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ABSTRACT

Understanding the state of lubrication in rotary compressors is of paramount importance for their reliability. This paper refers to an improvement of the lubrication in R410A rotary compressor. The lubricating conditions on the journal bearings can be evaluated by metallic contact that consists of measuring the electrical resistance between lubricated surfaces. The contact resistance can be used to indicate the degree of metal-to-metal contact between the sliding surfaces in the compressor. And some parameters of them are numerically analyzed. It is elucidated from the investigation that when unfavorable condition occurs, the metal contact between the journal and bearings become severe. And lubricating condition on the bearings in the compressor using high viscosity oil is better than that for the compressor using low viscosity.

1. INTRODUCTION

As alternative refrigerant of R22, R410A rotary compressors are widely used in room air conditioning units. Fig.1 shows the cross section of the rotary compressor. The rotary compressor is a high side compressor with the lubricant subjected to discharge conditions. And the crankshaft is under a large dynamic load including gas force and unbalanced mass forces of comprising mechanical parts (crank, roller, and balancers on motor rotor).As a result, lubrication conditions at bearings would become severe owing to the deformation of crankshaft. Therefore, to ensure rotary compressor operating well, the dynamic behavior of crankshaft at various conditions should be analyzed (Fei Xie *et al*., 2006) (Zengli Wang *et al*., 2013) (Haifeng Zhang *et al*., 2014). The discussions of the lubrication problem, which were reported previously (Masao Ozu *et al*., 1980) (Satoru Fujimoto *et al*., 1984) (Takashi Fukuda *et al*., 1996), have become increasingly important in designing of the rotary compressor.

In this paper, the dynamic behavior of the crankshaft for R410A rotary compressor were analyzed considering both unbalanced mass force and gas force. The influence of oil viscosity on the reliability is investigated. And we have tried to solve the problem with a method of electrical resistance between the lubricated surfaces.

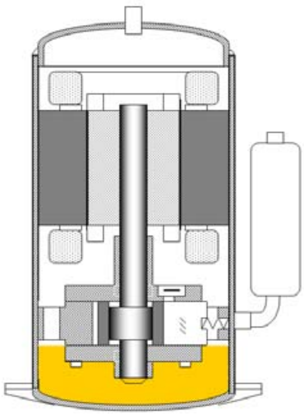


Figure 1: The cross section of the rotary compressor

2. NUMERICAL ANALYSIS

The loads acting on the crankshaft are load acting on the crank due to refrigerant pressure difference, centrifugal forces produced by the shaft itself and other attached parts such as upper and lower balance mass and a magnetic attractive force generated between the rotor and stator. And the shaft is supported by support forces of the bearings. At a rotation angle, the shaft is supposed to deform due to these forces.

2.1 Load Acting On The Crank

The crank is supported by the roller as shown in Fig.2a. The loads acting on the roller are defined as following (Katsuya, M.*et al*., 1998)

$$F_x = F_{gx} + F_{vx} + F_{ux} \tag{1}$$

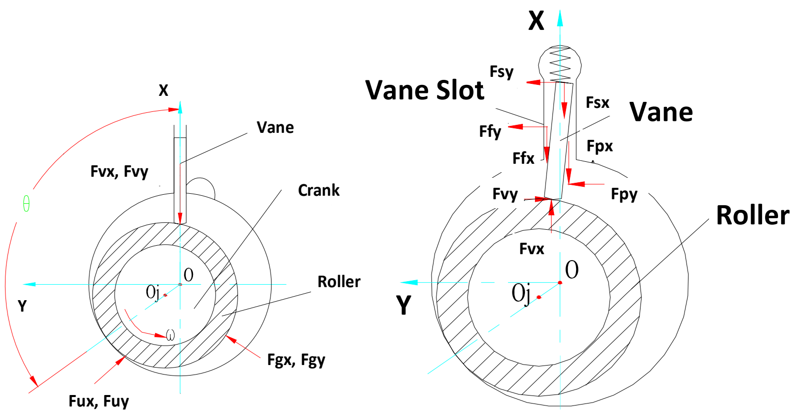
$$F_y = F_{gy} + F_{vy} + F_{uy} \tag{2}$$

Where F_{gx} and F_{gy} are the gas forces, F_{ux} and F_{uy} are the unbalanced forces, F_{vx} and F_{vy} are the forces at the contact point with the vane. F_{vx} and F_{vy} are defined as following(Katsuya, M.*et al*., 1998).

$$F_{vx} = F_{sx} + F_{px} + F_{fx} \tag{3}$$

$$F_{vy} = F_{sy} + F_{py} + F_{fy} \tag{4}$$

Where F_{sx} and F_{sy} are the vane spring forces, F_{px} and F_{py} are the forces produced by the difference of gas pressures around the vane, F_{fx} and F_{fy} are the frictional forces between the vane and the vane slot as shown in Fig.2b.



(a) The loads acting on the roller. (b) The loads acting on the vane.

Figure 2: Cross section of the cylinder

2.2 Support Force Of The Bearing

The dynamic bearing loads of the main bearing and sub bearing requires numerical solution to the Reynolds equations based on the finite length journal bearing theory as given by the following equations (Fei Xie *et al*., 2006) (Haifeng Zhang *et al*., 2014).

$$\frac{1}{R^2}\frac{\partial}{\partial\theta}\left(\frac{h^3}{\mu}\frac{\partial P_b}{\partial\theta}\right)+\frac{\partial}{\partial z}\left(\frac{h^3}{\mu}\frac{\partial P_b}{\partial z}\right)=6\frac{U}{R}\frac{\partial h}{\partial\theta}+12\frac{\partial h}{\partial t} \tag{5}$$

$$\begin{Bmatrix} F_{bx} \\ F_{by} \end{Bmatrix} + R\int_0^L\int_{\theta_1}^{\theta_2} P_b \begin{Bmatrix} \cos\theta \\ \sin\theta \end{Bmatrix} d\theta dz = 0 \tag{6}$$

Where P_b is the oil pressure between the bearing (the main bearing or sub bearing) and the shaft. It also means the bearing pressure. And the bearing forces F_{bx} and F_{by} are calculated by equation (6).

3. EXPERIMENT

As shown in Fig.1, there are two bearings in rotary compressor, such as main bearing and sub bearing. The two electrodes are fitted in the bearings to detect the contact. The position of the electrodes is decided on the basis of the system dynamic analysis and several reliability test results. In this evaluation, the electrical resistance change between sliding parts is monitored as the potential drop. The test system is shown in Figure 3. And Figure 4 explains the method. The electrodes are metallic pin, fitting in the bearings while insulated from the bearing around it. Electrical resistance of oil film between lubricated surfaces can be measured when the two surfaces are electrified with direct current. Differences in resistance caused by metallic contact between sliding surfaces, can be analyzed from the output voltage. When the lubricating condition is good enough, there is hydrodynamic lubricating oil film that can insulate between the bearing and crankshaft. However, as the condition becomes worse and the oil film is broken, the electrode and the crankshaft make direct contact, and the potential of electrode becomes the same as that for other parts. So, by monitoring the electrode potential as the voltage output, the lubricating condition changes during the operation can be monitored instantly (Masao Ozu *et al*., 1980) (Satoru Fujimoto *et al*., 1984) (Takashi Fukuda *et al*., 1996).

Figure 3: Test system

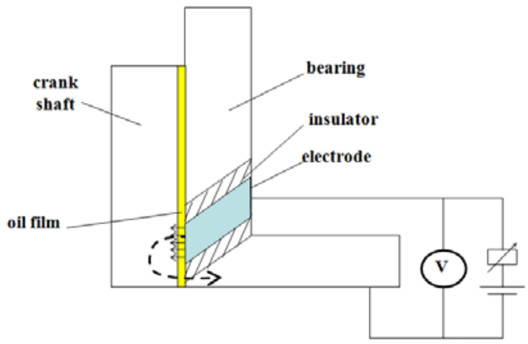


Figure 4: Electrical contact detection system

4. RESULTS AND DISCUCCION

4.1 Numerical results

The dynamic behaviors of the crankshaft in R410A rotary compressor are analyzed in this paper. The suction pressure is 1.2 MPa and the discharge pressure is 4.4 MPa. As a result of the elasticity of crankshaft, wear-out between journal and bearing usually occurs on four vertical planes, namely MBT (main bearing top), MBB (main bearing bottom), SBB (sub bearing bottom) and SBT (sub bearing top), as shown in Fig. 5. Besides, the impact between motor rotor and motor stator may occur at the section of MTop (the top rotor motor).

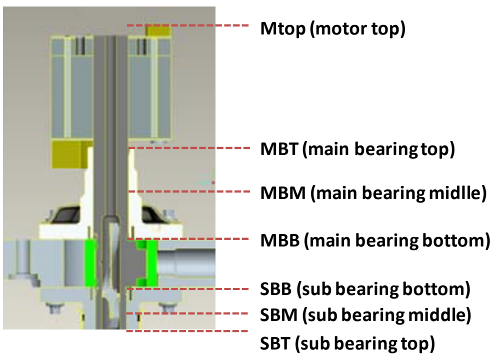
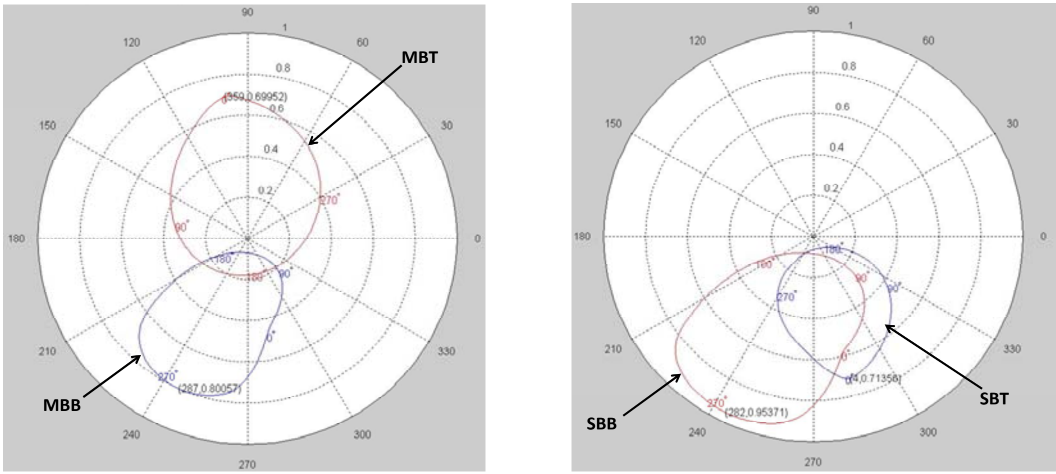


Figure 5: Vertical planes of the shaft

Journal orbit plays a key role in the dynamics of rotary compressor. The Journal orbits of the bearings are shown in Fig. 6. The journal orbits at SBB and MBB are relatively larger. And the wear-out may occur in these sections where oil film is much thinner.



(a) Journal orbits of main bearing (b) Journal orbits of sub bearing

Figure 6: Journal orbits of the bearings

And the analysis was examined under two kind of oil. The viscosity of oil is given by discharge pressure and temperature. In this paper, one is 3 cP. Another is 10 cP. Table 1 shows the minimum oil film thicknesses of the bearings. At low oil viscosity of 3 cP, the wear-out may occur in SBB where oil film is much thinner.

Table 1: Minimum oil film thicknesses

Viscosity/cP		3	10
Main bearing	Top	44%	100%
	Bottom	29%	74%
Sub bearing	Bottom	6%	48%
	Top	37%	81%

4.2 Experiment results

A test model ran under the condition (the suction pressure is 1.2 MPa and the discharge pressure is 4.4 MPa). The metallic contact signals change during the test of MBB and SBB are shown in Fig. 7. It shows that the condition becomes worse and the oil film is broken, the electrode and the crankshaft make direct contact. And it may indicate that the lubricating oil film condition on MBB is a little better than that on SBB. Because the voltage drop of SBB is larger than MBB. It agrees with the numerical results shown in Fig. 6 and Table 1.

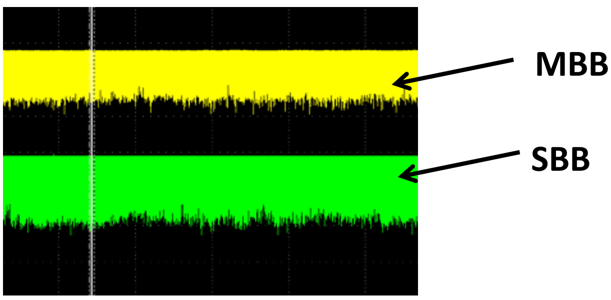


Figure 7: Metallic contact in MBB and SBB

5. CONCLUSIONS

In this paper, the dynamic behaviour of the crankshaft in R410A compressor has been studied. The vulnerable sections of crankshaft vary with the viscosity of oil. At low oil viscosity, the wear-out may occur in SBB. And the lubricating conditions on the journal bearings were evaluated by metallic contact that consists of measuring the electrical resistance between lubricated surfaces. The experiment results show that the condition of MBB and SBB becomes worse and the oil film is broken. It agrees with the numerical results.

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