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The Mechanism Discuss of Periodic Sound in Rolling Piston Compressor under Low Operating Frequency in Air-conditioner System

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ABSTRACT

With the popularization of the inverter-driven air-conditioner and the requirement of comfort and energy saving, the operating frequency of inverter-driven air-conditioner is lower and lower, even to 1Hz. But when the air-conditioner operates under the frequency of 10Hz, a periodic sound will appear in the air-conditioner outdoor unit, which should be researched and solved. According to the experiment test and theoretical analysis, it is found that the periodic sound is the excited resonance when the valve opens. The resonator is composed by the discharge port of top-flange and discharge cavity which is made up by cylinder, roller, top-flange and bottom-flange. In one cycle the characteristic of the periodic sound is that the sound will be only taken place when the valve opens and the frequency of the sound will be higher and higher with the crank angle increasing. According to the experimental testing about different type compressor and air-conditioner outdoor unit, it is found that this sound exists in every kinds of rolling piston compressor. Using proper muffler and increasing the thickness of the valve could both reduce this periodic sound.

1. INTRODUCTION

With the popularization of the inverter-driven air-conditioner and the requirement of comfort and energy saving, the operating frequency of inverter-driven air-conditioner is lower and lower, even to 1Hz. At the same time, the concern about the noise of air-conditioner is higher and higher. So noise level is the important factor of the air-conditioner performance.

Generally, the noise sources of air-conditioner outdoor unit are composed of two components, flow-induced noise and structure-induced noise. The characteristic of the flow-induced noise is low frequency and broad band spectrum, which is mainly related to the axial fan and the interaction between the fan and the shroud. The characteristic of the structure-induced noise is discrete frequency and the main sources of structure-induced noise are the noise radiating directly from compressor shell and secondhand noise from vibration of sub-structures by the compressor.

In this paper, when the air-conditioner operates under the frequency of 10Hz, a periodic sound appears in the air-conditioner outdoor unit, which should be researched and solved. Firstly, based on the position of sound emitting, it could be conformed that the sound is produced by compressor. Secondly, using the elimination method of different experimental testing it can be obtained the periodic sound is the excited resonance when the valve opens. Thirdly, the theory is established to explain how and why the periodic sound is produced. At last, using proper muffler and increasing the thickness of the valve could both reduce this periodic sound.

2. EXPERIMENTAL MEASURING AND ANALYSIS

2.1 Characteristic of the Periodic Sound

Figure 1 is the spectrum of the sound pressure with and without periodic sound. It can be seen that the frequency of the periodic sound is about from 400 to1780Hz, especially in 500-800Hz. Then according to the spectrogram of the sound pressure with periodic sound from figure 2, it can be obtained that in one cycle of the compressor the periodic sound is only taken place in certain angle range of a cycle and the frequency of the sound increases when the crank angle increasing.

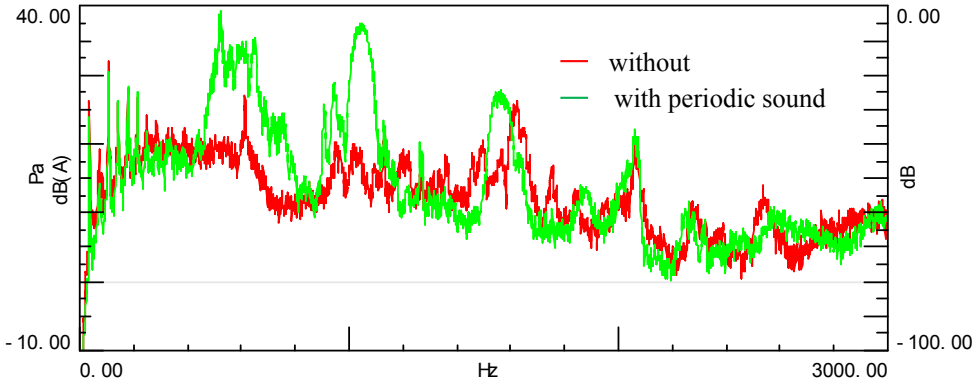

Figure 1: Spectrum of the sound pressure with and without periodic sound[1]

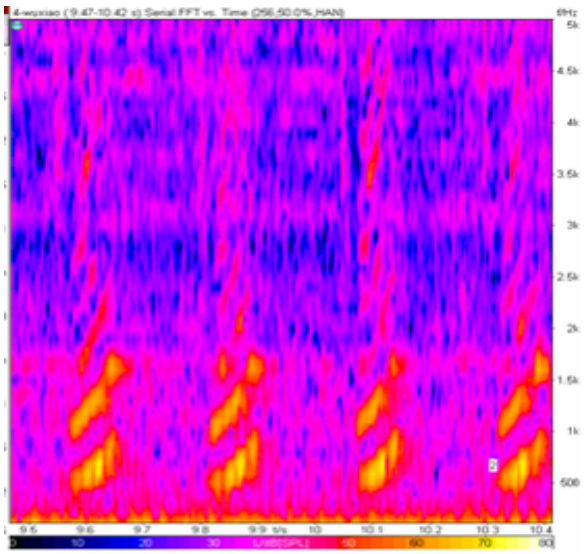

Figure 2: The spectrogram of sound pressure with periodic sound[2]

2.2 Noise Sources of Compressor Classify

The noise sources of compressor are mainly composed of aerodynamics noise, mechanism noise and electrical noise.

Based on the characteristic of the periodic sound and the noise sources of compressor, there may be some possible reasons of the periodic sound taking place, which are shown in figure 3.

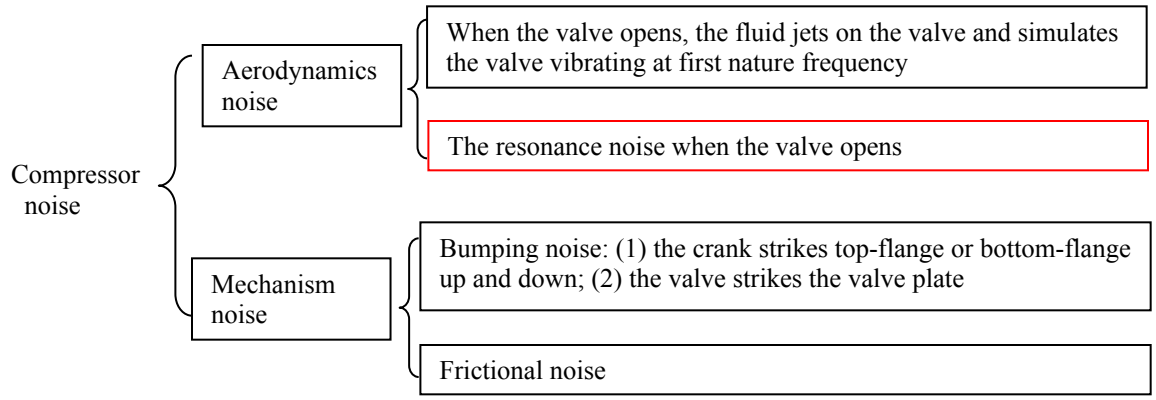

Figure 3: The possible reasons of the periodic sound taking place

Then according to elimination method, the reason of the periodic sound taking place is determined.

2.3 Project Measuring and Analysis

Project 1: controlling crank striking

In order to avoid the crank striking up and down, the rotor is 1.6 higher than original rotor which can make the composition of forces of the crank downwards. So the crank can only contact to the bottom-flange and the bumping noise will not be produced.

But this project is identified that the periodic sound is still existence. So according to this project, it is confirmed that the periodic sound is not bumping noise induced by the crank striking up and down.

Project 2: change the material of valve plate

In order to change the sound induced by striking between the valve and valve plate the material of valve plate is changed to PPS. If the periodic sound is induced by the valve striking the valve plate, the noise in this project compressor with PPS valve plate will disappear or decrease.

But it is measured that the periodic sound is still existence. So it is confirmed that the periodic sound is not bumping noise induced by the valve striking the valve plate.

Because it is found that the periodic sound is still existence when only rotating the pumping part, and according to compare the sound characteristic between rotating the pumping part and air-conditioner unit working, it is found that the periodic is produced by the pumping part from figure 4. Then other project is validated in pumping parts.

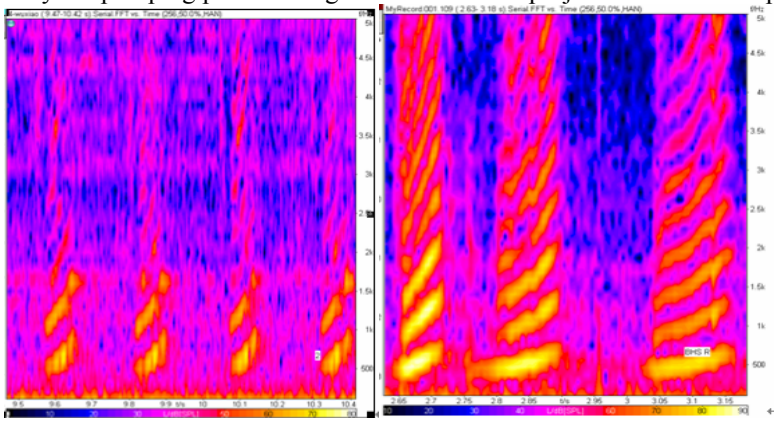

Figure 4: The spectrogram of sound pressure with periodic sound
left: in air-conditioner unit system; right: in pumping parts

Project 3: change the valve plate

After changing the valve plate, the restricted length of the valve is changed from 14.5 millimeter to 7.3 millimeter. Then the first nature frequency of valve is changed from 475Hz to 295Hz. If the periodic sound is induced by the

valve vibrating at the first nature frequency, the peak frequency of noise of this project pumping parts will change from 475Hz to 295Hz.
But from figure 4 it is found that the peak frequency is as same as before. So it is confirmed that the periodic sound is not the noise induced by the valve vibrating at nature frequency.

Project 4: frictional noise analysis
Because the frictional noise of compressor is generally in range of 1600-2000Hz. And the frictional noise generally doesn't have the accordant rule. So it is confirmed that the periodic sound is not the frictional noise.

According to the elimination of each project above, it can be assumed that the most possible reason of the periodic sound taking place is resonance. Then it is discussed theoretically below.

3. THEORETICAL ANALYSIS

3.1 Helmholtz Resonant Noise

A Helmholtz resonator, as shown in Figure 5, is an acoustic band-stop filter comprised of a rigid cavity with a protruding neck that connects the cavity to the system of interest. When the valve opens, the resonator is composed by the discharge port of top-flange and discharge cavity which is made up by cylinder, roller, top-flange and bottom-flange in discharge stage of the compressor. When the frequency of the discharge noise excited by gas pressure pulsation is agree with the resonant frequency, the resonance will be formed.

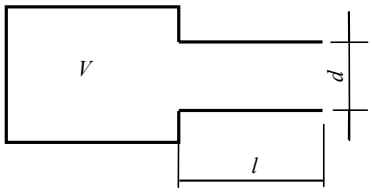

Figure 5: The resonator basic structure

The formula of frequency of Helmholtz resonant noise is below:

$$f = \frac{c}{4\pi}\sqrt{\frac{\pi d^2}{V_h(l+0.85d)}}$$

Where V_h is the operating volume of discharge cavity of cylinder, d is the diameter of the discharge port, l is the length of the discharge port and c is the sound speed.

The measuring results of acoustic characteristics of discharge cavity of cylinder in one certain rolling piston compressor at various crank angles[3] are shown in figure 6. It can be seen that many resonance frequencies appear in the cylinder cavity. At the same time, with the crank angle increasing, the resonance frequency corresponding to each order becomes progressively higher. This characteristic is the same as the characteristic of the periodic sound in air-conditioner unit.

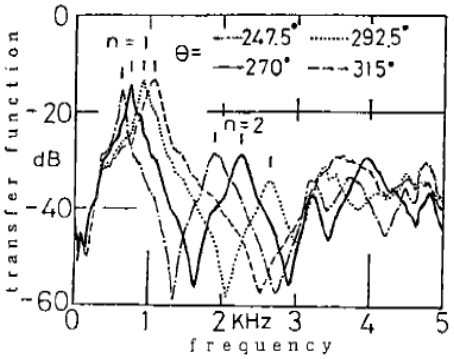

Figure 6: acoustic characteristic of discharge cavity of cylinder

3.2 Theoretical Analysis and Simulation

In the compressing stage of compressor, gas pressure is below[4]:

$$p_\theta = p_{s0}\left[\frac{(2-\tau)(\pi-0.5\beta)+(1-\tau)\sin\beta+0.25\tau\sin\beta}{(2-\tau)(\pi-0.5\theta)+(1-\tau)\sin\theta+0.25\tau\sin\theta}\right]^n$$

Where θ is the crank angle, p_θ is the gas pressure at θ crank angle, p_{s0} is the suction pressure, $\tau = e/R$, e is the eccentricity, R is the inner radius of cylinder, β is the start angle of compressing.

In this compressor, $\tau = e/R$, β can be obtained by the structure of compressor, p_θ and p_{s0} is obtained by the discharge pressure and the suction pressure. Then the crank angle θ is calculated and is shown in table 1.Then based on the starting angle, the resonant frequencies at starting angle simulated by FEM software are shown in table 1. At last, in the spectrogram of sound pressure with the periodic sound, the existence time of the periodic sound is about 1/3 cycle. So the closing angle is about 210 degree, which is equal to starting angle plus 120 degree. Then the resonant frequencies at closing angle simulated by FEM software are shown in table 1. From table 1 and figure 2, it can be seen that the calculated frequencies is consistent with the experimental frequencies.

Table 1: Resonant frequency at starting and closing angle

	Working condition	Starting angle (℃)	Resonant frequency at starting angle (Hz)	Closing angle (℃)	Resonant frequency at closing angle (Hz)
compressor	Light condition	155	727.9	275	1894.6
	1-10Hz working condition	90	526.5	210	989.3
		90	526.5	220	1070

According to the theoretical analysis, it can be confirmed that the periodic sound is the excited resonance when the valve opens. The resonator is composed by the discharge port of top-flange and discharge cavity which is made up by cylinder, roller, top-flange and bottom-flange. And according to the experimental testing about different type compressor and air-conditioner outdoor unit, it is found that this sound exists in every kinds of rolling piston compressor.

Because the periodic sound is discharge noise, using proper muffler and increasing the thickness of the valve could both reduce this periodic sound. And these two projects being experimentally verified are effective.

4. CONCLUSIONS

In this paper, when the air-conditioner operates under the frequency of 10Hz, a periodic sound will appear in the air-conditioner outdoor unit. According to the experiment test and theoretical analysis, it is confirmed that the periodic sound is the excited resonance when the valve opens. The resonator is composed by the discharge port of top-flange and discharge cavity which is made up by cylinder, roller, top-flange and bottom-flange. In one cycle the characteristic of the periodic sound is that the sound will be only taken place when the valve opens and the frequency of the sound will be higher and higher with the crank angle increasing. According to the experimental testing about different type compressor and air-conditioner outdoor unit, it is found that this sound exists in every kinds of rolling piston compressor. Using proper muffler and increasing the thickness of the valve could both reduce this periodic sound.

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