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Lingchao Kong
Gree Electric Appliances, Inc. of Zhuhai, China, People's Republic of, klc03@163.com

Liping Ren
Gree Electric Appliances, Inc. of Zhuhai, China, People's Republic of

Jia Xu
Gree Electric Appliances, Inc. of Zhuhai, China, People's Republic of

Yusheng Hu
Gree Electric Appliances, Inc. of Zhuhai, China, People's Republic of

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Lingchao Kong, Liping Ren, Jia Xu, Yusheng Hu

Compressor and Motor Institute of Gree Electric Appliances, Inc. of Zhuhai,
Jinji West Rd., Zhuhai City, 519070, P. R. China
Phone: +86-756-8669923, Fax: +86-756-8668386,
E-mail: klc03@163.com

ABSTRACT

The deflection of the crankshaft which transfers the power of motor to the pump of the compressor directly affects the vibration, noise and wear problems in the rotary compressor, therefore, with the requirement of higher reliability, it is important to obtain it exactly in compressor design. Various forces that the crankshaft suffers are calculated by theoretical analysis in the operation process of the compressor. And based on the finite element method (FEM), the deflection of the crankshaft is obtained by simulation in the rotary compressors. And then the measurement is performed concerning the orbit of the top dead centre of the crankshaft with non-contacting displacement sensors in the compressor. In comparison with the tests, the validity of the calculation method is verified. It is found that the results of calculation are good agreement with the tests'. In addition, several factors which affect the deflection of the crankshaft are analyzed with the FEM, and the influences of flange height, shaft diameter, mechanical air gap in the motor, rotor weight on the deflection are found distinctly, which as a primary theoretical basis is provided for the compressor design.

1. INTRODUCTION

As an important part in the compressor, the crankshaft plays a connecting role. The motor connected to the top provides power, and the pump connected to the bottom compresses refrigerant, two flanges support the crankshaft, as show in Figure 1. In order to ensure stability of the crankshaft at high speed, there are two balancers at top of the crankshaft to balance the eccentric portion of the crankshaft. But because of the location and size of the balances, the imbalance forces result in the deflection of the crankshaft, and a further deterioration of deflection will be caused in the effect of the other loads, as show in Figure 2.

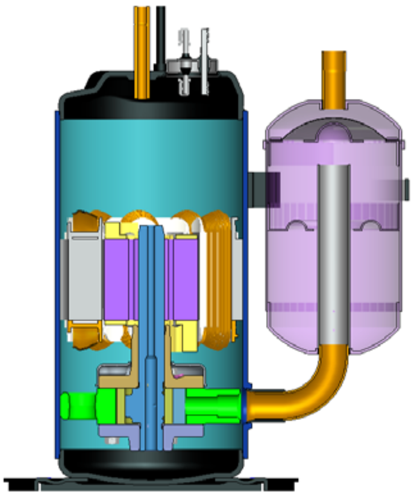

Figure 1: Rotary Compressor

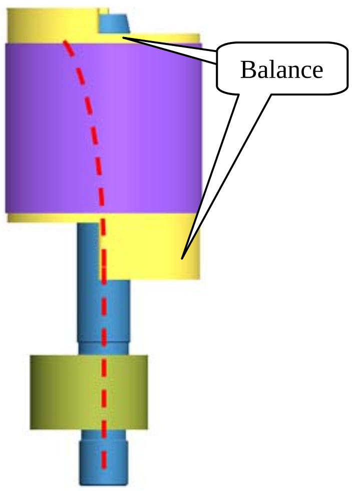

Figure 2: Crankshaft-Rotor System

Crankshaft deflection will directly affect the motor stator and rotor clearance, thereby affecting motor performances. Moreover it would increase the contact between the flange and crankshaft, and bring wear. So the deflection may cause the compressor noise and vibration problems.
Estimate of the crankshaft deflection, the experiment and simulation methods are generally used, but the accuracy is still low. Through various improvements and consideration of a more comprehensive factors, the paper establish a more accurate calculation method and experimental method, they are in good agreement, as a basis for future research.

2. FEM ANALYSIS

Based on the FEM, the FEM analysis model of the crankshaft is built up, as shown in Figure 3. It contains the crankshaft, top-flange and bottom-flange. The flanges are used for restricting the freedoms of the crankshaft.

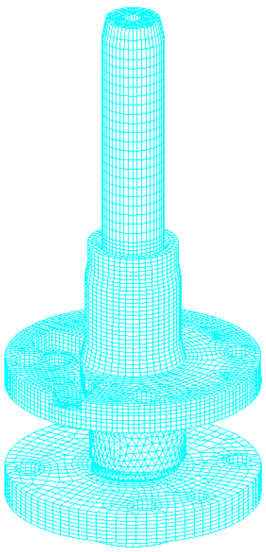

Figure 3: FEM Analysis Model

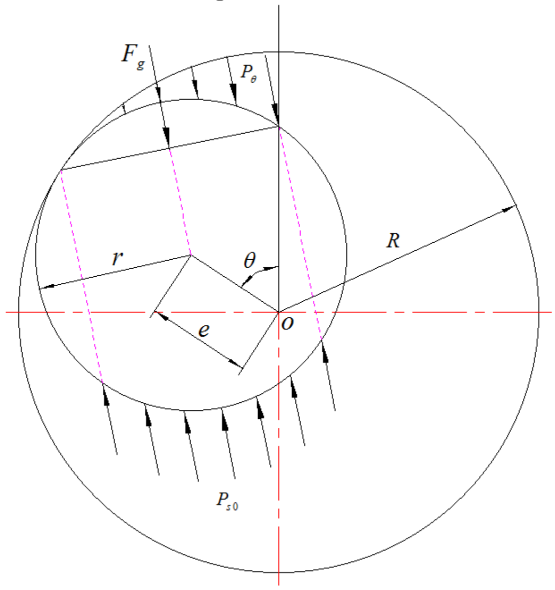

Figure 4: Gas Force Analysis

The loads that are applied on the crankshaft contain centrifugal inertia forces, gas force and imbalance magnetic force. These forces can be calculated by the equations as follows.
1) Gas force F_g (Figure 4):

$$F_g = RL(1-\tau)(P_\theta - P_{s0})\sqrt{2(1-\cos\theta)+\frac{\tau}{1-\tau}(1-\cos 2\theta)} \tag{1}$$

where $P_\theta = P_{s0}\left[\frac{(2-\tau)(\pi-0.5\beta)+(1-\tau)\sin\beta+0.25\tau\sin 2\beta}{(2-\tau)(\pi-0.5\theta)+(1-\tau)\sin\theta+0.25\tau\sin 2\theta}\right]^n$, $\tau = e/R$, e is eccentricity of the crankshaft, R is radius of the cylinder, L is height of the rolling, P_{s0} is suction pressure, P_θ is pressure of the exhaust cavity while the revolution angle is θ, n is multi-exponent, β is end suction angle.
2) Centrifugal inertia forces F_i :

$$F_i = m_i\omega^2 r_i \tag{2}$$

where m_i is mass of the eccentric parts(a pair of balancers, a rolling and a crankshaft eccentric part), ω is speed of rotation, r_i is the distances from the mass centre of the eccentric parts to the axis of revolution.
3) Imbalance magnetic force F_m :

$$\left.\begin{aligned} F_m &= K_m e_m \\ K_m &= \frac{\alpha \pi D l_{ef}}{\delta}\left(\frac{B_\delta^2}{2\mu_0}\right) \end{aligned}\right\} \qquad (3)$$

where K_m is magnetic force coefficient, α is experiential coefficient, δ is average gap, l_{ef} is height of rotor, D is diameter of rotor, B_δ is magnetic density in gap, μ_0 is air permeability, e_m is eccentricity of rotor.

The eccentricity of rotor e_m is related to the deflection of the crankshaft, so the imbalance magnetic force which is uncertain is applied with spring element in the analysis.

Generally the values of centrifugal inertia forces F_i are constant, and the gas force F_g is changing momently, so the maximum gas force is chose to be applied to the crankshaft eccentric part.

On the other hand, the crankshaft and flanges make up two sliding bearings filled with oil film. With the speed of rotation's increasing, the oil film thickness will be larger and larger. So for different speeds of rotation, different bearing clearances have be applied.

Based on a FEM analysis model, the deflections versus speed of rotation are calculated, as shown in figure 5, 6.

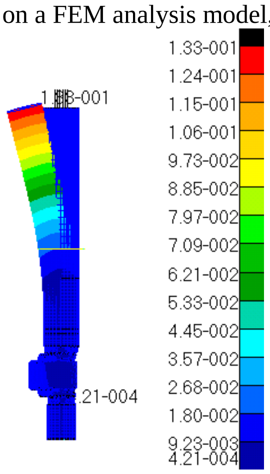

Figure 5: Deflection Fringe Result

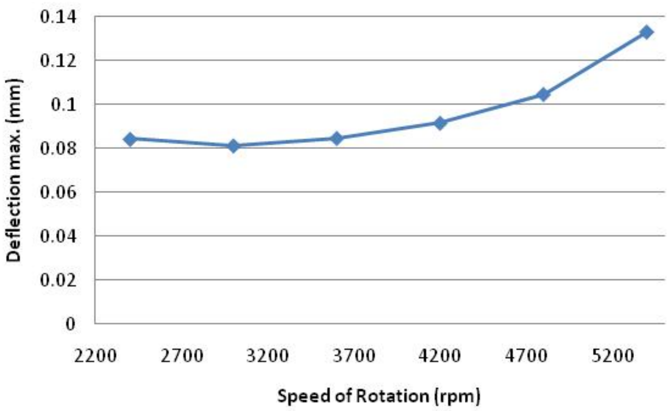

Figure 6: Calculated Deflection versus Speed of Rotation

The results show that with higher and higher speed of rotation, the deflection become more and more serious. The reason is that centrifugal inertia forces become larger.

3. EXPERIMENT

The test compressor that contains the normal compressor part and the measure part is built up, as show in Figure 7. Three eddy current type gap sensors setted at the top of the compressor are used to measure crankshaft deformation, as show in Figure 8. Sensor-Ⅰ is used to measure the direction-x deformation, while sensor-Ⅱ is used to measure the direction-y deformation. Sensor-Ⅲ is used to determinate the starting angle. Considering the characteristic of the sensor, a dish of wheel is setted at the top of the crankshaft. Therefor it is convenient for measurement and avoiding interference between sensors.

In the experiment, the first data is recorded when the compressor is running without load at speed of 60 rpm, the second data is obtained for different speeds of rotation within the range of 2400-5400 rpm in rated load running, then the deflection of the crankshaft is calculated by subtracting the first data from the second data. So the orbit of the top dead centre of the crankshaft is described in Figure 9, and the maximum deflections versus speed of rotation are plotted in Figure 10.

Figure 9 shows that the crankshaft is deflected toward to one direction in each operation cycle, and the oscillation of the orbit indicates the vibration of the crankshaft. From the experimental results, the crankshaft deflection increases as the speed increases, in good agreement with the calculated results. It is good to verify the accuracy and feasibility of the calculation method. Therefore, this method can be effectively used to guide the direction of compressor design to improve product reliability.

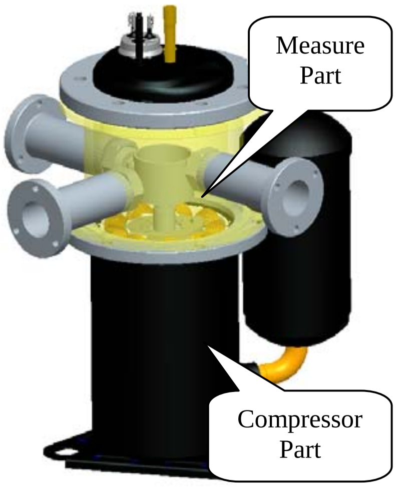

Figure 7: Test Compressor

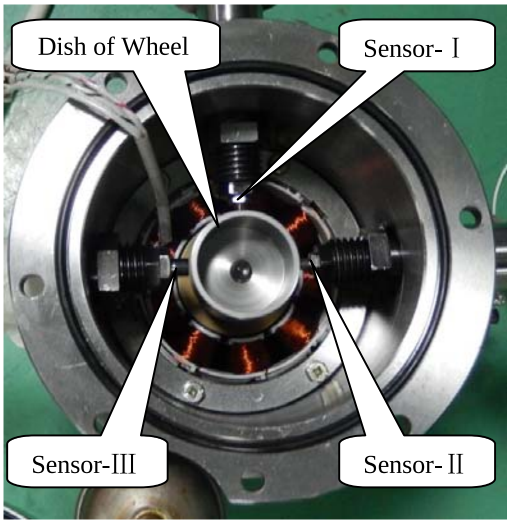

Figure 8: Location of Sensors

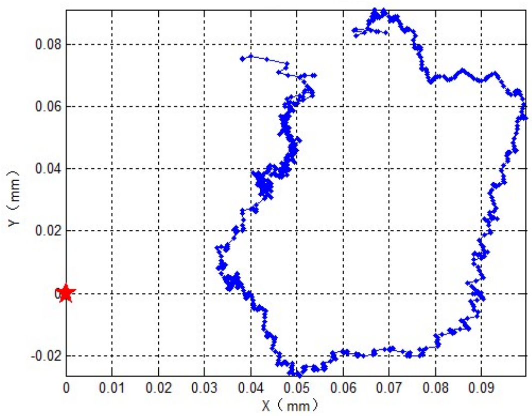

Figure 9: Orbit of the Top Dead Centre of the Crankshaft

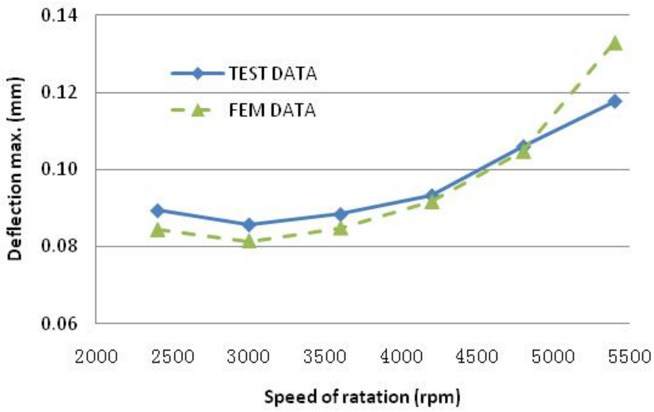

Figure 10: Measured Deflection vs. Calculated Deflection

4. INFLUENCE FACTORS

In the compressor, there are various factors that affect the deflection of the crankshaft. On the basis of the calculation method that has been previously established, several factors are respectively analyzed. The deflections of the crankshaft versus different heights of top-flange, different diameters of the crankshaft, different gaps of the motor and different weights of the rotor, are respectively as show in Figure 11, 12, 13, 14.

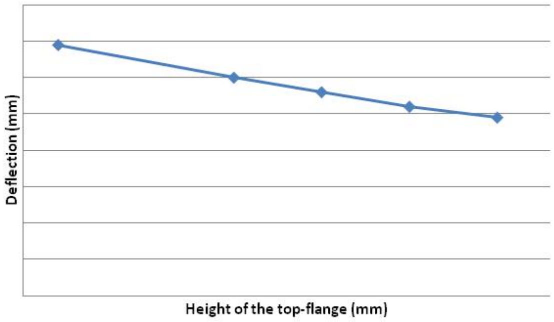

Figure 11: Deflection versus Height of the Top-Flange

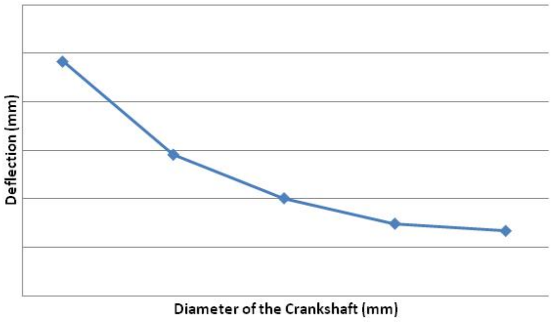

Figure 12: Deflection versus Diameter of the Crankshaft

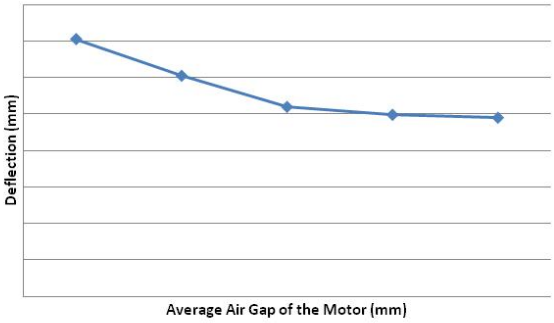

Figure 13: Deflection versus Motor Air Gap

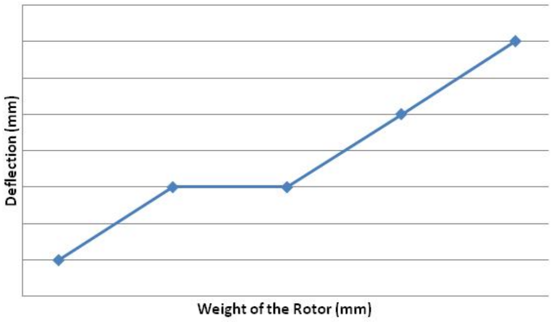

Figure 14: Deflection versus Weight of the Rotor

The following conclusions can be obtained from the results.
1) With the increase in the height of the top-flange, crankshaft deflection decreases linearly.
2) Crankshaft deflection decreases with increasing diameter of the crankshaft. But when the diameter reaches a predetermined value, the decreasing tendency of deflection slows.
3) The larger the gap, the smaller the crankshaft deflection. Also there is a Critical point.
4) Increase the weight of the rotor, the crankshaft deflection increases linearly.

5. CONCLUSIONS

By the crankshaft deflection measurement method that has been improved, the more accurate deflection data is obtained. At the same time, based on FEM, a simulation method of the crankshaft deflection is established, in good agreement with the experimental results. In addition, by calculating the effect of different factors on the crankshaft deflection, the analysis showed: with the increase of the height of top-flange, the diameter of the crankshaft and the motor air gap, crankshaft deflection decreases, and it increases with the increase of the weight of the motor.

REFERENCES

Jianping Huang, Yusheng Hu, Sihai Xia, Liping Ren, 2010, Dynamic Balance Technology of Inverter Controller Rotary Compressor,Proceedings Purdue Compressor Technology Conf., 1140: p1-6.