Purdue University
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International Compressor Engineering Conference

School of Mechanical Engineering

2012

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ABSTRACT

The discharge muffler of the rotary compressor is used to reduce the discharge noise produced by pressure pulsations. In order to obtain the transmission loss of discharge muffler, four microphone experimental devices used to measure the transmission loss of the muffler is established. The device is based on the transfer function method on the assumption that there is only plane wave in the tube, thus the measurement range of the device is discussed at the same time. Then the transmission loss of a contraction chamber is measured and calculated theoretically and the validity of the experimental device is verified through comparing the measurement and theoretical result. At last, a few various mufflers are measured using the experimental device and simulated by finite element method (FEM). The transmission loss of mufflers in the air is obtained and the experimental and simulation results are verified by each other.

1. INTRODUCTION

The discharge noise plays an important role in the noise of compressor. In order to reduce discharge noise, it is effectively to add discharge muffler. There are several parameters that describe the acoustic performance of a muffler. The TL is the difference in the sound power level between the incident wave entering and the transmitted wave exiting the muffler when the muffler termination is anechoic. The TL is a property of the muffler only, independent of the source. It is the most frequently used parameter to evaluate the acoustic performance of a muffler.

Because of the restriction of the muffler size, the muffler TL may be calculated from models but is difficult to measure. In order to enhance the design precision，it is urgent to establish measure method of transmission loss. This paper will focus on measuring the muffler transmission loss. For this research, an experimental test set-up was designed in order to measure the transmission loss of muffler configurations in stationary medium. The excitation consists of a random sine wave signal containing all frequencies of interest. In this paper, four microphones are used to measure TL of contraction chamber and compressor muffler.

The TL of contraction chamber and compressor muffler is also calculated by FEM. The measured transmission losses compared well for both cases demonstrating that transmission losses can be determined reliably by four microphones. This method combined test with FEM can shorten design cycle and reduce design budget. In the case, muffler for certain compressor is improved use this method and the compressor noise reduces 2.5~3.8dB (A).

2. THEORY

The most common approach for measuring the transmission loss of a muffler is to determine the incident power by decomposition theory and the transmitted power by the plane wave approximation assuming an anechoic termination. In practice, an anechoic termination could be constructed using high absorbing materials. However, a “fully” anechoic termination is difficult to build, particularly one that is effective at low frequencies. In order to enhance test precision at low frequencies, it is necessary to decompose incident and reflected waves. If two microphones are used for both forepart and back part, the sound pressure may be decomposed into its incident and reflected waves for both part. After the wave is decomposed, the sound power of the input wave may be calculated. In Figure 1 the schematic diagram of the set-up is shown.

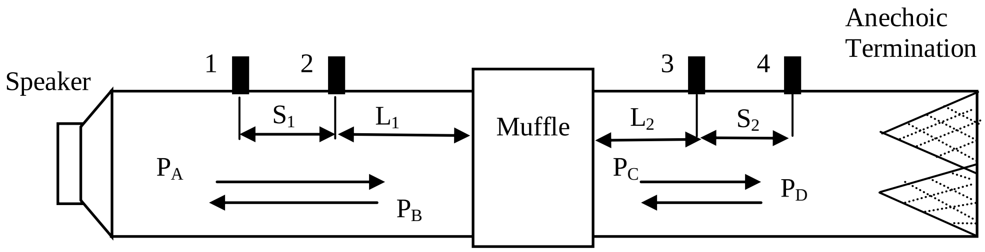

Figure 1: Schematic diagram of the set-up used four microphones

The sound pressure measured at location 1~4 is plural pressure which is sum of incident and reflected waves. The sound pressure of incident and reflected waves may be decomposed by four microphones.

Incident part：

$$P_1 = P_A e^{jk(L_1+S_1)} + P_B e^{-jk(L_1+S_1)} \tag{1}$$

$$P_2 = P_A e^{jkL_1} + P_B e^{-jkL_1} \tag{2}$$

Where P_A is the sound pressure of incident wave, P_B is the sound pressure of reflect wave. P_1 is the composite sound pressure in location 1, P_2 is the composite sound pressure in location 2.

By the wave decomposition theory, the sound pressure of the incident wave P_A can be calculated by Equations 1 and 2.

$$P_A = \frac{P_1 e^{-jkL_1} - P_2 e^{-jk(L_1+S_1)}}{e^{jkS_1} - e^{-jkS_1}} \tag{3}$$

Transmission part：

$$P_3 = P_C e^{-jkL_2} + P_D e^{jkL_2} \tag{4}$$

$$P_4 = P_C e^{-jk(L_2+S_2)} + P_D e^{jk(L_2+S_2)} \tag{5}$$

Where P_C is the sound pressure of transmission wave, P_D is the sound pressure of reflect wave in the back part of standing wave tube. P_3 is the composite sound pressure in location 3, P_4 is the composite sound pressure in location 4.

By the wave decomposition theory, the sound pressure of the transmission wave P_C can be calculated by Equations 4 and 5.

$$P_C = \frac{P_3 e^{jk(L_2+S_2)} - P_4 e^{jkL_2}}{e^{jkS_2} - e^{-jkS_2}} \tag{6}$$

It can be calculated from definition of transmission coefficient：

$$t_p = \frac{P_C}{P_A} = \frac{\sin kS_1}{\sin kS_2} \frac{P_3 e^{jkS_2} - P_4}{P_1 - P_2 e^{-jkS_1}} e^{jk(L_1+L_2)} \tag{7}$$

Formula (7) is the theoretical formula used for the analysis of test sound pressure data. It can be seen from this formula that L_1 and L_2 is only related with phase of t_p. Because the pressure near muffler is uneven and there is high power wave be excitated, L_1 and L_2 should be bigger than the diameter of tube. S_1 and S_2 should be equal better.

3. EXPERIMENTAL COMPONENT

The experimental set up is based in transfer function method. Figure 2 shows the experimental set up. The experimental set up is composed of loudspeaker, power amplifier, microphone, standing wave tube, NI gathering module, muffler, anechoic termination. The loudspeaker signal is generated by signal generator in NI gathering module and driven by power amplifier. The excitation consists of a random sine wave signal containing all frequencies of interest. A preamplifier amplifies the signal picked up by the microphones before it is fed to the computer-controlled Fourier analyzer. The assessed data are the power spectral densities and transfer functions of signals measured at different microphone locations. Making use of these measured data, the incident and transmitted sound power can be estimated and the transmission loss is calculated. Sound absorb material is used in the end of standing wave tube in order to reduce the transmission in the back part of tube.

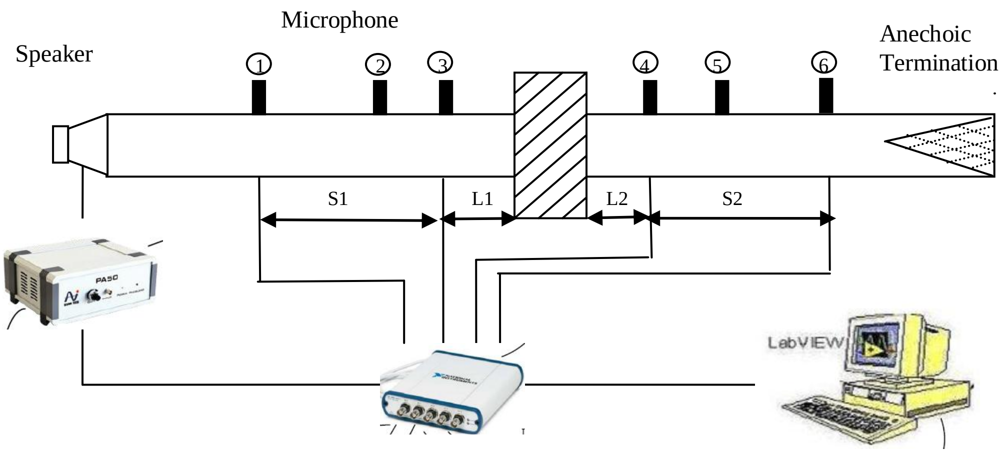

Figure 2: Experimental set-up

Because the section of sound tube is rotundity whose diameter is 30mm, the cut-off frequency of plane wave in tube is 6640Hz when sound speed of air is 340m/s. The distance between two microphones in the forepart and back part is set to 30mm. As a result, outlandish frequency of transfer function method is 5667Hz. For these reasons, the upper limit of measure frequency is set to 5000Hz. The lower limit is set to 566.7Hz because the distance between microphones should be bigger than 5 percent of wave length. In order to measure lower frequencies below 566.7Hz and enhance the measure accuracy, the distance of two microphones in the forepart and back part is also set to 100mm. In this case, the measure frequencies range from 200Hz to 1700Hz. In order to measure both high frequencies and low frequencies, 3 pressure-measuring points are located in each standing wave tube. In the forepart of tube the distance between location 1 and 3 is 100mm, while the distance between location 2 and 3 is 30mm. It is the same in the back part.

4. EXPERIMENTAL AND NUMERICAL RESULTS

In order to validate the accuracy, the contraction chamber is test first. Figure 3 shows the experimental, numerical and theoretical formula result. It was observed that in general a good agreement is obtained between the experimental, numerical and theoretical results. The combined analysis shows the validity of both numerical and experimental methodologies.

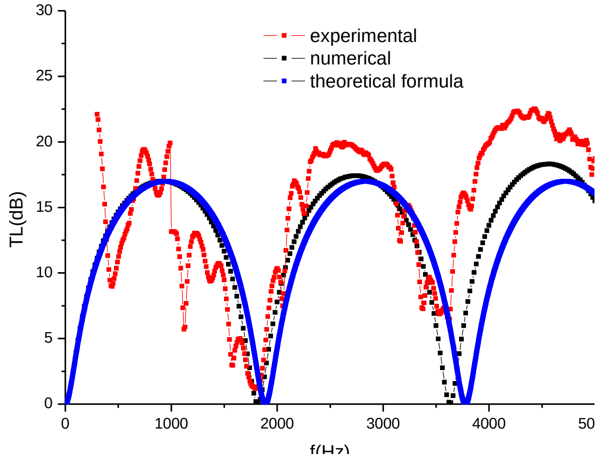

Figure 3: TL Comparison of a contraction chamber

In the base of accuracy of contraction chamber, muffler in certain rotary compressor is tested in order to validate the accuracy of experimental and numerical results for complex configuration. Figure 4 shows the experimental and numerical results of a certain muffler.

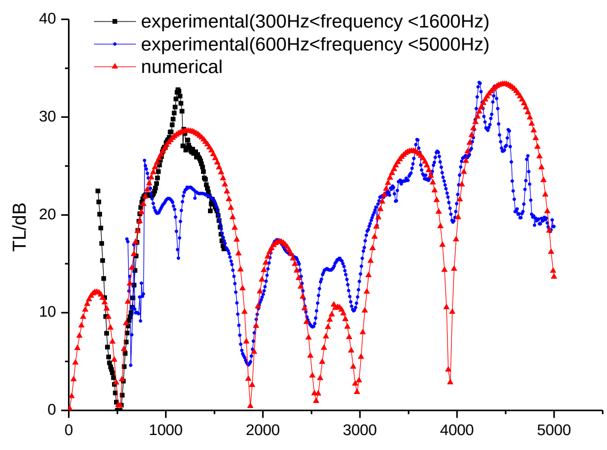

Figure 4: TL Comparison of a certain muffler

It is observed that this complex muffler presents five TL section from 500Hz to 5 kHz in the experimental TL. The numerical results predicted quite reasonably all of them. In addition, a good prediction of the drop in TL around 1800 Hz, 2500Hz, 3000Hz, 4000Hz is also observed.

5. CASE ANALYSIS

It is necessary to optimize muffler because there is discharge noise in a certain frequency conversion compressor. Firstly, numerical analysis is executed to select a better choice. Valve stop, top-flange and muffler are involved in the model. The mesh area is the flow area in the muffler. The mesh size is smaller than 1/5 or 1/6 of the analysis wavelength. A unit volume velocity added in the discharge port of top-flange and impedance ρc added in the outlet of muffler as boundary condition. In the simulation, an improved muffler is suggested. According to the measure situation, the medium in muffler is set as air. The TL of both original and improved muffler is shown in Figure 5. It can be seen from the figure that the TL of improved muffler between 1000Hz and 4500Hz is higher than the original muffler.

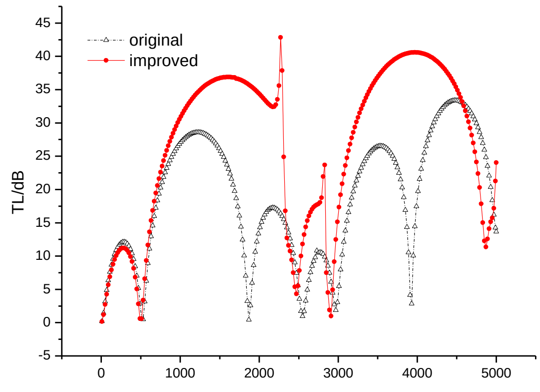

Figure 5: TL Comparison of a certain muffler

The TL of improved muffler is measured in air without flow in order to compare with the FEM result. Figure 6 shows the experimental and numerical result of improved muffler. It can be seen there is good agreement of experimental and numerical result. There is great enhancement from 1000Hz to 2200Hz and 3000Hz to 4500Hz in TL curve. The frequency is from 500Hz to 2400Hz when the medium is R410A.

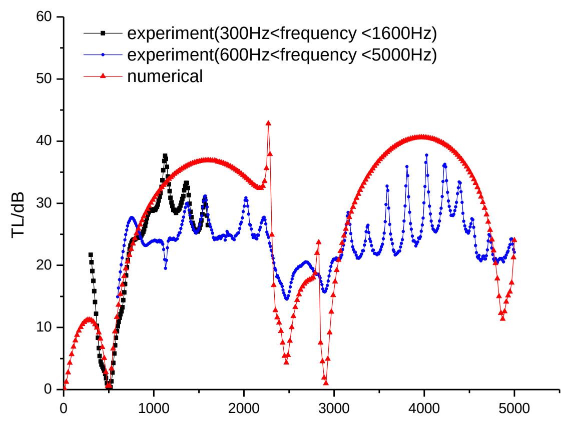

Figure 6: TL Comparison of improved muffler

The improved muffler is installed in the compressor of original type. The refrigerant in compressor is R410A. Noise experiment is executed for compressors for both original and improved muffler. Figure 7 shows the sound power level of compressors with original and improved muffler when operating frequency of compressor is 90Hz.

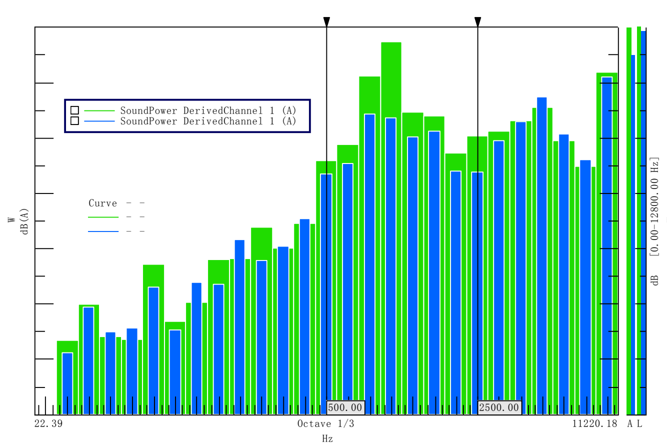

Figure 7: Sound power level comparison of compressors with original and improved muffler

It can be seen from the test result that there is great decline in sound power level from 500Hz to 2500Hz in 1/3 octave especially from 800Hz to 1000Hz. The total sound power level of compressor reduced 2.5~3.8dB (A) because of the decline in these frequencies when operating frequency from 30Hz to 90Hz. The decline of noise level indicates that the experimental and numerical method in this paper is valid to direct muffler design.

6. CONCLUSION

In this paper, four microphone experimental devices used to measure the transmission loss of the muffler is established. TL of contraction chamber and muffler is measured. The conclusions are:
(1) The TL can be measured accurately by the test set-up with four microphones.
(2) It was observed that a good agreement is obtained between the experimental, numerical and theoretical results. The FEM method is valid for muffler design.
(3) Combining the experiment and numerical method, an improved muffler is designed to decline the discharge noise. The sound power level of compressor with improved muffler reduced 2.5~3.8dB (A) when compressor operating at different frequencies.

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