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F. Nishiwaki
Matsushita Electric Industrial Co.

H. Hasegawa
Matsushita Electric Industrial Co.

M. lkoma
Matsushita Electric Industrial Co.

R. Matsuzaki
Matsushita Electric Industrial Co.

S. Muramatsu
Matsushita Electric Industrial Co.

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Mechanical Loss Reduction at Thrust Bearings of Scroll Compressors Using R407C

Fumitoshi Nishiwaki[1], Hiroshi Hasegawa[1], Mitsuhiro Ikoma[1]
Ryoichi Matsuzaki[2] and Shigeru Muramatsu[2]

1 Human Environment Research Laboratory, Matsushita Electric Industrial Co.,Ltd.
  3-1-1, Yagumo-Nakamachi, Moriguchi, Osaka 570, Japan
2 Compressor Division, Matsushita Electric Industrial Co.,Ltd.
  2275-3, Noji-cho, Kusatsu, Shiga 525, Japan

ABSTRACT

This paper presents the experimental research into high mechanical efficiency at thrust bearings of low-side scroll compressors for air conditioners with the new refrigerant R407C and Polyolester (POE) lubricant. In order to examine the friction loss at the thrust bearing under a test condition which is close to the actual running condition of compressors, the authors developed a friction test machine that could make the orbiting friction test under the pressurized refrigerant atmosphere. Subsequently, an evaluating method of the friction loss at the thrust bearing was established. In the present study, the effects of friction parameters on the friction loss and the coefficient of friction were clarified by evaluating the friction characteristics of the orbiting thrust bearing in the mixing environment of POE lubricant and R407C refrigerant. In addition, above mentioned results of the orbiting friction tests were confirmed by the results of compressor performance tests. As a result, the reduction of the friction loss at the thrust bearing of the scroll compressor was successfully accomplished.

1. INTRODUCTION

Because of the ozone layer depletion issue, alternative refrigerants HFCs have been examined as the refrigerants for air conditioners. It is known that HFCs refrigerants with no chlorine have poor lubricity due to the effect of extreme pressure agent by chlorine, compared with HCFC22 refrigerant[1,2,3]. Thus, in order to develop the high efficient and high reliable compressors for air conditioners with HFCs refrigerants, the improvement in mechanical efficiency and wear resistance are becoming more important.

In the scroll compressors for air conditioners, the improvement in mechanical efficiency necessitates the reduction of the friction loss at each scroll compressor element, such as the thrust bearing, the main journal bearing, the sub journal bearing, and so on. It is reported in a research concerned with the simulation for compressor performance that the friction loss at the thrust bearing is most large among the friction losses at sliding elements[4,5]. However, it is the real state that the friction loss at the thrust bearing of scroll compressors has not been well studied[4,5,6].

In the present study, the friction characteristics of the orbiting thrust bearing in the mixing environment of Polyolester (POE) lubricant and R407C refrigerant were described. In addition, the test results for the orbiting friction and the compressor performance were also discussed.

2. FRICTION TEST APPARATUS AND PROCEDURE

A schematic diagram of test apparatus and test conditions employed in this study is shown in Fig. 1 and Table 1, respectively. This friction test machine, which was equipped with the test section of the orbiting thrust bearing in the vessel filled with a high-temperature and high-pressure mixtures of refrigeration oil and refrigerant, was developed by the authors to evaluate the friction loss at the thrust bearing under the test condition which is close to the actual running condition of compressors. The orbiting thrust bearing consists of two specimens. The upper specimen makes a orbiting motion. The lower specimen is fixed and loaded against the upper specimen. Hereafter, the upper specimen and the lower specimen are expressed as the orbiting specimen and the fixed specimen, respectively.

Specifications of specimens are shown in Table 2, and the appearance of the orbiting and fixed specimens are shown in Fig. 2 and Fig. 3, respectively. R407C refrigerant, which is mixed refrigerants of HFCs, is used. Refrigeration oil is POE lubricant, whose kinematic viscosity is 65.6 $mm^2/s(@40°C)$ and 8.2 $mm^2/s(@100°C)$, without an extreme pressure agent. Test specimens were rinsed in acetone by the ultrasonic washer for 10 minutes and mounted in the friction test machine after dried.

Friction tests was conducted for about 14 hrs and the driven torque of the orbiting specimen was measured. The load was increased in steps by 245 N per 30 seconds from 980 N up to the value of the load shown in Table 1. The friction loss of the orbiting thrust bearing was calculated from following equation[5].

$$W_{t-b} = T_t \cdot 2\pi n/60 \tag{1}$$

where W_{t-b} is the friction loss of the orbiting thrust bearing, T_t is the driven torque of the orbiting specimen and n is the orbiting speed. Replacing the load acting uniformly on the sliding surface with the concentrated load acting at the center of the orbiting specimen, the coefficient of friction of the orbiting thrust bearing, μ, can be obtained as follows[5].

$$\mu = T_t/(F \cdot r_o) \tag{2}$$

where F is the load acting normally on the orbiting specimen and r_o is the orbiting radius. By measuring the driven torque of the orbiting specimen and using these equations, the friction loss and the coefficient of friction of the orbiting thrust bearing were calculated. Furthermore, elimination of T_t from equations (1) and (2) results in

$$W_{t-b} = \mu \cdot F \cdot r_o \cdot 2\pi n/60 \tag{3}$$

From equations (3), it is noticed that the friction loss of the orbiting thrust bearing is in proportion to the coefficient of friction, the load, the orbiting radius and speed. So, by substituting the coefficient of friction obtained by the friction test, the load, the orbiting radius and speed in actual compressors into equations (3), the friction loss at the orbiting thrust bearing in compressors can be predicted.

3. EXPERIMENTAL RESULTS AND DISCUSSION

A typical example of the test time dependence on the friction loss and the coefficient of friction is shown in Fig. 4. The fixed specimen is a thrust plate type (carbon tool steel). This type has been developed as a orbiting thrust bearing for HFCs refrigerants due to its excellent wear resistance. The friction loss and the coefficient of friction decreases rapidly for 8 hrs after the test was started to make, thus approaching to a constant value. This time which the friction loss and the coefficient of friction

become constant is the initial running-in time for the sliding surface. In actual compressor, it is well known that the input power decreases as the running time passes after assembling of compressor. In this study, the measured asymptotic value of the friction loss was defined as one of tested specimen. In the case of the thrust plate type (carbon tool steel), the friction loss was 45 W and the coefficient of friction was 0.048.

3.1 Effect of Surface Roughness

At first, the effect of surface roughness of fixed specimens on the friction loss and the coefficient of friction was examined. Fig. 5 shows the test data for the friction loss and the coefficient of friction vs. the surface roughness Ra (before test) of the fixed specimens for the type of plain disk. Surface roughness Ra (before test) of orbiting specimens were 0.28-0.49 μm. As can be seen, the friction loss and the coefficient of friction decreases, as the surface roughness Ra of fixed specimens decreases. In the case of the surface roughness Ra of 1.39 μm, the sliding surface of the orbiting specimen was worn by 9-22 μm and the color of POE lubricant became black. In other cases, wear was scarcely observed.

3.2 Effect of Oil Groove

Next, the friction characteristics were evaluated for the case with oil groove made on the sliding surface of fixed specimens in order to form oil film. The test data for a single groove and a double groove type are also shown in Fig. 5. If the surface roughness of fixed specimens is the same, the friction loss and the coefficient of friction for fixed specimens with oil groove become smaller than those for the plain disk type. The friction loss and the coefficient of friction were scarcely affected by the difference of the configuration between single groove and double groove shown in Fig. 3. It was concluded that the friction loss decreased since oil film was formed easily by making the oil groove.

3.3 Effect of Frictional Conditions

To clarify the effect of frictional conditions on the friction loss and the coefficient of friction, the friction characteristics for the fixed specimens of plain disk type were evaluated by changing frictional conditions.

(1) Effect of Load and Orbiting Speed

The effect of the load and the orbiting speed on the friction loss and the coefficient of friction are shown in Fig.6 and Fig.7, respectively. The friction loss increases proportionally to an increase in the load and the orbiting speed, but the coefficient of friction is almost constant.

(2) Effect of Orbiting Radius

Table 3 shows the effect of the orbiting radius on the friction loss and the coefficient of friction. In the present experiments, the effect of the orbiting radius on the friction loss was scarcely founded. However, as seen in Table 3, the coefficient of friction increased by decreasing the orbiting radius. It is considered for this reason that the oil film-forming properties become poor as the orbiting radius decreases.

(3) Effect of Oil Temperature

The effect of the oil temperature on the friction loss and the coefficient of friction is shown in Fig.8. The friction loss and the coefficient of friction at 60 ℃ and 75 ℃ were almost the same, but at 95 ℃ the friction loss and the coefficient of friction increased rapidly. In this case, the sliding surface of the orbiting specimen was worn by 13-22 μm and the color of POE lubricant became black. It is considered that the oil film-forming properties become poor as the oil viscosity decreases with an increase of the oil temperature.

4. COMPRESSOR PERFORMANCE TEST

Using the scroll compressor with 8 kW refrigerating capacity, the effect of the thrust bearing type on the compressor input power for R407C and R410A was examined in the ARI condition. The test results for the compressor performance and the orbiting friction are shown in Table 4. The tendencies of both test results were the same regardless of refrigerant types, and it was found that the friction loss for the single groove type is most low among these 3 types. Furthermore, it was revealed that the difference in the friction loss of the compressor input power between the thrust plate type (carbon tool steel) and the single groove type is about 10 % of the friction loss at the thrust bearing, considering the author's simulation results with regard to the compressor performance. As a result, by making the oil groove, the mechanical loss at the thrust bearing could be reduced by about 10 %.

5. CONCLUSIONS

In order to reduce the friction loss at the thrust bearing of the scroll compressors for alternative refrigerant, the effects of the friction parameters on the friction loss and the coefficient of friction were examined by conducting the orbiting friction tests under the pressurized mixing environment of POE and R407C. The following conclusions were obtained.
1) The friction loss and the coefficient of friction decrease by reducing the surface roughness of the sliding surface and making the oil groove.
2) The friction loss increases and the coefficient of friction is constant, as the load and the orbiting speed increase.
3) The test results for the orbiting friction agree with one for the compressor performance tests.

Furthermore, it was concluded that the friction loss at the thrust bearing of the scroll compressor could be reduced by optimizing the sliding material, the configuration of the sliding surface and the frictional condition.

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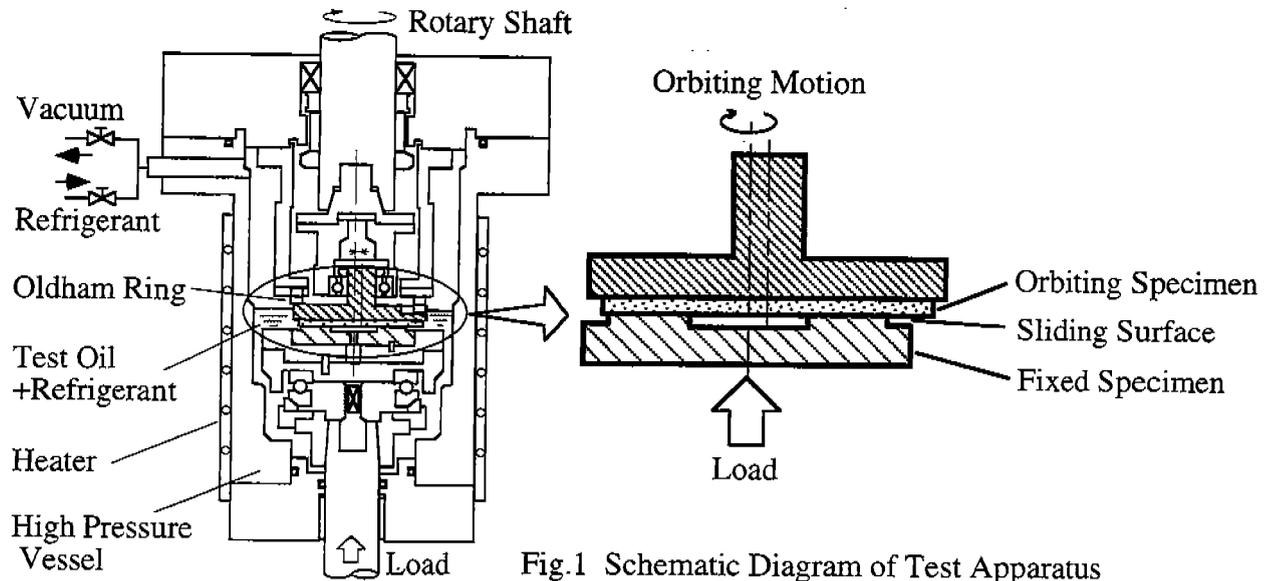
Fig.1 Schematic Diagram of Test Apparatus

Table 1 Test Conditions

Atmosphere	Mixing Environment of POE and R407C
Amount of Refrigeration	12 (wt%)
Amount of Oil	400 (cm3)
Oil Temperature	60, 75, 90 (℃)
Orbiting Radius	2.5, 3.4 (mm)
Load	1470, 2940, 4410 (N)
Orbiting Speed	600, 900, 1200 (rpm)

Table 2 Specifications of Specimens

Specimens	Types	Materials
Orbiting	Plain Disk	Eutectic Graphite Cast Iron
Fixed	Thrust Plate	Carbon Tool Steel
	Plain Disk	Gray Cast Iron
	Single Groove	Gray Cast Iron
	Double Groove	Gray Cast Iron
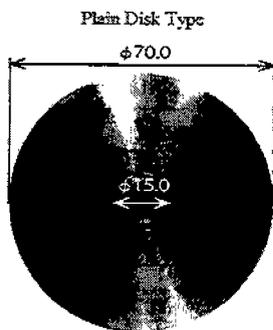
Fig. 2 Shape and Dimensions of Orbiting Specimen
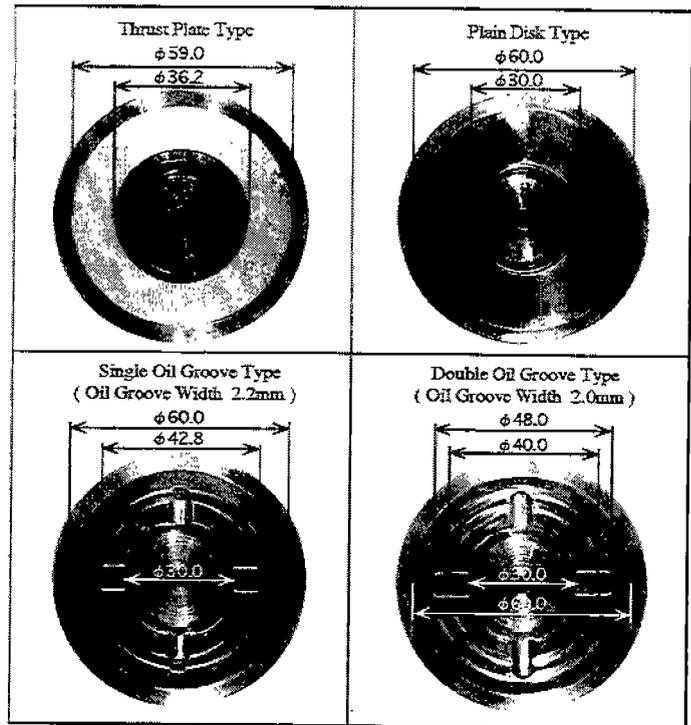
Fig. 3 Shape and Dimensions of Fixed Specimens

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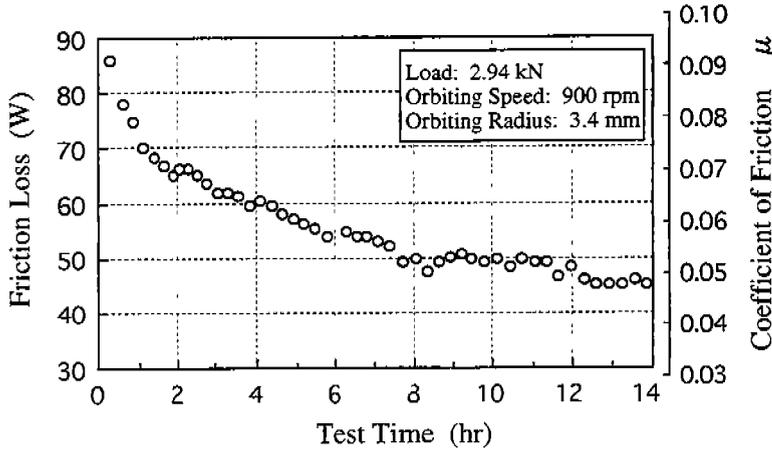
Fig.4 Test Time Dependence of Friction Loss and Coefficient of Friction
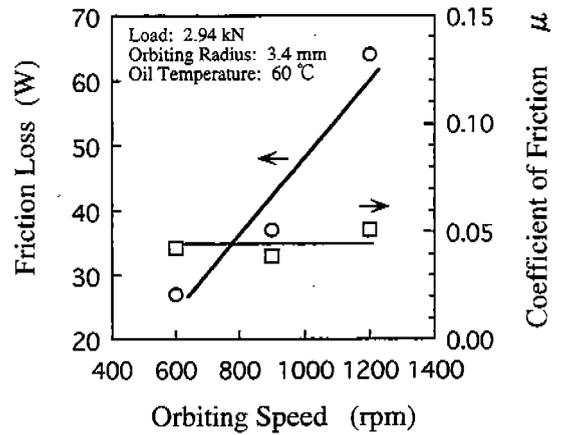
Fig.7 Effect of Orbiting Speed
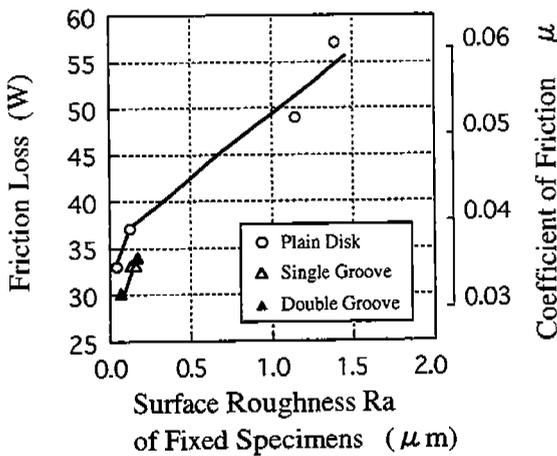
Fig.5 Effect of Surface Roughness of Fixed Specimens (Test Condition Load:2.94 kN , Orbiting Speed: 900 rpm, Orbiting Radius:3.4 mm)
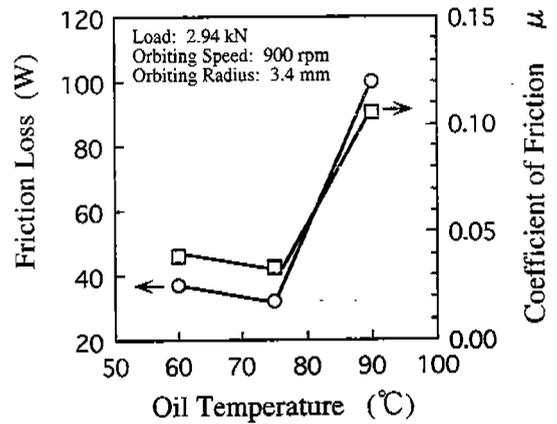
Fig.8 Effect of Oil Temperature
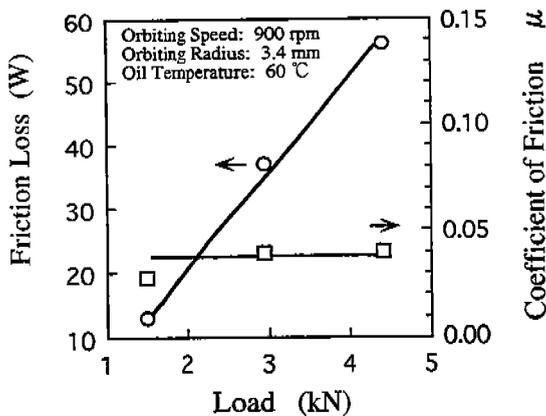
Fig.6 Effect of Load

Table 3 Effect of Orbiting Radius

Orbiting Radius(mm)	Friction Loss (W)	Coefficient of Friction μ
2.5	40	0.058
3.4	37	0.039

Table 4 Results of Compressor Performance Test and Orbiting Friction Test

Types of Thrust Bearing	Compressor Performance Test Input Power (W)		Orbiting Friction Test	
	R407C	R410A	Friction Loss (W)	Coefficient of Friction μ
Thrust Plate (Carbon Tool Steel)	3253~3232	3706	45	0.048
Plain Disk	3238	3675	37	0.039
Single Groove	3214	3666	33	0.035