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Analysis of Oil Pumping in the Hermetic Reciprocating Compressor for Household Refrigerators

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ABSTRACT

For a hermetic reciprocating compressor of the household refrigerator, it is not economic to set a separate oil pump, because of cost and space demands. Its oil supply system is mainly promoted by a reed pump and the spiral groove on the shaft. When the compressor is operating, the oil climbs up the inner wall of the reed pump because of the centrifugal force. The height to which the oil could climb is thus mainly determined by the rotation speed of the shaft. This paper presents a theoretical simulation of the effect of the centrifugal force on the oil flow. Results show that the reed pump will fail, when the rotation speed is below 2000rpm. For a variable speed compressor of the household refrigerator, the design of the reed pump must be optimized or a new design of the oil supply system should be found.

1. INTRODUCTION

In a hermetic household refrigerating compressor, the oil supply system is usually composed of a reed pump, shaft holes and oil grooves. The reed pump is immersed into the oil sump, at the bottom of the shell. During the operating process, the oil in the oil sump is pumped into the reed pump and delivered to the shaft bearing, connection rod and the piston. According to fluid dynamics, the centrifugal force and the shear force are basic functions of the oil pump. The centrifugal force results from the rotation of the shaft, and the shear force is produced by velocity differences between the shaft and the journal bearing.

Much research has been conducted on the oil supply system. Asanuma, Itami, and Ishikawa carried out experimental studies of the shaft oil feed mechanism of a rotary compressor (Asanuma et al., 1984). The research analyzed the effect of the centrifugal force on the oil feed mechanism in the reed pump and the main bearing of the shaft. It is valuable to investigate the oil flow rate. Many numerical research projects have been carried out to investigate the oil supply system of rotary compressors (Itoh et al., 1992, Kim and Lancey, 2003, Cui and Sauls, 2007, Kim and Ahn, 2007, Zhai et al., 2008). A network method was proposed by Kim and Lee to investigate the oil flow rate of the oil pump of the household reciprocating compressor (Kim and Lee, 2002, Kim and Lancey, 2003, Kim and Ahn, 2007). Lückmann, Alves and Barbosa carried out numerical simulation of the oil flow in the oil pump of the reciprocating compressor using an unsteady VOF model.

However, understanding the oil supply system based on existing research maybe not be enough to meet the development of the household reciprocating compressors. For example, the variable speed compressor is one of the main directions of the household refrigerator. The rotation speed of such a compressor will cover a large range, from,

even below 1000rpm to upper 4800rpm. Yet for a traditional household refrigerator, the rotation speed of the compressor is about 3000rpm. To ensure the reliability of the compressor, its oil supply must be quick and effective as soon as the compressor is started. Our experiments show that a traditional oil pump could not even supply oil to the journal bearing of the shaft at a low rotation speed of 1000rpm. So we are facing a challenge to design a new oil supply system to meet the demand of the low rotation speed operating conditions.

In this paper, we carried out theoretical research of the centrifugal force on the oil flow of a reciprocating compressor in the household refrigerator. Research results are valuable to indicate some design directions of the oil system to meet low rotation speed conditions.

2. THE OIL PATH IN A RECIPROCATING COMPRESSOR

The structure of a typical hermetic reciprocating compressor is shown in Fig. 1. It can be seen that the reed pump is set on the motor side of the shaft. The reed pump and the shaft are connected, and constitute the main oil path in the compressor.

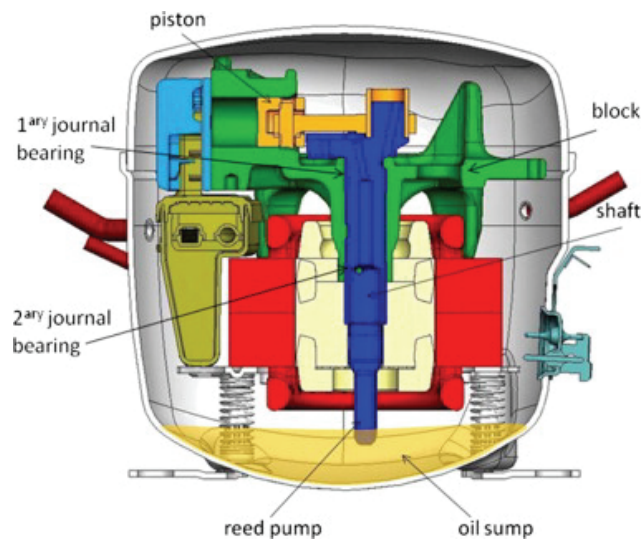


Fig. 1 Geometry of a typical hermetic reciprocating compressor (Lückmann et al., 2009)

As shown in Fig. 2, on the surface of the shaft, there is a spiral groove, which pumps oil to the journal bearing from the radial oil feeding hole. So the oil flows to the journal bearing through the reed pump, the radial oil feeding hole and the spiral groove. When the compressor is operating, the pump rotates with the shaft. Similar with a centrifugal pump, the reed pump could pump oil to the radial oil feeding hole under the effect of centrifugal force.

On the other hand, a large velocity difference between the spiral groove flank and the bearing wall leads to a shearing force on the oil. When the direction of the spiral groove is opposite to the rotation of the shaft, the shearing force becomes a driving force of the oil flowing up. Therefore, centrifugal force and shearing force are two main functions of the oil flow in the oil supply system.

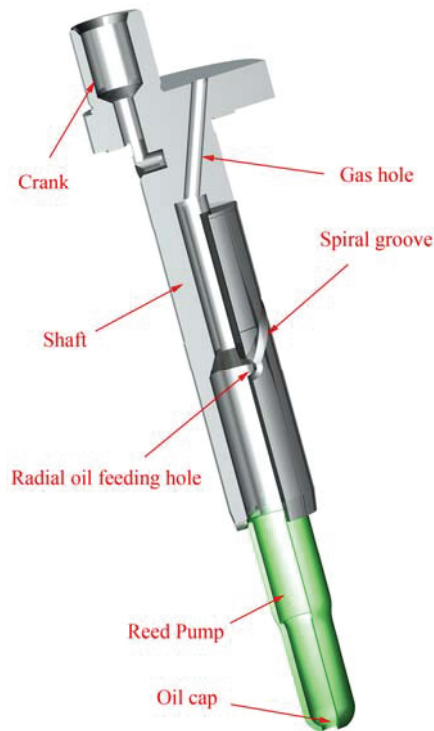


Fig. 2 The oil path in the shaft

3. EFFECT OF THE CENTRIFUGAL FORCE ON THE OIL FLOW

The effect of the centrifugal force on the oil flow could be simply described that when the reed pump rotates on its axis, the oil climbs up on the inner wall of the pump (Itoh et al., 1992). There is a parabola interface between the oil and the gas as shown in Fig. 3.

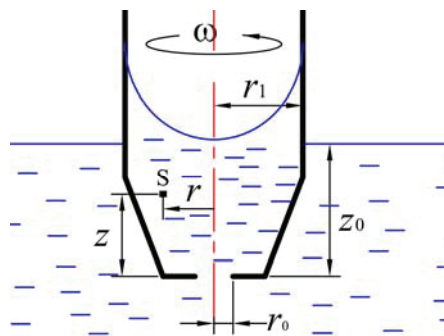


Fig. 3 Interface between the oil and the gas in the reed pump when rotating

At this point, we assume the reed pump has been rotating long enough at a constant rate of speed, ω , for the oil to have attained a rigid-body rotation. With the set coordinates r and z as shown in Fig. 3, the pressure distribution in the oil could be obtained easily (White, 2004):

$$p = \frac{1}{2} \rho \omega^2 r^2 - \rho g z + C \quad (1)$$

If the pressure at the entrance ($r=0, z=0$) is given by a reference pressure, p_0 , the constant C will be p_0 . Reference (Itoh et al., 1992) shows the pressure drop at the entrance is $\rho\omega^2 r_0/4$. Thus, it can be set that the reference pressure, p_0 , is $\rho g z_0 - \rho\omega^2 r_0/4$. Here, z_0 is the height of the oil level in the oil sump. Therefore, the surface of the oil now can be obtained. Say, $p=0$, Eq. (1) becomes (Kim and Ahn, 2007)

$$z = \frac{1}{4} \frac{\omega^2}{g} (2r^2 - r_0^2) + z_0 \quad (2)$$

Here, z_0 is the height of oil level in the oil sump, and r_0 is the radius of the oil cap. Eq. (2) shows a parabola oil surface in the reed pump. The equation also indicates that if the oil is expected to be pumped to a much higher position, the inner radius of the reed pump and the shaft must be much larger. However, a larger shaft will lead to a larger size of the motor, and thus will be much more costly. Similarly, when the rotation speed of the shaft is low, the pressure head of the oil out of the reed pump will sharply decreased.

4. DISCUSSION

Eq. (2) shows that the maximum oil pressure head the pump could provide occurs at the inner wall of the reed pump, where the radius is r_1 . As a result,

$$z_{\max} = \frac{1}{4} \frac{\omega^2}{g} (2r_1^2 - r_0^2) + z_0 \quad (3)$$

To supply the oil to the journal bearings, the oil must climb to the radial oil feeding hole, which delivers the oil to the spiral groove. If the height of the radial oil feeding hole is given as z_{rh} , the maximum pressure head, z_{\max} , must be larger than z_{rh} .

Now let's consider the influence of radius, angular velocity and oil level in the oil sump to the maximum oil pressure head.

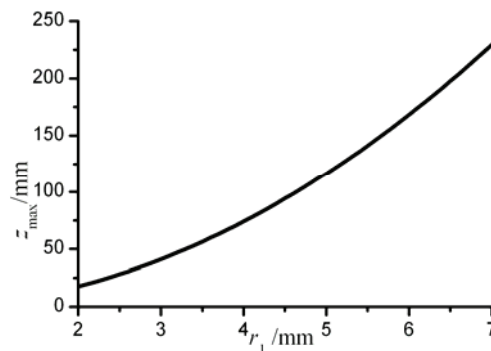


Fig. 4 Influence of the radius of the reed pump to the maximum pressure head

1) Influence of the radius of the reed pump, r_1 , to the pressure head, z_{\max} .

We set the rotation speed at 2900 rpm, the radius of the oil cap is 2.18mm, the oil level out of the reed pump is 10mm, and the height of the radial oil feeding hole, z_{rh} , is 68mm. the relation between the pressure head and the radius of the reed pump is shown in Fig. 4. It shows that when the radius, r_1 , exceeds 3.85mm, the maximum pressure head, z_{\max} , will exceed the height of the radial oil feeding hole, z_{rh} . For the hermetic reciprocating compressor for refrigerators, the popular design of the radius of the reed pump, r_1 , is about 5mm or bigger than it.

2) Influence of the radius of oil cap, r_0 , to the pressure head, z_{\max} .

As shown in Fig. 5, a bigger radius of the oil cap, r_0 , will lead to a lower maximum pressure head, z_{\max} . The reason for this phenomenon is that the centrifugal force in the reed pump needs a back support, and the oil cap hole means a loss of the support area. In this paper, the case allows for the oil cap radius, r_0 , to exceed 3mm, and the reed pump could still pump oil into the radial oil feeding hole.

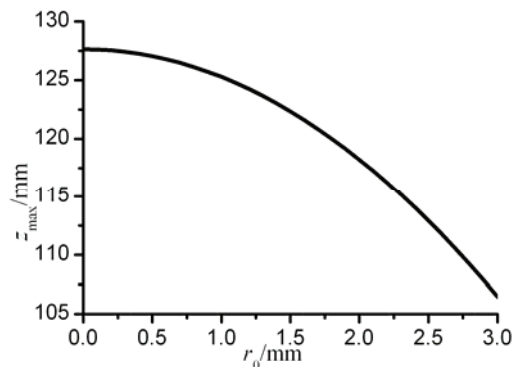


Fig. 5 Influence of the radius of the oil cap to the maximum pressure head

3) Influence of the oil level, z_0 , in the oil sump to the pressure head, z_{\max} .

As shown in Fig. 6, a higher level, z_0 , of oil in the oil sump will lead to a higher maximum pressure head, z_{\max} . However, the oil level must be below the rotor of the motor. This value is about 10mm to 20mm in most cases.

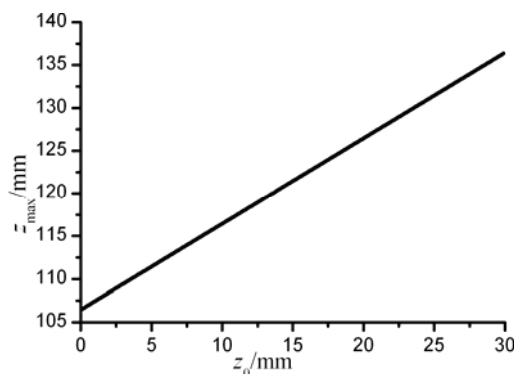


Fig. 6 Influence of the oil level to the maximum pressure head

4) Influence of the rotation speed, n , to the pressure head, z_{\max} .

As shown in Fig. 7, a fast motion of the shaft will lead to a higher maximum pressure head, z_{\max} . In the case presented in this paper, the rotation speed, n , of the shaft must be bigger than 2141rpm, or else the pump will fail to deliver oil to the radial oil feeding hole and supply oil to the whole system. This always become a deadly problem for variable speed compressors. As mentioned above, we sometimes need the compressor operating at a rotation speed of 1000rpm. Here, when the rotation speed is 1000 rpm, the reed pump could only provide an oil pressure head of 22.7mm, which means the whole system will lose lubrication. This is unacceptable.

To insure the pump could supply oil to the compressor at a rotation speed of 1000rpm, we can reduce the height of the radial oil feeding hole, z_{rh} , minimize the radius of the oil cap, r_0 , or increase the radius of the reed pump, r_1 , and enhance the oil level in the oil sump. We assume that the oil level, z_0 , in the oil sump is 20mm, the radius of the oil cap, r_0 , and is 0 (it is impossible, because it also means no flow rate). Based on these assumptions, the radius of the reed pump, r_1 , must be larger than 9.4mm to let the reed pump provide a pressure head larger than 68mm. obviously; this will greatly increase the cost of the compressor. On the other hand, reducing the value of the height of the radial oil feeding hole, z_{rh} , is another choice. However, it is difficult to reduce this, because z_{rh} it must be larger than the length of the motor.

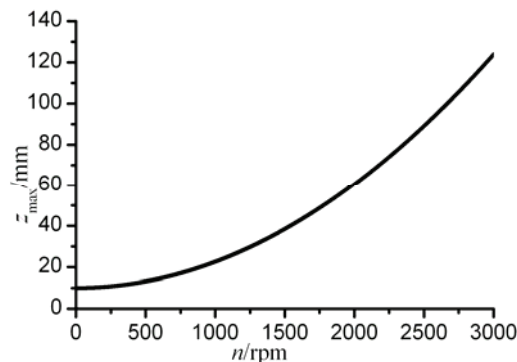


Fig. 7 Influence of the oil level to the maximum pressure head

Now, let's consider a perfect situation, z_{th} is reduced to 50mm (such a size maybe the terminal under the existing design), $z_0=20$ mm, and $r_0=1.5$ mm. Under these conditions, the radius of the reed pump must be larger than 7.5mm to ensure the maximum pressure head exceeding 50mm. Such a size is still too big.

5. CONCLUSION

For the oil supply system of hermetic reciprocating compressors in the refrigerator, centrifugal force induced by rotation of the shaft and the shearing force resulted from pressure difference are two main functions for oil pumping. For existing designs, the oil flow rate is mainly determined by the reed pump, i.e. the function of centrifugal force. Because the oil must be first be pumped into the radial oil feeding hole which connects to the spiral groove, and then the groove pumps the oil to the journal bearing, the crank shaft and the cylinder, etc.

This paper has carried out theoretical simulations on oil pumping for hermetic reciprocating compressors of the refrigerator, especially the effect of centrifugal force on the oil pumping. Obtained results show that the existing design of the reed pump will result in failure to pump oil to the oil system, when the compressor operates under a rotation speed of 2100rpm. To ensure the oil supply when the rotation speed is below 1000rpm, the radius of the reed pump must be larger than 7.5mm. However, such a size is too large in most cases. Therefore, for the variable speed compressor, if its operating speed is below 2100rpm, the design of the reed pump must be optimized or a new design must be found.

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