Experimental study on sound transmission in condenser

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ABSTRACT

Even though there are lots of work studying acoustic resonance in tube bundles, the sound transmission rules barely got researchers attention. And most papers published assume that there is no interaction between the acoustic and structure modes. This paper tries to realize how sound source affects the acoustic transmission and whether the acoustic resonance could couple with the structure. A series of tests on model condensers were conducted. Results show that sound source at steam inlet contributes the most to the sound level of water outlet. And the acoustic resonance could couple with the structure. Besides, the transmission of sound is dominated by the structure.

Keywords: Acoustic Transmission, Coupling, Condenser

1. INTRODUCTION

Heat exchanger is an important part in many industries. It is susceptible to serious damage duo to flow induced vibration (FIV). Many researchers have dedicated themselves to explore the nature of FIV. It is well known that the mechanisms of fluid induced vibration are vortex shedding, turbulent buffeting, fluid-elastic instability and acoustic resonance (1,2,3). Among which, acoustic resonance can cause serious noise problems, which can up to 173dB (3). Experiment results shows that acoustic resonance could couple with vortex shedding and fluid-elastic instability. To investigate the vortex shedding and acoustic resonance mechanisms, Eisinger (4) concluded that acoustic Strouhal numbers closely matched the vibratory ones, while Ziada (5) results gave some exceptions. Mahon (6) excited the duct acoustics modes at various loudness levels and found that second acoustic mode had an effect on fluid elastic instability in the pitch ratio of 1.32. Even though the principle of sound transmission in condenser is still not very clear, the acoustic systems used to monitor the leakage of the condenser tube get a great success. Firth (7) examined acoustic transmission properties experimentally and theoretically and found out the stopping/passing band behavior expected from periodic media and the transmission drop which occurs when an initially plane wave is diffracted in different directions. The novelty of this paper with all previous works is that this paper tries to realize how sound transmits without the attendance of fluid flow in model condenser. This setup isolates vortex shedding or fluid-elastic instability and adds the influence of real condenser's structure.

2. DESCRIPTION OF THE TEST APPARATUS

As is illustrated in Fig.1, tests were conducted on a contracted condenser, which has 2 spans. The tube bundle is formed in rotated triangular, whose pitch ratio is 1.31 and effective length is 1200mm. The outer/inner diameter is 16mm/14mm. There is 174 tubes in all. The distance from the baffle to the left endplate (d direction) is 730mm. The shell has a diameter of 400mm.

Artificial excitation of acoustic resonance in the condenser was performed using two 50 W speakers. One was fixed at location A; another was removable and can be put at point B or C. As is illustrated in Fig.1, location A was fixed inside the laryngeal region above the perforated plate, while B and C were outside the condenser. Point B was at the lateral face of water outlet, and C was at the same

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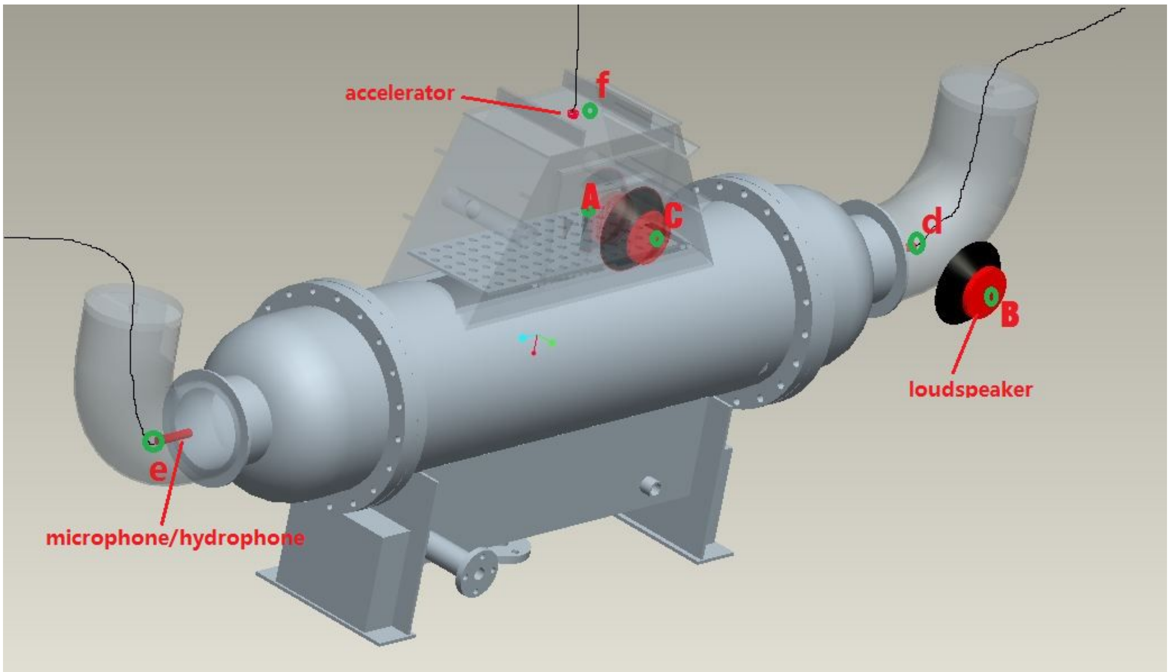


Figure 1 – Model condenser

plane with A. Point *d*, *e* were the place where BSWA MPA 201 microphones were put at the condition without water in tube side. While the tube side was fullfilled with water, two B&K 8103 hydrophones were used instead. An piezo-electric accelerator Type CA-YD-193 was put at position *f*, and its direction was adjust to *ed* direction. All the vents were blocked either by flange or plug. The schematic of the data acquiztation system is shown as in Fig.2. Careful calibration of sensors were done by B&K devices. Hydrophones were by using Hydrophone Calibrator Type 4229, microphones were by B&K microphone calibrator 4231, and the accelerometer was calibrated by Vibration Transducer Calibration System.

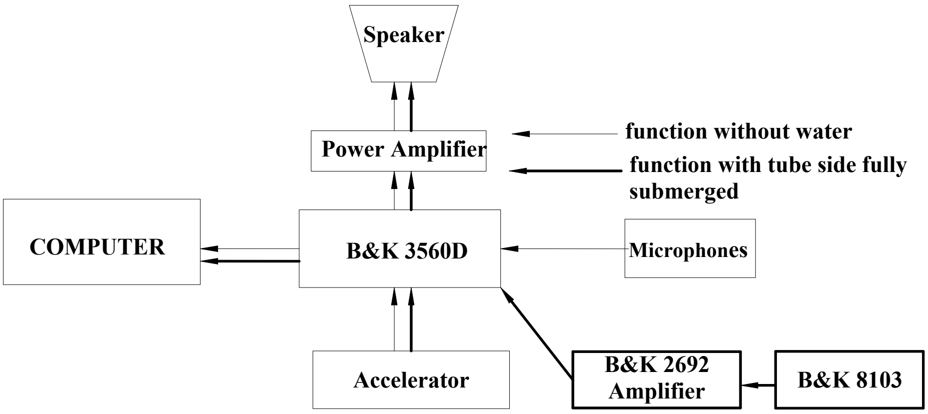


Fig.2 – Schematic of data acquisition system

The sampling ratio is 2.56, lines is set to 6400 and the frequency range is 7-3200Hz (by using a high-pass filter). And thus the definition of FFT is 0.5 Hz. Tests were conducted without water firstly, then fulfilled the tube side with water. Table 1 specifies the sound source operating conditions.

Table 1 – Sound source operating conditions

	SPEAKER	A	B	C
Test No.	1	×	×	×
	2	×	√	×
	3	×	×	√
	4	√	×	×
	5	√	√	×
	6	√	×	√

Note: √ for on, × for off

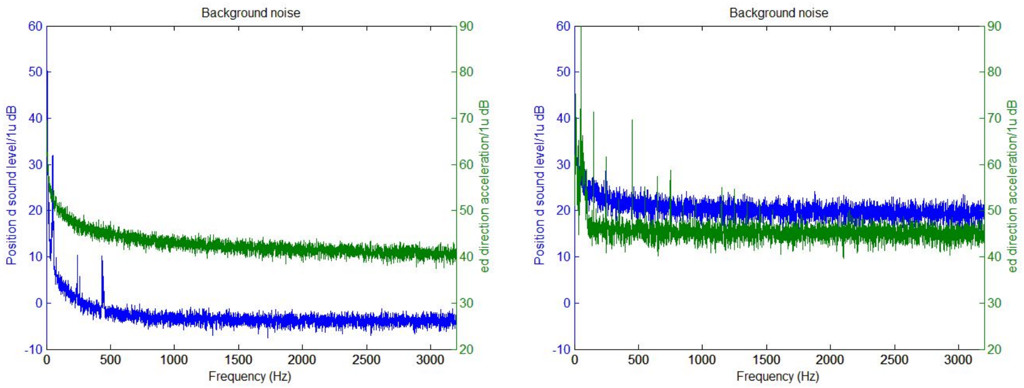
3. TEST PROCEDURE & RESULTS

Trying to avoid the influence of environmental random noise, all the tests were conducted at night. The sound pressure level (SPL) is defined as

$$SPL = 20\log_{10}\frac{P}{P_{ref}} \tag{1}$$

It should be noted that the reference pressure P_{ref} in air is 20×10^{-6}, while in water is 10^{-6}. Fig.3 gives the background noise level. It's rather ideal for conducting the following test. For comparison, the longitudinal acceleration is also transformed into decibels. After getting the background signal, an artificial random noise was used to excite the condenser. Because of the asymmetric of the baffle, signals from d, e had some differences. However, this paper only provides some results concerning *d* .

Impact tests were conducted before conducting test 2-6, table 2 gives the results.



a. Without water b. Tube side fulfilled with water

Fig. 3 – Background noise level

Table 2 – Natural frequencies of the model condensor

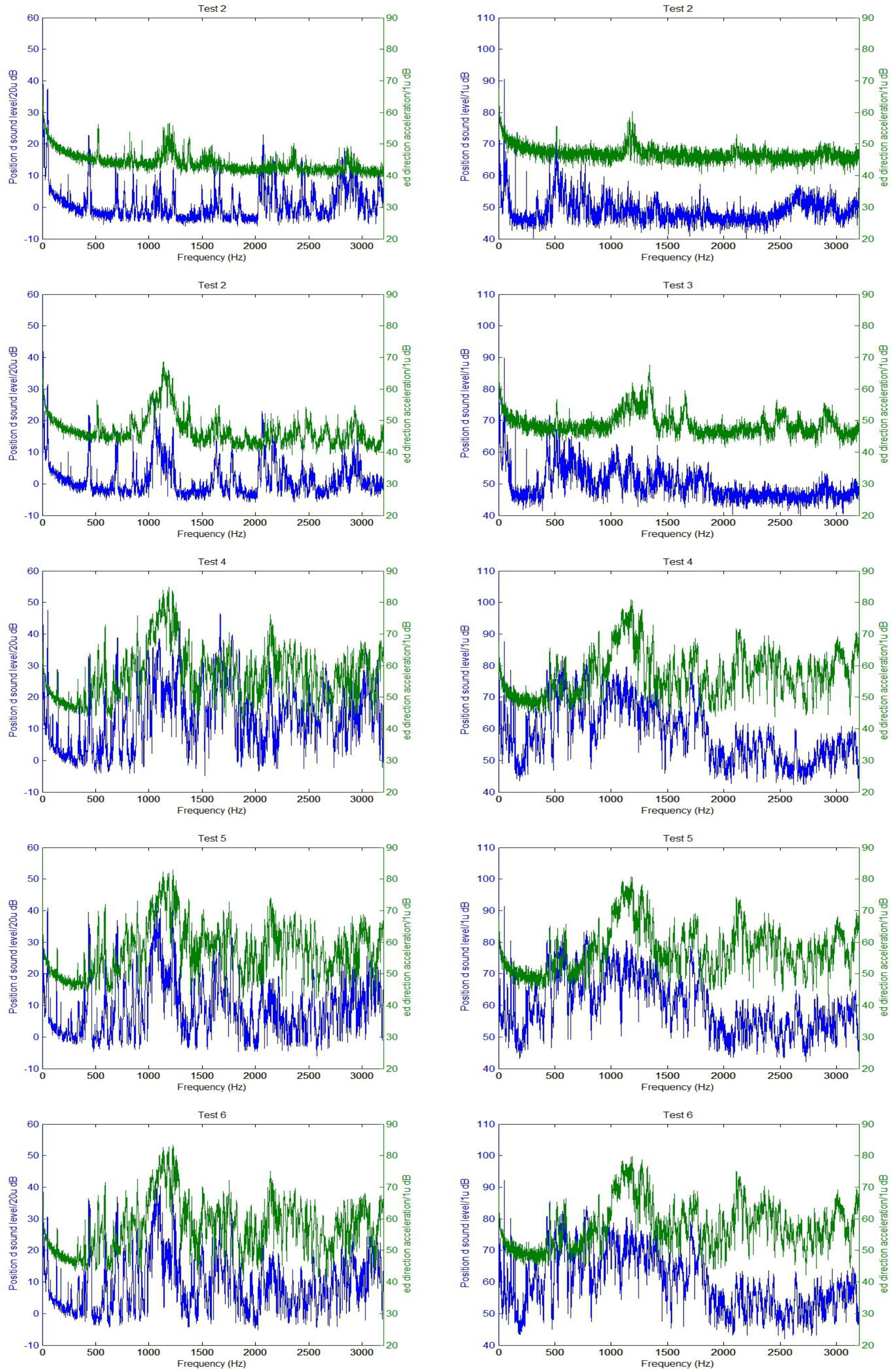
Order	1	2	3	4
Without water	518Hz	1000 Hz	1661 Hz	2891 Hz
With water	431.5 Hz	1139 Hz	1652 Hz	2504 Hz

As is shown in Fig.4, the same sound source at position C has a better effect than B, and C excites a significant peak at 1044Hz. This phenomenon suggests that this condenser C to d acoustic damping is larger than B to d. Hence, it's better to install equipment at B direction rather than C direction. B and C mainly excite peaks around the second structure mode, while A active the 3rd. As a result, the peak around the second structure mode becomes the highest one at test 5 and test 6. From the results of test 4-6, we can deduce that 450Hz, 1109 Hz, 1671 Hz, 2139 Hz are about this condenser's acoustic resonance frequencies. The resemblance between position d sound level and ed direction acceleration makes it safe to conclude that the sound excites the vibration of the structure and thus transmits sound to the air in the tube side chamber. It is easy to notice that there is discrepancy between two curves, which suggests the existence of the coupling. The coupling is rather weak. The sound level's trend is dominated by the acceleration one. Moreover, the speaker at B or C only changes the sound level amplitude at the highest peak by 1.3 dB. That is to say if any endeavor trying to reduce the sound level at d, measures should be taken to adjust the structure of A chamber.

In Fig.4, the acceleration curve barely changes despite the attendance of water in tube side. Moreover, the acceleration level is higher than sound in Fig.4a, while in Fig.4b the sound level leads. Compared with the condition without water, the first peak frequency of sound signal moves from 450Hz to 510Hz, and the band is wider than without water, which can be seen from Fig.4b. As to the response of d sound signal, speaker at C excites more peaks between 1000Hz and 2000Hz. It is easy to be seen that the sound level's trend is no longer dominated by the acceleration one. It is partly distributed to that the sound transmits faster than in air and the energy is still high enough to activate peaks at some frequency band, partly the coupling between the sound and the structure. In other words, the sound is strongly influenced by the structure and the structure changes a little because of the sound. Hence, the coupling effects are not equal. The sound to the structure is smaller comparing with the structure to the sound. As we all know, such a phenomenon has something to do with the thickness of the shell. Discrepancy and resemblance between two curves still exist, which once again validates that the sound transmits to the tube side fluid from the structure not from the condenser surrounding air. As a result, if we are trying to control the sound level in tube side, measures should be taken to control the structure vibration.

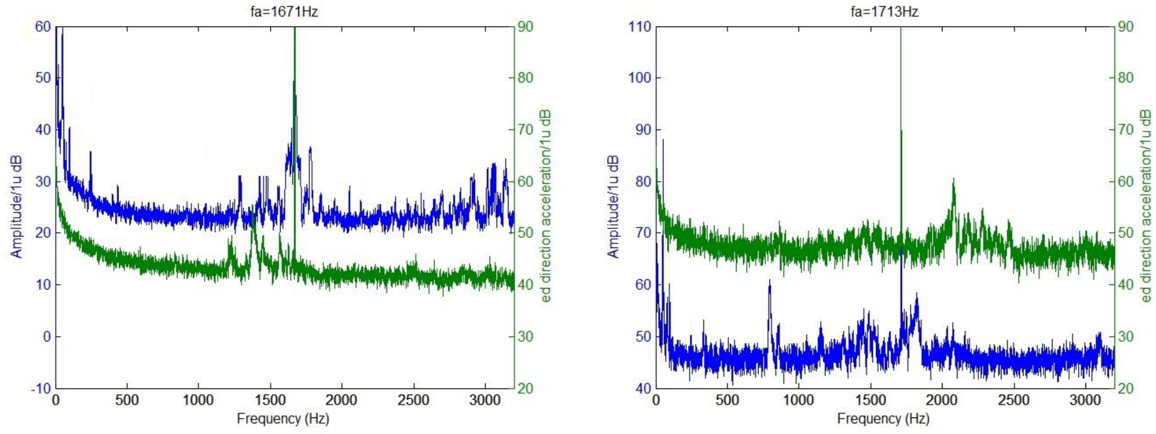
White noise produced by loudspeakers was used firstly to determine the appropriate resonance frequencies of acoustic mode from the frequency spectra of acoustic sensor signal (8). Duo to the limitation of the speaker power, it's impossible to excite all those frequencies simultaneously. Hence, a single frequency excitation was conducted. The peak frequencies of each test 4 were used. Confined by the length of this paper, here only gives the major peak frequency of each test condition in Fig.5.

As is shown in Fig.5 a, the two curves matches well at the imposed frequency, and the sound signal reaches 90dB at fa=1671Hz and accompany with it an amplitude increase of the frequency band (1255 Hz -1880Hz). From the response of the sound signal, it can be assured that 1671Hz is about the resonance frequency. Interestingly, the significant increased region of acceleration falls into the left part of the frequency band referred. However, in Fig.5b, that region switched to the left part. Besides, the highly response range in Fig.5b is wider than Fig.5a. This is rather difficult to explain because this condenser's structure is rather complicated. The following analyze is open to question. It is thought that the reason to such a phenomenon is duo to the following. Firstly, the fluid in the tube side carries the most weight. It seems that the sound transmits better in water. Secondly, the porosity of the perforated plate, the formation of tube bundle and the stiffness of the tube. In addition, there is a peak at 798Hz, which is about half the imposed frequency. This is attributed to the coupling and the meet of incident and reflect wave.



a. Without water b. Tube side fulfilled with water

Fig.4 – Random noise excitation



a. Without water b. Tube side fulfilled with water

Fig.5 – Single acoustic mode excitation and longitudinal acceleration (fa stands for the imposed acoustic mode frequency)

4. CONCLUSIONS

The sound transmission rules were investigated experimentally on a model condenser. By processing available experimental data, the following conclusions can be made for this model condenser:

(i) It is suggested that it is better to install other equipment with significant noise not at the steam inlet.

(ii) Sound source at steam inlet contributes the most to the sound level of water outlet.

(iii) The acoustic mode coincides with the longitudinal acceleration mode at around the second and the third of the structure.

(iv)With water fulfilled the tube side, the coupling is stronger than without.

(v) To lower the sound level of tube side, attention should be given to control the vibration

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