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ABSTRACT

The main bearing and sub bearing which support the crankshaft rotation often have wear in the rotary compressor, and the exceptional wear will cause a series of problems which contain the vibration, noises, frictional power rising and reliability reduced. The process of improving the actual exceptional wear problems of bearings is analyzed. And based on the finite element method (FEM), the results of the original and improved bearings are compared with each other; contact stress is chosen to be used to evaluate the wear condition of bearings. Then the influence of height, diameter and clearance of main bearing on the wear of the bearing is analyzed by the accelerated life test and the FEM simulation, and the feasibility of the bearing contact stress to evaluate the wear condition of bearings is further verified, at the same time it provides a theoretical basis for the design of compressor bearing.

1. INTRODUCTION

Internal parts cannot be removed and replaced in hermetic rotary compressor. As shown in Figure 1, the main bearing supports the upper part of the crankshaft, while the sub bearing supports the lower part of the crankshaft. Due to the long high-speed operation, improper design may cause the bearing wear, and cause a series of problems of compressor.

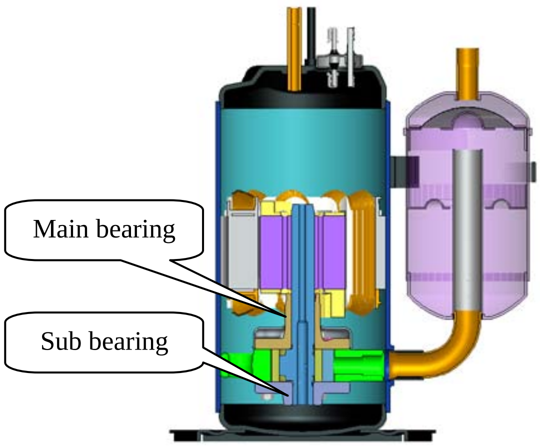


Figure 1: Rotary compressor

On the one hand, wear results in the change of bearing clearance which influence the stability of compressor pump, and then the noise and vibration problems will appear.
On the other hand, wear will make the friction power of bearings increase. As an important part of mechanical power in compressor, friction power increase will reduce the efficiency of the compressor.
Therefore, the effective evaluation method of wear is very important for the design of compressor.

Hydrodynamic lubrication theory is generally used for the analysis of the compressor journal bearing. The oil film pressure and thickness of the bearing which are used to evaluate the bearing are obtained by solving the Reynolds equation. Because the compressor bearing environment is complex, it is difficult to obtain accurate results using this method without overall consideration. In addition, the Reynolds equation needs to be solved by computer programming. In this paper, the contact stress between the crankshaft and bearing is obtained to evaluate the bearing wear by structural simulation analysis based on commercial finite element software. This method is simple and feasible, and it is very suitable for the application of engineering personnel.

2. EXCEPTIONAL WEAR ANALYSIS

In the process of R & D (Research & Development) of the compressor, there are two different types of compressor appearing large power, downtime and other anomalies. Abnormal wear of the crankshaft was found by dissecting, as shown in Figure 2.

Figure 2: Photo of the wear of the crankshaft

The crankshaft has had a severe adhesive wear. It is well known that adhesive wear is mainly affected by pressure and temperature. When the surface pressure reaches a certain critical value, the adhesion occurs (Figure 3). When the temperature reaches the critical value, the lubrication film is invalid and the adhesion is produced (Figure 4). The main influences on the temperature characteristics are surface pressure and sliding velocity. Therefore, controlling the pressure at a certain level is conducive to avoiding adhesive wear.

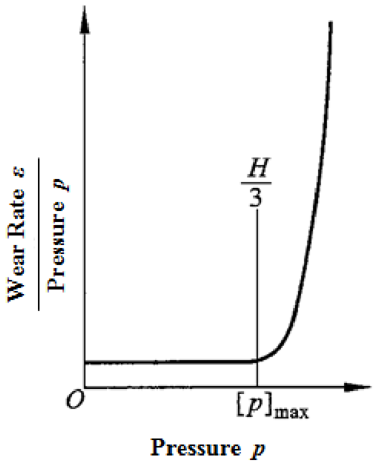


Figure 3: $\frac{\varepsilon}{p} - p$ Curve

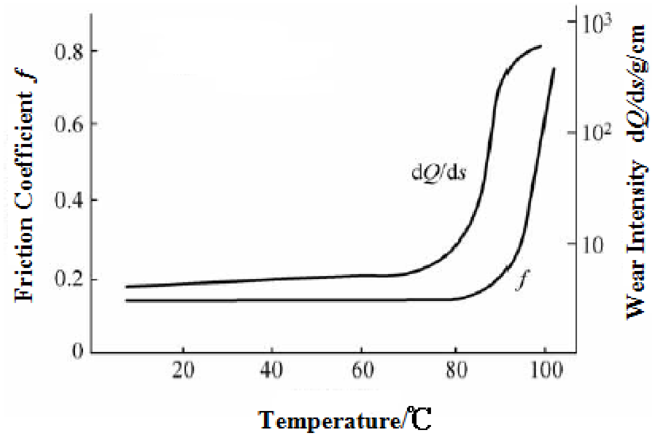
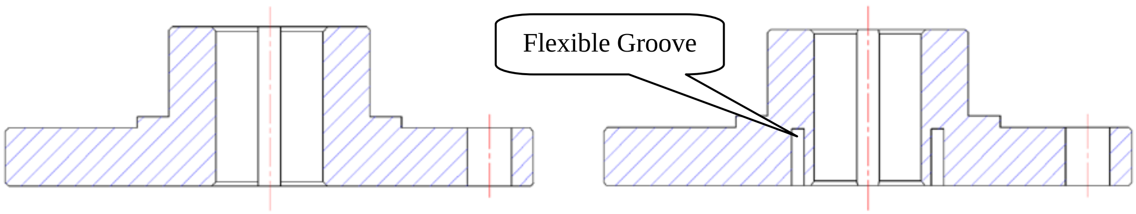


Figure 4: Influence of temperature on adhesive wear

After many studies, finally it is found that the design of the flexible structure of bearing can effectively solve the problem of abnormal wear of the crankshaft, as shown in Figure 5.



(a) Before improvement (b) After improvement

Figure 5: The structure of the bearing

The flexible groove is easy to deform due to its low stiffness. It can reduce the pressure between the crankshaft and the bearing, and then eliminate the adhesive wear.

3. FEM ANALYSIS

Based on the FEM, the static calculation is carried out before and after the improvement of the bearing. The FEM analysis model is built up, as shown in Figure 6. It contains the crankshaft, the main bearing and sub bearing. Because of not taking into account the oil film, the clearances between the crankshaft and bearings are cancelled.

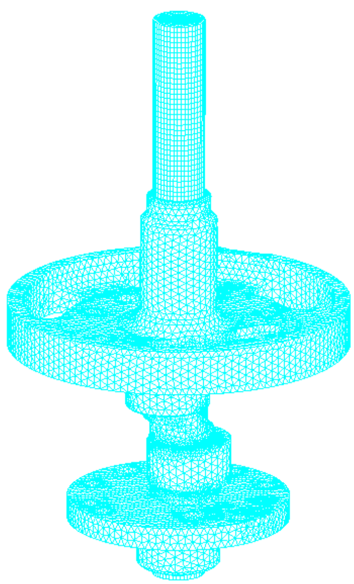


Figure 6: FEM analysis model

The loads that are applied on the crankshaft contain centrifugal inertia forces and gas force. These forces can be calculated by the equations as follows.

1) Gas force F_g :

$$F_g = RL\left(1-\frac{e}{R}\right)\left(P_d - P_{s0}\right)\sqrt{2\left(1-\cos\varphi\right)+\frac{e}{R-e}\left(1-\cos 2\varphi\right)} \tag{1}$$

where e is eccentricity of the crankshaft, R is radius of the cylinder, L is height of the rolling, P_{s0} is suction pressure, P_d is discharge pressure, φ is angle of starting to discharge.

2) Centrifugal inertia forces F_i :

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

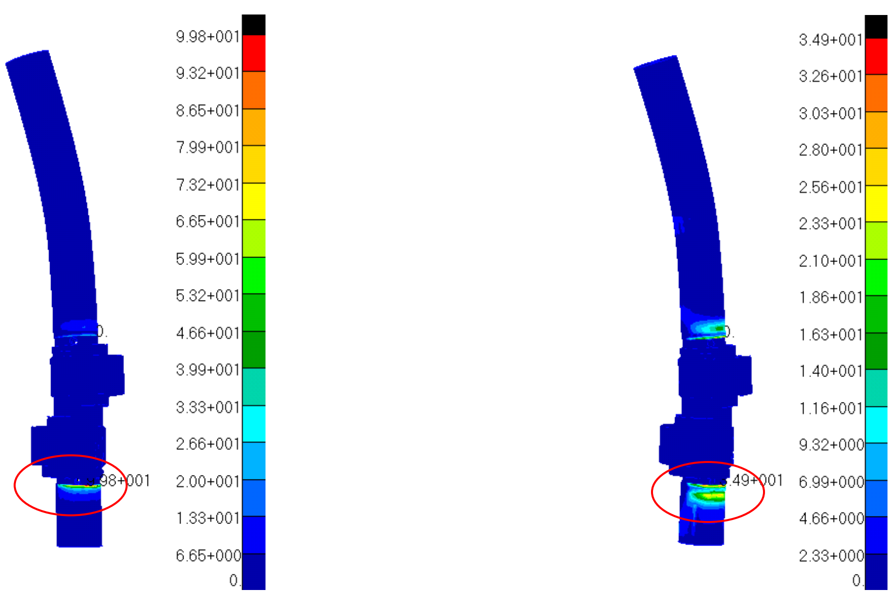
where m_i is mass of the eccentric parts (a pair of balancers, a rolling and a crankshaft eccentric part), ω is speed of rotation, r_i is the distances from the mass centre of the eccentric parts to the axis of revolution.

The top deflection of the crankshaft, the deformation of the eccentric part, the equivalent stress and the contact stress are calculated. Before and after improvement, the result maximums are compared, and the changes of the results before and after the improvement are obtained, as shown in Table 1.

Table 1: Computed results before and after improvement

	Top deflection	**Deformation of eccentric**	**Equivalent stress**	**Contact stress**
Original	0.0596mm	0.029mm	86.5MPa	99.8MPa
Improved	0.061mm	0.0317mm	86.4MPa	34.9MPa
Change	2.35%	9.31%	-0.12%	-65.03%

From Table 1, compared with the original scheme, the top deflection of the scheme with flexible groove has increased a little, and the deformation of eccentric increases by 9.31%, while the equivalent stress is basically unchanged, and the contact stress is greatly reduced by 65.03%.
The contact stress reflects the bearing surface pressure. The flexible groove effectively reduces the surface pressure of bearing. It is consistent with the front analysis.
The distributing state of the contact stress of the crankshaft is shown in Figure 7, and it is compared with the actual exceptional wear (Figure 2). It is found that the locations of the maximum contact stress and the actual wear are consistent. And the contact area becomes larger after improvement. It is one of the reasons for the contact stress reduced.



(a) Before improvement (b) After improvement

Figure 7: Contact stress fringe result

On the basis of the previous analysis the contact stress can be used to evaluate the bearing wear.

4. INFLUENCE FACTORS AND EXPERIMENTS

For much better design of bearing, the influence of main bearing parameters on bearing wear is analyzed by the forenamed method. And experiments are performed to validate the influence.

4.1 Influence Factors

The main parameters of the bearing design include the height, diameter and clearance. Because the clearance is not considered in the calculation method, the effect of height and diameter on the wear of the bearing is analyzed. Changing the height of the main bearing and the diameter of the crankshaft, the changing trend of the bearing contact stress is shown in Figure 8, 9.

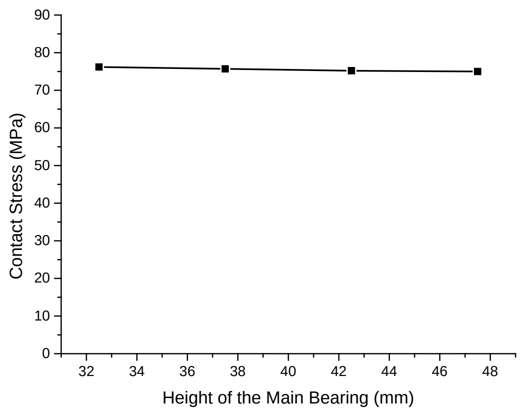


Figure 8: Contact stress vs. height of main bearing

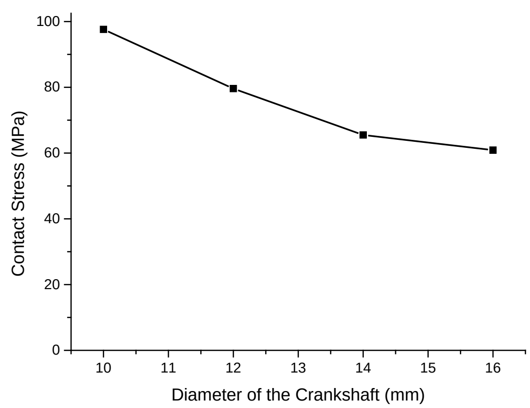


Figure 9: Contact stress vs. diameter of the crankshaft

These results show that:

1) With the increase of the height of the main bearing, the contact stress is basically unchanged. It indicates that the main bearing height has little influence on the contact stress, which has little effect on the bearing wear.
Because the bearing height is limited, it cannot represent the results of other limit values.

2) With the increase of the diameter of the crankshaft, the contact stress gradually decreases, and the decreasing tendency becomes slow. It indicates that the larger the bearing diameter, the better the improvement of bearing wear. But the bearing diameter increases to a certain extent, the effect of improvement become weak.

4.2 Experiments

According to the previous analysis, two schemes have been designed, one: reducing the height of the main bearing, and the other: reducing the diameter of the crankshaft. Through the accelerated life test, the wear condition of the crankshaft is obtain, and compared with the normal compressor.
The anatomical images of crankshaft wear of different schemes are shown in Figure 10, 11, 12.

Figure 10: Wear of the crankshaft of the normal

Figure 11: Wear of the crankshaft with short main bearing

Figure 12: Wear of the crankshaft with small diameter of crankshaft

Although the height of the main bearing decreases, the crankshaft wear state is consistent with the normal compressor. The height of main bearing has little effect on the bearing wear.
As the diameter of the crankshaft decreases, the crankshaft wear increases. The small diameter of the crankshaft will increase the bearing wear. Reducing the diameter of the crankshaft will aggravate the wear of bearings.
The test results of two schemes are all consistent with the calculation results. The influence of height and diameter of main bearing on bearing wear is further demonstrated, at the same time the feasibility of the evaluation method is confirmed.
In addition, because the calculation method cannot deal with the clearance of bearing, the influence of the clearance on the bearing wear is analyzed by the accelerated life test. The scheme with small clearance bearing is designed. And its anatomical image of crankshaft wear is shown in Figure 13.

Figure 13: Wear of the crankshaft with small clearance bearing

A severe adhesive wear is found on the crankshaft when the clearance of bearing decreases. This shows that the clearance of bearing has considerable influence on bearing wear. The decrease of the clearance possibly changes the lubricant state, thus causing exceptional wear.

5. CONCLUSIONS

A method of using contact stress to evaluate the bearing wear has been put forward on the basis of FEM. By the experiments, it is validated that the method has certain feasibility. But there are also limitations.

The influence of several parameters on bearing wear is analyzed, it shows that: the height of main bearing has little effect on the bearing wear; the decrease of the diameter of crankshaft will aggravate the wear of bearings; small clearance of bearing will cause exceptional wear.

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