Study on the Contribution of Compressor noise to Refrigerator Overall Noise

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ABSTRACT

Recently, greater attention is being paid to refrigerator noise. As we know, compressor is an important part of refrigerator, and it's also a very important noise soure. Based on comparison between compressor noise spectrum and refrigerator noise spectrum, the contributions of compressor noise to the refrigerator overall noise are discussed. Besides compressor direct radiation noise, compressor pressure pulsation and vibration also make great influence on refrigerator noise. A suction and discharge pressure pulsations test bench was built, and then the compressor pressure pulsation data were tested. By compressor suction and discharge pipelines optimization, the pressure pulsations and refrigerator noise were reduced. Vibration transmission path from compressor to refrigerator was investigated, and resonance frequencies on the vibration transmission path were identified. By refrigerator connection pipe optimization, refrigerator noise was reduced.

1. INTRODUCTION

Noise is one of the most easily perceived refrigerator characteristics. Recently, more and more attentions are being paid to the noise. Refrigerator noise is a complicated problem, and it can be affected by many aspects. Refrigerator noise is not only related to its own design, but also affected by the application environment and user preferences. Refrigerator produces different sounds in different seasons and regions. Different user preferences can also make the noise different. The complication also performs as that the noise is not stable and static. When compressor is starting the noise may be a little bit higer, and when it is stopping, maybe a sudden and short abnormal noise appears. Also the noise is not objective, different persons have different impressions on the same noise, and sometimes we have to make a subjective evaluation.

Compressor as one of the core components of refrigerator is closely related to the refrigerator noise.It is one of the most important noise and vibration sources. Baratti *et al.* (2012) identifed the vibration energy and acoustic energy paths in interaction between compressor and refrigerator. Olavo *et al.* (2014) researched the compressor supporting plate optimization for reducing the vibration energy transmission. Jeong *et al.* (2008) proposed the methods to reduce the low frequency noise of a reciprocating compressor in a refrigerator. Elvedin *et al.* (2008) researched the influence of the discharge port shape on screw compressor acoustic performance.

In this paper, the influence of the compressor on the operating noise of the refrigerator was discussed. Refrigerator noise spectrum and compressor noise spectrum were compared, and the reasons for the differnce were discused. Besides the compressor direct radiation noise, compressor suction and discharge pressure pulsations and vibration can also make great influence on the refrigerator noise. The compressor pressure pulsations were tested, and the refrigeator noises with different compressors were compared. The vibration transfer paths from compressor to refrigerator were analyzed, and the inherent frequencies of vibration transmission parts were indentified. After vibration transmission path redesign, the refrigerator noise was reduced.

2. REFRIGERATOR NOISE AND COMPRESSOR NOISE COMPARISON

Typical noise spectrums of compressor and refrigerator are shown in Figure 1. The compressor noise was tested using the load system. To make sure that the spectrums are compariable, the suction and discharge pressures of compreesor were tested when it was running in refrigerator. When testing the compressor noise in the lab, the same suction and discharge pressures were applied.

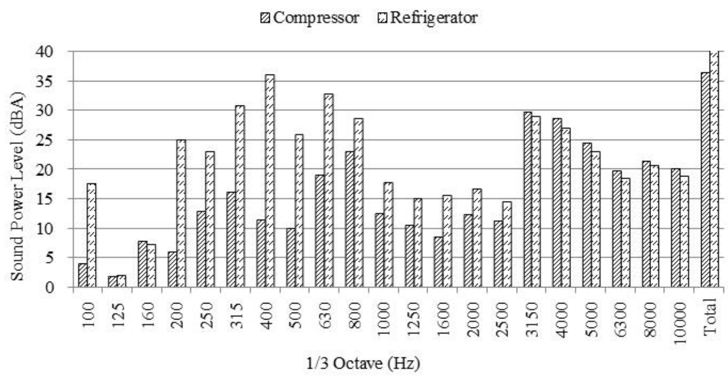


Figure 1: Compressor and refrigerator noise spectrums comparison

Figure 1 shows that there are great differences between the compressor noise and refrigerator noise: a) The refrigerator noise is mainly at the low frequencies, less than 1000 Hz in 1/3 octave; the compressor noise is mainly at the high frequencies, higher than 2500 Hz in 1/3 octave. b) For the high frequency noise (higher than 2500Hz), refrigerator noise spectrum is similar to the compressor noise spectrum, just the sound power level value is a litter smaller. c) For the low frequency noise (lower than 1000Hz), refrigerator noise is obviously higher than the compressor noise nearly in each 1/3 octave band.

Refrigerator compressor is hermetic; most parts are closed in the shell. Most noise is gererated form the inner of the compressor, the noise has to go out through the shell, in other words, most of the compressor noise propagates by the shell radiation. The shell has sound insulation effect, especially for the noise which frequency is lower than the first order natural frequency of the shell. Usually the size of refrigerator compressor shell is small, the first order natural frequency is higher than 3000 Hz. Therefore, the shell can make more sound insulations for the lower frequency noise.

Compared to compressor, refrigerator has much bigger size, it has foam layers, pipes, plates, and so on. Usually the stiffness of those parts are not high, the inherent frequencies of them are lower than 1000 Hz, so refrigerator is easy to produce low frequency noise. In addition, many refrigerator parts have damping, they are not good for high frequency noise propagation, so most refrigerator system noise is low frequency, the refrigerator's high frequency noise (higher than 3000Hz) comes from the direct radiation of the compressor noise.

Besides compressor direct radiation noise, suction and discharge pressure pulsations and vibration contribute to refrigerator noise. During suction and discharge phases, compressor suction and discharge pressure pulses respectively, the pulsations make involved pipes vibrating and generate extra noise. Section 3 addresses the contribution of compressor suction and discharge pressure pulsations to refrigerator overall noise. And section 4 focuses on the influence of compressor vibration on it.

3. INFLUENCE OF COMPRESSOR PRESSURE PULSATIONS ON REFRIGERATOR NOISE

Refrigerator compressor is the reciprocating compressor. Due to the periodical suction and exhaust, it caused suction and discharge pressure fluctuations. The compressor suction and exhaust pressure pulsations test bench was built, the pulsations were tested. Different suction and exhaust designs were discussed. When installing the different compressors in regrigerator, the refrigerator noise was tested. The influence of compressor pressure pulsation on refrigerator noise was analyzed.

3.1 Compressor Suction and Discharge Pressure Pulsations Test

Compressor suction and exhaust pressure pulsation test bench is shown in Figure 2. It also can be used to test the pressure pulsations in the refrigerator. The dynamic pressure sensors were fixed in suction pipe and discharge pipe, the pressure sensor sensitivity is 450mV/bar, the sensor can catch the pressure pulsation upto 3000Hz. Data was collected by a NI PCI-4472 8 channels acquisition card, a data analysis program was coded by Labview. After the compressor operation was stable, the pressure data was collected. By Fast Fourier Transform (FFT), the spectrum of pressure pulsations were got.

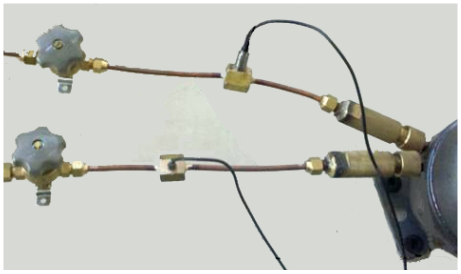
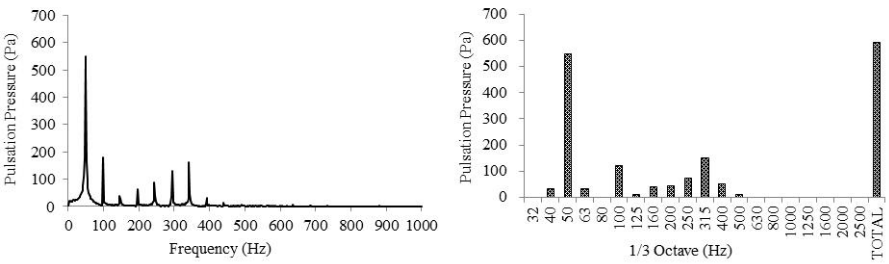


Figure 2: Compressor pressure pulsation test bench

The suction pressure pulsation data is shown in Figure 3. Figure 3.a) is the FFT data of pressure pulsation, Figure 3.b) shows the pressure pulsation in 1/3 octave, the reference pressure is 2E-5 Pa.

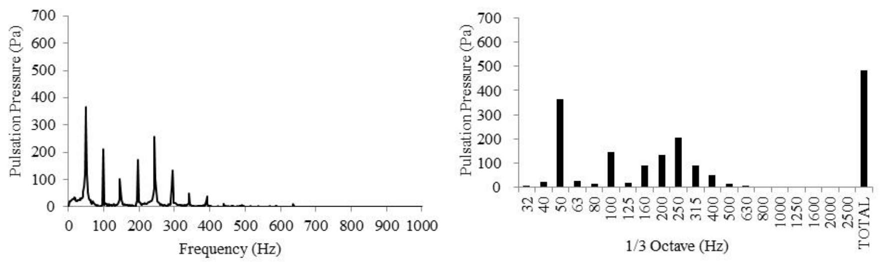


a) FFT data b) 1/3 Octave data

Figure 3: Compressor suction pressure pulsation

Figure 3 shows that most of the suction pressure pulsation frequecies are lower than 1000Hz, and the frequencies are harmonic, they are multiples of the fundamental frequency of the compressor. The maximum value appears in the compressor working frequency 50Hz, that is easy to understand. The total suction pulsation pressure is 500Pa.

The discharge pressure pulsation data was listed in Figure 4. Figure 4.a) is the FFT data, Figure 4.b) is the 1/3 octave data, the reference pressure is also 2E-5 Pa.



a) FFT data b) 1/3 Octave data

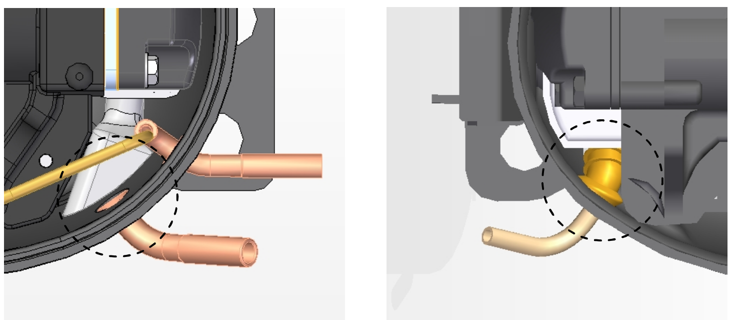
Figure 4: Compressor discharge pressure pulsation

Figure 4 shows that the peak valve of the compressor exhaust pressure pulsation is also at the working frequency

50Hz, and the pressure pulsation is harmonic, the pulsation frequencies are less than 1000Hz. The total discharge pulsation pressure is 800Pa.

3.2 Suction Pressure Pulsation Optimization and Refrigerator Noise Test

For the reciprocating compressor, the suction pressure pulsation is unavoidabel, but we can optimize the pressure pulsation by structure redesign. Figure 5 shows two typical designs for compressor suction system, one is direct suction compressor, the other is semi-direct suction compressor. The main difference is that there is a rubber connection between the shell and suction muffler in the direction suction compressor, the semi-direct suction doesn't have this part. For the direct suction compressor, the suction muffler is directly connected with the shell, and the refrigerant gas in the suction pipe is directly sucked into the muffler. For the semi-direct suction compressor, the refrigerant gas goes into the shell cavity, then be sucked from the cavity. The shell cavity acts as a big cushion chamber.



a). Semi-direct suction b). Direct suction

Figure 5: Semi-direct suction and direc suction structures

The suction pressure pulsations of the two different compressors were tested; the results are listed in Figure 6. It shows that the prssure pulsation of semi-direct suction compressor is much smaller than that of direct suction compressor. Press pulsation is reduced from 500Pa to 60 Pa. And in 315 Hz frequency band, 400Hz frequency band, pressure pulsations are reduced obviously.

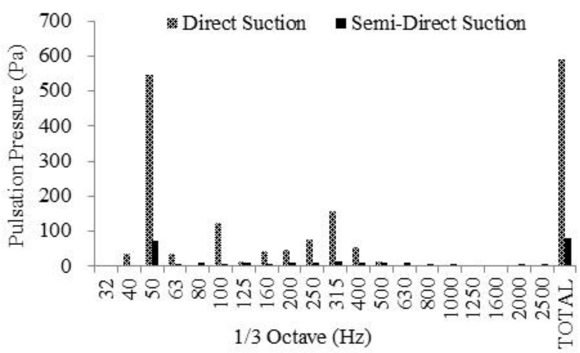


Figure 6: Suction pressure pulsation of direct suction and semi-direct suction compressors

Installing the above two compressor in the same refrigerator separately, the refrigerator noise was tested, and result is shown in Figure 7. It shows that, for the refrigerator with semi-direct suction compressor, the noise in 50Hz, 315Hz and 400Hz frequency bands reduced a lot. Compared to the pressure pulsation test results in Figure 6, we can find that the frequency bands where the pressure pulsation reduced are corresponding to frequency bands where the refrigerator noise reduced. So the pulsation pressure results in refrigerator additional noise in the corresponding frequency bands.

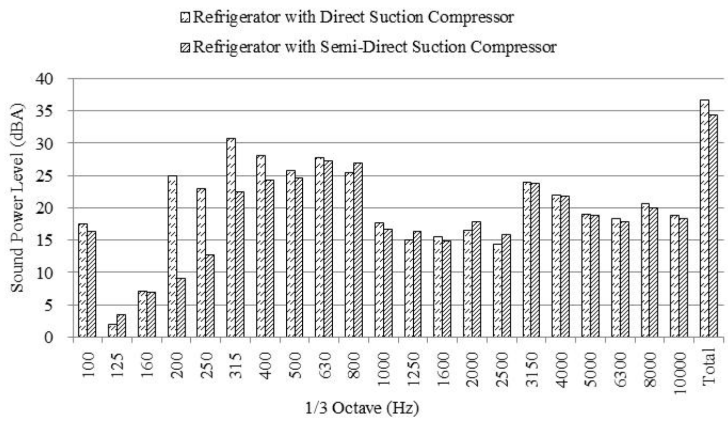


Figure 7: Refrigerator noise with direct suction and semi-direct suction compressors

3.3 Discharge Pressure Pulsation Optimization and Refrigerator Noise Test

Compressor also can produce pressure pulsation in the discharge side as in the suction side. The pressure pulsation can be optimized by discharge line redesign. Figure 8 shows a discharge line of a compressor.

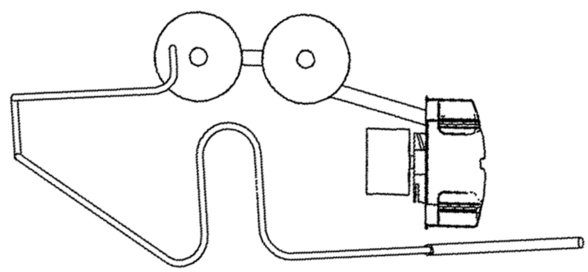


Figure 8: Discharge line of compressor

In order to reduce the discharge pressure pulsation, two buffer cavities had been arranged in the exhaust line, and the throttle orifice was arranged in the pipe between the two cavities. The inner discharge pipe was designed to be long and thin. To reduce the pulsation furthermore, each buffer cavity volume was extended to two times of the original. And the discharge pressure pulsation was tested. The data is shown in Figure 9.

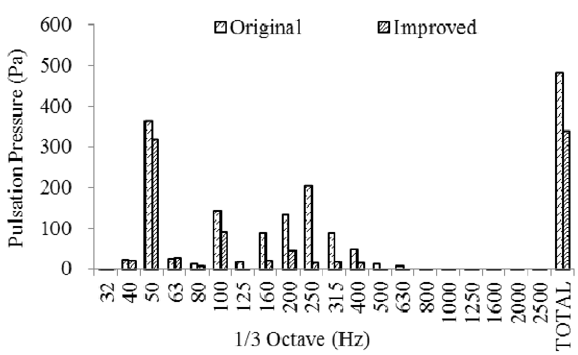


Figure 9: Discharge pressure pulsation of two designs

Figure 9 shows that the compressor discharge pressure pulsation is reduced significantly by doubling the volume of the buffer cavities. The compressors were installed on the refrigerator, the refrigerator noise was tested, shown in Figure 10.

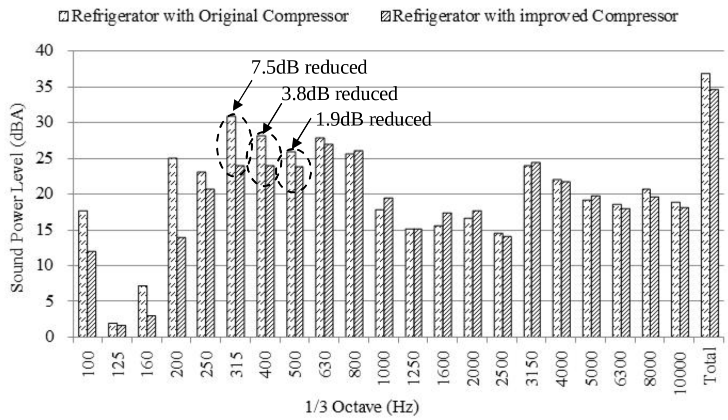


Figure 10: Refrigerator noise comparison

Figure 9 and Figure 10 show that, when the discharge pressure pulsation is reduced in the 315Hz, 400Hz, 500Hz frequency bands, the noise of the refrigerator in those frequency bands is also reduced.

4. INFLUENCE OF COMPRESSOR VIBRATION TRANSMISSION ON REFRIGERATOR NOISE

Compressor is connected to refrigerator by connection pipes and supporting rubber grommets. The compressor vibration can be transmitted to refrigerator by them. According to the vibration theory, when the frequency of the vibration is the same as or similar to the natural frequency of the transmission path, it will cause resonance, noise will be very large. The resonance frequencies of the refrigerator pipe lines were studied. A case showed that the refrigerator noise was reduced by reducing the compressor vibration transmission of connection pipes.

4.1 Vibration Transmission Path Analysis and Transmission Functions Test

Many parts of refrigerator are made by pipes, for example evaporator and condenser, most of them are not completely fixed, fixation stiffness is not high, and their inherent frequencies are low. They are easy to transmit vibration, cause resonance, and produce noise. Indentifing the inherent frequencies, and then avoiding them similar to source's vibration frequency, is a good way to avoid refrigerator additional noise. Suction pipeline inherent frequencies were tested, as shown in Figure 11.

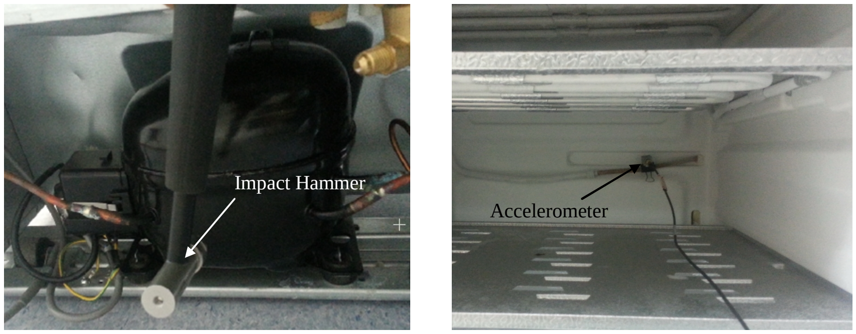


Figure 11: Vibration transmisson functions test

The accelerometer was installed on the pipeline, the hammer was used to knock the compressor to give a excitation. The transmission functions from hammer to the accelerometer can be got from the test; the inherent frequencies can be identified. One transmission function is shown in Figure 12. Figure 12 shows that, several inherent frequencies are lower than 1000Hz for the suction pipe line. When the excitation frequency is close to the inherent frequency, it will produce resonance and refrigerator noise.

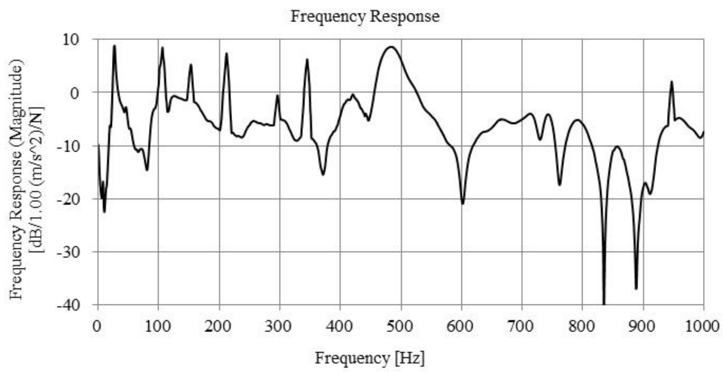


Figure 12: Vibration transmission function

4.2 Connection Pipe Optimization and Refrigerator Noise Comparation

Figure 13 shows one refrigerator connecting pipe. When using this pipe, the pipe and compressor vibrations are great. The pipe was modified and the inherent frequencies were optimized by using Finite Element Method (FEM), shown in Figure 14. The modified pipe was installed in the refrigerator, and the refrigerator noise was tested, the result was shown in Figure 15. The experiment shows that, optimizing the connection pipes frequencies to reduce the vibration transmission can be helpful for reducing refrigerator noise.

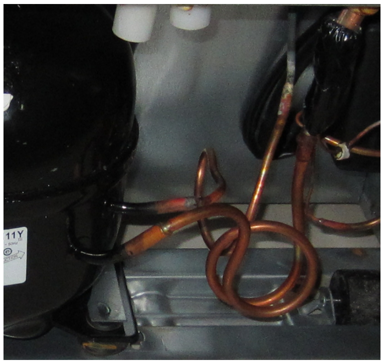


Figure 13: Refrigerator connecting pipes

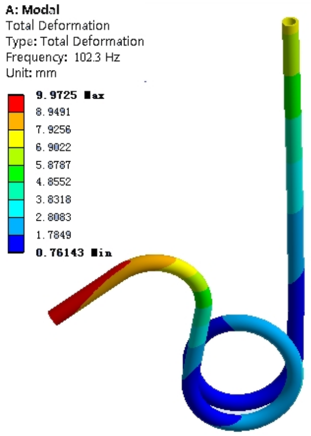


Figure 14: Connection pipe modal analysis using FEM

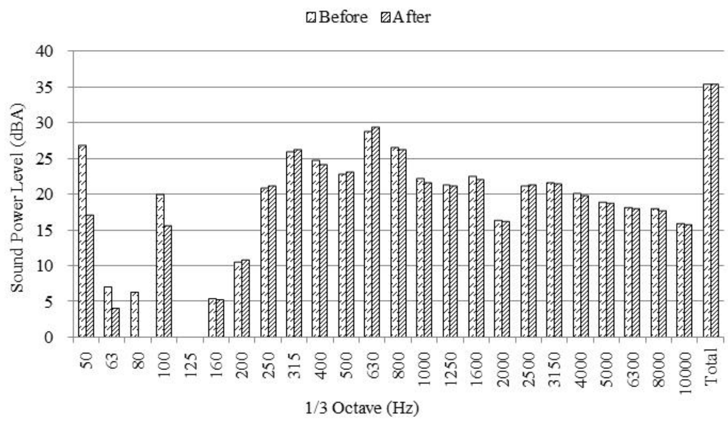


Figure 15: Refrigerator noise comparison

5. CONCLUSIONS

The compressor and refrigerator noise spectrums were compared, the differences between of them were discussed. The compressor noise is mainly at the high frequencies for the reason of the shell sound insulation; the refrigerator noise is mainly at the low frequencies for that, the inherent frequencies of most refrigerator parts are not high, these parts are easy to produce low frequency noise.

Besides the compressor radiation noise, compressor suction and discharge pressure pulsations and compressor vibration also make great influence on the refrigerator noise. A suction and discharge pressure pulsation test bench was built, and then the compressor pressure pulsation data were tested. By compressor suction and discharge pipelines optimization, the pressure pulsations and refrigerator noise were reduced. Vibration transmission path from compressor to refrigerator was investigated, and resonance frequencies were identified. By refrigerator connection pipe shape optimization, refrigerator noise was reduced.

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