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ABSTRACT

In the design of rotary compressor, Helmholtz resonator is always used in the discharge port of cylinder to reduce noise. The effect of Helmholtz resonator on the discharge port is restricted because of the narrow frequency band of Helmholtz resonator. In this paper, multi-Helmholtz resonator on the top-flange is used to reduce the discharge noise of different frequency bands, which does not change clearance volume. The experimental results show that multi-Helmholtz resonator can effectively reduce the peak values of different frequency noise of inverter-driven compressor. The sound power level of compressor can be reduced by 0.9~2.7dB (A) under different operation conditions.

1. INTRODUCTION

With the popularization of air-conditioner especially inverter-driven air-conditioner, more and more users concern about the noise of air-conditioner. As the main noise source of air-conditioner outdoor unit, the noise character of compressor directly impact on the noise character of air-conditioner outdoor unit. It deserves our attention to analyze the noise character of compressor.

The main air-borne noise of a rotary compressor is discharge noise. The compressed refrigerant exhausts from the outlet of cylinder, expands, and then forms turbulent jet noise. In order to reduce the discharge noise, Helmholtz resonator is always used on the discharge port of cylinder. But common Helmholtz resonator on the discharge port can only reduce single peak value of noise because it just has one resonant frequency. In addition, the volume of Helmholtz resonator is restricted because Helmholtz resonator in this position will increase the clearance volume, which reduces the performance of compressor. In this paper, multi-Helmholtz resonator on the top-flange is proposed to reduce the discharge noise of different frequency bands, which does not change the clearance volume.

2. HELMHOLTZ RESONATOR PRINCIPLE

2.1 Helmholtz Resonator Basic Principle

A Helmholtz resonator, as shown in Figure 1, is an acoustic band-stop filter comprised of a rigid cavity with a protruding neck that connects the cavity to the system of interest. The behavior of a Helmholtz resonator is analogous to that of a vibration absorber. The volume of air in the neck of the Helmholtz resonator behaves much like a vibration absorber mass and the volume of air in the cavity acts like compliance.

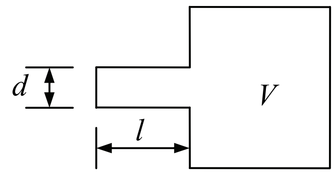


Figure 1: Helmholtz resonator basic structure

The excitation is provided by tonal pressure fluctuations acting over the opening of the neck. The pressure increase within the cavity provides a reacting force analogous to that of a spring. Damping appears in the form of radiation losses at the neck ends, and viscous losses due to friction of the oscillating air in the neck.

Resonance takes place when the exciting frequency equal to the resonance frequency of the cavity. In this situation, the viscous loss is the biggest. In this way, Helmholtz resonator attenuates the single resonance frequency noise and the noise with narrow band around the resonance frequency.

The resonance frequency of a Helmholtz resonator is approximately given in Equation (1)

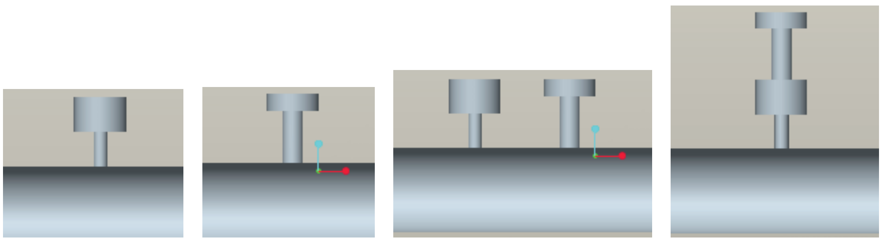
$$f = \frac{c}{4\pi}\sqrt{\frac{\pi d^2}{V l_d}} \qquad (1)$$

where $l_d = l + 0.85d$, d and l are respectively the neck diameter and the neck length， V is the resonator volume, and c is the sound speed. It can be seen that the resonance frequency is a function of the cavity volume and neck dimensions, but independent of the cavity dimensions.

The character of Helmholtz resonator is that the noise damping is notable near the resonance frequency but descend quickly in other frequency. Helmholtz resonator is widely used to reduce the peak value of noise spectrum. It is feasible to design multi-Helmholtz resonator to reduce different peak value of noise.

2.2 Comparison Between Shunt-wound and Series-wound Helmholtz Resonator

Multi-Helmholtz resonator has two types, shunt-wound Helmholtz resonator and series-wound Helmholtz resonator. The configurations of different Helmholtz resonators are shown in Figure 2. As show in Table 1, Helmholtz resonators with different type are designed. The theoretical resonance frequencies of single Helmholtz resonator computed by formula are listed. Parameters sound velocity c is chosen according to actual situation of R410A. Common Helmholtz resonators with resonance frequency 1785Hz and 3091Hz are respectively shown in Figure 2 (a) and (b). Shunt-wound Helmholtz resonator and series-wound Helmholtz resonator consisted of (a) and (b) are shown in Figure 2 (c) and (d) respectively. The resonance frequencies of different configurations computed by FEM software are shown in Table 1.



(a) (b) (c) (d)

Figure 2: Helmholtz resonator configuration of different type

Table 1: Resonance frequency of resonator (refrigerant: R410A)

Helmholtz resonator	Theoretical resonance frequency/Hz	FEM result frequency/Hz			
		1	2	shunt-wound	series-wound
1	1785	1780	------	1780	1360
2	3091	------	2960	2960	4000

The relationship between the single Helmholtz resonator, shunt-wound Helmholtz resonator and series-wound Helmholtz resonator is shown in Table 1 and Figure 3. It can be seen that the resonance frequency of shunt-wound Helmholtz resonator equal to the resonance frequency of single Helmholtz resonator 1 and 2. Simultaneity, the resonance frequency of series-wound Helmholtz resonator offset from the resonance frequency of single Helmholtz resonator 1 and 2. Considering the convenience of resonance frequency calculation and process of Helmholtz resonator, shunt-wound Helmholtz resonator is used in rotary compressor.

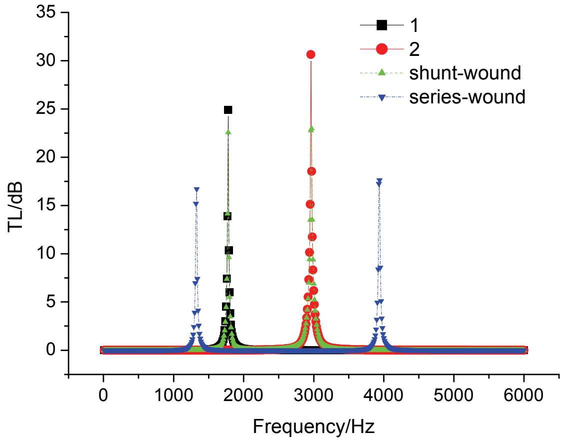
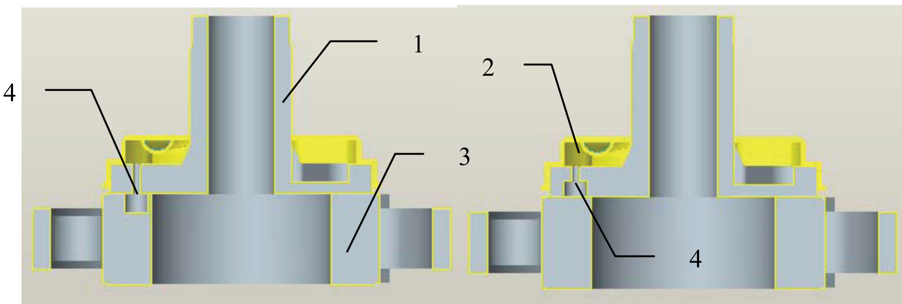


Figure 3: Transmission loss (TL) of Helmholtz resonator

3. DESIGN OF MULTI-HELMHOLTZ RESONATOR

Noise is attenuated by multi-Helmholtz resonator when compressed refrigerant discharged into the cavity between muffler and top-flange. Multi-Helmholtz resonator used in rotary compressor can be processed on top-flange and cylinder. Top-flange with neck and cylinder with cavity is shown in Figure 4(a). Top-flange with both neck and cavity is shown in Figure 4(b). The position where neck and cavity locate depends on the dimension of the Helmholtz resonator. Helmholtz resonator shown in Figure 4 has no effect on clearance volume of compressor because resonator is designed outside the compressed cavity. Meanwhile, it can reduce discharge noise of different frequencies when more than one Helmholtz resonator processed on top-flange along the pathway of refrigerant.



(a) (b)

Figure 4: The position of multi-Helmholtz resonator on top-flange and cylinder
(1) top-flange (2) muffler (3) cylinder (4) multi-Helmholtz resonator

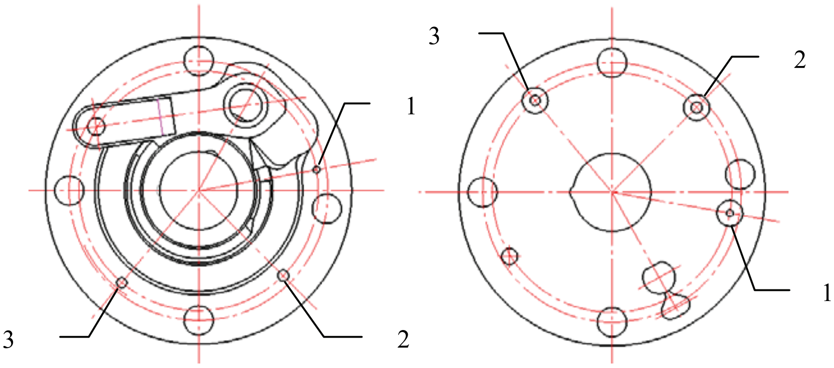
According to the peak value distribution of discharge noise in the compressor noise test, a multi-Helmholtz resonator with three resonance frequencies is designed. Considered resonance frequency and dimension of multi-Helmholtz resonator, multi-Helmholtz resonator with both neck and cavity on top-flange is designed. The resonance frequencies are listed in Table 2.

Table 2: Resonance frequency of multi-Helmholtz resonator (refrigerant: R22)

Helmholtz resonator	Theoretical result Frequency/Hz	FEM simulation Frequency/Hz
1	1690	1750

2	2928	2770
3	4709	4930

The position of multi-Helmholtz resonator on top-flange is shown in Figure 5. The necks on the top surface and the cavities on the bottom surface of top-flange are shown in Figure 5(a) and Figure 5(b) respectively. The resonance frequency of Helmholtz resonator 1, 2 and 3 are listed in Table 2. The location of necks must be set in the position where matches the cavity of muffle, or else, the design is invalid because the multi-Helmholtz resonator is connected with the cavity of cylinder.



(a) (b)

Figure 5: Positions of multi-Helmholtz resonator on top-flange

(1) Helmholtz resonator 1; (2) Helmholtz resonator 2; (3) Helmholtz resonator 3

The transmission loss (TL) curve of muffler with and without multi-Helmholtz resonator on top-flange used FEM software is shown in Figure 6. Parameters sound velocity c is chosen according to actual situation of R22. There are three more peak values in the transmission loss curve of muffler with multi-Helmholtz resonator compared with the original one. It can be seen that the frequencies of three peak value exactly match the resonance frequencies designed before. The enhancement of TL in the three resonance frequencies is about 10dB~18dB. The frequency band width, where the enhancement value of TL is more than 10dB, is nearly 100Hz. The error percentage of FEM result and theoretical result is less than 5%.

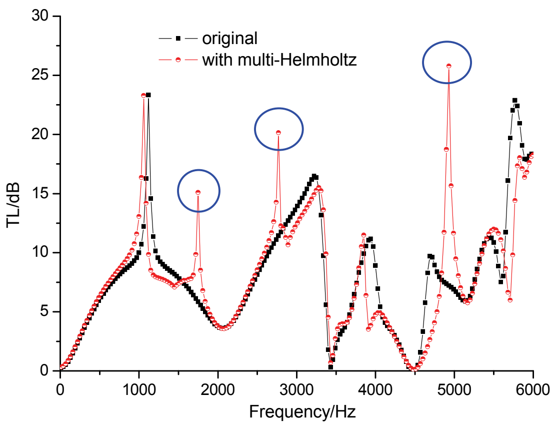
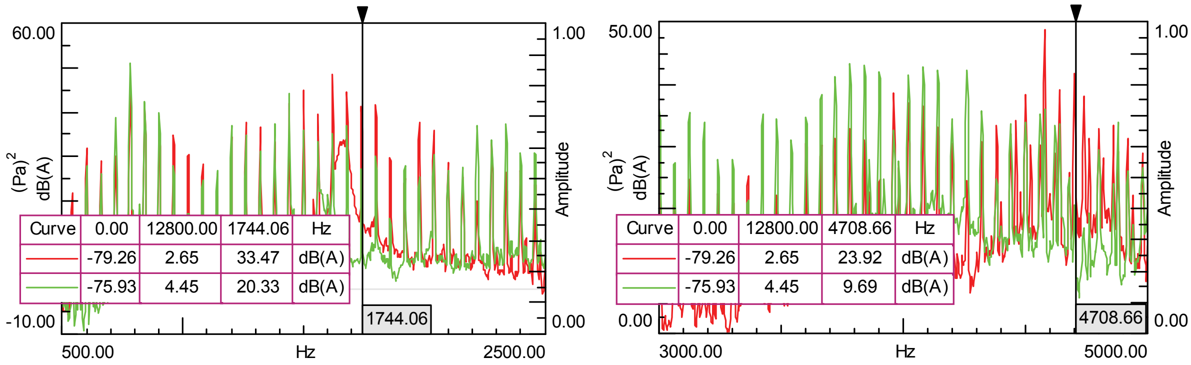


Figure 6: Transmission loss of muffle with and without multi-Helmholtz resonator

4. EXPERIMENT

According to the design in section 3, several compressors with multi-Helmholtz resonator on top-flange are manufactured. The desired resonance frequencies are around 1750Hz, 2770Hz and 4930Hz. The segmental frequency spectrum of compressor with and without multi-Helmholtz resonator test in semi-anechoic room is shown in Figure 7. Local frequency spectrum between 500Hz and 2500Hz is shown in Figure 7(a). Local frequency spectrum between 3000Hz and 5000Hz is shown in Figure 7(b). Green curve and red curve are sound pressure level (SPL) curves of compressor with and without multi-Helmholtz resonator respectively.



(a) 500Hz~2500Hz (b) 3000Hz~5000Hz

Figure 7: SPL of compressor with and without multi-Helmholtz resonator

The sound pressure level (SPL) of compressor with multi-Helmholtz resonator is reduced approximately by 13 dB (A) at 1744 Hz and 14 dB (A) at 4708Hz respectively, compared with the compressor without multi-Helmholtz resonator. The frequencies exactly match the resonance frequency of multi-Helmholtz resonator. The multi-Helmholtz resonator can attenuate not only the noise of single resonance frequency but also the noise with the frequency band width of 300Hz around the resonance frequency. It can be suggested from the result that multi-Helmholtz resonator has good effect on reducing target frequencies noise.

The noise of inverter-driven compressor is particularly high when compressor runs at high operation frequency. The sound power level decrement of compressors with multi-Helmholtz resonator is shown in Table 3 when operation frequency range is from 60Hz to 85Hz. The sound power level decrement of every operation frequency listed in Table 3 is computed by the average value of all compressors manufactured. The effect of multi-Helmholtz resonator used in compressor is obvious as shown in Figure 8. From the data it can be seen that the sound power level can be reduced by 0.9 dB (A) ~ 2.7 dB (A) with multi-Helmholtz resonator under different operation frequency.

Table 3: The decrement of Sound power level of compressors with multi-Helmholtz resonator

Operation Frequency/Hz	60	70	80	85
Sound power level decrement /dB	2.1	1.5	0.9	2.7

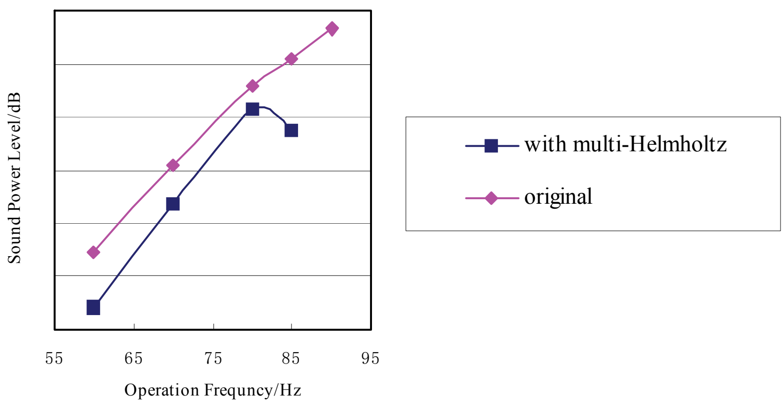


Figure 8: Sound power level of compressors with and without multi-Helmholtz resonator

5. CONCLUSIONS

In this paper, multi-Helmholtz resonator processed on top-flange and cylinder is proposed to reduce different peak value noise. It is proved that multi-Helmholtz resonator has good effect on reducing peak value noise of target frequencies under numerical and experimental methods executed in this paper. Proper design can effectively reduce the sound power level of compressor under different operation frequency. Additionally, multi-Helmholtz resonator can be processed on both top and bottom flange if the cylinder of compressor has two discharge ports.

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