1998

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M. Fukuta  
*Shizuoka University*

T. Yanagisawa  
*Shizuoka University*

N. Somchai  
*Shizuoka University*

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PRESSURE CHARACTERISTICS OF OIL-REFRIGERANT MIXTURE IN CLEARANCE BETWEEN OSCILLATING PLATES

Mitsuhiro FUKUTA, Tadashi YANAGISAWA and Ngamkitcharoenlap Somchai

Department of Mechanical Engineering, Shizuoka University, 3-5-1, Johoku, Hamamatsu, 432-8561, JAPAN

ABSTRACT

It is important to clarify lubricating condition at sliding parts in compressors for HFC refrigerants. This paper investigates experimentally pressure characteristics of oil-refrigerant mixture in a small clearance between oscillating plates as the first step of research on the lubrication characteristics of oil film in the refrigerant compressor. We measured the oil film pressure by using not only pure oil but also mixture of oil and refrigerant, and the influences of cavitation or separation of refrigerant vapor from the mixture as well as the magnitude of clearance, amplitude of the oscillation of the plate and oscillating frequency on the oil film pressure were investigated. We confirmed the phenomena of cavitation, occurrence of negative pressure, different behavior between the pure oil and the oil-refrigerant mixture and influence of flow existing in the clearance on the pressure characteristics.

INTRODUCTION

It is reported that lubricating condition at sliding parts in compressors for HFC refrigerants is severe as compared with that in CFC or HCFC compressors/1,2/. Many experimental works and researches have been done on compatibility of materials and characteristics of wear in the compressor/3,4/, and the lubricating characteristics of the sliding parts were examined accurately by the hydrodynamic lubrication theory/5/ or the elastohydrodynamic lubrication theory/6/. When these lubrication theories are applied to the sliding parts, the boundary condition of Gümbel or Reynolds, which assumes that oil film pressure never becomes lower than surrounding pressure, is generally used/7/. It is, however, expected that pressure lower than the surrounding occurs at the sliding portion filled with highly pressurized oil in the refrigerant compressor. Moreover, refrigerant dissolving in the lubricating oil in the compressor may separate from the oil with pressure reduction of the oil film, and babbles caused by the separation of refrigerant is expected to influence the oil film pressure in the clearance. Although there are some studies which focused on cavitation phenomena in the field of tribology/8-11/, there are few study about the oil film pressure of oil-refrigerant mixture/12/. In this study, we investigate experimentally the pressure characteristics of oil-refrigerant mixture in a clearance between oscillating plates as the first step of research on the lubrication characteristics of the oil film in the refrigerant compressor.

EXPERIMENT

Figure 1 shows an experimental apparatus. In order to investigate the pressure characteristics of oil-refrigerant mixture in a clearance between oscillating plates, experiments were done by using a swing oscillation plate, i.e. one end of the plate is fixed and the other end oscillates sinusoidally. Such swing oscillation mode of clearance occurs at a vane side of rotary compressors or vane compressors. The lower plate is ground surface of steel and the upper plate (length $L=40$ mm, width $W=30$ mm) is glass in order to observe the occurrence of cavitation. Clearance height at the fixed end of plate, $h_0$, is set by using a thickness gauge. The upper plate is driven by a piezo electronic oscillator through a steel rod. The frequency, $f$, and amplifier, $a$, of the oscillator are controlled by a function generator and a power amplifier.
respectively. The movement of plate is measured by a gap sensor with a small plate fixed on the rod. The oscillating upper plate is sandwiched by side blocks with a minimum clearance to prevent a leakage flow at the plate sides and to realize one-dimensional pressure distribution of oil film in the clearance. Pressurized oil is supplied to the oscillating end when it is needed to investigate an influence of oil flow. The oscillating plate is enclosed in a pressure vessel with a sight glass. Pressure in the vessel is measured by a Bourdon-tube pressure gauge. Pure refrigeration oil or oil-refrigerant mixture is stored in the vessel to fill the clearance and the pressure variation due to the oscillating motion of plate are measured by semiconductor type pressure transducers at two points, point A is 25mm and point B is 10mm far from the fixed end respectively. Both pressure and plate's movement were monitored by an oscilloscope and their signals were recorded by a computer through an A/D converter. In the experiments, the magnitude of clearance, oscillating frequency, amplitude of oscillation, surrounding pressure, mixing ratio of refrigerant in the oil and condition of flow in the clearance are changed. Mineral oils of VG56 and VG18, mixture of mineral oil(VG56) and HCFC22, mixture of ester oil(VG56) and HFC134a and mixture of PAG(VG56) and HFC134a are used as a working fluid. We investigated their influences on the oil film pressure with special attention to an occurrence of negative pressure and the cavitation.

RESULTS AND DISCUSSION

Case of Pure Oil

Figure 2 shows variation of clearance height at the oscillating end, $h_1$, and pressure at the point A during one cycle. Experimental conditions are: clearance height at the fixed end $h_0=200\mu m$, frequency of oscillation $f=20Hz$, amplitude of oscillation $a=44\mu m$ and surrounding absolute pressure (=mean pressure) $P_m=101.3kPa$. The working fluid is pure oil and the viscosity of oil $\eta =160mPa\cdot s$. In the figure, a thin solid line shows measured value of $h_1$, a thick solid line shows measured pressure and a thin dotted line shows approximation of $h_1$ by sinusoidal curve. A thick Dotted line shows a theoretical pressure variation based on the approximated displacement of $h_1$. The pressure is calculated under the assumption of non-compressible and viscous fluid and expressed by the following equation derived from the Reynolds equation/5/.

$$P(t,x) = A_1 \eta a \omega \cos(\omega t) / L + A_2 P_0 + A_3 P_1$$

$$A_1 = \frac{6}{k^3} \left\{ \log \frac{h}{h_0} - \frac{h^2}{h_0} \right\} \left\{ 1 - \frac{h^2}{h_0^2} \right\} \log \frac{h}{h_0} - \frac{2h^2h_1}{h^2(h_0 + h_1)} + \frac{2h_0}{h} - \frac{2h_0}{h_0 + h_1} \right\}$$

$$A_2 = \frac{h_0^2}{(h_0 + h_1)kL} \left( \frac{h_0^2}{h^2} - 1 \right)$$

$$A_3 = \frac{h_0^2}{(h_0 + h_1)kL} \left( 1 - \frac{h_0^2}{h^2} \right)$$

Where $P$ is the pressure at an arbitrary position $x$ along longitudinal direction, $h$ is clearance at the position $(h=h_0+kx)$, $k$ is inclination of the plate, $L$ is length of the plate, $P_0$ and $P_1$ are pressures at the fixed end and the oscillating end respectively, $t$ is time and $\omega$ is angular velocity. The pressures shown in Fig.2 are always higher than absolute zero although they decrease below the surrounding pressure. In this case the cavitation was not observed. There is a good agreement between the calculated pressure and the experimental one. Pressure variation measured at the point B, though it is not shown in Fig.2, is about 40% smaller than that at the point A and it also agrees with the calculated one.
Figure 3 shows results for the case of smaller clearance ($h_o=50\mu m$). Note that the viscosity of oil is also smaller than that for the case of Fig.2. Although the calculated pressure shown by a dotted line reaches the value less than the absolute zero during the increasing phase of clearance, the measured pressure does not show the negative value. Build-up of positive pressure of measured one is delayed and maximum positive pressure is much smaller than the calculated one. In this case babbles, whose diameter is 1-2mm, caused by the cavitation were observed in the clearance. The pressure variation is influenced by the compressible bubbles in the oil film which remain even when the pressure becomes positive. Gas in the cavitation babbles, therefore, are not vapor of the oil but such noncondensing gas as air dissolved into the oil. This type of cavitation is classified into the gas cavitation/9/. Pressure variation at the point B is shown in the lower figure. The measured pressure is almost constant equal to the surrounding pressure since the babbles caused by the cavitation gather toward the fixed end where the point B locates. Besides, the cavitation disappeared with increasing the surrounding pressure and the pressure variation in the clearance became large like the calculated one.

At the lubricating clearance in compressors, flow usually exists in the clearance due to pressure difference or sliding effect (shear effect). The pressure characteristics for the case that the oil flow exists in the clearance were examined by supplying the pressurized oil at the oscillating end ($P_1=255kPa$). The results are shown in Fig.4. The experimental conditions are almost the same as that for the case of Fig.3 and average flow velocity in the clearance is 0.02m/s. The pressure measured at the point A goes down about -300kPa and the positive pressure increases in comparison with Fig.3. This is because the bubbles caused by the cavitation are swept away toward the fixed end by the flow. Though the measured absolute pressure of negative value may not be accurate enough because the semi-conductor pressure transducer is not suitable to measure tensile stress, it is concluded that the pressure in the clearance have the negative value when the clearance is filled by oil and the influence of babbles is eliminated. On the other hand, the pressure measured at the point B has a constant value at the absolute zero during a half period of the cycle. This is caused from the cavitation babbles gathered near the point B. But the positive value of the pressure becomes large in comparison with Fig.3.

**Case of HCFC22/Mineral Oil Mixture**

In general, some amount of refrigerant dissolves in refrigeration oil in compressors during a practical operation. Figure 5 shows the pressure characteristics of oil-refrigerant mixture. The experimental conditions are: $h_o=30\mu m$, $f=20Hz$ and amplitude of oscillation $a=44\mu m$. The oil is mineral oil of VG56 and the refrigerant is HCFC22. Saturation pressure is 618kPa and corresponding concentration of the refrigerant in the oil is 23 wt%. More amount of babble than that in the case of pure oil was observed since the refrigerant vapor separates from the oil with pressure reduction. It was expected that the refrigerant vapor separates from the oil when the pressure reduces to the saturation pressure. But the measured pressure in Fig.5 becomes lower than the saturation pressure.

Figure 6 shows variations of viscosity, saturation pressure and calculated maximum and minimum pressures at the point A against to solubility of refrigerant. Calculated conditions for Fig.6 are: $h_o=30\mu m$, $f=20Hz$, $a=44\mu m$ and temperature is 17°C. On the other hand, Fig.7 shows experimental results under three kinds of frequency of 20, 40 and 50Hz and temperature between 16-19°C. As shown in Fig.6, the viscosity and the amplitude of calculated pressure increase exponentially with reducing solubility. The measured pressure amplitude shown in Fig.7, however, is small as compared with calculated one (Note that scale of pressure is different from Fig.6) and is almost constant regardless of the solubility and the frequency. These figures show necessity to take into account of the influence of the bubbles caused by the separation of refrigerant on the pressure characteristics. Figure 8 shows results for the case that the oil flow exists in the clearance ($P_1-P_0=100kPa$, $\bar{v}=0.01m/s$). The maximum pressures become about two
times as large as that shown in Fig. 7 since the bubbles in the clearance are swept away by the flow. The pressure amplitude is almost constant against to the solubility and the frequency. It is found from Figs. 7 and 8 that the minimum pressure of the oil film under the cavitation condition reaches 100-200 kPa lower than the saturation pressure of the oil-refrigerant mixture.

Case of HFC134a/Synthetic Oil Mixture

We also used mixture of HFC134a and ester oil as the working fluid and measured the pressure characteristics of oil film. The viscosity of HFC134a/ester oil mixture was slightly larger than that of HCFC22/mineral oil mixture. From eye observation, amount of bubble is more than that in the case of Fig. 7. The results are summarized in Fig. 9 for the case of no flow. The pressure amplitude is about half as compared with Fig. 7. The minimum pressure in Fig. 9 is about 100 kPa lower than the saturation pressure, and it seems to be easier to occur the cavitation or separate the refrigerant vapor from the oil than HCFC/mineral oil mixture. On the other hand, the results with oil flow are shown in Fig. 10. As concerns the pressure amplitude, the maximum pressures are 2-3 times as large as that for no flow.

Moreover, we also examined mixture of HFC134a and PAG oil. The results have the almost same tendency as that for HFC/ester mixture. The cavitation seemed to occur slightly easier than HFC/ester mixture.

Temperature Variation

We measured temperature of oil film during the cavitation by using a oscillating steel plate on which a thermocouple was mounted. Since mass of refrigerant separated from oil is very small, no temperature change by the cavitation is measured although some amount of heat is needed when refrigerant vapor separates from the oil.

CONCLUSIONS

As the first step of research on the lubrication characteristics of the oil film in the refrigeration compressor, we measured the oil film pressure between oscillating plates. The results are summarized as follows.

(1) In the case of pure oil the gas cavitation occurs at the absolute zero pressure. Since the bubble caused by the cavitation hardly disappear in the clearance, the build-up of positive pressure is delayed and the maximum positive pressure decrease due to the bubble.

(2) The pressure in the clearance have the negative value when the clearance is filled by the pure oil and the influence of bubbles is eliminated by the oil flow.

(3) In the case of HCFC/mineral oil mixture the minimum pressure of the oil film under the cavitation condition reaches 100-200 kPa lower than the saturation pressure of the oil-refrigerant mixture regardless of the refrigerant concentration and the oscillating frequency. The maximum pressure with the oil flow is two or three times as large as that without the oil flow.

(4) In the case of the mixture of HFC134a and the synthetic oil such as ester or PAG it seem to be easier to occur the cavitation or to separate the refrigerant vapor from the oil than in the case of HCFC/mineral oil mixture.

REFERENCES


Fig. 1 Schematic view of experimental apparatus

Fig. 2 Plate's movement and oil film pressure

Fig. 3 Oil film pressure during cavitation

Fig. 4 Oil film pressure with flow stream in clearance
Fig. 5 Oil film pressure of oil-refrigerant mixture

Fig. 6 Theoretical pressure characteristics of oil-refrigerant mixture

Fig. 7 Experimental pressure characteristics of HCFC22/mineral oil mixture

Fig. 8 Pressure characteristics of HCFC22/mineral oil mixture with oil flow in clearance

Fig. 9 Pressure characteristics of HFC134a/ester mixture

Fig. 10 Pressure characteristics of HFC134a/ester mixture with flow