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Friction Characteristics Between Vane and Rolling Piston in a Rotary Compressor Used for Refrigeration and Air-Conditioning Systems

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Abstract: The rolling piston type rotary compressor has been widely used for refrigeration and air-conditioning systems due to its compactness and high-speed operation. The present study is one of studies to maximize the advantages of refrigerant compressors. In addition, because friction characteristics of the critical sliding component is essential in the design of refrigerant compressors, the present study also analyzed the lubrication characteristics of a rotary compressor used for refrigeration and air-conditioning systems. In order to measure the friction force between the vane and the rolling piston, an experimental apparatus known as the Pin-on-Disk was used. Load is applied by the hydraulic servo valve controlling the pressure of the hydraulic cylinder. The results showed that the rotational speed of the shaft, the operating temperature, and the discharge pressure significantly influenced the friction force between the vane and the rolling piston.

Keywords: *rotary compressor, vane, rolling piston, friction characteristics*

1. Introduction

The rolling piston type rotary compressor has been widely used for refrigeration and air-conditioning systems because of its compactness, low cost and high-speed operation. The rotary compressor changes the compression volume by using the rolling piston, which rotates around an eccentric shaft and on its axis, and using the vane, which has a reciprocating motion in the cylinder slot.(Cho, I.S., Oh, S.H. and Jung, J.Y., 1996)
Because of the mechanism, the system has many sliding components. In particular, the vane, which divides the chamber into two parts, the suction chamber and the compression chamber, pushes the rolling piston with high force, overcoming the force in the compression chamber. And, because the relative velocity between the vane tip and the rolling piston is very low and the vane tip is lubricated with a lubricant, whose viscosity decreases because of solute refrigerant gas, lubrication characteristics between the vane and the rolling piston is very severe, and the formation of the lubrication film becomes difficult. Therefore, lubrication characteristics between the vane and the rolling piston are the most important mechanical characteristics affecting the performance and reliability of a rotary compressor used in.(Cho, I.S., 2001 and Jang, S., 2004)

The study of lubrication characteristics in the critical sliding component of a refrigeration and air-conditioning is essential in the design of refrigerant compressors. Therefore, the present study experimentally examines the lubrication characteristics between the vane and the rolling piston of a rotary compressor for refrigeration and air-conditioning systems.

2. Apparatus and Method for Experiment

2.1. Modeling for Experiment

In practice, the mechanical behavior between the vane and the rolling piston of a rotary compressor includes various complicated interactions. Therefore, in order to measure the friction force between the vane and the rolling piston precisely, extra modeling of the interactions is essential.
Figure 1 shows the cylinder part of a rotary compressor. To analyze the mechanical behavior of the cylinder, clockwise direction and counter-clockwise direction are defined as positive for θ and α_p, respectively.(Cho, I.S., Oh, S.H. and Jung, J.Y., 1996)

The contact between the vane and the rolling piston in Fig. 1 can be represented by the equivalent cylinders, as shown in Fig. 2, to measure the precise friction force between the vane and the rolling piston.
In Fig. 2, u_1, u_2 are the surface velocities of two sliding components in the x-direction.

As shown in Fig. 2, the model of 2-dimensional flow, in which the vane with the radius of curvature, R, under the load of w per unit length moves with the velocity of u_1 along the

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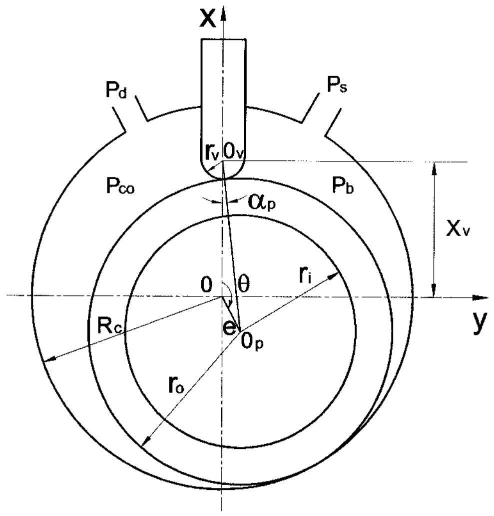

Fig. 1. Schematic diagram of the cylinder part

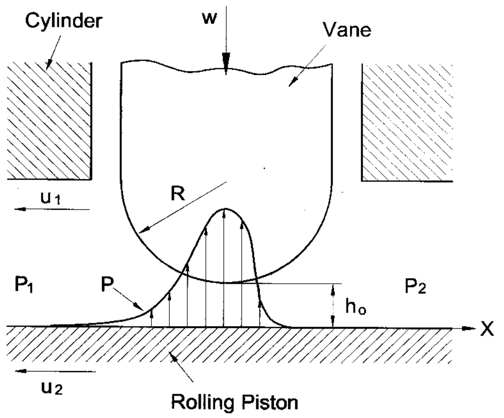

Fig. 2. Model of a line contact

semi-infinite body of the rolling piston with the velocity of u_2, was taken as the object of the experiment. And, in order to understand the friction characteristics of the vane tip, basic values to be used in the experiment such as velocities, load are acquired through the dynamic analysis of the rolling piston.(Cho, I.S., Oh, S.H. and Jung, J.Y., 1996)

2.2. Experimental Apparatus

This experiment aims to investigate friction characteristics by the relative motions of the vane tip and rolling piston that the lubrication characteristics are severest in the rotary compressor. The relative motions are important factors affecting the performance and reliability of the rotary compressor, and these components are modeled as though they are relatively instant sliding motion in line contact under a periodically varying load. And, to approximate the magnitude of the varying load under a practical operating condition, the values of the load and the velocity obtained by calculating the mechanical quantities of each relative sliding part under practical operation are applied as experimental boundary conditions, that is, the load and the velocity applied to the vane and the rolling piston.

With these experimental conditions, a dynamic friction experimental apparatus using hydraulic system was designed and made to measure the friction force between the vane and the rolling piston in line contact under varying loads, and Fig. 3 shows the whole apparatus and Fig. 4 shows the main body of the test part to measure the friction force between the vane and the disk.

The main test body is composed of a disk with radius of 180mm, and the device that pushes the vane to the disk which is 75mm away from the axis of the disk. The hydraulic system uses a small hydraulic cylinder to control the input load to push the vane so that the normal load can be applied as desired. This input load can be checked on the monitor through a force sensor fixed under the vane. And, because the signal inputted by the servo valve is feedback to the controller, the maximum value of the varying load applied to the vane is always the set value.

With above condition, the waveform, frequency, amplitude, and offset value of the load can be set as desired by the function generator, and the friction force according to the input load can be obtained by the vane supporter through the friction sensor, and the data, after shown on the monitor through the A/D converter, are saved. Also, the velocity of relative sliding between the vane and the rolling piston under practical operation is 0~20 m/s. The rotating speed of the disk, driving the disk by V-belts, is measured by a tachometer. Also, the rotating speed of the disk controlled by the motor controller is set to that under practical operation.

2.3. Experimental Method

The experiment was carried after 30-minute of test run to stabilize the system with 7MPa of the supply pressure of servo valve, and 500 rpm of the disk rotating speed.

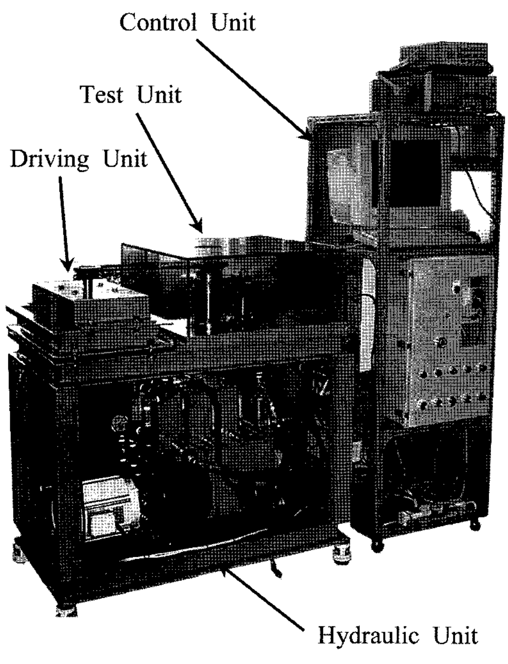

Fig. 3. The total system of the experimental apparatus

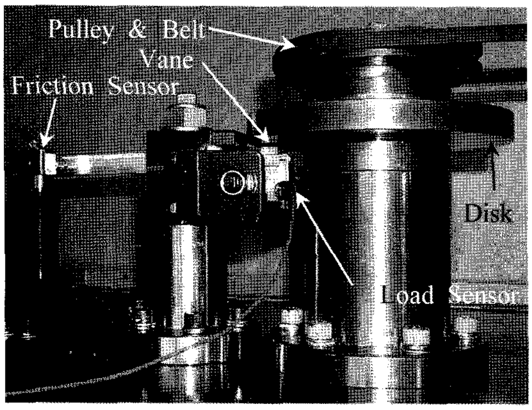

Fig. 4. Photograph of the main test body

And, after checking whether the supply of the lubricant was sufficient, the disk was rotated regularly by using the tachometer in the control unit, and the amplitude, frequency, waveform, and offset value of the input load were controlled by the function generator, and the friction force was measured under these conditions. The obtained friction force was converted by the A/D converter, and inputted and saved to the PC.(Bak, U.S., Jung, S.H., Oh, S.H. and Jung, J.Y., 1995)

In this study, the parameters, rotating speed, temperature, and load, were used in the experiment. Also, the results obtained from the dynamic analysis of motion of the rotary compressor were taken as the input for the magnitude of each parameter. The disk rotating speed ranged from 0~250rpm, the range obtained from the velocity between the vane and the rolling piston, and the input load ranged from 0~250N, the range obtained from the normal load between the vane and the rolling piston. The input value was sampled at every 10° of the axis angle, and the velocity of the relative sliding and the normal load between the vane and the rolling piston of each angle were used in the experiment.

3. Results and discussions

The geometrical shapes and properties of experimental specimens and oil are summarized in Table 1.

Table 1. Geometrical shapes and properties of experimental specimens and oil

Items	Values	Unit
Oil viscosity at 40°C	0.050	$Pa \cdot S$
Oil viscosity at 120°C	0.003	$Pa \cdot S$
Disk diameter	18	cm
Disk thickness	1.8	cm
Vane tip radius	0.4	cm
Vane thickness	0.4	cm
Vane height	1.2	cm
Vane width	1.6	cm
Vane material	SKH-9	
Vane hardness	60~64	H_RC
Vane roughness	0.8	μmR_{max}
Disk material	SUJ-2	
Disk hardness	Above 64	H_RC
Disk roughness	1.6	μmR_{max}

3.1. Results of experiment

The results of experiment using Pin on Disk to measure the friction force between the vane and the rolling piston, which were severest in a rotary compressor, and are important factors affecting the performance and reliability of a rotary compressor, are as follows.

The results from dynamic analysis taking sampling values as experimental conditions are show in Fig. 5~Fig. 7. In the figures, the friction forces are within the range of 1~8N, and there are two peak points. The positions of these points are close to the axis angles where the relative sliding velocity between the vane and the rolling piston is zero, and because the film that formed between the vane and the rolling piston became thin, the friction force becomes extremely high. And the friction force is relatively small, except for the two peak points, because the friction between the lubricated surfaces under relative motion results from the shear stress of the oil film.

Figure 5 shows the lubrication characteristics between the vane and the rolling piston according to the rotating speed of the rotary compressor at 0.52 MPa suction pressure, 2.0 MPa

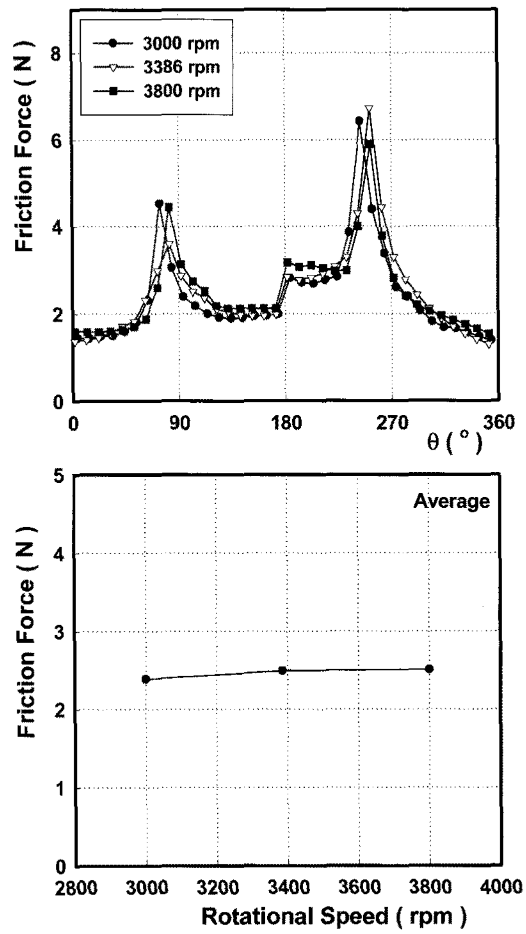

Fig. 5. Friction forces to the variation of rpm

discharge pressure, and 60°C operating temperature.

Also, two peak points correspond to the axis angle where the relative sliding velocity and the oil film thickness between the vane and the rolling piston are almost zero. Therefore, it seems, at this point, almost all region of the vane tip are in dry contact. Also, at 180° of the axis angle, the relative sliding velocity and the oil film thickness between the vane and the rolling become almost the maximum, and, because the oil film thickness is thick, most of the friction force between the vane and the rolling piston resulted from the shear stress of the oil film. And, the friction force increased as the step shape near 180° because of the load increased dramatically near the point. When the rotating speed increases, the average of the friction force between the vane and the rolling piston increases.

Figure 6 shows the lubrication characteristics between the vane and the rolling piston according to the discharge pressure of the rotary compressor at 0.52 MPa suction pressure, 3386 rpm rotating speed, and 60°C operating temperature.

The graph shows shape similar to that of Fig. 5. As the discharge pressure increases, the friction force between the vane and the rolling piston increases because when the discharge pressure increases, the normal load applied to the vane increases.

Figure 7 shows the lubrication characteristics between the vane

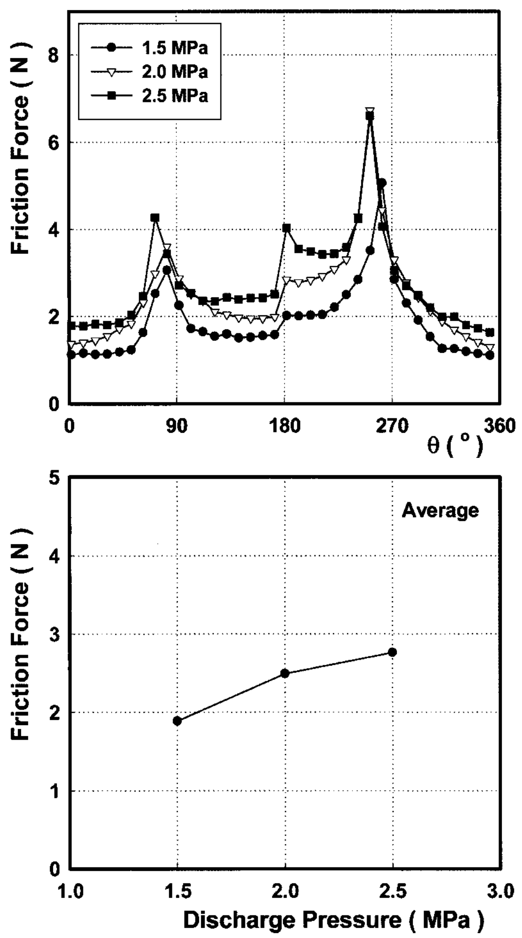

Fig. 6. Friction forces to the variation of discharge pressure

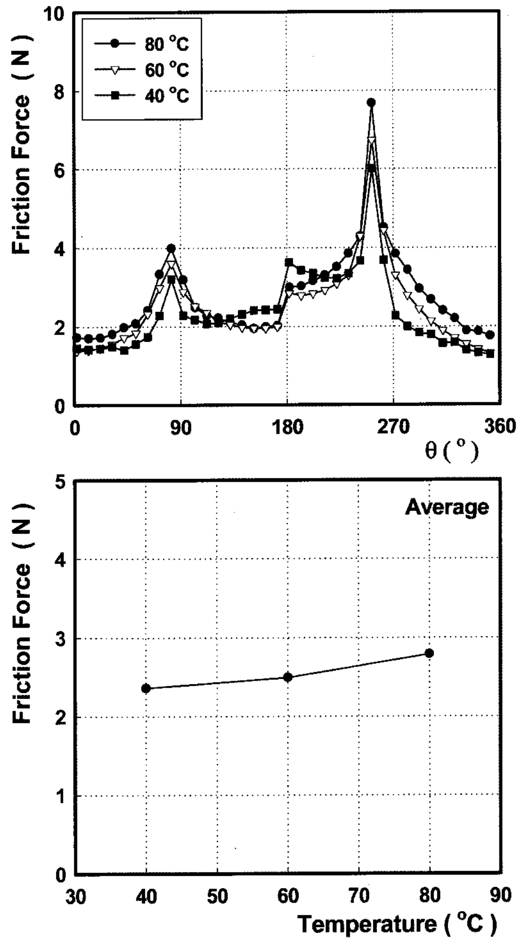

Fig. 7. Friction forces to the variation of temperature

and the rolling piston according to the operating temperature at 0.52 MPa suction pressure, 2 MPa discharge pressure, and 3386 rpm rotating speed.

As the temperature increases, the friction force between the vane and the rolling piston increases. This is because the load carrying capacity of oil film decreases resulting from the lowered viscosity of the lubricant as the temperature rises and dry contact occurs. Because of this phenomenon, the hydrodynamic friction force decreases and the dry friction force increases.

3.2. discussions

In Fig. 8, the friction coefficients from the friction force measured in the experiment range are fitted in the Stribeck diagram to presume the lubrication characteristics between the vane and the rolling piston. S value in the X axis, non-dimensional quantity used to display the lubrication characteristics between two surfaces, are the same as $\eta\, u/w$, μ in the y axis is the friction coefficient. Here, η, u, and w represent the viscosity of the lubricant, the relative sliding velocity according to the rotating speed of the shaft, and the force per unit length, respectively. The friction coefficients in y the axis are represented by dividing the measured friction force in the experiment by the normal load applied to the vane and

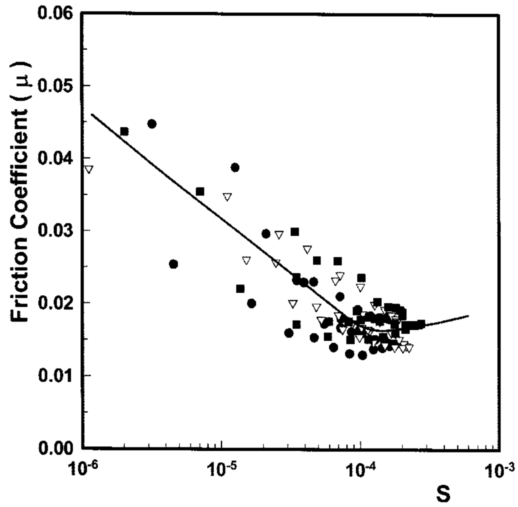

Fig. 8. Stribeck diagram of the experimental results

the rolling piston.

In a hydrodynamic lubrication condition, μ, the friction coefficient, because it is in proportion to the viscosity and the speed, and in inverse proportion to the load, w, is positioned in upper right of the Stribeck diagram, and has a positive slope. In the figure, it can be guessed that, because the graph is close to that trend above $S=\eta u/w = 2\times10^{-4}$ region, so that it is said that "Hydrodynamic lubrication is practicable". But when S becomes lower than 1.5×10^{-4}, the friction coefficient, μ, becomes minimum value, after which it increases as S decreases. This result shows that about $S=\eta u/w = 2\times10^{-4}$ region, boundary lubrication begins to appear, and when S becomes lower than 1.5×10^{-4}, mixed lubrication, which consists of both the boundary lubrication and the hydrodynamic lubrication, begins to appear. In this region, a part of the load is supported by the oil film, and the other part by the metal contact of surfaces. Therefore, the lubrication characteristics between the vane and the rolling piston obtained by the experiment are in the region of mixed lubrication, because the more increases, the more the friction coefficient decreases.

4. Conclusions

In this paper, the results of the experiment of the lubrication characteristics of the vane and the rolling piston of a rotary compressor with alternative refrigerants for refrigeration and air-conditioning systems can be summarized below.

(1) The friction force between the vane and the rolling piston decreases as the rotating speed of the shaft increases, but increases as the discharge pressure increases.

(2) As the temperature rises, the fluid friction force decreases, and the solid friction force increases. Therefore, we can expect an optimum temperature which the friction force becomes the minimum.

Also, the friction force between the vane and the rolling piston include the friction by the oil film, and the friction by the dry contact. And the friction by the dry contact appear in the almost part. Therefore the lubrication characteristics between the vane and the rolling piston are very severe mixed lubrications.

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