

# Research on Noise Reduction of Reed Valves of a Hermetic Refrigerator Compressor

Zhilong He<sup>1</sup>, Qian Chen<sup>1</sup>, Dantong Li<sup>1</sup>, Ju Wang<sup>2</sup>, Pu Xia<sup>3</sup>, Tao Wang<sup>1\*</sup>

<sup>1</sup> Xi'an Jiaotong University, Xi'an, China

<sup>2</sup> Nanjing Engineering Institute of Aircraft Systems, Nanjing, China

<sup>3</sup> Carrier SRDC, Shanghai, China

\*Corresponding Author

E-mail: taowang@stu.xjtu.edu.cn

**Abstract.** The noise level of the refrigerator compressor has received more and more attention in recent years. As the key component of a compressor, reed valve is its main noise source. In this paper, a new noise reduction technology of coating on reed valve surface is proposed and verified by experiments. Firstly, the reed valves were coated, and their surface characteristics were checked. Then, the refrigerator compressor p-V diagram test was carried out to investigate the influence of doped diamond-like carbon (DLC) coating on power consumption. Finally, the noise test rig for the refrigerator compressor was set up. Based on the standard test method, noise spectrum was measured in a semi-anechoic room under standard working condition. Research results showed that the compressor noise was significantly reduced by 1.8dB (A) after coating. Moreover, the effect of aerodynamic noise reduction at suction side is better than that at discharge side. However, the influence of the film thickness on noise reduction value is little. The COP was reduced by 0.6% as compared to the compressor with uncoated reed valves.

Key words: Refrigerator compressor; Reed valve; Noise; Coating; p-V diagram

## 1. Introduction

Valve noise often acts as the main source of compressor noise in a hermetic refrigerator compressor. It consists of mechanical and aerodynamic noise generated by the intermittent movement of the reed valve. The suction and discharge valves repeatedly hit the valve seat or lift guard producing mechanical noise. Additionally, the periodic motion of reed valves results in the pulsation of refrigerant pressure and velocity, leading to aerodynamic noise. It is visible that the intermittent movement of the reed valve has a significant influence on the mechanical and aerodynamic noise of a compressor. The major findings and contributions of the compressor noise reduction are summarized as follows:

Soedel classified valve noise sources as gas pulsations, valve-to-stop noise, and impact noise. He also proposed some noise reduction measures: using mufflers at suction and discharge sides, optimizing the valve port, changing the surface characteristics of the valve seat [1]. Kral PJ optimized reed thickness, stiffness and other parameters of the compressor through numerical simulation and experimental verification [2]. The noise can be reduced by decreasing the rigidity, thickness and density of the reed valve. In China, Zou Qiang introduced a reed valve made of polyether-ether-ketone plastic which not only reduces noise but also improves the life span of a reed valve[3]. Guan Hua et al. stated the reed valve noise was mainly caused by its vibration under the high-speed flow of working medium and suggested it can be reduced via optimizing the valve structure and thickness [4].



From above research work, it can be concluded that the noise reduction technology of the reed valve is well achieved by changing its basic structure, material and surface characteristics. Nevertheless, the optimization of reed valve and lift guard change its shape or weight and also affect suction and discharge efficiency or other performances of the compressor. Little attention has been paid to this aspect.

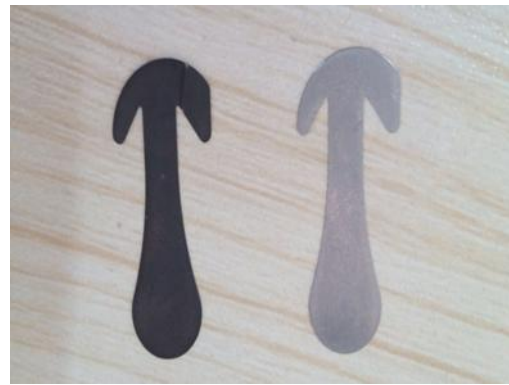
Therefore, this study introduces a new noise reduction technology: doped diamond-like carbon coating on the surface of suction and discharge valves of a compressor.

## 2. Experiment of film coating on reed valve surface

In this study, the doped diamond-like carbon film was prepared on the substrate of reed valves by unbalanced magnetron sputter equipment. Figure 1 and 2 present the conventional uncoated reed valves and the improved coated reed valves, the left side for the improved samples, the right side for the conventional samples.



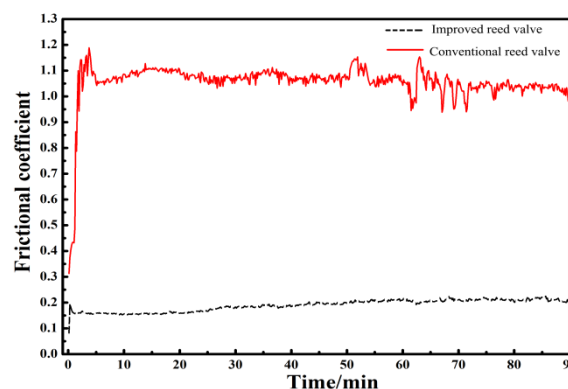
**Figure 1.** Comparison of conventional and improved suction valves.



**Figure 2.** Comparison of conventional and improved discharge valves.

### 2.1. Friction and wear test

Figure 3 presents the friction coefficient vibration of conventional and improved samples. Pin-on-disc experiment showed that DLC films possessed excellent wear resistance and presented low values of friction coefficient ( $f_c=0.2$ ) when it was sliding against SiC grinding disc.



**Figure 3.** Friction coefficient vibration of conventional and improved samples.

In Figure 3, it also has been manifested that the DLC films provided a self-lubricating mechanism, which is critical for the tribological performance of the nano-composite DLC coatings [5, 6]. Compared with the improved sample, the conventional one exhibited high values of friction coefficient, accompanying a severe fluctuation, which means that DLC coated reed valves have advantages of both wear resistance and antifriction properties.

If the suction valve of a refrigerator compressor is regarded as a throttle element, it can be derived the following equation from the empirical formula [7]. The relationship between the SPL and pressure loss is defined by the formula:

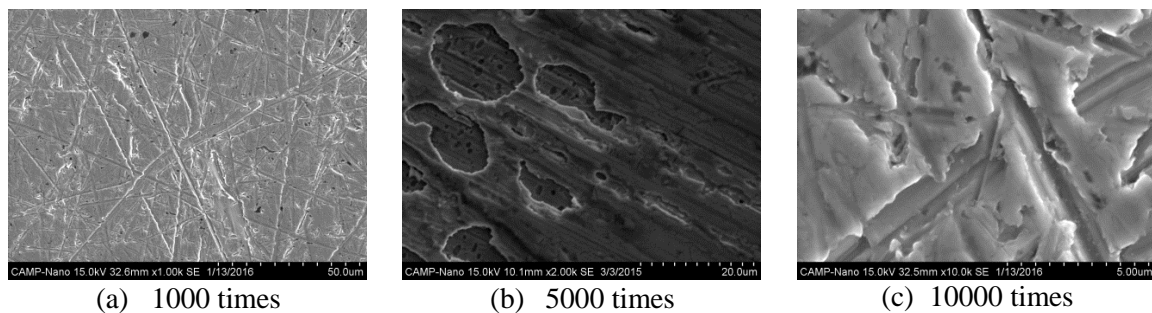
$$L_p = 80 + 20 \lg \frac{\Delta p^2}{0.5(p_s^2 - \Delta p^2)} + 20 \lg D \quad (1)$$

Where  $L_p$  is the SPL (dB),  $p_s$  is the suction pressure (Pa),  $\Delta p$  is the valve resistance pressure (Pa),  $D$  is the suction port diameter (m).

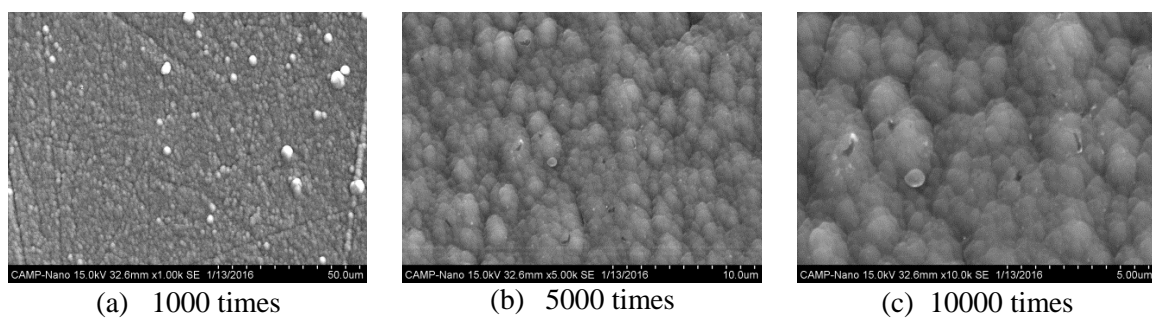
When the reed valve friction coefficient is reduced, the valve pressure drop is declined. So the reed valve noise can be indirectly decreased.

## 2.2. Scanning electron microscopy (SEM)

SEM images are listed as follows (Figure 4 and 5) to analyze the surface microstructure of samples. It can be obtained from these pictures that the surface roughness of the conventional reed valve is poor, also existing many cracks. These defects can be considered the failure source of the suction and discharge valves of the refrigerator compressor. By contrast, the surface of the coated reed valve is smooth, and the grain of diamond-like carbon film is evenly and densely distributed on its surface. Furthermore, no obvious pores are detected in the films, indicating the films are dense, promising for a better adhesion [8].



**Figure 4.** Surface morphology of conventional samples.



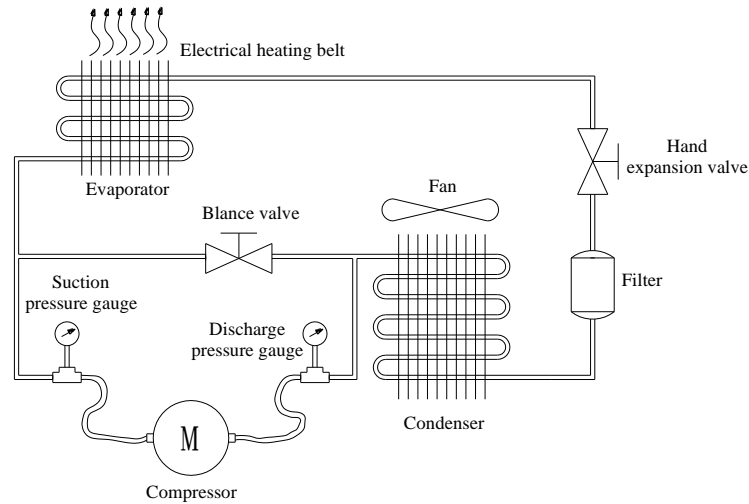
**Figure 5.** Surface morphology of improved samples.

## 3. Noise test

To analyze the valve noise characteristics of a refrigeration compressor, the noise test of the refrigerator compressor was carried out in the noise test rig.

### 3.1. Experiment setup

Figure 6 shows the schematic diagram of the experimental setup and main test rig components. The compressor used in this experiment is a hermetic refrigerator compressor of Qianjiang Wansheng, and its model is 153YV.



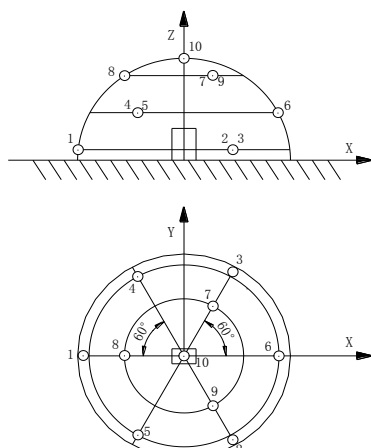
**Figure 6.** Noise test rig.

Based on the standard test method, noise spectrum on ten specified points around the compressor was measured in a semi-anechoic room under a standard condition for the pressure of  $96\text{kPa} \pm 10\text{kPa}$ , the temperature at  $20^\circ\text{C} \pm 5^\circ\text{C}$ . According to Chinese national standard “GB/T 9098-2008 Hermetic motor-compressors for refrigerators”, the noise test condition is presented in Table 1.

Table 1. Noise test condition.

Refrigerant	Discharge pressure /MPa	Suction pressure/MPa	Reflux temperature/ $^\circ\text{C}$
R600a	$0.68 \pm 0.05$	$0.072 \pm 0.01$	$32.2 \pm 3.0$

According to the obtained spectral characteristics of 1/3 octave sound power level, the noise reduction target frequency was identified. Figure 7 shows the location of noise test points and Figure 8 shows a semi-anechoic room of noise test.



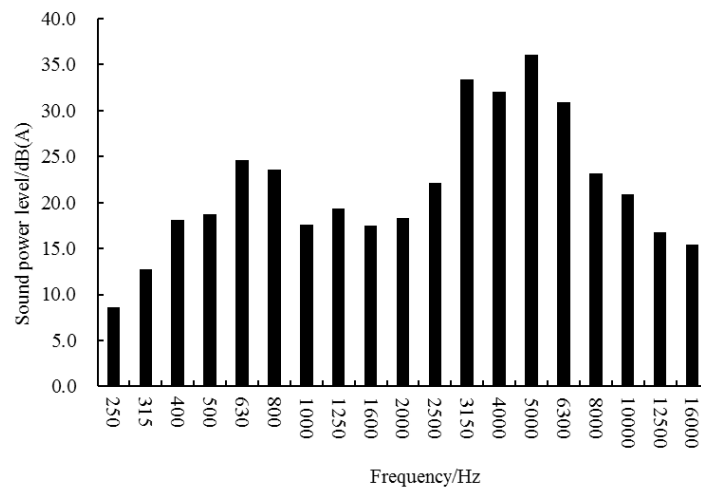
**Figure 7.** Location of noise test points.



**Figure 8.** A semi-anechoic room of noise test.

### 3.2. Noise reduction target frequency

Figure 9 illustrates the 1/3 octave band frequency spectra of A-weighted sound power level. It can be seen that the noise of a domestic refrigerator compressor is most prominent in the 500Hz-800Hz and 3150Hz-6300Hz frequency ranges. Generally, it is believed that the mechanical noise was caused by crankshaft unbalanced force and the electromagnetic noise was caused by the motor, which are both distributed below 400Hz. The aerodynamic noise and mechanical noise are generated by the cyclical movement of suction and discharge valves, which are mainly distributed at the central frequency of 630Hz, 800Hz, 3150Hz and 4000Hz [9]. Therefore, the noise reduction target of the paper is in these frequency band areas.



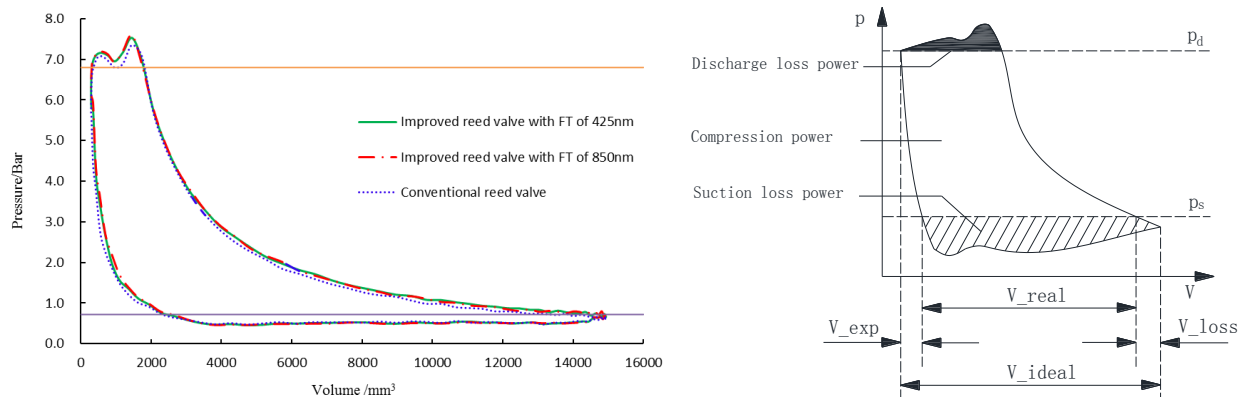
**Figure 9.** 1/3 octave band frequency spectra of A-weighted sound power level.

#### 4. p-V diagram analysis

An experimental study on recording the p-V diagram was conducted, aimed to investigate the effect of film coating on power consumption. This experiment was performed under the standard condition when the film thickness is 0nm, 425nm and 850nm, respectively. The evolution of the pressure with the volume is obtained from the p-V test system of a refrigerator compressor, as shown in Figure 10.

From Figure 10, it can be seen that there are some slight differences among these p-V diagrams, which may be the influence of the hardness and stiffness of improved reed valves. These differences were mainly reflected in suction and discharge pressure.

As shown in Figure 11, the p-V diagram is divided into three parts: suction, compression and discharge. Where  $p_s$  is the evaporation pressure,  $p_d$  is the condenser pressure,  $V_{ideal}$  is the theoretical displacement of the compressor,  $V_{exp}$  is the pre-expansion gas volume,  $V_{loss}$  is the displacement loss,  $V_{real}$  is the actual displacement of the compressor.



**Figure 10.** p-V diagram of compressor under different conditions.

**Figure 11.** Analysis of the compressor p-V diagram.

The analysis of pressure loss at suction and discharge sides is presented in Table 2. It can be concluded that pressure loss at suction side changes a little, while pressure loss at discharge side is increased by 0.19Bar after reed valves were coated.

**Table 2.** Analysis of pressure loss at suction and discharge sides.

Valve type	Pressure loss at suction side /Bar	Relative pressure loss at suction side	Pressure loss at discharge side/Bar	Relative pressure loss at discharge side
Conventional	0.24	33.33%	0.54	7.94%
Improved (film thickness of 425nm)	0.25	34.72%	0.73	10.73%
Improved (film thickness of 850nm)	0.25	34.72%	0.80	11.76%

According to the previous analysis, the noise at suction and discharge side is related to the pressure loss of suction and discharge reed valve. However, the increase of pressure loss at discharge side does not result in larger noise. To some extent, it is considered that the aerodynamic noise of the refrigerator compressor is focused on the suction side, instead of discharge side. Thus, the effect of coating on the discharge valve surface on noise reduction and compressor performance is not ideal. It provides a theoretical basis for the future study of film coating optimization of the refrigerator compressor reed valve.

Table 3 shows that the suction, discharge and compressed gas power consumption of the compressor. In addition, the compressed gas power consumption represents the indicated power without the suction and discharge power consumption. It can be observed that the valve power consumption at discharge side is lower than that at suction side. Because the coating increases the reed valve hardness and stiffness, so the suction, discharge, compressed gas power consumption and valve power loss also increase, especially the discharge power consumption. The discharge power consumption of an improved compressor with the film thickness of 425nm is increased by 52.30% compared with the conventional compressor. In the end, the indicated power consumption of the whole machine is increased by 5.31W than that of a conventional compressor. The three power consumption is also growing slightly with the increase of the film thickness.

**Table 3.** The power consumption of conventional and improved compressor.

Valve type	Suction power consumption/W	Discharge power consumption/W	Compressed gas power consumption/W	Indicated power /W	valve power loss
Conventional	11.75	1.74	102.83	116.32	13.1%
Improved(film thickness of 425nm)	12.44	2.65	106.54	121.63	14.2%
Improved(film thickness of 850nm)	13.04	2.71	106.80	122.55	14.7%

Table 4 shows the performance analysis of the conventional refrigeration system with uncoated reed valves and the improved refrigeration system with coated reed valves. It can be obtained that the

actual displacement of the compressor is improved although its each part of power consumption becomes larger after the reed valves were coated. Consequently, the COP of the coated one is decreased by 0.6% as compared with the conventional system. Hence, it can be considered that the COP of the compressor nearly remains unchanged.

**Table 4.** Performance analysis of the refrigeration system.

Valve type	V <sub>ideal</sub> /cc	V <sub>exp</sub> /cc	V <sub>loss</sub> /cc	V <sub>real</sub> /cc	Cooling capacity/W	COP
Conventional	14.62	2.05	1.04	11.53	Q	$\epsilon$
Improved(film thickness of 425nm)	14.62	2.18	0.45	11.99	1.04Q	0.994 $\epsilon$
Improved(film thickness of 850nm)	14.62	2.23	0.57	11.82	1.03Q	0.972 $\epsilon$

## 5. Results and discussion

The experiment was performed to investigate the influence of film coating, film thickness and discharge pressure on compressor noise. It was also carried out in the noise test rig according to the above test method.

### 5.1. Noise performance analysis of a compressor

In this study, the suction and discharge valves of the refrigeration compressor were coated, and other components were not coated. Three experiments were carried out, aimed to obtain the compressor noise level under different conditions.

The first group experiment is to test the noise level of a conventional compressor and an improved compressor with the film thickness of 850nm under standard condition.

The second group experiment is to test the noise level of an improved compressor with the film thickness of 425nm and 850nm under standard condition.

The third group experiment is to test the noise level of an improved compressor with the film thickness of 425nm under discharge pressure for 0.68MPa, 0.6MPa and 0.5MPa, respectively.

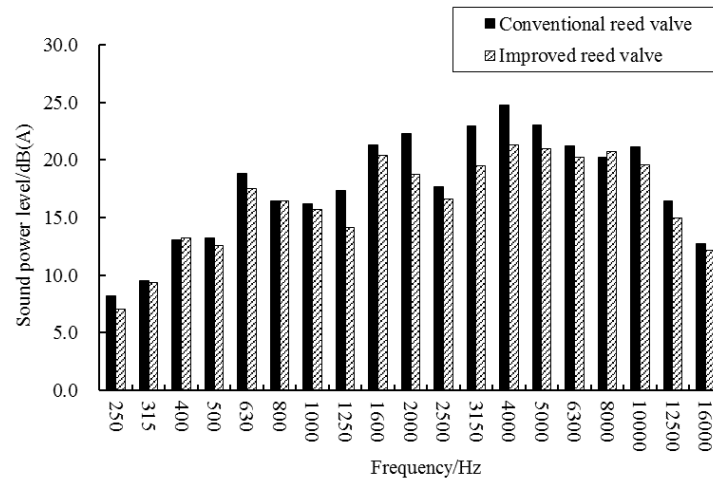
### 5.2. The first group test results.

Table 5 shows the A-weighted sound pressure level of each test point under the first condition. It can be observed that the A-weighted sound power level of the conventional compressor is 32.86dB (A), and that of the improved compressor is 31.06dB (A). Thus, the total noise level is significantly reduced by 1.8dB (A) when the reed valves were coated.

**Table 5.** The A-weighted sound pressure level of each test point under the first condition.

A-weighted sound pressure level of each test point /dB(A)										
Location	1	2	3	4	5	6	7	8	9	10
SPL(conventional)	23.7	23.9	25.0	23.2	23.4	23.7	27.1	24.1	23	28.1
SPL(improved)	23.3	23.8	23.6	22.1	22.4	23.4	21.9	22.1	21.9	25.1

The 1/3 octave band frequency spectra of A-weighted sound power level under the second condition, as shown in Figure 12. It can be seen that the sound power level of the compressor noise is remarkably reduced at 630 Hz, 3150 Hz and 4000 Hz, especially at 3150 Hz and 4000 Hz.

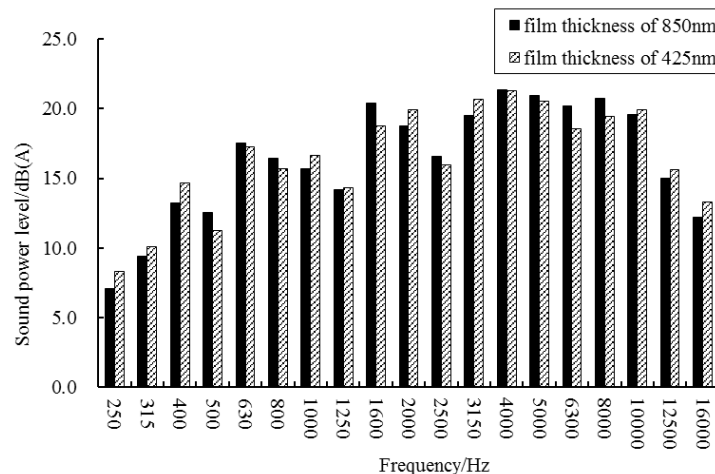


**Figure 12.** 1/3 octave band frequency spectra of A-weighted sound power level under the first condition.

### 5.3. The second group test results.

Table 6 presents the A-weighted sound pressure level of each test point under different film thicknesses. The A-weighted sound power level of the improved compressor characterized by the film thickness of 850nm is 31.06dB (A), and that of the other improved compressor is 31.03dB (A). It can be seen that the total noise level is only decreased by 0.03dB (A), indicating that the film thickness has little effect on noise reduction value.

The 1/3 octave band frequency spectra of the A-weighted sound power level of the improved reed valves is depicted in Figure 13. It can be obtained that the amplitude of the sound power level in the four target bands changes a little. The film thickness has little effect on mechanical noise of the reed valve, although the hardness of the reed valves was improved. However, it has a greater impact on the aerodynamic noise.



**Figure 13.** 1/3 octave band frequency spectra of A-weighted sound power level under the second condition.

**Table 6.** The A-weighted sound pressure level of each test point under the second condition.

A-weighted sound pressure level of each test point /dB(A)										
Location	1	2	3	4	5	6	7	8	9	10
SPL(film thickness of 425nm)	23.7	23.7	24.8	22.7	22.1	23.1	21.6	20.9	21.8	24.4
SPL(film thickness of 850nm)	23.3	23.8	23.6	22.1	22.4	23.4	21.9	22.1	21.9	25.1

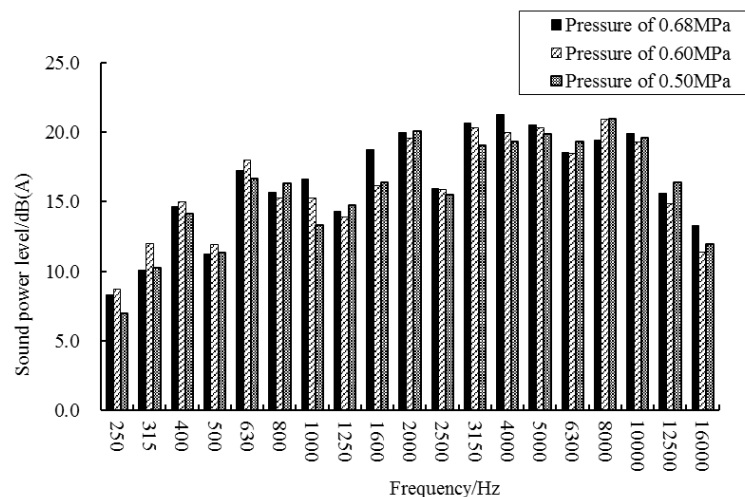
#### 5.4. The third group test results.

Table 7 shows the measured SPL under different discharge pressure. The A-weighted sound power level was 31.03dB (A), 30.87dB (A) and 30.83d (A) when the compressor was tested under the pressure of 0.68MPa, 0.6MPa and 0.5MPa, respectively. Besides, the smaller the discharge pressure is, the lower the compressor noise is. But the noise reduction effect is not obvious with the lower discharge pressure. It can be considered that the discharge side noise plays an unimportant role in the compressor noise source.

Figure 14 illustrates that the amplitude of the sound power level at the four target frequency bands is decreased when the discharge pressure is reduced, especially at the central frequency of 3150Hz and 4000Hz.

**Table 7.** The A-weighted sound pressure level of each test point under the third condition.

A-weighted sound pressure level of each test point /dB(A)										
Location	1	2	3	4	5	6	7	8	9	10
SPL(P=0.68MPa)	23.7	23.7	24.8	22.7	22.1	23.1	21.6	20.9	21.8	24.4
SPL(P=0.60MPa)	23.8	23.4	25.3	21.7	22.5	22.0	22.6	20.9	22.8	22.3
SPL(P=0.50MPa)	23.2	23.1	25.4	20.6	23.5	22.9	21.6	21.1	22.7	22.4



**Figure 14.** 1/3 octave band frequency spectra of A-weighted sound power level under the third condition.

## 6. Conclusions

In this study, a new noise reduction technology was proposed based on the theoretical and experimental analysis. The noise is reduced by doped diamond-like carbon coating on the surface of suction and discharge valves of a refrigeration compressor. On the other way, it also improves the reliability and life of the valve. The conclusions are as follows:

- The noise of the compressor was significantly reduced by 1.8dB (A) when the reed valves were coated. The effect of the aerodynamic noise reduction at the suction side was more obvious than that at discharge side. However, the influence of the film thickness of the noise reduction can be ignored.
- The actual displacement and cooling capacity were raised although the compressor indicated power was increased by 5.31W after coating. Consequently, the COP nearly remains unchanged.
- The friction of reed valve was reduced and wear performance of reed valve was dramatically enhanced after coating. The surface defects of the reed valve were also improved, which can effectively prevent the generation of crack on reed valve surface.

## References

- [1] W Soedel 1984 "Designs and Mechanics of Compressor Valves" (Short Course Text, Purdue University).
- [2] Kral PJ 2008 Influence of constructional parameters of small reciprocating compressors on sound power emissions. *Journal of the Acoustical Society of America*, 123(5):3316.
- [3] Qiang Z 2002 Polyether ether ketone(PEEK) and its application in compressor valves. *Compressor Technology*, (5): 26-29.
- [4] Hua G and Jiahua Y 1996 Experimental analysis for lowering the noise of refrigerator compressors. *Journal of Beijing University of Technology*, 22(2): 92-98.
- [5] Voevodin A.A, O'Neill J P and Zabinski J S 1999 Tribological performance and tribochemistry of nanocrystalline WC/amorphous diamond-like carbon composites. *Thin Solid Films*, 342(1–2):194-200.
- [6] Liu Y, Erdemir A and Meletis E I 1997 Influence of environmental parameters on the frictional behavior of DLC coatings. *Surface & Coatings Technology*, s 94–95(545): 463-468.
- [7] Dayou M, Peizi L, Genhau D and Hongyu W 1978 Pressure dependence of turbulent Tet Noise. *Chinese Journal of Physics*, 27(2): 121-125.
- [8] Sun F H, Zhang ZM, Chen M and Shen H S 2003 Improvement of adhesive strength and surface roughness of diamond films on co-cemented tungsten carbide tools. *Diamond & Related Materials*, 12(3–7): 711-718.
- [9] Chongming Z 2010 Research on vibration and noise of compressor (Doctoral dissertation, Shanghai: Shanghai Jiao Tong University).