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EXPERIMENTAL STUDY OF ORIFICE-INDUCED PRESSURE FLUCTUATION AND PIPE VIBRATION

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ABSTRACT

This paper presents the hydraulic test for studying the orifice induced pressure fluctuation and vibration in pipeline. Based on the preliminary test results, which has been presented in paper ICONE13-50931, modification of experimental facility has been made. With more test conditions, the statistical characteristics of the fluctuating pressure and structure acceleration response have been studied. The latest test results confirm that these modifications effectively solved the previous problems. The natural frequencies and the strain response of the structure are also obtained to provide comparison to the numerical mathematical model of the pipe and the response calculation in the near future.

Keywords: Orifice plate, Fluctuating pressure, Hydraulic test, Flow-induced vibration.

1. INTRODUCTION

Although orifice plate has been widely used to control flow rate in piping system, the orifice-induced vibration and noise are seldom studied in literature. However, many malfunctions in nuclear engineering practice caused by orifice-induced vibration and noise are reported (U. S. NRC, 1998; Mao et al., 2003). The tests presented by Mao et al. (2005) and this paper aim to study the characteristics of the pressure fluctuation before and after orifice from the flow-induced vibration point of view and measure the natural frequency of the pipe, which will be used to build the mathematical model of the fluid excitation and structure. In order to provide comparable test data for the coming numerical simulation, the acceleration and strain response of the structure are also obtained.

2. SUMMARY OF PREVIOUS STUDY

Preliminary test has been made last year in State Key Laboratory of Multiphase Flow in Power Engineering of Xi'an Jiaotong University. Paper ICONE13-50931 introduces the research background, test loop layout, instrumentation, data collection system and test conditions. Test results and brief discussion are also included. It is realized that the dominating energy is concentrating at the lower frequency range though the pump induced pressure pulsation produces a high amplitude peak in both the pressure power spectrum density and coherence function and acoustic waves also contribute to the results. However, several problems in the test have been found after the review of test results. An improvement of the test facility is needed. A water block tank has been installed at the pump outlet to absorb the pump induced pressure pulsation wave and other acoustic waves before they can enter the test segment, and another water block tank has been put at the outlet of the test segment to eliminate the backwards propagated acoustic wave. The anchor supports of the test segment have been strengthened to block off the vibrations transmitted from the test loop. Therefore, semi-flexible hoses, which have been used in the previous test, can be removed.

After the modification of the test facility, the test has been redone this year with more measure points, more orifice plates and some adjustment of the data collection methodology. This paper presents the updated test results and discussions. In order to give an overview, the test facility and test process are also included in this paper regardless the repetition of paper ICONE13-50931.

3. EXPERIMENTAL FACILITY

The hydraulic test loop is based on nuclear engineering pipe system. This loop is driven by a centrifugal pump, which is capable of providing 50-ton water flow per hour. It is installed in another room far from the test segment to minimize the possible vibration influence from the ground. Check valves situated on the main loop and bypass loop control the flow rate. The test segment is situated at the flow fully developed area. It is a straight pipe made of stainless steel with orifice equipped in the middle, 6-meter long, 90-millimeter diameter, and 2.5-millimeter thickness, and anchored at both ends. Since the wall roughness is one of the important factors that influence the characteristic of the fluctuating pressure, the inner surface of the test segment has been treated to meet the roughness requirement of nuclear pipe.

The sketch of the test facility is shown in figure 1.

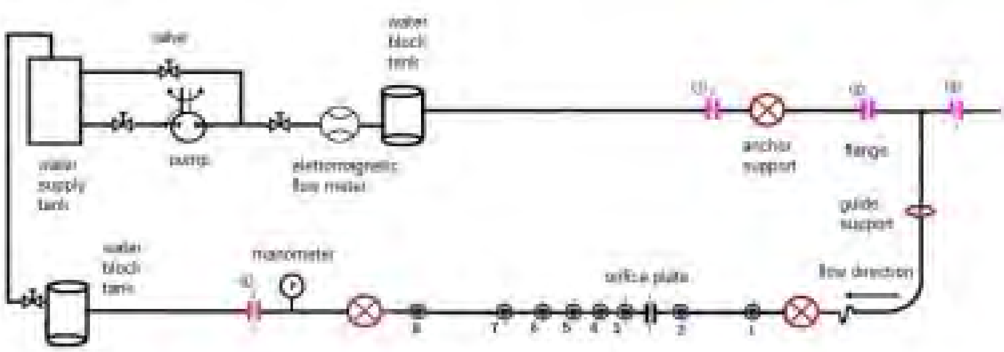

Fig. 1. Sketch of hydraulic test loop

4. TEST PROCESS

4.1 Instrumentations and Data Collection System

Dynamic pressure transducers, which can distinguish millisecond fluctuation, are mounted before and after the orifice to measure the pressure fluctuation caused by the orifice. The mount of pressure transducer needs special attention to avoid the influence to the flow field. Some of the discussions can be found in the literatures (Au-Yang et al., 1980; Kinsler et al., 1982). To study the dynamic pressure fluctuation in both the longitudinal and circumferential directions, two sets of layout schemes have been used: one is to place the pressure transducers along the pipe at the position a, b and c in figure 1, and the other is to place them around the pipe at the same cross section of position b. In order to determine the position of the transducers, Computational Fluid

Dynamic computer code CFX is used to simulate the flow field around the orifice plate, which gives us the idea of the eddy shape and dimension. The position of the transducers have been chosen to be able to pick up the most significant pressure pulsation caused by the disturbance of the orifice plate.

Figure 2 and figure 3 show the picture of axial and radial mounted dynamic pressure transducers, respectively.

Fig. 2. Placement of dynamic pressure transducer in longitudinal direction

Fig. 3, Placement of dynamic pressure transducer in circumferential direction

Besides pressure transducers, manometers are also used to measure the static pressure before and after the test segment, while electromagnetic flow meter provides the information of main loop flow rate. Armoured thermocouple, which is not showed in figure 1, detects the flow temperature.

The data collection and analysis of fluctuation pressure have been done by NI PCI – MIO - 16XE - 10/SCXI - 1120 and Labview7.1. The collected time-history signal has been treated to Power Spectral Density (PSD). Data average is needed to reduce the signal noise effect.

Two vibration accelerometers are mounted before and after the orifice to measure the structure vibration due to the pressure fluctuation. After amplified by B & K 2626 and 2610, the signals are collected and analyzed by HP35670A. The strain responses of the structure are picked up by strain gauges. Sound level meter is also used to measure the noise level radiated from the turbulence flow inside the pipeline.

4.2 Test Conditions

The natural frequency of the test segment has been measured before the hydraulic test, which provides information to validate the finite element modeling of the random vibration analysis. When the pump is shutdown and the loop is full of water, hammer is used to excite the test pipe and accelerometers pick up the free vibration signals of the structure.

The hydraulic test and measurements have been fulfilled under room temperature with the flow rate of 15, 25, 40 m^3/h and orifice hole ratio (the ratio of orifice hole diameter and pipe inner diameter) of 0.255, 0.304, 0.335, respectively. Furthermore, fluctuation pressure and acceleration data have also been collected for the test section without orifice plate. These data are used to compare with the data collected for the test segment with orifice plate to eliminate the effect of other causes such as support transmitting vibration or acoustic noise from upstream section.

5. RESULTS AND DISCUSSION

5.1 Natural Frequency

The first look of the test result is natural frequency of the test segment, which is obtained by FFT of the free vibration signals of the structure. Figure 4 is the Fourier spectrums that show the frequency distribution from 0 to 450 Hz. The lower frequencies of 8.0 Hz, 23.0 Hz, 45.0 Hz, 81.0Hz are corresponding to the beam modes of the test segment. After the modification of test loop, the first beam mode has been increased from 6.75Hz to 8.0Hz.

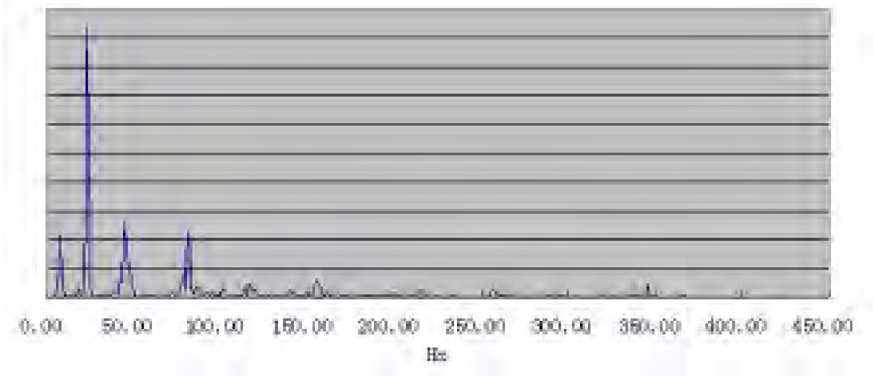

Fig. 4. Fourier spectrums of free vibration signal when pump is shutdown

Comparing with the preliminary test, we significantly increased the maximum test flow rate from 25-ton to 40-ton. However, the decrease of the pipe frequency along with the increase of flow rate inside the pipe is still not visible. The calculation using simplified equation in Mao and Zhang (2004) shows that the maximum flow velocity is still not higher enough to make difference.

5.2 Joint Power Spectral Density of the Fluctuating Pressure

Each pressure time-history signal picked up by pressure transducers has been used to calculate the joint Power Spectral Density, which is the input data for calculating the random vibration response of the structure. Figure 5 is the pressure PSD at measure point 3 when the orifice plate is not mounted, and figure 6 gives the PSD at the same position with orifice. It shows that orifice plate significantly disturbed the pipe flow and greatly increased the pressure fluctuation level.

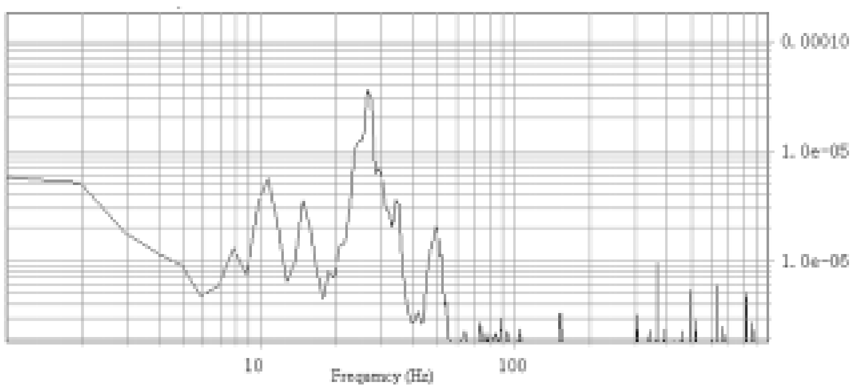

Fig.5. Pressure PSD of measure point 3 without orifice plate

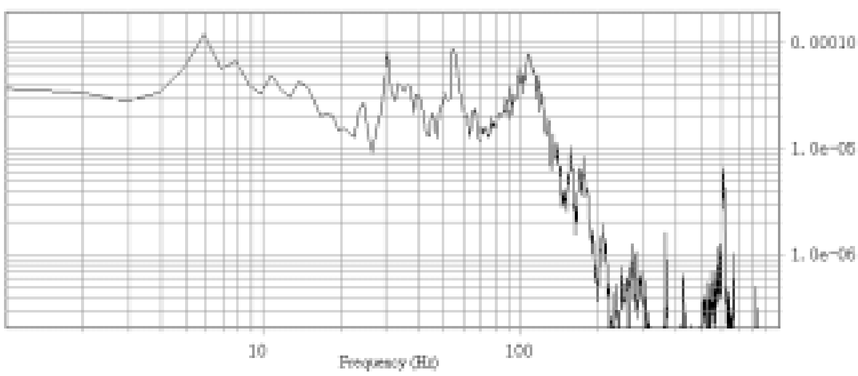

Fig.6. Pressure PSD of measure point 3 with orifice plate

Similar as preliminary test, the energy of the fluctuating pressure is concentrated on the lower frequency range (0-200Hz). Above 200Hz, scarcely any energy can be found. Figure 7 and 8 show the pressure PSD at measure point 7 and 8, which is measured at the same test condition with the same orifice plate as figure 6. Measure point 3 is the first point after the flow passed the orifice plate, while measure point 7 and 8 are much far apart. The distance effect of the fluctuation pressure from the orifice plate can be realized after comparing figure 6, 7 and 8. Again, the energy of the fluctuating pressure at the lower frequency range makes the most significant difference. The farther the distance from the orifice plate, the less the energy contained at the lower frequency range, which let us believe that the orifice disturbance is localize in the vicinity of orifice plate and belongs to near field turbulence, and the main energy content is concentrated at the lower frequency range. This fits in with the statement that the turbulence water flow always contains lower frequency energy in our nature (Au-Yang et al., 1980).

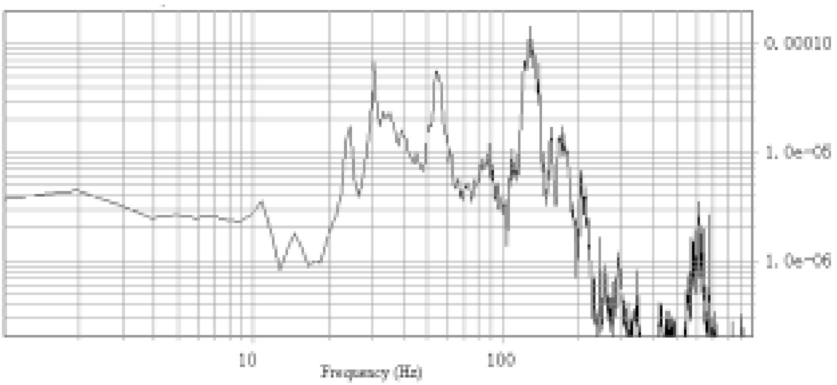

Fig.7. Pressure PSD of measure point 7 with orifice plate

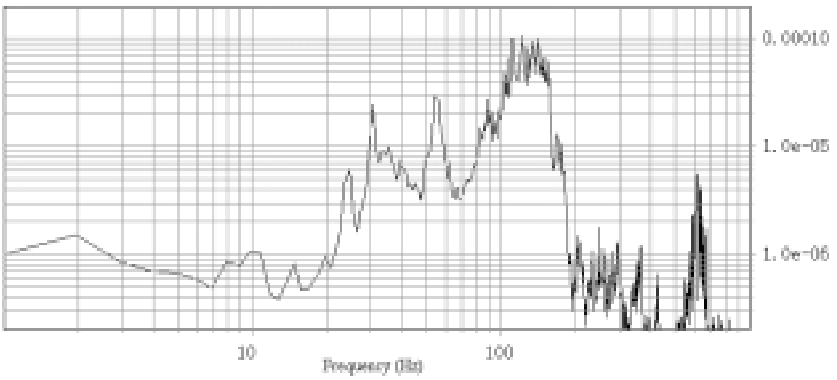

Fig.8. Pressure PSD of measure point 8 with orifice plate

A high peak has been found at 244Hz on almost all of the pressure PSD curves for the preliminary test, which is attributable to pump induced pressure pulsation. From the above pressure PSD curves, one can see that the pump induced pressure pulsation frequency has been eliminated after the water tanks have been added in the test loop before and after the test segment.

Acoustic effects can be also found in the pressure PSD curve. For example, the standing wave that is transmitted along the test loop is one of the causes of the acoustic frequencies, which belongs to far field turbulence rather than near field turbulence. Considering the energy content, acoustic frequencies do not play a very important role in the pressure PSD curve.

5.3 Vibration Accelerations

The time history signals of the structure vibration accelerations measured by the accelerometers and the strains measured by strain gauges are also converted into PSD. Figure 9 shows one of the PSD curves of acceleration response of the test segment. One can notice that the first four peaks are corresponding to the lower four beam modes of the test pipe. The main purpose of measuring the acceleration and strain responses is to provide comparable data for the succedent numerical prediction of flow-induced vibration analysis.

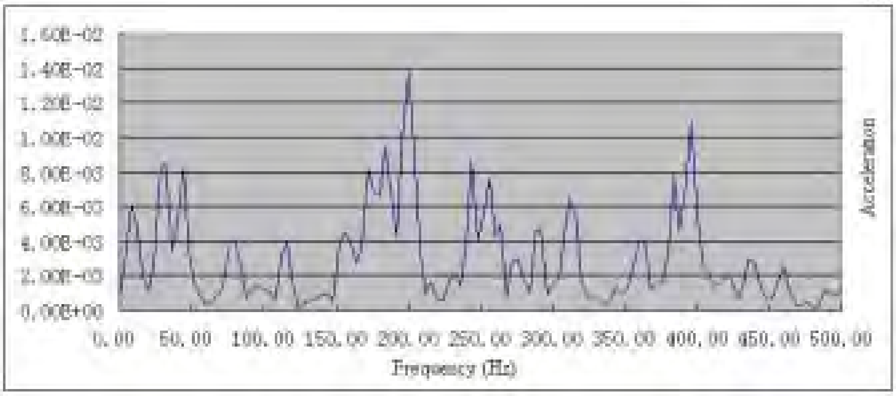

Fig.9. Acceleration PSD of the structure vibration response

6. CONCLUSIONS

Hydraulic test of orifice-induced pressure fluctuation and vibration presents the statistical characteristics of the flow pressure and structure acceleration response under different flow conditions and orifice ratios. After preliminary test, several modifications have been made on the test loop and the latest test results confirm that these modifications effectively solved the previous problems.

Although the maximum test flow rate has been significantly increased, the decrease of the pipe frequency along with the increase of flow rate inside the pipe is still not visible. It is very unlikely to observe this phenomenon in nuclear engineering practice because the combined effect of pipe stiffness and flow velocity.

Comparing the pressure PSD curves obtained from the test conditions with and without orifice plate, it shows that orifice plate significantly disturbed the pipe flow and greatly increased the pressure fluctuation level. Regarding the characteristics of the fluctuation pressure caused by orifice plate, one can notice from the measured PSD curves that it is a near field turbulence and the dominating energy is concentrating at the lower frequency range. The farther the distance from the orifice plate, the less the energy contained at the lower frequency range.

To meet the conference schedule, this paper can only provide a very rough review and first look of the test results. Detail data analysis and disturbance flow excitation modeling will soon be available. With this excitation model, the flow-induced vibration response analysis using random vibration theory may become possible.

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