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DISCHARGE CHARACTERISTICS OF AN OIL FEEDER PUMP USING NOZZLE TYPE FLUIDIC DIODES FOR A HORIZONTAL COMPRESSOR DEPEND ON THE DRIVING SPEED

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ABSTRACT

An oil feeder pump, novel to a horizontal rotary compressor for household refrigerators, has been developed. This pump makes use of the reciprocating movement of the vane which is used as a part of a compressor. Additionally, this pump replaces conventional suction and discharge valves by using fluidic diodes. These fluidic diodes have a characteristic that the resistance in the reverse flow direction is larger than that in the forward direction and they have no moving portion.

In this paper, we investigate the operation of this pump, and the relation between the discharge characteristics of this pump and the diameter of the fluidic diode depending on the driving speed.

NOMENCLATURE

- A cross sectional area
- d, D diameter
- g gravitational acceleration
- H head
- l length of oil feeding pipe
- $m_i^2 = d_i^2/D_i^2$ area ratio of exit of fluidic diode to flow tube
- P pressure
- q flow rate
- Q average discharge of the pump
- v velocity
- R radius of the cylinder
- r radius of the piston
- β crank angle
- ζ resistance coefficient of fluidic diode
- λ friction factor
- ρ density
- ν kinematic viscosity
- ω angular velocity

Subscripts

- 1-3 points in the pump system
- a in the case
- D discharge
- p at the oil feeding pipe
- S suction

INTRODUCTION

In recent years, horizontal rotary compressors have become used in household refrigerators.(1) By using this type of compressor the inner space of a refrigerator is increased because the size of this compressor is smaller than that of a reciprocating one having the same capacity. This space saving characteristic is also enhanced by using a horizontal rotary compressor. In developing a horizontal type compressor, it has been necessary to develop a new oil feeder pump for supplying lubricating oil to the sliding surfaces.

This pump makes use of the reciprocating movement of the vane which is one of the parts in a compressor. Additionally, this pump does not have conventional suction and discharge valves because it has fluidic diodes. These fluidic diodes have a characteristic that the resistance in the reverse flow direction is larger than that in the forward direction and they have no moving portion.

High-speed driving of a variable speed compressor is available for the quick-freezing ability which is one of the recent requests for refrigerators. We studied the discharge characteristics of the oil feeder pump depending on the driving speed and also investigated how the diameter of the nozzle type fluidic diode effects on the discharge characteristics of this pump.

A HORIZONTAL ROTARY COMPRESSOR AND ITS OIL FEEDER PUMP

Fig.1 shows a sectional view of a horizontal rotary compressor. The crank-shaft and the motor are horizontally mounted in this case. The oil feeder pump for lubrication is constructed of a suction fluidic diode located in the main bearing, a discharge fluidic diode fixed in the sub bearing and an oil feeding pipe. The vane divides the cylinder room into a compression space and a suction space, and it is supported by a spring, while its tip end is kept in contact with the piston, and it reciprocatingly moves in a groove in the cylinder. A pumping chamber is located at the rear of the vane and it is enclosed by the cylinder groove and other parts. The volume of the pumping chamber varies and the pumping operation is performed by the reciprocating movement of the vane. The oil is sucked into the pumping chamber through the suction diode and then discharged into the oil feeding pipe through the discharge diode. This pump supplies the oil to the axial bore of the crank-shaft and then feeds it to bearings and other sliding surfaces. Furthermore, since the suction fluidic diode opens downward to the bottom of the case, it is less risky that the entrance of the diode will come out above the oil surface even when the oil level becomes low.

NOZZLE TYPE FLUIDIC DIODES

The nozzle type fluidic diode, which has a truncated cone shape as shown in Fig.2, was chosen among many types. Since this type of fluidic diode is simple and compact, it is appropriate for a small hermetic-type compressor.

One of the factors that have an effect on the discharge characteristics of this pump is the ratio of the pressure drop in the reverse flow direction to that of the forward flow direction at the same flow rate. Now, we call this ratio the fluidic diode ratio. The larger this ratio is the greater the discharge of the pump becomes, and this ratio depends on the shape of the fluidic diode. We studied experimentally the relation between the discharge characteristics of this pump and the shape of the fluidic diodes.(2)

Based on the results of the former study, the shape of the nozzle type fluidic diode is optimized to obtain the greatest discharge of the pump as follows. The angle of the taper portion is 60°. The edge of the exit of fluidic diode is as sharp as posible (the roundness of its edge is about 0.1 mm), and the exit of the suction fluidic diode projects to the center of the pumping chamber.

The resistance coefficient of this fluidic diode is investigated experimentally as shown in Fig.3. This figure shows the ralation betweem the resistance coefficient and the area ratio of fluidic diods. We measured its pressure drop at steady state by using water. The coefficient ζ is expressed in the flowing manner.

$$\Delta P=\zeta\frac{v_t^2}{2g} \qquad (1)$$

where ΔP is the pressure drop at the fluidic diode, and v_t is the average velosity at the exit of it.

The coefficient increases in both flow direction as the reduction of the diameter of the fluidic diode's exit. And, as the diameter of it is larger the fluidic diode ratio becomes greater.

PUMPING OPERATION

Fig.4 shows the simulated model of the oil feeder pump. In the discharge stroke when the volume of the pumping chamber is decreasing, the oil is distributed to the discharge line as well as the suction one. More of the oil is discharged into the discharge line than into the suction line because its resistance is less than that of the other. On the contrary, in the suction stroke, more of the oil is sucked from the suction line than from the discharge line since its resistance is smaller than that of the other.

The balance of the flow resistance of both the suction and discharge line decides the discharge of the pump. The resistance of each line depends on not only the pressure drop of the fluidic diodes, but also the friction and the inertia of the oil in the oil feeding pipe. We analyzed the resistance of each section of this pump system and calculated the change of the flow rate in each cycle and discharge rates.

In this calculation, we assumed as follows

(1) The oil that is working fluid is incompressible.

(2) The resistance coefficient of the fluidic diode is given by the experiment shown in Fig.3.

(3) The friction loss at the feeding pipe is based on friction factors for flow in tubes at steady state.

(4) The discharge and suction heads are constant and both head are expressed with respect to the level of the oil surface.

The equations of energy between point 1 and 3, and between point 2 and 3 are expressed as follows.

$$P_1 - \rho g H_3 + \rho \frac{v_1^2}{2} + \rho \zeta_D \frac{v_D^2}{2} = P_3 - \rho g H_3 \qquad (2)$$

$$P_2 - \rho g H_S + \rho \frac{v_2^2}{2} + \rho \zeta_S \frac{v_S^2}{2} = P_3 - \rho g H_3 \qquad (3)$$

The equation of motion of the oil in the feeding pipe is given as follows.

$$\rho \frac{l_P}{A_P} \frac{dq_1}{dt} \pm \rho \lambda \frac{l_P}{d_P} \frac{v_P^2}{2} = P_1 - (P_a + \rho g H_D) \qquad (4)$$

where the sign ± on the left side is positive for $q_1 \geqq 0$ and negative for $q_1 < 0$.

Since the suction line is short, the friction loss and the inertia of oil are omitted. The equation of motion at this line is written as follows.

$$P_2 = P_a + \rho g H_S \qquad (5)$$

The equation of continuity is given by

$$q_1 + q_2 = q_3 = -\frac{dV}{dt} \qquad (6)$$

where q_1, q_2 is equal to q_D, q_S respectively and when the oil flows out from the pumping chamber the flow rate is expressed as positive, whereas when it flows into the pumping chamber it is expressed on the contrary.

The volume of the pumping chamber V is obtained as follows.

$$V = V_0 + A_c\{R - [r^2 - (R-r)^2 \sin^2 \omega t]^{1/2} - (R-r)\cos \omega t\} \qquad (7)$$

where V_0 is the volume of the pumping chamber at the dead center of the pump.

Solving Eqs.(2)-(7), the flow rates in the dicharge line and the suction one are given, and we can calculate the average discharge of the pump by the following equation.

$$Q = \frac{\omega}{2\pi} \int_0^{2\pi/\omega} q_1 dt = -\frac{\omega}{2\pi} \int_0^{2\pi/\omega} q_2 dt \qquad (8)$$

RESULTS

Experimental Apparatus

Fig.6 shows the experimental apparatus. The compressor is operated by the variable speed control motor. Maintaining the temperature of the oil constant, the kinematic viscosity was kept constantly 3×10^{-6} m^2/s (3 cSt). We measured the discharge of the pump by measuring the flow rate that comes out from the end of the main bearing and the hole communicated with the axial bore of the shaft. Additionally, we measured the pressure of the pumping chamber by means of a pressure transducer.

Change of Flow Rates

Some examples of the change of flow rate and the discharge of the pump were calculated based on Eqs.(2)-(8). In this case, the diameter of the suction fluidic diode is 2.5 mm (m_S=0.10), that of the discharge fluidic diode is 4 mm (m_D=0.25) and the operating speed is 50 s^{-1}(3000 rpm).

The example of the rate of the volumetric change of the pumping chamber is shown in Fig.7. This rate is equale to the volume rate of working fluid that is pushed out from the pumping chamber to the discharge and the suction line, and it changes similarly to a sine wave. The change of flow rate in the discharge line and the suction one were calculated numerically and shown in Fig.8. These flow rates are distributed from the rate of the volumetric change of the pumping chamber according to the resistance balance between the both lines, and both flow rates are out of phase with the rate of that by the effect of the inertia of the oil in the feeding pipe. And, as shown in fig.9, the calculated change of the pressure in the pumping chamber is simular to the experiment. By this reason, it is considered that the results of the calculation is close to the real pumping operation.

Discharge Characteristics

Based on Eq.(8), the average discharge of the pump can be calculated by subtracting the reverse flow rate from the forward one shown in fig.8. Fig.10 shows the relation between the discharge characteristics of the pump and the discharge head of it depending on the diameter of the suction fluidic diode. In this figure, the discharge characteristics are shown by the volumetric efficiency dividing the average discharge by the displacement of the pump (Q/Q_0). It is found in this result that there is the optimum diameter at which the volumetric efficiency of the pump becomes the greatest, and this optimum diameter varies with the discharge head. Because the discharge head is added to the resistance of the discharge line constantly, the discharge of the pump decreases as the discharge head becomes larger. Since the resistance of the large diameter fluidic diode is small, the discharge is inclined to decrease by the effect of the discharge head. On the contrary, since the fluidic diode ratio becomes larger as the diameter of the fluidic diode enlarges as shown in Fig.3, this is a factor to increase the discharge of the pump. So, in the case of low discharge head, the larger diameter fluidic diode is adequate for the discharge of the pump.

In Fig.11, the calculation results of the discharge characteristics of the pump due to the change of the driving speed are shown along with the experimental results. These characteristics are expressed by using the same volumetric efficiency as Fig.10. At low speed, these efficiency are low, but they are inclined to increase as the speed increases, and approach to the some value. Because the resistance of the suction fluidic diode is small at low speed, the volumetric efficiency becomes lower by the effect of the discharge head. Because the resistance of the smaller diameter fluidic diode is larger than that of a larger diameter one, the discharge of the pump with it is greater than that with the larger diameter one at low speed. On the contrary, at high speed, since the resistance of the fluidic diode becomes large, the effect of the discharge head reduces. The pump with the larger diameter fluidic diode having large fluidic diode ratio obtains greater discharge than that with the smaller diameter one.

CONCLUSIONS

(1) The fluidic diode ratio increases as the diameter of the fluidic diode is enlarged.
(2) There is the optimum diameter of the fluidic diode that presents the greatest discharge of the pump at some discharge head. But it varies with the discharge head.
(3) At low operating speed, the discharge of the pump with the smaller diameter fluidic diode is greater than that with the larger diameter one. On the contrary, at high speed, the larger the diameter fluidic diode is, the greater the discharge of the pump presents.

REFFERENCES

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(2) Takebayashi,M. et al.,"Discharge Characteristics of an Oil Feeder Pump with Nozzle Type Fluidic Diodes", Trans. Jpn. Soc. Mech. Eng., 51-465,B(1985)

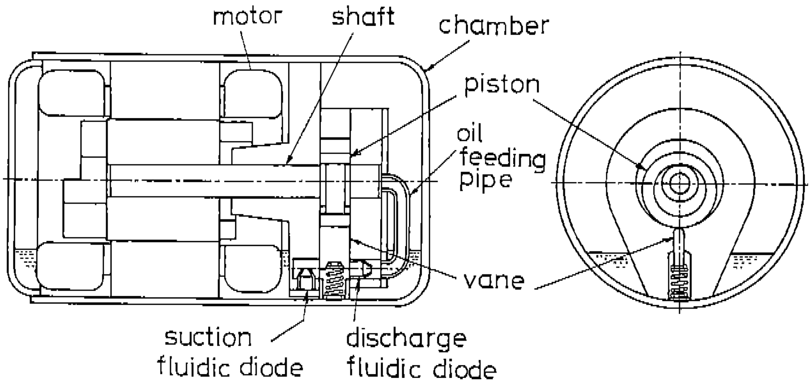

Fig.1 Horizontal Rotary Compressor and Oil Feeder Pump

Table.1 Dimensions of the Oil Feeder Pump

Vane Stroke Cross sectional area Displacement		 6 mm 40 mm^2 240 mm^3
Discharge head	H_D	30 mm
Suction head	H_S	16 mm
Pump center head	H_3	8 mm

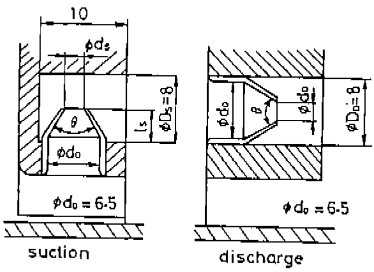

Fig.2 Nozzle Type Fluidic Diode

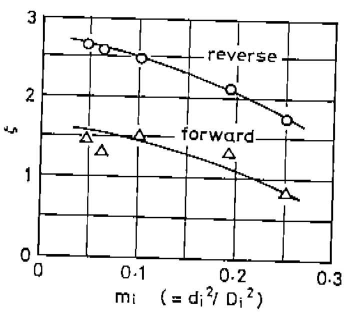

Fig.3 Resistance Coefficient of Nozzle Type Fluidic Diode

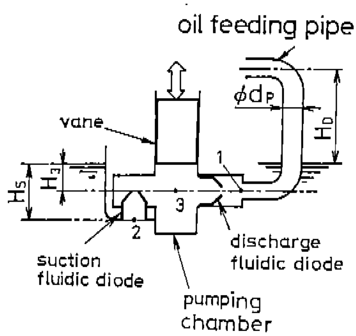

Fig.4 Simulated Model of the Oil Feeder Pump

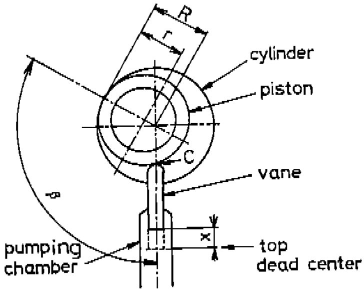

Fig.5 Cross Sectional View of the Cylinder

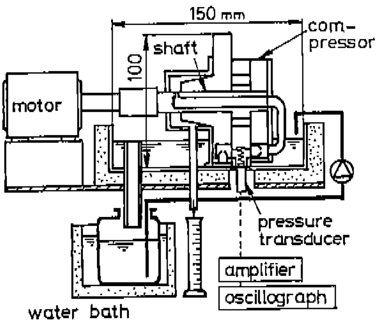

Fig.6 Experimental Aparatus

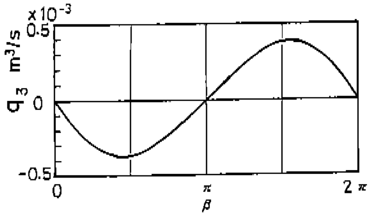

Fig.7 Change Rate of Pumping Chamber Volume

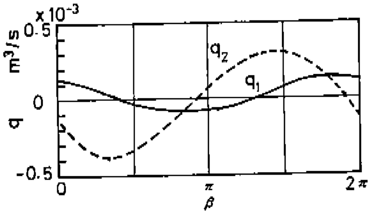

Fig.8 Change of Flow rate

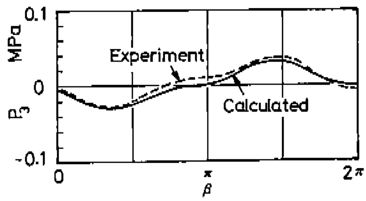

Fig.9 Change of Pressure in the Pumping Chamber

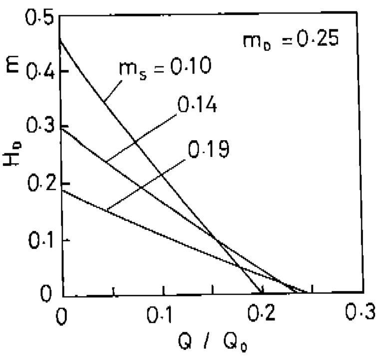

Fig.10 Relation Between Discharge of the Pump and Discharge Head

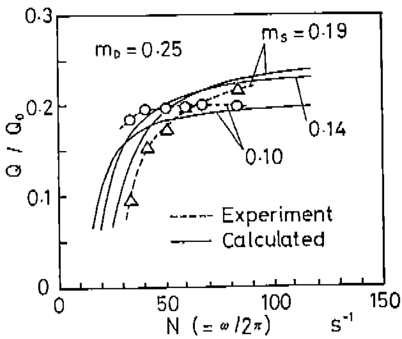

Fig.11 Discharge Characteristics of the Oil Feeder Pump