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International Compressor Engineering Conference

School of Mechanical Engineering

2018

Study on Mechanism and Improvement of Triple Frequency Noise of Rotary Compressor

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ABSTRACT

With the continuous improvement of social life, people's requirements for the noise of home air conditioners are becoming increasingly strict. As the kernel of an air conditioner, compressor provides power for the whole system, inevitably generating vibration and noise. Therefore, reducing the vibration and noise of the compressor has significant influence on the noise reduction of the air conditioner. Generally, vibration is mainly transmitted through the suction and discharge pipes to the air conditioning pipe system. However, due to the complicated configuration, there are intensive modals for the pipe system, especially those in low frequency ranges, which may lead to resonance and large acoustic radiation. This paper studies on the generation and transmission mechanism of triple frequency vibration of the compressor. The compressor's discharge pressure fluctuation causes the discharge pipe to vibrate, and then results in vibration of the air conditioning pipe systems; and vibration generated by the rotor is transferred to suction pipe via the accumulator, which will cause the pipe systems to vibrate. Based on this research, we find some main factors which influence the triple frequency vibration and noise of the compressor, including the discharge pressure pulsation, the natural frequency of the rotor-crankshaft system swing, and the natural frequency of the accumulator swing. Then, the aforementioned factors which affect the compressor vibration and noise are analyzed separately. Finally, noise tests on the improved compressor at 90Hz are conducted. The results show that the compressor noise are reduced by 29.8% at 250Hz band expressed in 1/3 Octave.

1. INTRODUCTION

Rotary compressors have some advantages of simple structure, small size, stable operation and high efficiency. They are commonly used in household air conditioners. However, those compressors are generally eccentric, the noise and vibration are still large at running, and those vibrations will cause the pipe system and the sheet metal parts of the air conditioner to vibrate. Usually the sheet metal parts and soundproof cotton in the air conditioning system have a certain effect on sound insulation, but the low frequency noise has a strong penetrability, which is difficult to be eliminated by the way of sound insulation. Moreover, low frequency noise does not sound well, so it reduces the user's comfort. This is a common problem in household air conditioners. Therefore, it has a great significance to study the low frequency vibration and noise problems of rotary compressors. At present, many studies have been done in reducing the compressor's low frequency vibration and noise. Soedel (1974) told us that in the process of muffler design the first and key step is to investigate pressure pulsation in the discharge side, then estimate the natural frequency of the discharge system to avoid resonance. Zengli Wang et al. (2012) analyzed the vibration characteristics of the rotor-journal bearing system, and found that long dimensions of the length of the journal bearing led to bad stability of the rotor-journal bearing system and long journal bearing increased the probability of deformation and instability. Binsheng Zhu et al. (2008) studied the effects of the accumulator on the low frequency noise of rotary compressor through experiments and simulations. This paper takes the triple frequency vibration of the compressor as an example to analyze the mechanism and transmission path of the low frequency vibration of the compressor, and reduce the vibration and noise of the compressor by structure improvement. As a result, low frequency noise of the air conditioner is improved.

2. PROBLEM ANALYSIS OF TRIPLE FREQUENCY NOISE

2.1 Noise Problem of Air Conditioner

A rotary compressor equipped with inverter air conditioner, and abnormal noise in the outdoor unit of the air conditioner always appears with the running frequency of 90Hz as shown in Figure 1. The abnormal noise frequency band is mainly located at the 250Hz band in 1/3 octave, actually the peak frequency expressed by line spectrum is located at 270Hz, which is triple times of the compressor's operating frequency. Because the noise of this frequency has a strong penetration, so it is not easily blocked, and it doesn't feel good. This is a common noise problem in air conditioners.

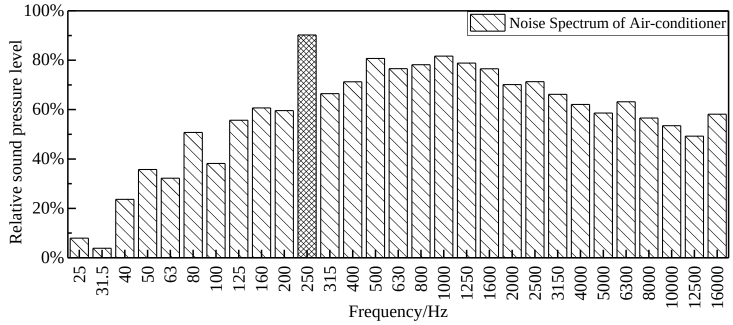


Figure 1: Noise spectrum of air conditioner

A standard 10-point noise test was performed on the rotary compressor in a semi-anechoic room. The test results in Figure 2 show that the rotary compressor has a relatively large noise value at the 250 Hz band, which is the source of abnormal noise in the outdoor unit of the air conditioner.

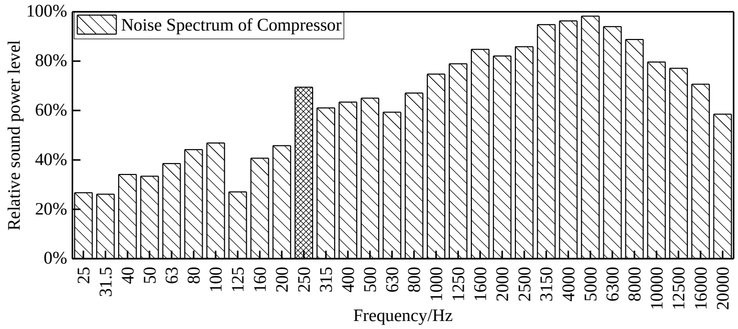


Figure 2: Noise spectrum of compressor

2.2 Analysis of Triple Frequency Noise's Transfer Mechanism

The compressor acts as a power for the air conditioner, and the vibration and noise generated by compressor have an important influence on the noise of the air conditioner. In the structure of the outdoor unit, the compressor is connected to the pipe system of the outdoor unit and the chassis through the suction pipe, the discharge pipe and the feet, and the vibration of the compressor is also transmitted to the outdoor unit through these three paths, which will cause the vibration of the outdoor unit, and radiation noise.

In order to reduce the vibration transmission to the chassis of the outdoor unit, three rubber mats are installed between the compressor feet and the chassis of the outdoor unit, which can reduce the natural frequency of the compressor below 30Hz, and it has a very obvious vibration isolation effect on triple frequency vibration of the compressor. Therefore, the primary transmission of the triple frequency vibration was not caused by the path from the compressor's feet to the chassis of the outdoor unit.

The pipe systems of the outdoor unit are connected to the suction and discharge pipes of the compressor by welding. The vibration of the compressor can be directly transmitted to the outdoor unit through the suction and discharge pipes, which will cause the vibration of the pipe system and radiation noise. They are the main transmission routes of the triple frequency vibration of the compressor. For rotary compressors, the main sources of triple frequency vibration are mechanical vibration and pressure pulsation. The mechanical vibration is mainly generated when the rotor rotates. The rotor-crankshaft system transmits the vibration to the outer shell and accumulator, and then passes through the discharge pipe on the outer shell and the suction pipe on the accumulator to the pipe system of the outdoor unit. The pressure pulsation is generated when the compressor periodically discharges the refrigerant, and this process will cause vibration and then enters into the pipe system of the outdoor unit. The air conditioner's triple frequency noise transmission path is shown in Figure 3.

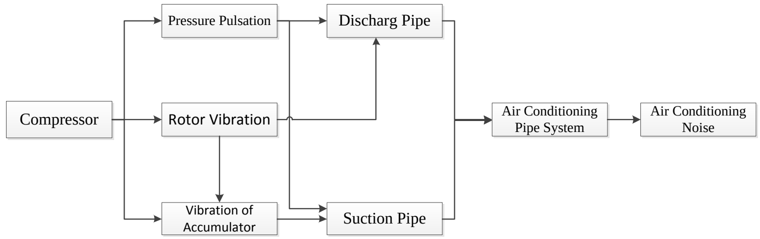


Figure 3: Transmission path of triple frequency noise of air conditioner

2.3 Analysis of Compressor's Triple Frequency Noise

From previous analysis, the air conditioning triple frequency noise is mainly caused by the pressure pulsation and rotor vibration. The pressure pulsation generates noise by causing the pipe system to vibrate. The rotor vibration transmits into the compressor shell and the accumulator through the rotor-crankshaft system, and then transmits the vibration to the air conditioning pipe system through the suction and discharge pipes, in which process the noise is irritated. Based on the source of vibration and transmission path, relevant tests and analysis were conducted.

2.3.1 Natural frequency test of the accumulator swing: The vibration of rotary compressor is mainly based on rotation. Therefore, the natural frequency of the accumulator in the compressor rotation direction has an important influence on the transmission of the triple frequency vibration. The natural frequency of the accumulator swing was tested by hammering. The test diagram is shown in Figure 4, and the test results are shown in Figure 5.

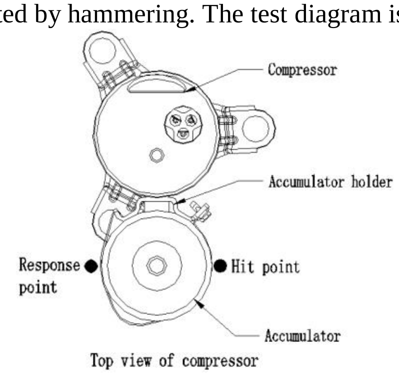


Figure 4: Test diagram

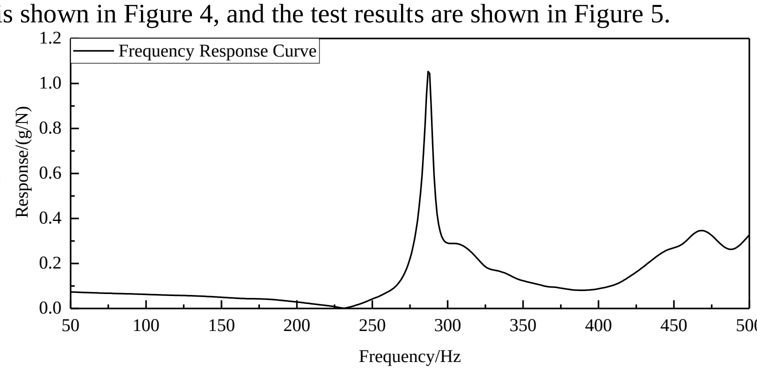


Figure 5: Test results of the accumulator swing natural frequency

Test results show that the natural frequency of the accumulator swing is 283Hz, which is similar to the triple frequency of the compressor. The triple frequency vibration of the compressor can easily be amplified by the accumulator, then enters into the air conditioner.

2.3.2 Natural frequency test of the rotor-crankshaft system swing: The rotor-crankshaft system, as the only way of vibration transmission of the rotor in rotary compressor, has an important influence on the transmission of the triple frequency vibration. The natural frequency of the rotor-crankshaft system swing was tested by hammering, and the results are shown in Figure 6.

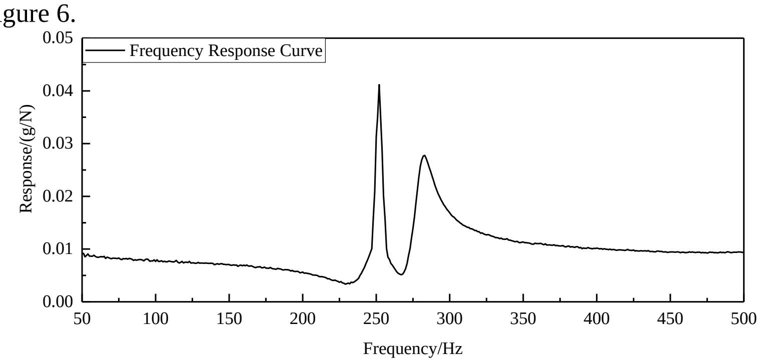


Figure 6: Natural frequency of rotor-crankshaft system swing

From the frequency response curve, the natural frequency of the rotor-crankshaft system swing is 252 Hz, which is similar to the triple frequency. They are very likely to resonate and amplify the triple frequency vibration.

2.3.3 Pressure pulsation test: Due to periodic suction and discharge, pressure pulsation has become one of the inherent properties of rotary compressors. The pressure pulsation, as one source of the vibration, can excite the air conditioning pipe system to radiate noise outward. We installed two pressure pulsation sensors on the suction and discharge pipes of the compressor and tested the pulsation. When the compressor is running at 90Hz, the pressure pulsation test results are shown in Figure 7.

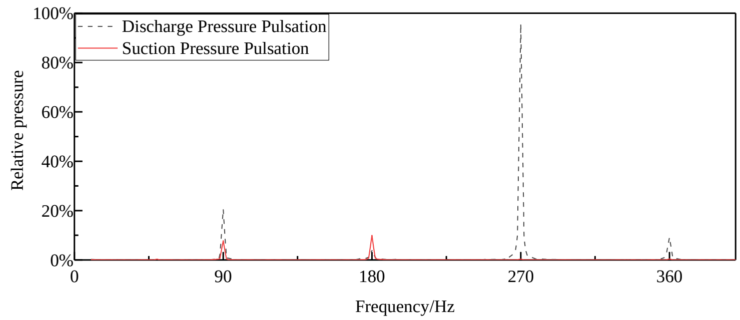


Figure 7: Suction and discharge pressure pulsation of compressor

The test results show that the suction pressure pulsation of the compressor is small, and it has less influence on the triple frequency vibration of the compressor and the pipe system; the discharge pressure pulsation has a large value at the triple frequency, and it obviously has a higher influence than other frequencies. After the pressure pulsation enters the air conditioning pipe system, it will stimulate the vibration, which will cause a large triple frequency noise.

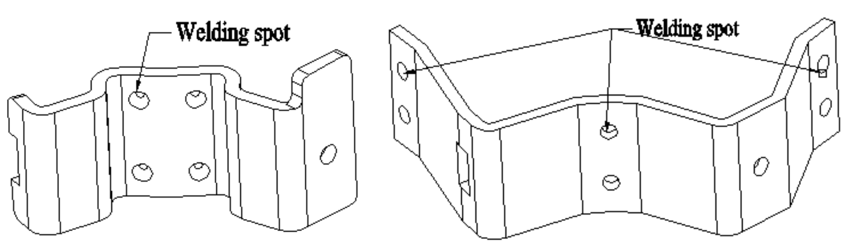
3. TRIPLE FREQUENCY NOISE OPTIMIZATION

The incentive source and transmission paths of the triple frequency noise were analyzed and there are three main influencing factors: the natural frequency of the rotor-crankshaft system swing, the natural frequency of the accumulator swing, and the discharge pressure pulsation.

3.1 The Fixed Structural Optimization of Accumulator

The accumulator of the rotary compressor is placed outside the compressor shell, and the bottom is fixedly connected to the cylinder through a communication pipe, while the upper part is connected to a holder on the compressor shell by a strap. The natural frequency of the accumulator swing is determined by the upper support in this connection. So, if we want to change the natural frequency of the accumulator swing, we need to change the support components of the accumulator.

The original holder of the accumulator is welded to the compressor shell via four intermediate points. Through modal simulation calculations, we found that the support points of the accumulator swing are the four welding spots. As shown in Figure 8, we have optimized the holder of the accumulator. We changed the four welding spots of the original holder into six welding spots, with two welding spots in the middle of the holder and two welding spots at each end. The way of fixing the accumulator and the holder does not change. After optimization, the natural frequency of the accumulator swing can be increased to 546Hz, which avoids the stimulation band of the triple frequency.

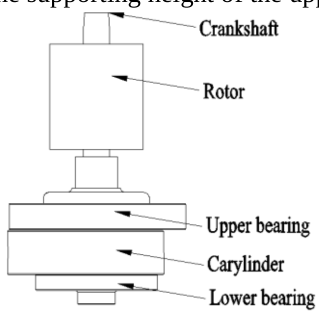


a) original holder of the accumulator b) optimized holder of the accumulator

Figure 8: Before and after optimization of the holder

3.2 Structural Optimization of Rotor-Crankshaft System

The structure of a rotor-crankshaft system of the rotary compressor is shown in Figure 9. The rotor is fixed on the upper part of the crankshaft, and the lower part of the crankshaft is simultaneously supported by the upper bearing and the lower bearing. According to the support method of the rotor-crankshaft system, the model can be simplified as shown in Figure 10. The rotor is fixed on the upper part of the crankshaft, and the lower part of the crankshaft is simultaneously supported by two supporting points. These two supporting points represent the upper bearing and the lower bearing, respectively. From the simplified model, the factors influencing the natural frequency of rotor swing include rotor mass, crankshaft stiffness, support point height, and rotor height. Combining with the structural characteristics of the compressor, the rotor mass, the rotor height, and the supporting height of the lower bearing cannot be changed. Therefore, if we want to increase the natural frequency of the rotor swing, we need to optimize the crankshaft stiffness and the supporting height of the upper bearing.



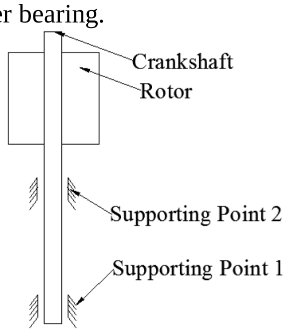
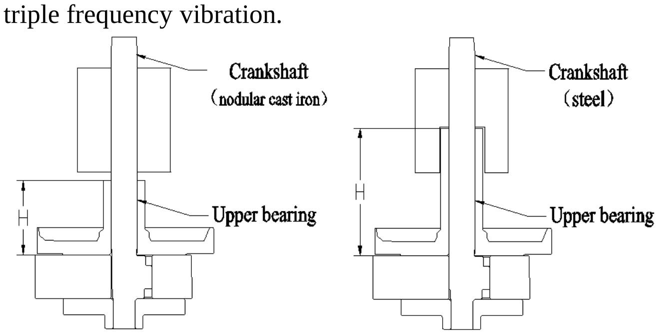


Figure 9: Rotor-crankshaft system **Figure 10:** Simplified model

From the aforementioned simplified model in Figure 10, it can be seen that increasing the height of the supporting point 2 or the rigidity of the crankshaft can effectively improve the natural frequency of the rotor swing. Thus, a new rotor-crankshaft system was designed as shown in Figure 11. In the optimized rotor-crankshaft system, the supporting height of upper bearing was increased by 62.6%, while the material of the crankshaft was changed from nodular cast iron to steel. Both can greatly increase the natural frequency of the rotor swing to 440Hz, effectively avoiding the stimulation of triple frequency vibration.



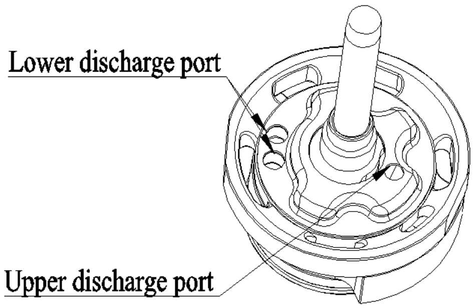
a) original rotor-crankshaft system b) optimized rotor- crankshaft system

Figure 11: Comparison of rotor-crankshaft system before and after optimization

3.3 Pressure Pulsation Optimization

The pressure pulsation test shows that the discharge pressure pulsation of the triple frequency is abnormally high, which has a large impact on the triple frequency noise of the air conditioner. Therefore it needs to be optimized. The discharge structure of the original compressor is discharged on both sides of the single cylinder, as shown in Figure 12. The refrigerant discharged from the lower bearing does not enter into the cavity of the compressor together with the refrigerant discharged from the upper bearing, but enter directly.

In this discharge structure, the distance traveled of the refrigerant discharged by the upper and lower bearing is not the same, and the time for reaching the same location is also not the same, so the two flows are very likely to form pulsations. Moreover, the refrigerant discharged from the lower bearing directly enters into the cavity of the compressor, and its pulsation is not effectively attenuated. Both are not conducive to the improvement of pressure pulsation. According to these factors, a new discharge structure was designed, as shown in Figure 13. This structure has only one discharge port located on the upper bearing and forms a buffer cavity outside the lower bearing, which can effectively reduce the pulsation.



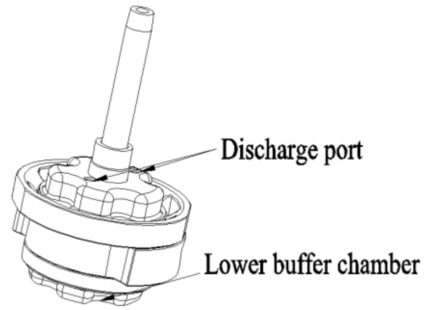


Figure 12: Original discharge structure **Figure 13:** Optimized discharge structure

Then a model for simulation calculation was established to compare the pressure fluctuation of the discharge structure before and after optimization. The results in Figure 14 show that the pressure pulsation of the triple frequency has improved by about 58%.

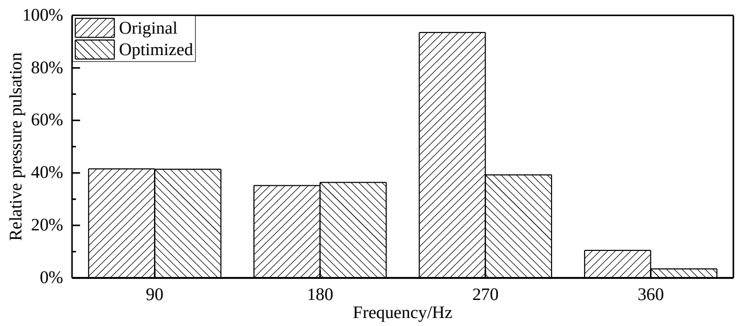


Figure 14: Comparison of discharge pressure pulsation before and after optimization

4. NOISE TEST

4.1 Noise Test of Compressor

In order to verify the influence of the above optimization, the optimized three components are assembled in the same compressor, and the noise test was conducted at 90 Hz. The test results in Figure 15 show that the noise of the compressor at the 250Hz band is 29.8% lower than the original.

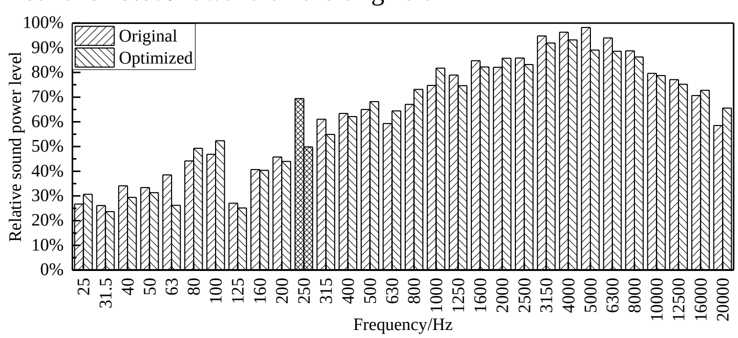


Figure 15: Comparison of compressor's noise before and after optimization

4.2 Noise Test of Air Conditioner

The above compressor was installed into the outdoor unit of the air conditioner and a noise test was conducted. The test results in Figure 16 show that the noise of the triple frequency of the outdoor unit is decreased by about 21.3%, and the abnormal noise of the outdoor unit is significantly decreased.

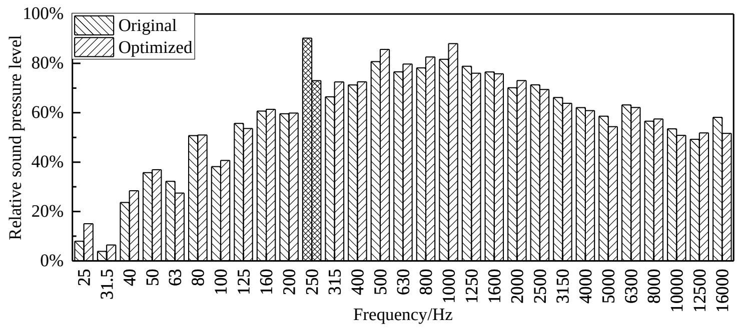


Figure 16: Comparison of air conditioning noise before and after optimization

5. CONCLUSIONS

In this paper, the mechanism of generation and transmission of triple frequency noise in the compressor are studied. There are mainly two transmission paths of triple frequency noise. The first path is the vibration of the rotor transmitted into the accumulator through the rotor-crankshaft system, and then transmitted into the outdoor unit of the air conditioner to radiate noise. The second path is the pressure pulsation from the compressor's discharge into the outdoor unit's pipes, causing the pipes to vibrate, which in turn radiates noise. By analyzing the structure of the rotary compressor, three main factors affecting the triple frequency vibration of the compressor are found. These are the discharge pressure pulsations, the natural frequency of the rotor-crankshaft system swing and the natural frequency of the accumulator swing. Finally, by optimizing the above three influencing factors, the compressor's triple frequency noise is decreased by 29.8%, and the outdoor unit's triple frequency noise is decreased by 21.3%. The abnormal noise problem of the outdoor unit is significantly improved.

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