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Technical note

Study of multi-chamber micro-perforated muffler with adjustable transmission loss

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ABSTRACT

The noise behavior of the blower used on fuel cell vehicles is measured and analyzed. According to the noise behaviors, the multi-chamber micro-perforated muffler with adjustable transmission loss is proposed for silencing. The adjustment is achieved by the change of the third chamber length. The relation model between the chamber length and the muffler resonant frequency is fitted. In addition, the muffler sample is manufactured for experiment. According to the study, the blower noise contains the wide band noise with frequency range of 500–1000 Hz and the narrow band harmonics with frequency range of 2000–3500 Hz. The experimental results show that the proposed muffler is effective and efficient to attenuate the low-medium frequency wide band noise and the narrow band harmonics simultaneously.

1. Introduction

Blower is one of the main noise sources of the fuel cell vehicles [1]. The blower noise energy lies on wide band frequency and changes with the working conditions of the blower. In addition, the dissipative muffler is not suitable here due to the cleaning requirement of the fuel cell. Accordingly the micro-perforated structure could be used to attenuate the blower noise.

Micro-perforated panel is a new kind of absorbing materials with wideband high absorbing coefficients and was first reported by Dah-You Maa [2]. This material has been used for duct silencing as micro-perforated mufflers [3–4], which are non-polluted due to the lack of porous materials [5].

The transmission loss (TL) is determined by the structure of the muffler and is often used to evaluate its acoustic performance [6–8]. Traditional mufflers, whose performance is untunable due to their fixed structures [9–11], are not suitable for the varying noise of the blower used on fuel cell vehicles. The mufflers with adjustable TLs are therefore preferred and extensively studied. For instance, Lamancusa [12] first proposed a kind of resonant structure with changing volume. Matsuhisa et al. [13] reported the Helmholtz resonator with adaptable volume and resonant frequency which is adjusted according to the phase of the pressure in the chamber and the pipe. Fukami and McLean [14,15] proposed to change neck length and cross sectional area of the resonator to modify the resonant frequency. Singh [16] adjusted the resonant frequency according to the difference of the pressure phase between the chamber and the interface of neck and central pipe. Cherrier et al. [17] proposed the resonator using two perforated plates to form connected pipe with changeable cross section and they established the acoustic impedance model, which were modified and validated by experiment later by themselves [18]. However, the aforementioned studies mainly focus on the Helmholtz resonators with adjustable TL, which may cause large pressure drop for duct silencing.

In this paper, an experiment is carried out to study the noise behaviors of the blower. Based on our experiments, we propose a kind of multi-chamber micro-perforated muffler with adjustable TL and established the relation model between the chamber length and the resonant frequency. In addition, the muffler was manufactured to validate the frequency adjustment behavior and the silencing performance.

2. Noise behavior test and analysis

Here the experiment is conducted to study the noise behaviors of the blower used on fuel cell vehicles and the test bench is shown in Fig. 1. The experiment is carried out in a semi-anechoic room with background noise of 18 dB(A) and lower cut-off frequency of about 40 Hz. The suction port and the discharge port are placed outside the room to eliminate the jet noise. The drive electric motor is wrapped with sound absorbing material to reduce the

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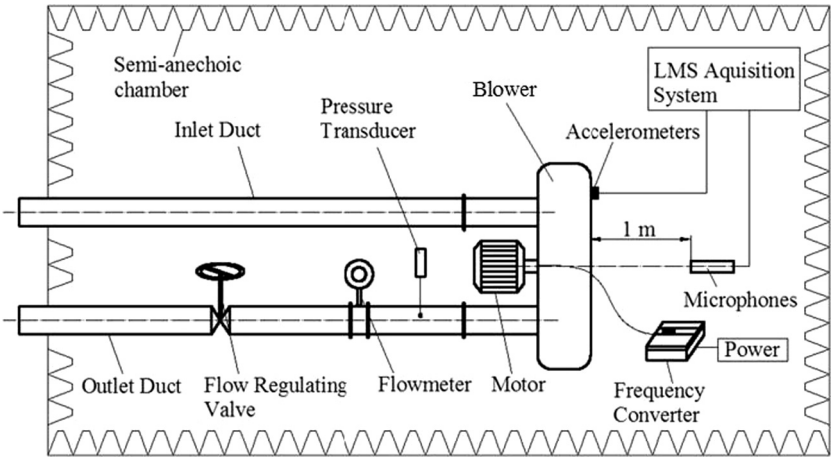

Fig. 1. Sketch of blower noise test bench.

contribution of motor noise. The LMS SCADAS III data acquisition system is applied to measure the noise.

Fig. 2 shows the blower noise under accelerating working conditions It suggests that the blower noise contains the wide band noise in the frequency range of 500–1000 Hz and the narrow band harmonics in the frequency range of 2000–3500 Hz. The further study indicates that the narrow band harmonics is the blade passing frequency (BPF). Since there are 55 blades in total, the noise is the 55th order harmonics of the rotation frequency and the frequency is given by [1]

$$f = \frac{n}{60} \times N \tag{1}$$

where n is the rotation speed, N is the number of the blades. Here $N = 55$.

We also analyzed the blower noise behaviors under steady working conditions. The blower noise spectrum with the rotation speed of 2000 r/min, 3000 r/min and 3800 r/min are shown in Fig. 3. It is obvious that the outstanding noise component is the 55th order harmonics, which is in agreement with Eq. (1). Moreover, there is also wide band noise in the frequency range of 500–1000 Hz.

For the fuel cell vehicle, the blower outlet is connected with the fuel cell stack which means that the noise mainly spreads out from the inlet. So the noise could be attenuated by mufflers mounted on the inlet of the blower.

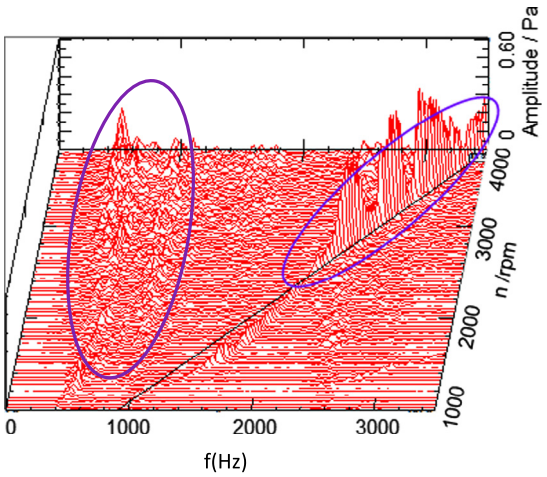

Fig. 2. Blower noise behaviors under accelerating working conditions.

The porous materials of dissipative mufflers may fall off and get into the fuel cell because of the flow, which makes the dissipative mufflers not suitable here. In addition, reactive mufflers are often used to attenuate the narrow band low-frequency noise. Considering the requirement of low pressure drop, we decide to use micro-perforated muffler for silencing. In order to maintain good performance for different working conditions of the blower, it is necessary to design a new kind of micro-perforated tube muffler with adjustable TL.

3. Design of multi-chamber micro-perforated muffler with adjustable TL

3.1. Structural design

The one-chamber micro-perforated muffler with adjustable TL could be used to attenuate the narrow band harmonics. However, its performance in low-medium frequency is limited [19]. In order to simultaneously control the wide band noise with frequency of 500–1000 Hz and the narrow band harmonics with frequency of 2000–3500 Hz, it is necessary to design a multi-chamber micro-perforated muffler with adjustable TL.

The three-chamber micro-perforated muffler with adjustable TL is designed and is shown in Fig. 4. The structural parameters of the front two chambers remains unchanged, while the length of the third chamber could be changed with the axial movement of the piston driven by the motor.

First, the rotation speed of the blower is used to calculate the harmonic frequency according to Eq. (1). Next, the controller determines the required length of the third chamber on the basis of the relation between the chamber length and its resonant frequency. Subsequently, the controller drives the motor and the gears to move piston and ensure that the third chamber can achieve the desired length. In this way, the length of the third chamber could change with the blower rotation speed to maintain good performance to attenuate the narrow band harmonics with frequency range of 2000–3500 Hz. In addition, the front two chambers are designed to attenuate the wide band noise with frequency range of 500–1000 Hz.

3.2. Analysis of TL adjustment behaviors

The next step is to establish the relation model between the length of the third chamber and its resonant frequency.

The TL values of the three-chamber micro-perforated mufflers with different lengths of the third chamber are calculated. The