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ABSTRACT

With a typical rotary compressor as the research object, the vibration mechanism of a rotary compressor was analyzed in detail in this work. And according to the work, two formulations of the tangential vibration and the radial vibration were proposed for the rotary compressor. First, the oil film stiffness and the damp coefficient were obtained by coupling the experimental method and numerical simulation method. Then a dynamics simulation was conducted for the rotor system and the critical speed for the current rotor system was obtained, which was used to judge if the rotor system is a kind of flexible rotor. After that, with the aerodynamic force and the crankshaft deformation under consideration, the electromagnetic force, the electromagnetic torque and the resultant moment were calculated and analyzed based on an electromagnetic simulation analysis for the motor of the rotary compressor. Finally, the tangential vibration and the radial vibration on the shell and the reservoir of the rotary compressor were obtained by using a dynamics simulation with the resultant moment as the load for the rotor system. According to the simulation result, the prediction results are in good agreement with the test results. This work in this paper and the method used in this work provide a good reference for prediction of the vibration and resolving vibration problem of the rotary compressor.

1. INTRODUCTION

With the popularity of air conditioning, the noise and vibration problems of air conditioners are becoming the center of attention. For an air conditioning system, rotary compressor is one of the main noise sources, and the vibration and associated noise problem of rotor compressors has become the focus of compressor manufacturers and air conditioning manufactures. Due to the vibration of the compressor, air conditioning pipe may produce an annoying buzzing noise, and eventually indirectly lead to fatigue fracture lines, as a result, reduce the service life and reliability of the air conditioning machine. Therefore, the analysis and control the vibration of rotary compressors are very important. Based on vibration characteristics of the constant speed air conditioning compressor, for example, by using the method of combining the theory and experimental methods, the dynamic simulation analysis of a typical rotary compressor is carried out and several conclusions are obtained. This paper provides a good reference for the study of vibration and noise of compressors.

2. NUMERICAL ANALYSIS OF COMPRESSOR VIBRATION

The vibration of rotor compressor under the action of air force includes mainly tangential vibration, radial vibration and axial vibration. This paper will mainly study the tangential vibration and radial vibration of the compressor.
The tangential vibration equation of compressor rotor system can be expressed as follows.

$$I_r \frac{d\omega}{dt} = T_m - T_{comp} \qquad (1)$$

In which, I_r is the moment of inertia of the rotor system, T_m is the motor output torque, T_{comp} is pump body gas compressive resistance moment, $d\,\omega/dt$ is the angular acceleration.

According to the tangential acceleration equation of the rotor system as shown above, in order to reduce the tangential vibration of the compressor, it is necessary to increase the rotary inertia of the rotor system or reduce the electromagnetic torque fluctuation.

The radial vibration equation of compressor rotor system can be expressed as follows.

$$M\ddot{x}+(C(\omega)+C_1(\omega))\,\dot{x}+(K+K_1(\omega)+K_2)\,x=F(\omega)+F_g \qquad (2)$$

In which, M is the quality of shaft, K is the axial stiffness matrix, $C(\omega)$ is the gyroscopic matrix, $C_1(\omega)$ is the bearing damping, $K_1(\omega)$ is the bearing stiffness matrix, K_2 is the stiffness matrix due to the radial unbalance electromagnetic force, $F(\omega)$ is the unbalanced rotational inertia force, F_g is the gas force.

It can be seen from the radial vibration equation of rotor system that the radial vibration of compressor is related to the unbalanced rotational inertia force, the gas force, the unbalanced electromagnetic force, the support stiffness and the damping coefficient. Therefore, the radial vibration of the compressor can be improved mainly by reducing the unbalanced rotational inertia force, reducing the unbalanced electromagnetic force and increasing the bearing stiffness.

3. DYNAMIC CHARACTERISTICS OF COMPRESSOR ROTOR

The rotor compressor belongs to a kind of rotating machineries. When the rotor is running at high speed, whether the crankshaft is deformed or whether it belongs to the flexible rotor, the rotor dynamics analysis of the rotating subsystem is required. In this paper, the critical speed calculation is carried out with a rotor type compressor with a fixed speed of 3480rpm. The rotor is supported by the upper bearing, the lower bearing and the oil film to support the radial stiffness, and the tangential rotation speed is driven from 0~17000rpm. The stiffness of the oil film is 2.E5 N/mm, and the oil film damping is 100 N•s/mm based on the experiment and the numerical simulation analysis results.

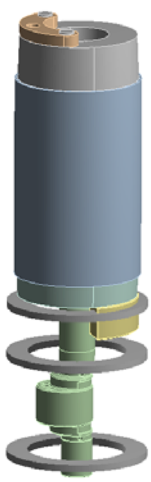

Figure 1: 3d model of compressor rotor system

Considering the gyro effect and the damping of the complex modal calculation, we get the Campbell diagram as shown in figure 2.

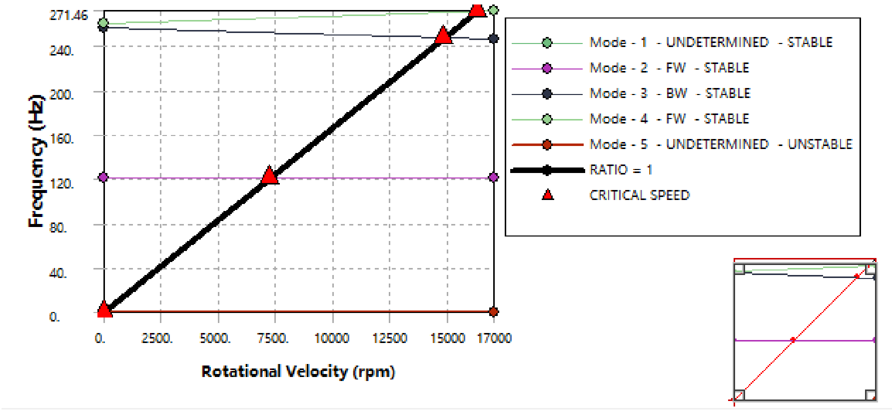

Figure 2: Campbell diagram of compressor rotor system

The results are shown in Figure 2, the first third-order critical speed is 7231rpm, 14730rpm and 16290rpm, while the first-order critical speed is 7231rpm. If the rotor's working speed is much lower than the first-order critical speed, the rotor is a rigid rotor. At this time, the unbalanced centrifugal force is smaller and the rotor is rigid, so the deflection of the rotor caused by unbalanced force is very small, which can be neglected. The rotor deflection caused by imbalance is as follows.

$$r = \frac{e\Omega^2}{\omega^2 - \Omega^2} = \frac{e\left(\dfrac{\Omega}{\omega}\right)^2}{1-\left(\dfrac{\Omega}{\omega}\right)^2} \quad (3)$$

In the formula, r is the rotor deflection, e is the rotor eccentricity, Ω is the working speed, ω is the rotor speed. In this paper, the working speed of the fixed speed compressor is 3480rpm, and the first-order critical speed of the rotor is 7231rpm, then Ω/ω =3480/7231=0.481 < 0.5, and the rotor is considered as a rigid rotor, while the rotor deflection r < 1/3e. The crankshaft deflection caused by unbalanced force can be ignored.

4. DYNAMIC SIMULATION ANALYSIS AND EXPERIMENTAL RESULTS

The rotor compressor is mainly driven by the gas force and the electromagnetic force, namely the gas resistance moment and the electromagnetic moment in the tangential direction, resulting in the tangential vibration and the radial vibration.

With the compressor gas drag torque, the electromagnetic torque and the composite moment under consideration, a dynamics simulation analysis of the rotary compressor was conducted in this work, and the simulation results are consistent with the test results.

4.1 Gas resistance moment of compressor

As for a typical rotary compressor as shown in Figure 3, the gas resistance moment of the compressor can be calculated based on the basic parameters of the compressor and the suction and the exhaust pressure of the operating condition.

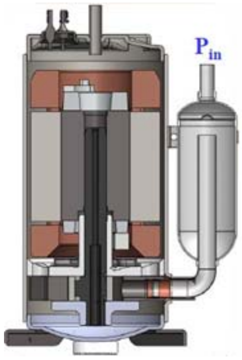

Figure 3: Geometry model of rotary compressor

The gas resistance moment curve in a period of 0~360 degrees is calculated as follows.

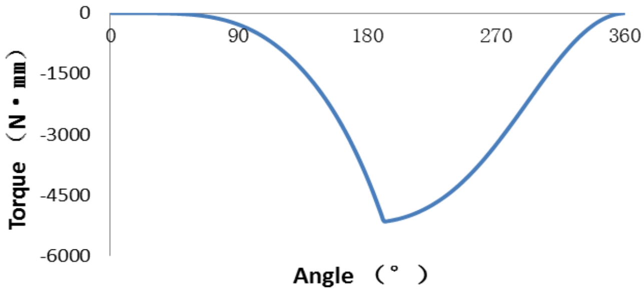

Figure 4: The curve of a periodic gas resistance moment

The spectrum of the gas moment after FFT analysis is shown in Figure 5.

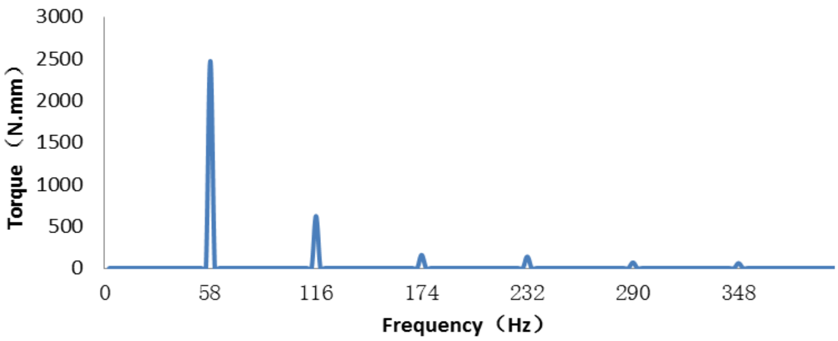

Figure 5: Spectrum of the gas moment

4.2 Electromagnetic Torque of Compressor

A geometric model is established in the motor simulation software, and the parameters of the motor are set up, including motor number of turns, the diameter of the line and the thickness. According to the loading gas resistance moment, the electromagnetic torque is obtained in the electromagnetic simulation software. Based on the numerical simulation result, the electromagnetic torque is shown in Figure 6.

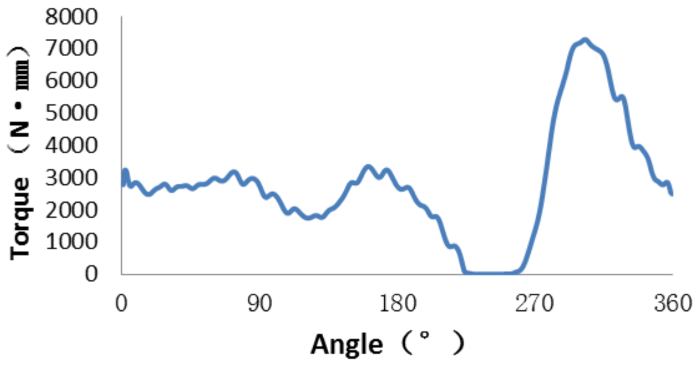

Figure 6: Electromagnetic torque distribution along angle of rotation

4.3 The Combined Torque of the Compressor is Calculated

The resultant torque is obtained by synthesizing the gas and the electromagnetic moment.

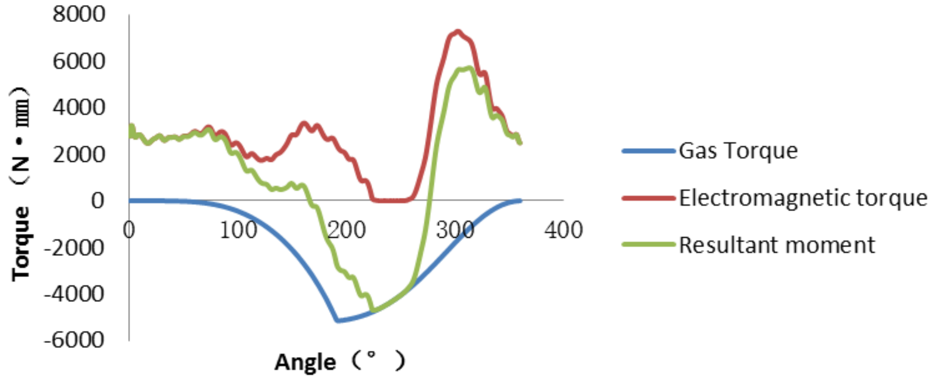

Figure 7: The resultant moment of in a period

By using FFT analysis of the combined moment in time domain, the spectrum of the combined torque is shown in figure 8.

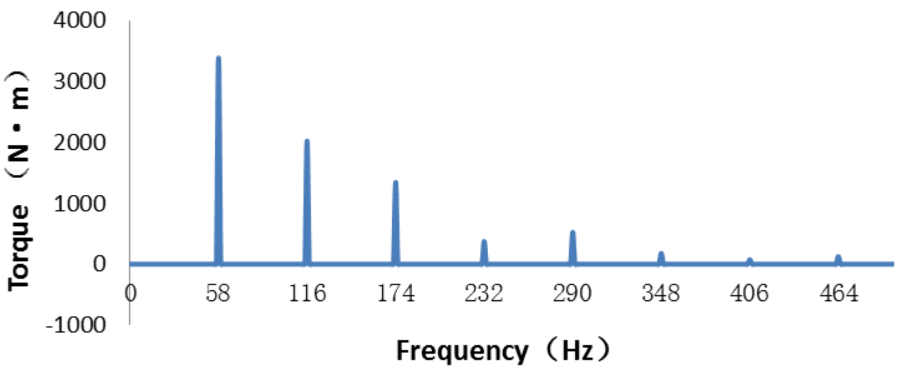

Figure 8: The spectrum of the combined torque

The combined torque spectrum of the compressor is obtained, and the combined torque spectrum curve shows that torque of the compressor on the base frequency is about 3.5N•m. With the combined torque of the compressor as the excitation force, a dynamic simulation analysis of the compressor was carried out and the vibration distribution was predicted accurately.

4.4 Dynamic simulation analysis of compressor vibration

The finite element model of compressor is shown in figure 9. In order to reduce the calculation requirement, all the shell elements are used, and the internal structure is simplified appropriately.

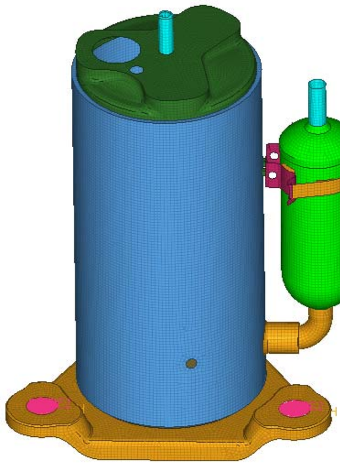

Figure 9: Finite element model of the rotary compressor

The rubber foot pad at the bottom of the compressor is simulated with the equal stiffness spring element. The spring tangential and radial stiffness is 10N/mm, and the axial stiffness is 40 N/mm. With the resultant torque as an incentive, a dynamic simulation analysis of the rotary compressor is carried out. The vibration response of the compressor reservoir in the base frequency is shown in Figure 10. The acceleration obtained in this paper is the resultant acceleration of three directions, and the acceleration unit is mm/s^2.

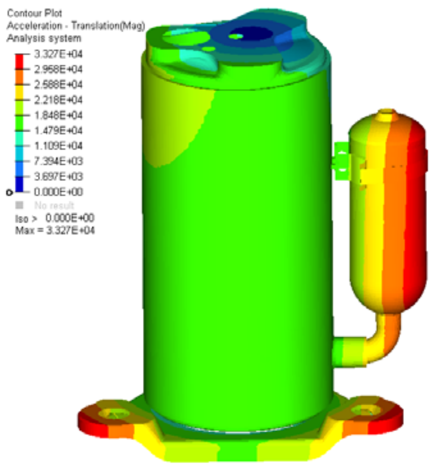

Figure 10: Distribution of vibration acceleration of the rotary compressor

4.5 Vibration Test Results of Compressor

In the semi-anechoic chamber, at the maximum load condition of the refrigerant, the vibration test of the compressor is carried out by placing a number of vibration acceleration test sensors on the compressor, as shown in Figure 11.

Figure 11: Compressor vibration test fixture

The maximum position of the tangential vibration acceleration on the compressor is at the outside of the reservoir, as shown Table 1. The acceleration results obtained based on numerical and experimental test respectively on the compressor reservoir are listed in the table.

Table 1. Comparison of vibration acceleration results at different frequencies.

	58Hz	**116Hz**	**174Hz**	**232Hz**	**290Hz**
Test (m/s^2)	38.2	20.9	12.0	2.9	10.5
Simulation(m/s^2)	33.3	18.5	10.4	3.8	8.9
Error(%)	4.9	2.4	1.6	-0.9	1.6

The results listed in Table 1 show that the simulation results are in good agreement with the experimental results. Therefore, the dynamic simulation analysis method based on the compressor excitation source loading can be used to predict the vibration distribution of compressors.

5. CONCLUSIONS

In this paper, with a constant speed air conditioning compressor as an example, the critical speed of compressor rotor system is calculated based on the rotor dynamic characteristics analysis, and the compressor is a rigid rotor compressor. In addition, the electromagnetic torque of the compressor is obtained by means of the gas force and the physical force, and the resultant torque of the compressor is obtained, which is then used as the incentive source for the dynamic simulation analysis of the compressor. The vibration distribution of the compressor is obtained through the finite element dynamic simulation analysis. Finally, the test results are compared with the simulation data and good match is obtained. The method used in this work provides a good reference for prediction of the vibration and resolving vibration problem of the rotary compressor.

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