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# ANALYSIS OF ACOUSTIC CHARACTERISTICS OF THE MUFFLER ON ROTARY COMPRESSOR

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## ABSTRACT

Muffler is the major factor influencing the noise of rotary compressor. How to analyze the acoustic characteristics of muffler is essential. In this paper, the transmission loss (TL) of muffler is analyzed by FEM calculation. According to the standing wave tube method, an experimental setup with four-microphone is also established to measure the TL of muffler. The result of numerical calculation is consistent to the experiment. Based on the above method, a muffler weak at 1600Hz, 2000Hz, 3000Hz is improved and the compressor noise reduces 2 dB(A)。

## 1. INTRODUCTION

Compressor is the main noise source of air-conditioner. With the increasing demands for quiet environment and quiet air-conditioner, it's becoming important to reduce the compressor noise.

The main contributor of noise of rotary compressor is the acoustically amplified pressure pulsation in the discharge manifold of the compressor (Kiyoshi Sano, 1984). As an important method to control pressure pulsation, the discharge muffler is a crucial part influencing the compressor noise.

In the past, the analysis and design of the muffler has been largely by cut-and-try method. Due to the complexity of the geometry and assembly or test instability, it's hard to get the right result until after large mounts of repeated experiments. In this paper, a new numerical calculation with FEM model and a standing wave tube experimental setup with four-microphone are developed to analyze TL. This method can shorten design cycle and reduce design budget. The method is validated by a sample. In the case, a muffler weak at 1600Hz, 2000Hz, 3000Hz is improved and the compressor noise reduces 2dB(A).

## 2. NUMERICAL CALCULATION

There are four different indices to describe the acoustic features of a muffler, namely the Transmission Loss(TL),the Insertion Loss(IL),the Noise Reduction(NR) and Attenuation. TL is the sole index to evaluate the acoustical characteristic of a muffler element only (Rajendra Singh, 1976).

TL is the difference between the levels of the input and output power of a muffler. With the assumption that it's the plane wave to propagate in the muffler, TL can be deduced by transfer matrix (Jeong-Ho Lee, 2002). The relation between input wave and transmission wave can be written as the following

$$\begin{bmatrix} p_{in} \\ v_{in} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} p_{out} \\ v_{out} \end{bmatrix} \tag{1}$$

Four-pole parameters are given by

$$A_{11} = \left. \frac{p_{in}}{p_{out}} \right|_{v_{out}=0} \tag{2}$$

$$A_{12} = \left. \frac{p_{in}}{v_{out}} \right|_{p_{out}=0} \tag{3}$$

$$A_{21} = \left. \frac{v_{in}}{p_{out}} \right|_{v_{out}=0} \tag{4}$$

$$A_{22} = \left. \frac{v_{in}}{v_{out}} \right|_{p_{out}=0} \tag{5}$$

By imposing closed end tube condition Equations (2)(4) can be computed and imposing open end tube condition Equations (3)(5) can be computed. The final equation is the following

$$TL = 20\lg\left[ \left( \frac{S_{in}}{S_{out}} \right)^{\frac{1}{2}} \frac{1}{2} \left| \left( A_{11} + \frac{A_{12}}{\rho c} + A_{21}\rho c + A_{22} \right) \right| \right] \tag{6}$$

## 3. EXPERIMENTAL MEASUREMENT

It is a typical method to measure acoustic characteristics in standing wave tube in the muffler acoustic research. With the plane wave formed in the tube, we can get TL strictly abide by its definition, which is quite appropriate to theoretical analysis and can reach approving precision in engineering measurement.

According to the TL definition, it's crucial to realize an anechoic termination to eliminate the sound reflection influence in the standing tube in the experiment. In order to get this, the termination is required to be long enough (P.C.C Lai, 1996). However, four-microphone method doesn't need this requirement. With two microphones respectively upstream and downstream the muffler, the influence around the termination can be effectively eliminated and measurement accuracy in low frequency improved (Bo Qu and Beili Zhu, 2002).

Fig.1 is the experimental setup for the muffler TL measurement. It just employs four-microphone method. Because of wide frequency range desired, we locate 3 pressure-measuring points in each standing wave tube, which can cover all the test frequency range by combination of microphones pairwise (Beili Zhu and Jinxin Xiao, 1994)( Songling Zhao, Ye Yin, 1995).

Fig.2 shows the comparison among theoretical, numerical and experimental results of an expansion chamber muffler served as a standard sample. Experiment is carried out at ambient temperature(20$^{o}$ C) with no air flowing through the tube. The noise source is a loudspeaker excited by an audio sinusoidal signal generator. Acoustic pressures are recorded by B & K Pulse 3560. As been shown, the results are in good agreement, especially in the frequency of TL minimum values.

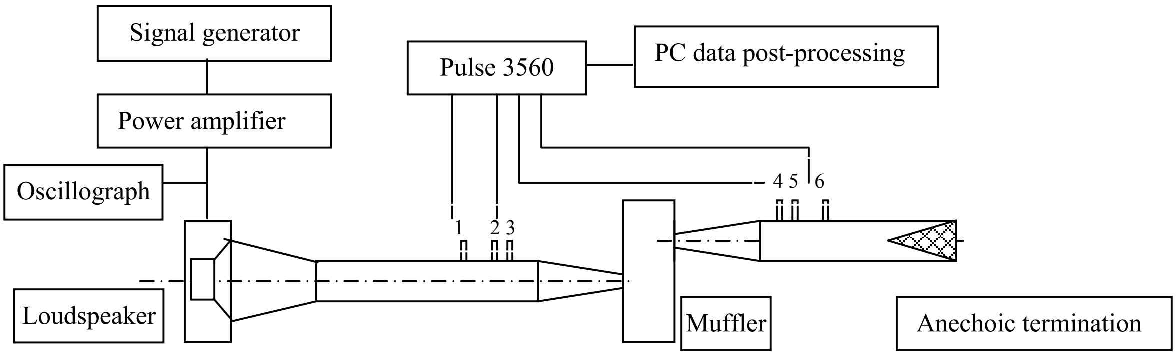


Fig.1 experimental setup for TL measurement

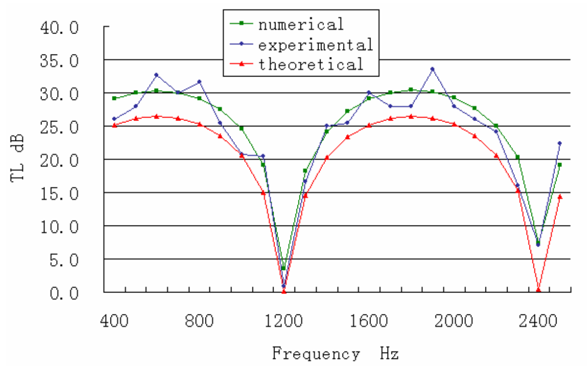


Fig.2 TL Comparison of a standard muffler

## 4. CASE ANALYSIS

Fig.3 is the model of muffler *A*. It's a 3-D FEM model of the muffler alone created for the TL analysis. The valve stop and discharge port are also include in the model. A unit volume velocity source at the discharge port provides the excitation to the model. An impedance $\rho c$ at the outlet face serves as the anechoic condition. The model is meshed with four-node quadrilateral elements. In general, the mesh size should not be large than 1/5 or 1/6 minimum wavelength in interest. For a maximum frequency of 6000Hz in air, the mesh should be less than 9.5mm.

Then, we measure the TL on the muffler *A* . The valve is removed while stop left in place. Fig.4 compares test result and calculation of TL in air. They show a good agreement. They both show that the muffler is weak especially at 1600Hz, 3000Hz, 4000Hz and 5800Hz in air.

Muffler A can be regarded as two expansion chambers connected in serious. Shortening expansion chamber length can increase TL in high frequency. A new muffler *B* in this idea is developed with its TL comparison (also in air) shown in Fig.5. The TL in the above points is improved, particularly at points 3000Hz, 4000Hz and 5800Hz . These points correspond to 1580Hz, 2100Hz and 3057Hz when the sound propagation medium is Freon22. When assembled in a compressor, the new muffler *B* reduces the SPL at 1600Hz and 3150Hz 4dB(A) respectively and 2000Hz 5dB(A). The total noise reduces 2dB(A) as shown in Fig,6. Therefore, It's improved that the numerical and experimental methods in this paper are effective to analyze acoustic characteristics of the muffler.

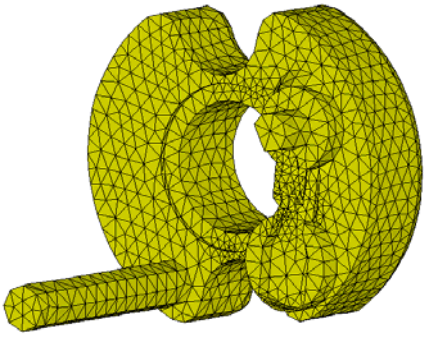

Fig.3 FEM model of muffler *A*

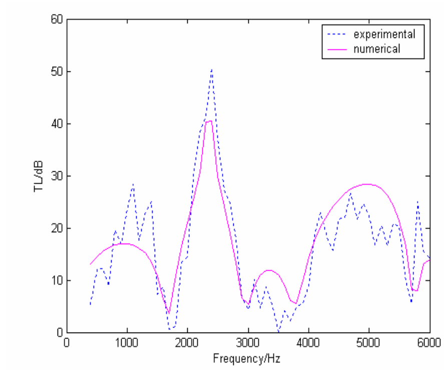


Fig. 4 TL comparison of muffler *A*(in air)

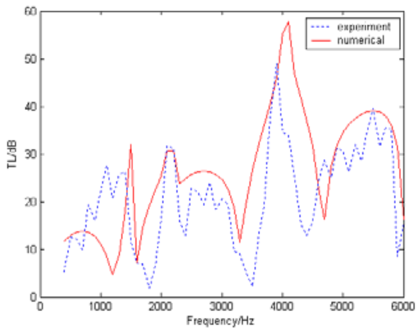


Fig.5 TL comparison of muffler *B* (in air)

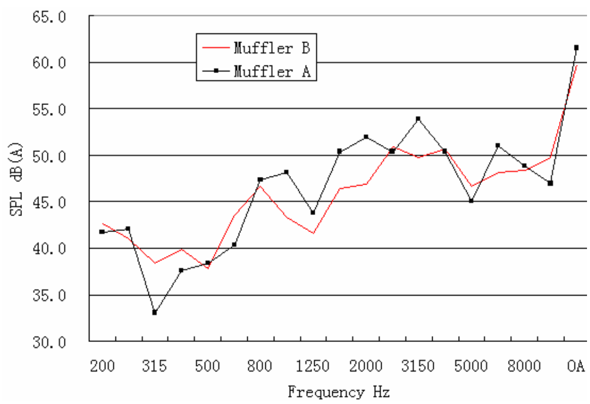


Fig.6 comparison of compressor noise

## 5. CONCLUSIONS

This paper tries to summarize what has been done in analyzing the acoustic characteristics of the muffler of rotary compressors. The numerical and experimental methods developed in this paper have been proved to be effective and reliable through result comparison between calculation and measurement and a practical case.

## NOMENCLATURE

| | | | | |
|---|---|---|---|---|
| $TL$ | transmission loss | (dB) | **Subscripts** | |
| $p$ | acoustic pressure | (Pa) | | |
| $c$ | sound velocity | (m/s) | *in* | muffler's inlet |
| $v$ | particle velocity | (m/s) | *out* | muffler's outlet |
| $\rho$ | density of medium | ($Kg/m^3$) | | |
| $S$ | area | ($m^2$) | | |

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