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# DEVELOPMENT OF LIQUID REFRIGERANT PUMP FOR ICE-STORAGE PACKAGED AIR-CONDITIONERS

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## ABSTRACT

This paper presents the development of the low cost liquid pump. The rotary compressor developed as the gas compressor for the residential air-conditioner was converted into the liquid refrigerant pump. Problems of the liquid refrigerant pump are the reliability assessment of sliding parts and the reduction of the noise generated by discharge pulsation in this development. Therefore some modifications, i.e., from the high pressure housing to the low pressure one, and from the compression process with a discharge valve to the direct discharge compression process, were made.

By solving the problems mentioned above, the development of the liquid refrigerant pump using in the ice-storage packaged air-conditioners with the low costs and the high reliability has been achieved.

## INTRODUCTION

Recently, the new air-conditioning system which is so-called ice-storage packaged air-conditioners are accepted in a market. In this ice-storage system, the cluster ice is frozen with the electric power during the night and the liquid refrigerant which is cooled by the ice is utilized for air conditioning at daytime in order to decrease the demand of electric power in the daytime of summer<sup>(1)</sup>. But, in this ice-storage system, the cost of additional equipment such as the ice storage tank and the pump for circulation of liquid refrigerant was the significant problem.

## STRUCTURE AND SPECIFICATION OF LIQUID REFRIGERANT PUMP

Figure 1 shows the structure of the liquid refrigerant pump for ice-storage packaged air-conditioners. It has the following two characteristics.

### (1) Direct suction and direct discharge

Compression process with direct suction and direct discharge is applied so that the pump housing is not filled with the liquid refrigerant. If the liquid refrigerant level increases inside the housing, the power increases because of the motor stir and the insulation of a terminal decreases.

### (2) Resonator

The pulsation of the rotary compressor with single cylinder is much larger than the other liquid pumps. Therefore the resonator is applied in order to reduce the discharge pulsation.

The cooling capacity of ice-storage packaged air-conditioners is 28kW. Therefore the required amount of the refrigerant circulation is approximately 500kg/h in the regenerative cooling operation. From this requirement, the theoretical displacement and rotating speed were designed to be 9.5cm<sup>3</sup>/rev and 15Hz<sup>(9)</sup>. The maximum difference 0.29MPa between discharge pressure and suction pressure is also required by taking the resistance of the tube and the difference of head between the indoor unit and the outdoor unit into consideration. Consequently, the specification of liquid refrigerant pump was determined as table 1.

## RELIABILITY OF THE LIQUID REFRIGERANT PUMP

### Spring pushing blade

The difference between the compressor for air-conditioner and the liquid refrigerant pump is the pressure in the housing. The inside of the compressor housing for air-conditioner becomes discharge pressure. But the inside of the liquid refrigerant pump housing becomes suction pressure. Therefore the force of the spring pushing the blade for the liquid refrigerant pump is larger than that for air-conditioner.

Figure 2 shows the forces acting on the blade. The spring constant and the initial displacement was determined from eq.(1) and eq.(2) in order to contact between the blade and the rotor.

$$k \cdot \delta_0 > (HP-LP+Pul) \cdot h \cdot (b/2) \quad - (1)$$

$$k \cdot (\delta_0 + \delta) > (HP-LP+Pul) \cdot h \cdot b \quad - (2)$$

where HP : discharge pressure

LP : suction pressure

Pul : (pulsation(P-P))/2

h : blade height

b : blade width

k : spring constant

$\delta$  : displacement

$\delta_0$  : initial displacement

### Reduction of discharge pulsation

The pulsation of the rotary compressor with single cylinder is much larger than that of the other liquid pumps. One of the problems in the development of the liquid refrigerant pump is the reduction the noise generated by discharge pulsation. Therefore the resonator is applied in order to reduce the discharge pulsation.

Figure 3 shows the resonator of the liquid refrigerant pump. Liquid and gas refrigerants exist in the housing of the resonator. The electric heater is set at the upper part of the resonator in order to maintain the optimum liquid level for the resonance.

Figure 4 shows the effect of the resonator. Even if the difference of pressure is large, the output pulsation can be reduced sufficiently.

### **Seizing of bearing**

The bearings of the liquid refrigerant pump were cooled and lubricated with the liquid refrigerant. The seizing of the bearings was studied based on the water lubrication of which the abundant data have been obtained, because water has the similar viscosity to liquid refrigerant. Figure 5 shows the reliability of the bearing for seizing. It is predicted that the seizing of the upper and lower bearings are not generated because the PV value are lower than the limit.

### **Wear of bearing**

The wear of the bearing was evaluated from the fundamental test in the liquid refrigerant. Figure 6 shows the wear test equipment. The liquid refrigerant(R141b) of the high boiling point was used in order to be soaked the liquid refrigerant in the atmosphere. The liquid refrigerant was cooled by the freezer and circulated by the pump in the test chamber in order to simulate the operating condition of the liquid refrigerant pump. Table 2 shows the test conditions and the size of test pieces. The test pieces of the same material and with the same dimension of the liquid refrigerant pump were used in the fundamental test.

Figure 7 shows the relationship between Sommerfeld number and specific wear amount. Specific wear amount decreases when Sommerfeld number increases. When Sommerfeld number increases, the hydrodynamic load capacity of the bearing increases. By taking the load capacity of the liquid refrigerant in the load term into consideration, the wear volume was predicted with eq.(3). The load capacity of the liquid refrigerant was calculated from the initial surface roughness and the edge load. The ratio of the load by the liquid refrigerant and total load was defined as ratio of hydrodynamic load  $\phi$ .

$$W = K \cdot F \cdot (1 - \phi) \cdot L \quad (3)$$

where W :wear volume

K :specific wear amount

F :load

$\phi$  :ratio of hydrodynamic load(from zero to one)

L :sliding distance

Figure 8 shows the relationship between specific wear amount and normalized decline of the shaft. Specific wear amount was calculated with eq.(3). The variance of specific wear amount was reduced to 40% by considering ratio of hydrodynamic load. The average specific wear amount calculated with eq.(3) was  $1.1 \times 10^{-11} \text{mm}^2/\text{N}$ .

Figure 9 shows the relationship between the ratio of the measured wear volume and the permission wear volume, and the ratio of the predicted wear volume and the permission wear volume calculated with eq.(3). The wear volume can be predicted within the accuracy from 40% to 340%.

### **Assessment of the wear prediction method**

Figure 10 shows the prediction of wear volume for the liquid refrigerant pump. The wear volume can be predicted within the accuracy from 80% to 190%. As the result, it is conformed that the wear volume of the liquid refrigerant pump bearing was predicted within the same accuracy obtained in the fundamental test.

## CONCLUSIONS

The problems of the structure and the reliability in the development of the liquid refrigerant pump were studied. As the result, the followings were confirmed and the development of the liquid refrigerant pump with low costs and the high reliability has been achieved.

- (1) The direct suction and discharge structure must be applied.
- (2) By the applying the resonator with the heater, the discharge pulsation was reduced sufficiently.
- (3) The wear volume can be predicted within the accuracy from 40% to 340% by considering ratio of hydrodynamic load.

## REFERENCES

- (1) T.Otsuka, M.Fujitani et al., Development of Ice-Storage Packaged Air-Conditioners, Mitsubishi Heavy Industries, Ltd. Technical Review, Vol.33, No.2(1996-3), P106~109 (in Japanese)
- (2) M.Takeuchi, M.Fujitani et al., Liquid Refrigerant Pump for Ice-Storage Packaged Air-Conditioners, Proceeding of The 30th Japanese Joint Conference on Air-Conditioning And Refrigeration, (1996-3), P189~192 (in Japanese)

Table 1 Specification of liquid refrigerant pump

Rotating Speed (Hz)	15
Maximum Difference of Pressure (MPa)	0.29
Theoretical Displacement (cm <sup>3</sup> /rev)	9.5

Table 2 Test conditions and test pieces

Test Conditions		
Atmosphere	Liquid Refrigerant (R141b)	
Load / Maximum Load For Liquid Refrigerant Pump	1 ~ 5.3	
Rotating Speed (Hz)	10 ~ 25	
Test Pieces		
Bearing	Material	Sintered Steel Metal
	L / D	0.9
	C / D	0.0005, 0.0011, 0.0018
Shaft	Material	FCD500

L : length, D : Diameter, C : Clearance

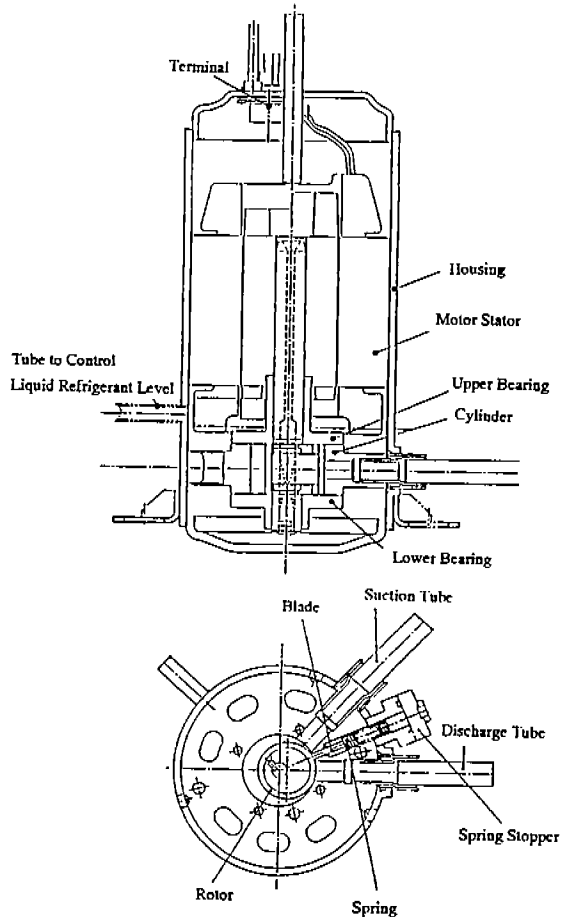


Figure 1 Structure of liquid refrigerant pump

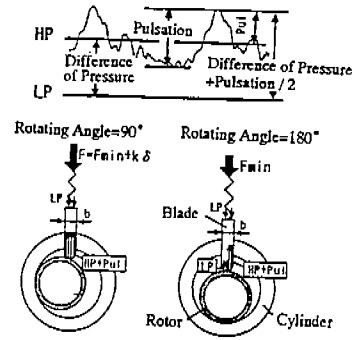


Figure 2 Forces acting on blade

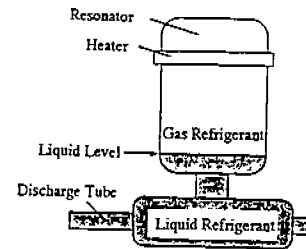


Figure 3 Resonator of liquid refrigerant pump

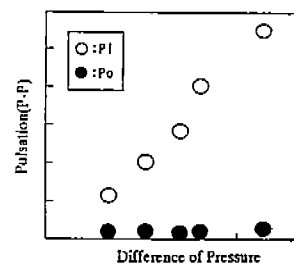
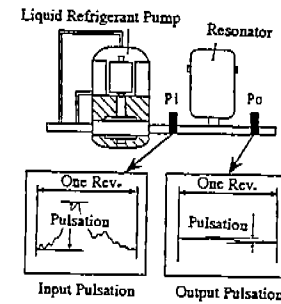


Figure 4 Effect of resonator

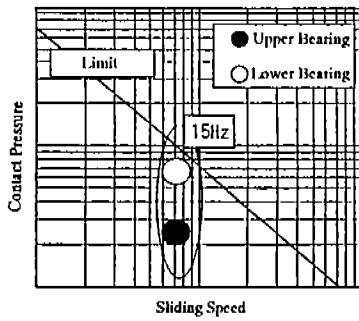


Figure 5 Reliability of bearing for seizing

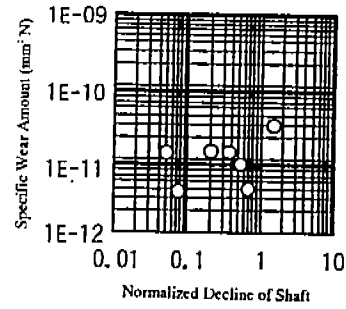


Figure 8 Relationship between specific wear amount and normalized decline of shaft

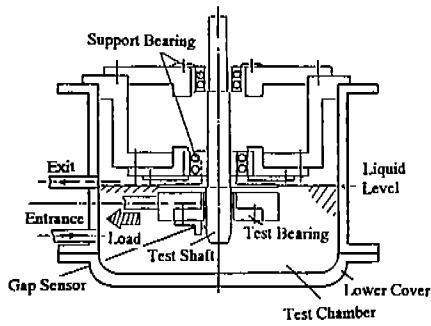


Figure 6 Wear test equipment used in fundamental test

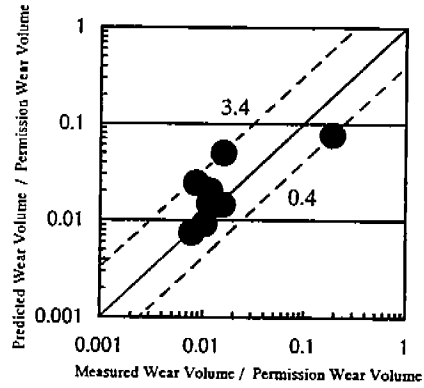


Figure 9 Relationship between measured wear volume and predicted one for fundamental test

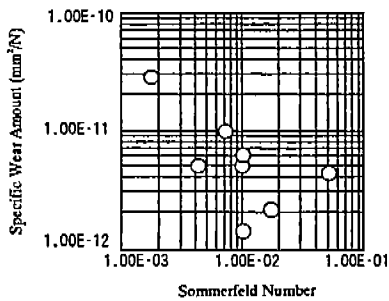


Figure 7 Relationship between Sommerfeld number and specific wear amount

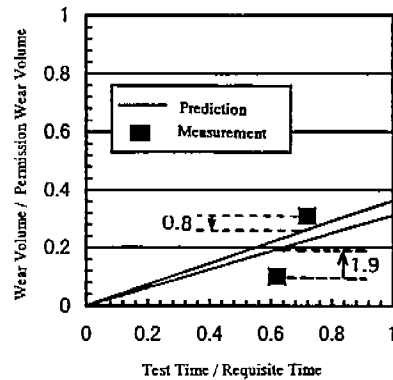


Figure 10 Prediction of wear volume for liquid refrigerant pump