Study on Vibrations of Inverter Refrigerator Compressor

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ABSTRACT

Vibration is a very important characteristic of inverter compressor, and it’s critical for refrigerator running speeds selection. First, the reasons why the compressor vibrates are discussed, unbalanced forces of compressor moving parts are the source of the vibration. The flexible parts in the vibration transmission route are also very critical, they are inner discharge tube, suspension springs, rubber grommets, and so on. When the natural frequencies of the system are similar to the source excitation frequencies, resonance will happen, vibrations will be very large. Second, one inverter compressor vibrations were tested, and the results show that the vibrations varied a lot in different speeds and directions. Then the reasons why the inverter compressor vibrations are very large in some speeds are analyzed in the third part. The natural frequencies of shell and grommets system and inner discharge tube were got by experiment or simulation. The results show that those natural frequencies are too close to the source excitation frequencies in some speeds, that is the reason why the compressor vibrates so large. By the grommets and inner discharge tube redesigns, the natural frequencies are moved far away from excitation frequencies, the compressor vibrations are reduced. The methods suggested in this research are helpful in reducing inverter compressor vibrations.

1. INTRODUCTION

Vibration is one of the most important characteristics of compressor, it also can make big influence on refrigerator noise and reliability. Compressor is connected to the cooling system by pipes, when compressor vibrates too large, it will cause large stress and strain of the connection pipes, and may cause the pipes to break. When compressor vibrations are transferred to other parts of cooling system, they will produce noise and even resonances. Recently, great attention is being paid to compressor vibrations. Dugast (2008) studied a method of compressor noise level calculation from vibrations measurement results. Bratti et al. (2012) identified the vibrations energy path in the interaction between compressor and refrigerator. Gu et al. (2012) researched the compressor vibrations identification based on angle domain analysis method. Kuan and Kim (2014) did a theretical analysis of revolving compressor vibrations.

Compared to fixed speed compressor, inverter compressor has advantages in many aspects, such as precise temperature control, food preservation, energy conservation, etc. More and more inverter compressors are to be used in refrigerators. For vibrations control, inverter compressor is much more difficult than the fixed speed compressor. Inverter compressor has many speeds, we have to research the vibrations at each speed that may be used in the refrigerator.

In the second part, factors that affect inverter compressor vibrations are discussed. In the thrid part, inverter compressor vibrations in the whole speed range were tested. In the fourth part, the cause of large vibrations in inverter compressors is explored. The methods suggested are helpful in reducing inverter compressor vibrations.
2. FACTORS AFFECTING INVERTER COMPRESSOR VIBRATIONS

Most refrigerator compressors are reciprocating compressors that use piston driven by a crankshaft to deliver gases at high pressure. The reciprocating movement of piston and rotation of crankshaft produce unbalanced forces, unbalanced forces cause compressor to vibrate, and then vibrations transmit from inner of compressor to the outside. Unbalanced forces are the source of compressor vibrations.

The formula for calculating the reciprocating unbalanced force \( I_s \) is,

\[
I_s = m_s r \omega^2 \cos \omega t + \lambda m_l r \omega^2 \cos 2\omega t
\]  

(1)

\( m_s \) is reciprocating unbalanced mass, \( r \) is radius of rotation, \( \omega \) is crankshaft rotation speed, \( \lambda \) is the ration of \( r \) and rod length.

Formula for calculating rotational unbalanced force \( I_r \) is:

\[
I_r = m_r r \omega^2
\]  

(2)

\( m_r \) is rotational unbalanced mass. Formula 1 shows that, reciprocating unbalanced force can be separated into two parts, one is the same frequency as the shaft rotation, the other is two times frequency of the shaft rotation. The unbalanced force is proportional to the unbalanced mass and square of rotating speed.

From vibrations transmission view, vibrations transmit from crank to shell mainly by two paths. One is inner discharge tube, the other is suspension spring. So they are critical parts for compressor vibrations isolation.

When the compressor is installed in refrigerator, shell vibrations are transferred to the refrigerator mainly through three paths, one is suction connection pipe, the second is discharge connection pipe, and the third is rubber grommets. The vibrations transmission of the compressor can be shown as Figure 1.

![Figure 1: Compressor vibrations analysis](image)

The unbalanced forces are the fundamental reason for the vibrations. The inner discharge tube, suspension springs, connection pipes, grommets are the main paths for vibrations transmission.

3. INVERTER COMPRESSOR VIBRATIONS TEST

The invert compressor vibrations were tested in speeds of 1200 rpm to 4500 rpm. The compressor was put on the rubber grommets, three accelerometers were attached to the shell in three directions. The running speed was adapted by the inverter board. The vibration data and directions are shown in Figure 2. X direction is the direction of piston moving, Y direction is normal to X in the horizontal plane, Z direction is the vertical direction.

Figure 2 shows that there are four peak values in the whole speed range in three directions. There is one peak at
about 38 Hz in X direction. There are two peaks in Y direction, one is at 22 Hz, the other is at 66 Hz. There is one peak at about 72 Hz in Z direction.

Figure 2: Inverter compressor vibrations in three directions

4. INVERTER COMPRESSOR VIBRATIONS ANALYSIS AND OPTIMIZATION

To reduce the vibrations of the compressor, to find the reasons why there are large vibrations is the most important. Usually, the compressor was put on four rubber grommets, the shell and grommets composed a spring-mass system. In each direction there is a natural frequency, that is to say, it may cause one peak value in each direction. But in Y direction, there are two peaks. We think that the second peak in Y direction may come from the inner discharge tube. Because, the stiffness of inner discharge tube is not very high, the natural frequencies may be close to the excitation frequency, and the vibrations that inner discharge tube transfers to shell are mainly in y direction.

To verify the conclusion, the natural frequencies of the shell and grommets system and inner discharge tube were tested. When doing the test, a impact hammer was used to knock one end of the tube, and an triaxial accelerometer was used to pick the response at the other end. Then we got the transmission functions from the test system, and resonance frequencies were identified, mostly they are the natural frequencies of the tube. The test system we used is PULSE from Bruel & Kjær, the impact hammer is 8206-002, the accelerometer is 4525-B-001. The test results showed that there was a resonance frequency at 132 Hz, it is just two times of the shaft rotation frequency at the speed of 66 Hz, so we conclude that the peak value in Y direction at 66 Hz comes from the resonance of inner discharge tube. To avoid the resonance of inner discharge tube, the shape of the discharge tube was redesigned. The vibrations of the compressor with new inner discharge tube were tested. The results showed that the resonance of the inner discharge tube was disappeared.

4.1 Natural Frequencies Test of the Shell and Grommets System

To test natural frequencies, Bruel & Kjær PULSE test system was used. Impact hammer 8206-002 was used to give an excitation, and accelerometer 4514-001 was used to pick the response. By doing classical modal analysis, the modal parameters can be identified. When doing this test, compressor shell was put on the grommets, MTC simple hammer method was used to do the modal analysis. Hammer was used to knock shell in x direction, the accelerometer was put in x direction. The transfer function can be got from the test. The same tests had been done in y direction and z direction. The tested transfer functions in three directions were shown in Figure 3.

Figure 3 shows that, in x direction, there is a natural frequency at about 22 Hz, the x direction vibrations also has a peak value at about 22Hz; in y direction, there is a natural frequency at about 38 Hz, the y direction vibrations also has a peak value at about 38Hz; in z direction, there is a natural frequency at about 73 Hz, the z direction vibrations also has a peak value at about 72 Hz. The three natural frequencies are consistent with the peak value frequencies in the vibrations test. It is concluded that the natural frequency is the reason for the peak value in the vibrations test. Except the three peak values, there is another peak value at about 66 Hz, the reason might be the natural frequency of inner discharge tube.
4.2 Inner Discharge Tube Natural Frequency Simulation and Optimization

The modal analysis simulation of inner discharge tube was done by using finite element method, shown in figure 4.

![Modal analysis of inner discharge tube](image)

Figure 4: Modal analysis of inner discharge tube

Its first six order natural frequencies are shown in Table 1. The first order natural frequency is 132 Hz. In the vibrations test, there was a peak at about 66 Hz, 132 Hz is just two times of 66 Hz. According to section 2, when the compressor is running at 66 Hz, the unbalanced force also has a component at 132Hz, so there is a excitation force at 132Hz. When the excitation frequency is similar to the natural frequency, resonance happens, and then the compressor vibrations are large.

<table>
<thead>
<tr>
<th>First Order</th>
<th>Second Order</th>
<th>Third Order</th>
<th>Fourth Order</th>
<th>Fifth Order</th>
<th>Sixth Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>132</td>
<td>167</td>
<td>211</td>
<td>350</td>
<td>414</td>
<td>626</td>
</tr>
</tbody>
</table>

To avoid the inner discharge tube resonance, we redesigned the tube and the 1 order natural frequency was improved to 160Hz.

4.3 Vibrations Test and Verifications

To verify the influence of the inner discharge tube, the compressor vibrations with the redesigned inner discharge tube was tested. The vibrations of the compressor are shown in Figure 5.

Compared with the previous vibrations test results in Figure 2, the peak value at 66 Hz is disappeared, the above conclusion is verified. The peak values of the other three points are also reduced after using new grommets. That is to say, vibration transmission parts can make great influence on compressor vibration, and to avoid resonance is a basic and effective way for solving vibration problems. Especially for inverter compressor, it has many speeds, we should be more careful for the resonance problems.
5. CONCLUSIONS

The factors which influence the inverter compressor vibrations were discussed, and the vibrations transmission paths were analyzed. It shows that unbalanced forces of compressor moving parts are the source of the vibration. The flexible parts such as inner discharge tube, suspension springs, rubber grommets are critical for vibrations transmission. The inverter compressor vibrations were tested in whole speed range from 1200 rpm to 4500 rpm, the results show that compressor vibrates very large in some speeds, and the reasons were analyzed. The most important reason is that the natural frequencies of the shell and grommets system and inner discharge tube are too close to excitation frequencies, and resonances happen. After inner discharge tube and grommets redesigns, the compressor vibrations are reduced.

REFERENCES


