Vortex shedding, Simulation
I-INCE Classification of Subject Number:76

1.INTRODUCTION

The three-way pipeline is shownas Figure 1. The strong vortex shedding phenomenon causes pressure waves to be transmitted to the branch pipe, and the pressure fluctuation is locked by the fluid of the branch pipe and amplified (acoustic vibration). The acoustic vibration frequency coincides with the frequency of the pipeline structure, which leads to violent vibration in pipeline, which greatly exceeds the pipeline vibration limit and seriously affects the safety and reliability of the pipeline.

Due to the fast and large flow rate of the medium in the main pipeline, there is a stagnant dead water zone in the branch pipe, and the incoming flow forms a shear flow at the junction of the main pipe and the branch pipe, so that the flow of the main pipe and the branch pipe are separated. The branch pipe fluid is retained, and the shear flow is simultaneously moved from the inlet to the outlet at a certain period. When the vortex shear flow hits the outlet side, the vortex is dispersed into the dead water zone of the branch pipe and the outlet side, the small vortex is formed and continues to develop. Thereby, pressure fluctuations with a certain periodicity are formed, which exacerbates the turbulence in the pipeline.

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For the phenomenon of vortex shedding in the three-way pipes, large of the researches have focused on air, dry steam, and wet steam [1-2], forming a series of criteria for evaluating vortex shedding. The most representative criteria is St number (Stoluha number), St is used as a dimensionless parameter to evaluate the vortex shedding, and is related to the vortex shedding frequency, fluid velocity, pipe diameter, etc. The study shows that the vortex shedding phenomenon is obvious when the St number is near 0.4 and the pressure fluctuation is large. It is easy to induce the acoustic resonance and increase the magnitude of the vibration.

The relevant research on water medium in the vortex shedding phenomenon of the three-way pipeline is not found. In order to explore the mechanism of vortex shedding in water medium, and form an evaluation criterion that can be applied quickly, this paper studies the influencing factors of the numerical calculation model of vortex shedding in air medium. The CFD fluid calculation method is adopted to simulate the phenomenon. And the St is specificed to calculate the vortex shedding characteristics. The key simulation parameters is obtained relying on experience in the most of the existing research. The research on the influencing factors of the simulation model is not found. Therefore, The effects of different factors of three-way vortex shedding and acoustic resonance simulation are verified in this paper by setting different air fluid medium characteristics compressibility, turbulence model, model size and boundary layer, etc. Finally, the accurate simulation calculation model for simulating the vortex shedding phenomenon of three-way pipeline is obtained, which lays a foundation for the vortex shedding CFD simulation model under water medium.

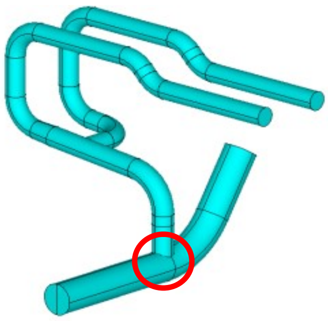

Fig 1 The Three-way Pipe

2. ANALYSIS MODEL

In this paper, a representative three-way pipe is selected to study. The geometric and finite element model is established. The main pipe diameter is D. The branch pipe diameter is d, and D/d=10/3. The branch length is D, and the main pipe length is 11D,which meet the requirements of full development of fluid calculations and can avoid the impact of inadequate flow on the results. The air medium is used in fluid domain. The speed inlet boundary conditions are set as follows: T=300K, P=0.1Mpa, V= 55m/s; the outlet is set as pressure boundary; other parts are set to have no sliding wall condition.

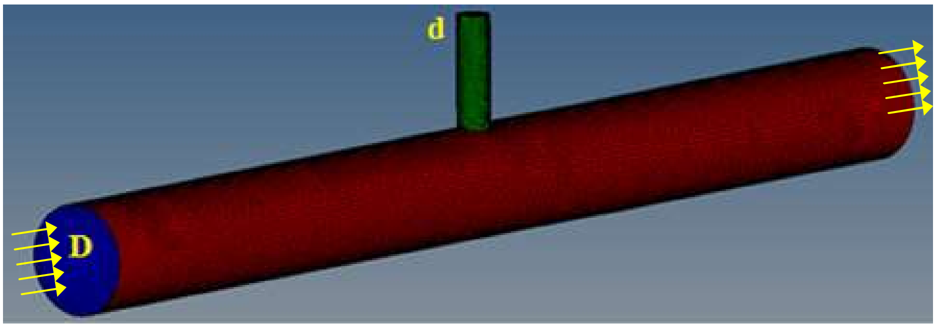

Fig 2 The Whole Calculation Model

The analysis model of Fig. 3(b) is used When verifying the effect of the boundary layer on the vortex shedding. The model with boundary layer in Fig. 3(a) is used when verifying other influencing factors. The internal structure of the two models is shown in Figure 3.

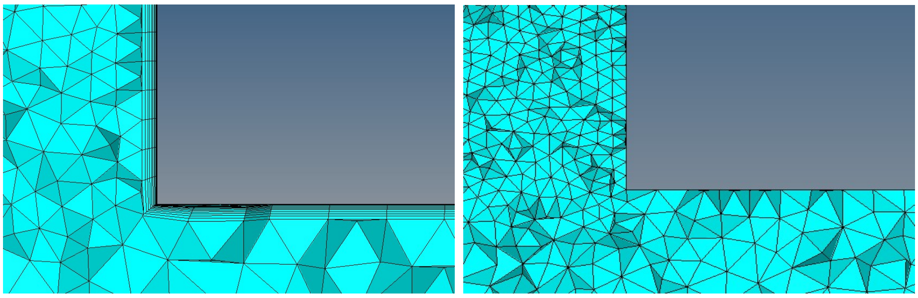

Fig 3 The Internal Structure of Fluid

（a) with boundary; （b) without boundary

The monitoring points are set at the same position under each calculation condition. The monitoring points Point1-Point5 are distributed in the three-way branch pipe and connection between the main pipe and the branch pipe. The position of the monitoring points is shown in Figure 4.

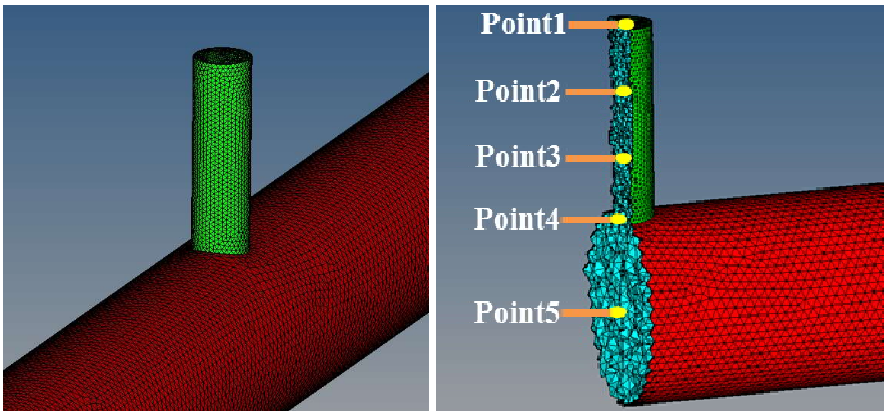

Fig 4Monitor Pionts of Pipe

The acoustic resonance problem caused by the vortex shedding phenomenon in the three-way pipe is generally evaluated by St[3]. The acoustic resonance frequency of the pipeline can be quickly calculated using the St and the pipe size. The formula is as follows:

Assuming that the inlet velocity of the three-way pipe is U, the diameter of the branch pipe is d, and the resonance frequency f_n , the dimensionless parameter St can be obtained, where f_n is the first-order acoustic resonance frequency along the branch pipe[4-6],.

$$f_n = \frac{c}{\lambda} = \frac{c}{\left(4\left(h + C_0 d\right)\right)} \qquad \text{Equation 1}$$

$$S_t = \frac{f_n \times d}{U} \qquad \text{Equation 2}$$

Where c: sound speed; c_0: correction factor, generally taken as 0.4.

The acoustic resonance is caused by the periodic vortex shedding in the three-way pipe, so the frequency of the acoustic resonance is caused by the vortex shedding, which causes serious vibration and noise problems. From the literature[1], it can be seen that the vortex shedding phenomenon is most obvious when the dimensionless vortex shedding frequency St=0.414, so the St number is 0.414 for calculation in this paper.

3. RESULT ANALYSIS

In order to explore the influencing factors of the the numerical simulation model of vortex shedding, The influence of different parameters on the vortex shedding phenomenon is obtained. Based on FLUENT calculation, the numerical simulation model of the vortex shedding of the three-way pipeline is established. The following four influencing factors is included: turbulence calculation model, boundary layer, fluid compressibility and the model size.

In the calculation of the vortex shedding phenomenon, the influence factors mentioned above are verified and compared. Firstly, the influence of the turbulence model is studied. When different turbulence calculation models are used, the requirements of fluid properties and model mesh quality are different, so that the number of calculated differential equations is different and the the application range of each turbulence model is also different. Three common turbulence models in FLUENT are used. The different turbulence models are calculated and compared to obtain the vortex shedding phenomenon. Figure 5 is a pressure cloud and vorticity cloud of the vortex shedding phenomenon in the three-way pipe at a certain time using the LES turbulence model.

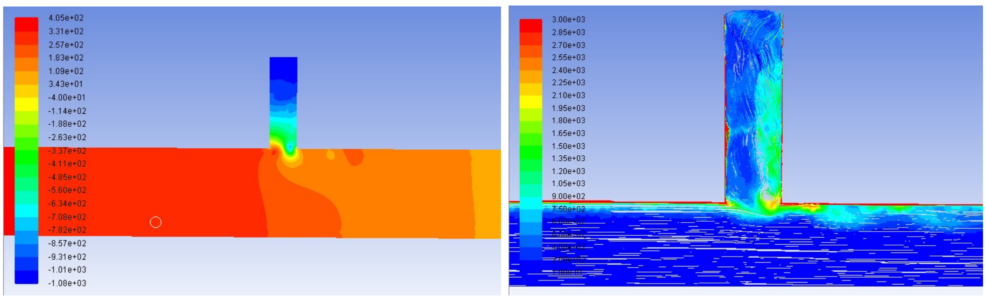

Fig 5 The Phenomenon of Vortex Shedding

（a）pressure cloud; （b）vorticity cloud

3.1 Turbulence model influence

By calculating the vortex shedding phenomenon under three different turbulence models: k-ε, SST and LES (large eddy simulation), the pressure pulsation time history of the same monitoring point(Point1)in the branch pipe is extracted. The monitoring data is converted to frequency domain and is shown as Figure 6 - Figure 8. It can be found that the amplitude of the pressure fluctuation under the k-ε and SST turbulence models is larger than that under the LES turbulence model. And from the spectrogram, there is no obvious characteristic frequencies using k-ε and SST turbulence models. Compared with the data in Figure 9, the LES turbulence model calculating results have a good coincidence with experiment. So, the large eddy simulation (LES) turbulence model can accurately simulate the vortex shedding phenomenon.

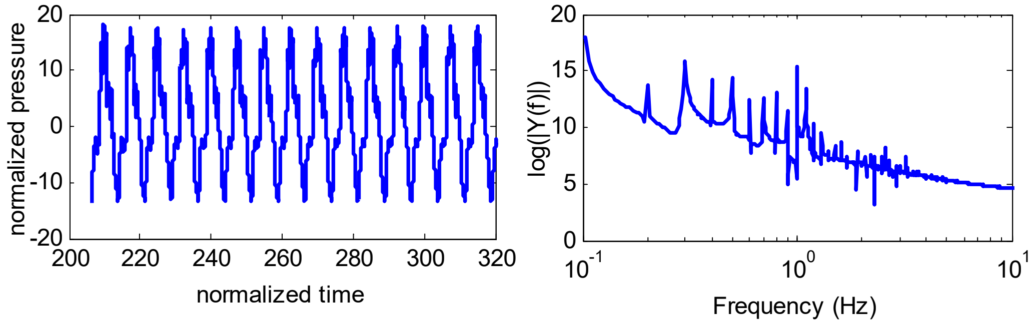

Fig 6 k-εTurbulence Model

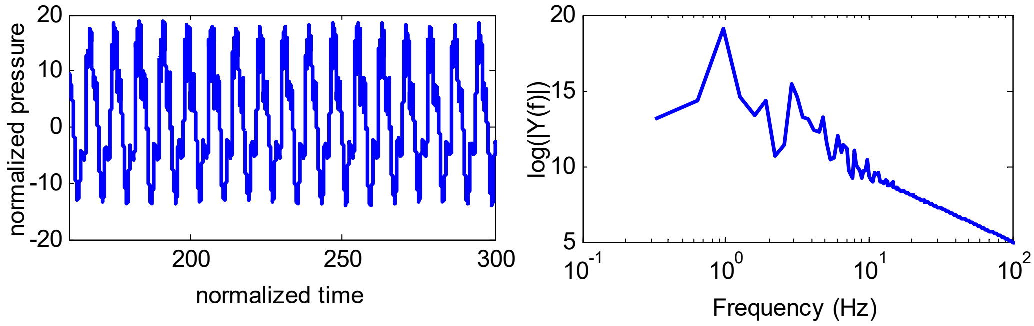

Fig 7 SST Turbulence Model

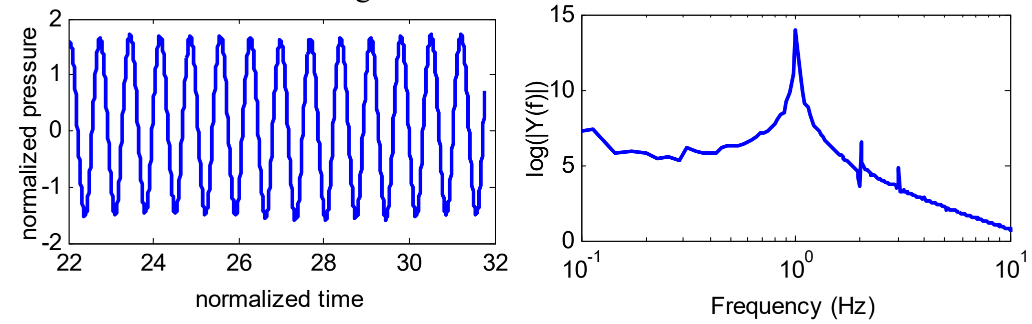

Fig 8 LES Turbulence Model

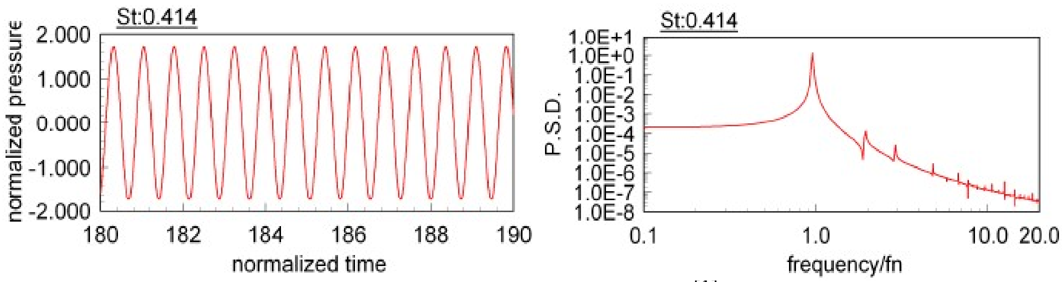

Fig 9 Experimental Results[1]

3.2 Boundary layer influence

Different partial differential equations are established according to the flow state during the fluid calculation. And the fluid state is divided into laminar flow and turbulent flow. For the vortex shedding phenomenon in the three-way fluid pipeline, the appropriate is established in the numerical simulation model for calculation. The boundary layer also have great effect on the calculation results. The comparative model in the calculation is shown in Figure 3. Comparing Fig. 10 with Fig. 11, it can be found that when there is no boundary layer in the model, the pressure time history amplitude of the same monitoring point will decrease, and the characteristic frequency region will diverge. Although there is a main peak in the frequency domain, there appears frequency oscillation which can not reflect the periodic variation of vortex shedding in the higher frequency domain. Compared with the experimental results in Figure 9, it can be known that the numerical model of the vortex shedding in the three-way pipe should be set according to the actual flow in the pipe.

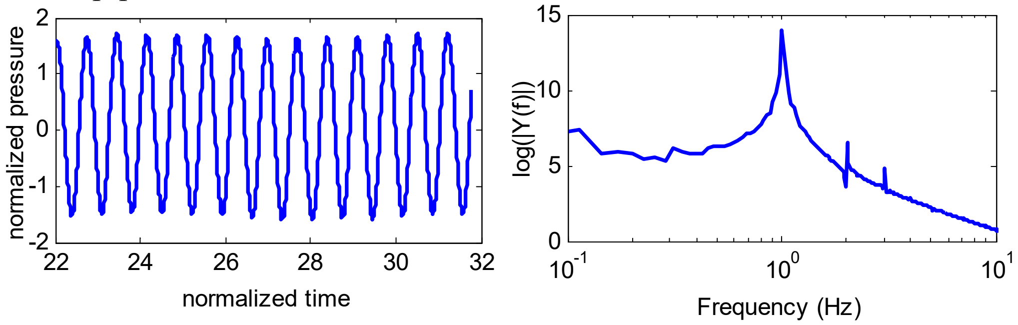

Fig 10 With Boundary

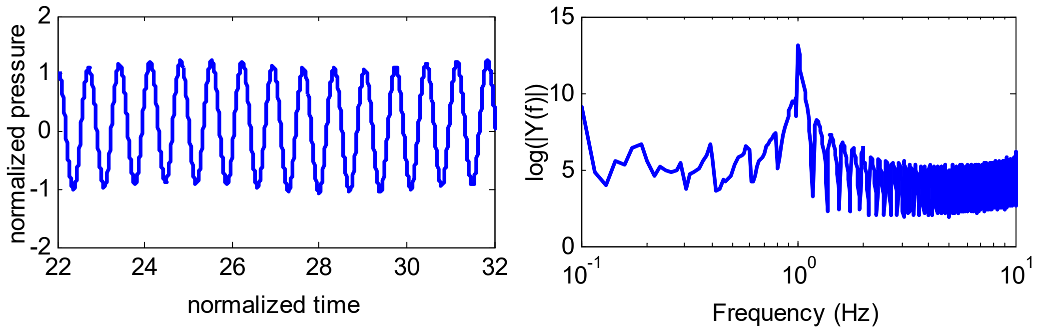

Fig 11Without Boundary

3.3 Compressibility influence

For fluid simulation calculations in air media, FLUENT has a variety of gas properties to choose. Different gas properties are adapted to solve different working conditions, which needs to choose the appropriate gas model based on practical problems. The main reason for the formation of vortex shedding in the three-way pipe is the generation of pressure waves in the pipe. So the gas compressibility has a great influence on the calculation results. The effect of fluid compressibility on the vortex shedding characteristics was verified by setting the numerical calculation of the air compressibility in the model. The calculation results are shown in Fig. 12-13.

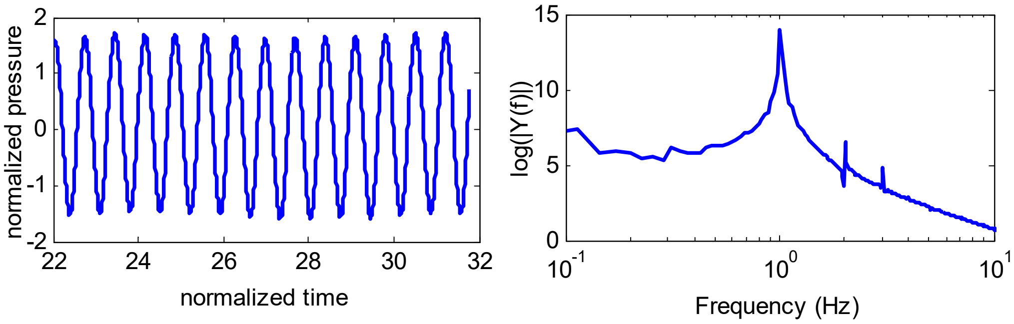

Fig 12Compressible fluid

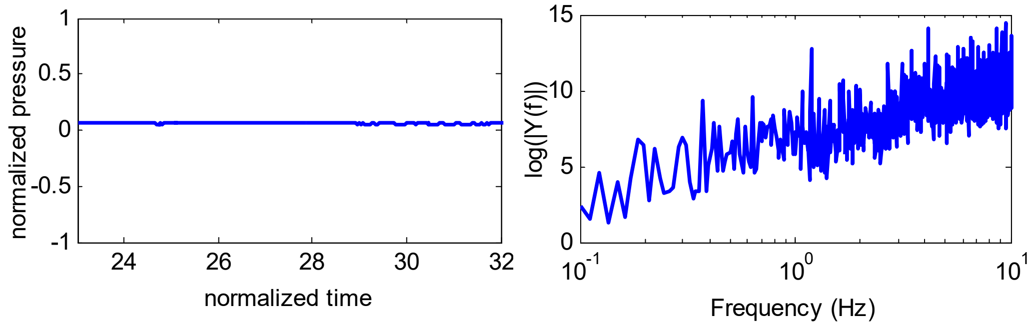

Fig 13Incompressible fluid

Comparing Fig. 9, Fig. 12 and Fig. 13, it can be seen that the compressible gas in the computational simulation model can accurately reveal the periodic characteristics of the vortex shedding phenomenon. For the incompressible gas, the periodic characteristics are almost completely submerged, and there is also no obvious peak in the frequency domain data, which indicates that the compressibility of the fluid needs to be considered in the numerical simulation model of the vortex shedding.

3.4 Model size influence

In order to verify the irrelevance of the size effect of the calculation model, the paper calculated and compared the calculation results of the vortex shedding phenomenon of the three-way flow channel under different scaling models. Under the same St. The amplitude of the vortex shedding pressure fluctuation under different scales is about the same, and the frequency has a corresponding multiple relationship, and also the characteristic frequency is obvious. It is indicated that due to the dimensionless of St, the calculation model size has no effect on the calculation results. As long as the St number is consistent, accurate calculation results can be obtained.

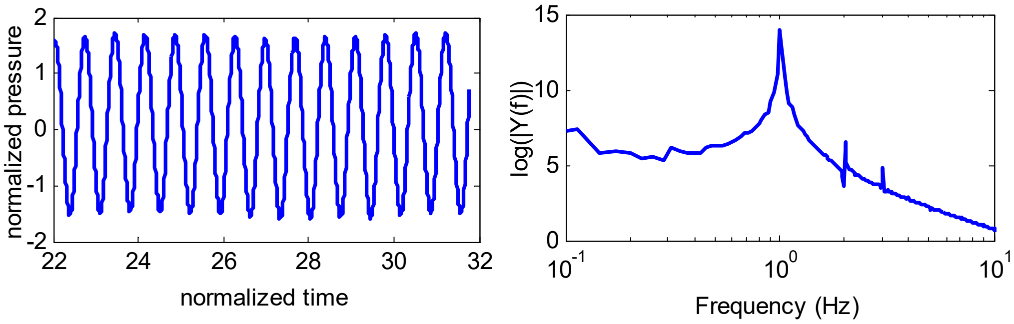

Fig 14 1:1 Model

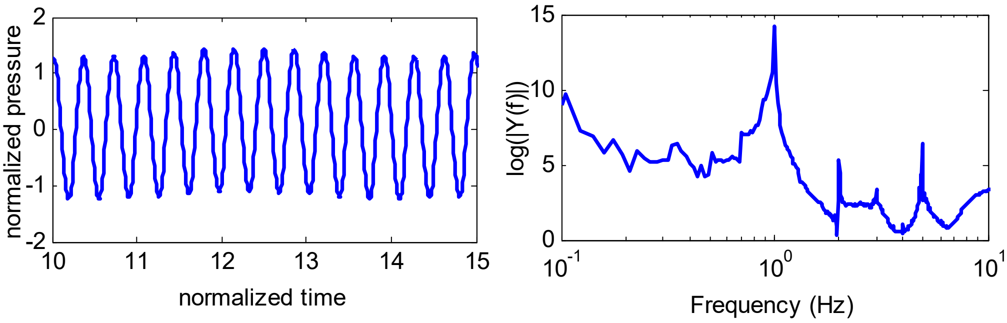

Fig 15 Scale Model

3.5 Verification of numerical models

Through the study, the numerical calculation CFD model which can simulate the vortex shedding in the three-way pipe is obtained. In order to verify the correctness of the model, this paper will use the final simulation model to calculate and compare the calculated results with the experimental data. Firstly, the vortex shedding in the three-way pipe at St=0.414 is calculated, the pressure pulsation of Point1-Point5 is monitored, and the corresponding experiment is carried out. The monitoring point setting is the same as in the calculation model, and the pressure pulsation time history data of the monitoring points are extracted for comparison. Figure 16 shows the time history of Point1 (red line), Point4 (black line), and Point5 (blue line). The left ordinates of both (a) and (b) are Point1 axes. Due to the position of the monitoring point error between the calculation and the experiment, the amplitude of the monitoring point data has some little difference, but it is completely within the acceptable error range. Therefore, the pulsation data calculated by the simulation model is almost consistent with the experimental values, which fully proves the correctness of the model.

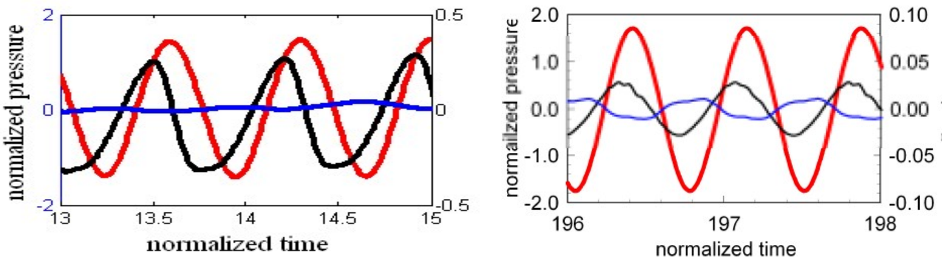

Fig 16 Comparison of Pressure inPipes

（a）calculation results; （b）experiment results[1

4. CONCLUSIONS

In this paper, the vortex shedding in the three-way pipeline is studied, and the simulation model of vortex shedding in the air medium is established. By comparison, the large eddy simulation (LES) turbulence model, the boundary layer and the fluid compressibility is necessary to simulate vortex shedding phenomenon and the calculation model size ratio has no effect on the calculation result. Finally, the proper simulation model is used to calculate the vortex shedding characteristics under St=0.414, and the corresponding monitoring points are set. Compared with the experimental data, the simulation and experimental pressure pulsation data are in good agreement with the frequency domain characteristics. The four factors are verified in the simulation model. The vortex shedding simulation calculation model that meets the engineering needs is obtained. At the same time, the foundation for the establishment of the simulation analysis model of the vortex shedding phenomenon under the water medium is laid.

5. ACKNOWLEDGEMENTS

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