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Study on Oil Free Dual Resonant on Compressor

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STUDY ON OIL FREE DUAL RESONANT PISTON COMPRESSOR

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ABSTRACT

The resonant piston type oil free compressor which was driven by a linear motor was studied. To reduce the vibration, two pistons move oppositely, so the reciprocating inertia force is able to cancel each other. The PTFE(poly tetra fluoro ethylene) piston rings were used for the operation under oil free condition. This paper describes its design and test results on performance characteristics.

INTRODUCTION

The compressor for air conditioning and refrigeration systems has used the oil to seal the gas and to lubricate the sliding surfaces. The lubrication oil circulates in the refrigerant cycle with the discharged gas. The circulating oil prevents the heat transfer in the heat exchanger, so its cooling capacity is decreased. Also, the setup direction of the compressor is restricted, so that the oil behavior is controlled by gravity. This paper is concerned with the realization of oil free compressor.

The typical types of small refrigerant compressor are reciprocating type, rolling piston type, and multi vane type. It will be difficult to realize the no oil mechanism of the sliding of the vane for the rolling piston type and multi vane type. However, the piston ring as the compliant seal mechanism is suitable for the oil free condition, so that the reciprocating type is chosen for this study.

There are two typical driving mechanisms, (1) the crank mechanism using the ceramic dry ball bearing, and (2) the linear mechanism using the linear motor.

The side force on the linear moving piston does not operate by adopting the second mechanism theoretically, and the piston is supported by the simple guide ring only. The dual resonant piston type is designed for this study. In the arrangement, two pistons move oppositely each other. So the vibration of the piston movement is able to cancel each other.

DESIGN

Considerations

The following points are taken into consideration to design the compressor.

(1) the mechanism which drives the piston directly with the linear motor is selected, so that the piston side force is not theoretically caused. Piston rings and guide rings made of PTFE is mounted to the piston.

(2) the drive system is simulated, in which the gas leakage on the compression process and the frictional force of piston ring are considered.

(3) the moving coil type linear motor with the high efficiency magnetic cycle is designed.

Driving Mechanism

Figure 1 shows the construction of the compressor. The moving coil method is selected as the driving mechanism. Because it has been used by the linear driving machine, and the resonant spring can designed smaller than the case of the moving magnet design. In order to reduce the moving weight of pistons and moving coil, they were made of aluminum. The coil bobbin was also made by aluminum, so that eddy current may occur by the reciprocating motion. To prevent the eddy current, the 32 slits were placed in the bobbin. Figure 2 shows the cutting pattern.

To improve the motor efficiency, the rare metal permanent magnet was used. The flux of magnetic induction reaches at 0.45T. Two pistons move oppositely each other, so that two magnet circuits can be integrated, and the yoke weight can be saved. The coil spring was constructed between the cylinder and the coil.

As the coil reciprocates at 60Hz, the lead electric wire which connect between the coil and the terminal may be broken. So the lead electric wire in which a bunch of small diameter wire is rolled by the copper foil is applied.

Compression Mechanism

The compression volume is consisted by two piston and the cylinder as shown in figure 1. The discharge valve design is the lead valve arrangement which is assembled to the cylinder wall. Suction valves were assembled to the each piston. Its over compression loss is low, and the time lag of the closing is short. Two PTFE piston ring with backup ring is installed to seal compression gas.

MEASUREMENT

Figure 3 shows the test equipment. The piston displacement is measured by the laser beam displacement sensor not to disturb the motion of the piston. The pressure in the compression chamber is taken by the piezo electric pressure transducer. The electric signal of the displacement and the pressure are stored by the digital memory. After sampling data, they are sent to the personal computer. The pressure-volume diagram, efficiency, loss analysis are calculated. One of results are shown in figure 4 and figure 5. In figure 4, from the top to the Bottom, the voltage, the pressure, the right piston displacement and the left piston displacement are shown. The zero of the piston displacement is the center of the cylinder.

TEST RESULT

Motor

The motor loss is measured by driving it without the suction valve and the piston ring. So the motor loss includes the Joule loss and the eddy current loss. The relation of the motor loss and the piston stroke is shown in figure 6. The relation of the motor loss and frequency is shown in figure 7. From figure 6, the 32 slits in the bobbin is applied to reduce the eddy current loss. The 60 slits bobbin gave almost the same loss as the 32 slits bobbin. The motor loss increases rapidly when the frequency shifts from the turned position.

Compression Mechanism

From data which was shown in figure 4, the loss analysis was done. On the operation condition in table 2, the indicated work ratio, the over-shoot loss ratio, the mechanical loss ratio and the motor loss ratio are calculated as shown in figure 8. The motor loss are calculated from the result of the linear motor test in figure 6. The over-shoot loss and the indicated work are calculated from the pressure and volume diagram.

The indicated work ratio becomes large at the case of the short piston stroke, because the clearance of the piston becomes large, and the unavailable compression work increases. The over-shoot loss ratio becomes large at the case of the long piston stroke, because the fluid resistance of the suction valve and the discharge valve increases. The mechanical loss consists of (1) the friction between the piston and the cylinder by the side force of the spring, (2) the friction of the piston ring and the cylinder liner by the pressure between the compression chamber and the suction side. And the mechanical loss ratio increase when the piston stroke becomes long.

It is needed that the clearance of the top of the piston has to be kept as small as possible and then the dead volume is reduced. Also it will be needed that the resonant spring is to be made precisely not to cause the side force.

Vibration

In table 3, data of the vibration acceleration are shown. The linear compressor was set on the rubber plate. And the vibration acceleration of the axial direction, the horizontal direction and the vertical direction are measured. The horizontal and vertical data are measured at three points, the left, center and right of the compressor.

The biggest vibration acceleration is 0.59G at 60Hz. The vibration of the center of the horizontal and vertical direction were small. It is the reason that the linear compressor was vibrated around the center. As figure 4 shows, the left piston movement and the right piston movement are almost same, then the inertia force is canceled. So it is thought that the vibration is caused by the spring motion.

CONCLUSION

The resonant piston type oil free compressor which was driven by the linear motor was studied. The linear motor efficiency was dependent on the driving frequency and the countermeasure for eddy current loss. The efficiency of the compression mechanism is discussed by the loss analysis. It was proved the dead volume should be kept as small as possible.

The prototype compressor will be suitable to be used not only for the residential heat pump but for the cooling and the heat pump system for the space application.

REFERENCES

[1] R.V.Cadman, "A Technique for Design of Electrodynamic Oscillating Compressors", Ph.D.Thesis, Purdue University, 1967-8.

[2] T.Ogushi, et al., "Development of a Heat Pump Thermal Control System for Spacecraft", Proc. of 16th Int. Symp. on Space Technology and Science.

Table 1 Specication of Linear Compressor

Cylinder Dia.	30mm
Moving Mass	1kg
Spring Constant	142kN/m
Initial Piston Position	7mm
Resistance of Coil	1.54Ω
Inductance of Coil	10.1mH
Gap Magnetic Induction	0.45T

Table 2 Specication of Linear Compressor

Operate Gas	Freon R12
Suction Pressure	0.25MPa
Discharge Pressure	0.70MPa
Suction Gas Flow	50ℓ/min
Operate Voltage (0-P)	50~80V
Frequency	60Hz

Table 3 Vibration Acceleration of Compressor

Piston Stroke	Axial Direction	Radial Direction					
		Horizontal			Vertical		
mm	G	Left G	Center G	Right G	Left G	Center G	Right G
8	0.248	0.257	0.1506	0.260	0.460	0.1703	0.314
10	0.318	0.255	0.1485	0.254	0.483	0.164	0.349
12	0.351	0.327	0.1484	0.286	0.538	0.1966	0.384
14	0.463	0.358	0.1463	0.296	0.590	0.190	0.421

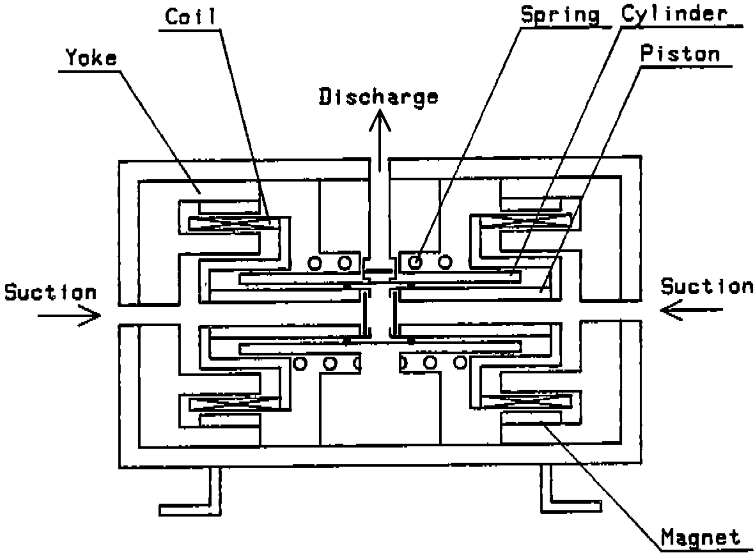

Figure 1 Linear Compressor (Front view)

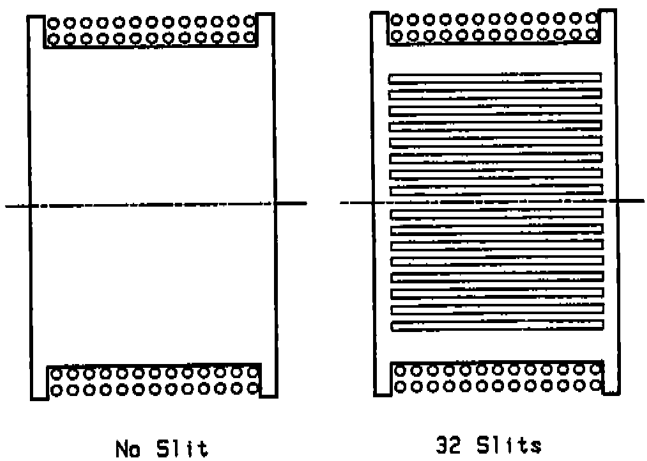

Figure 2 Coil Bobbin (Front view)

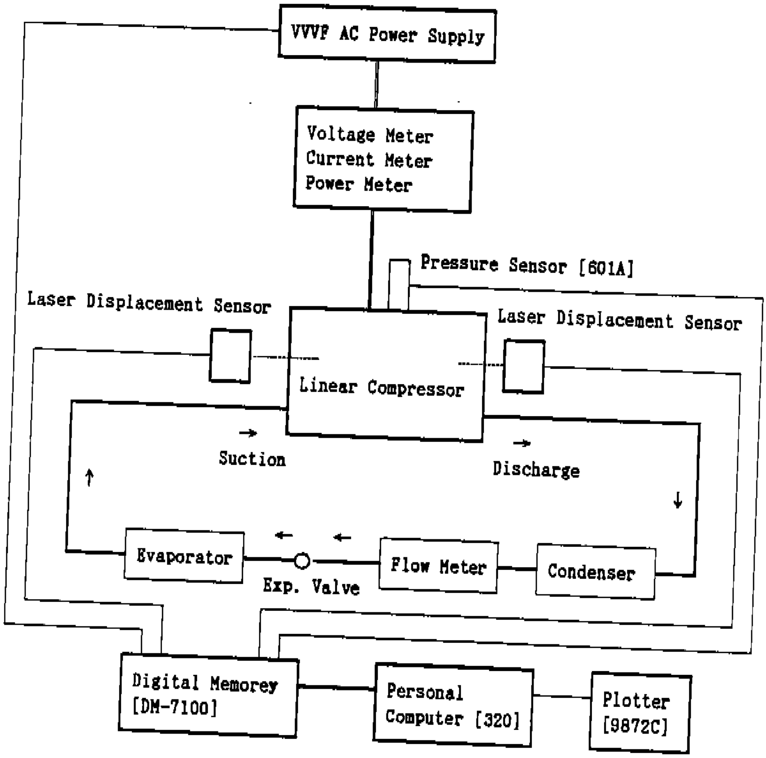

Fig.3 Measurement System

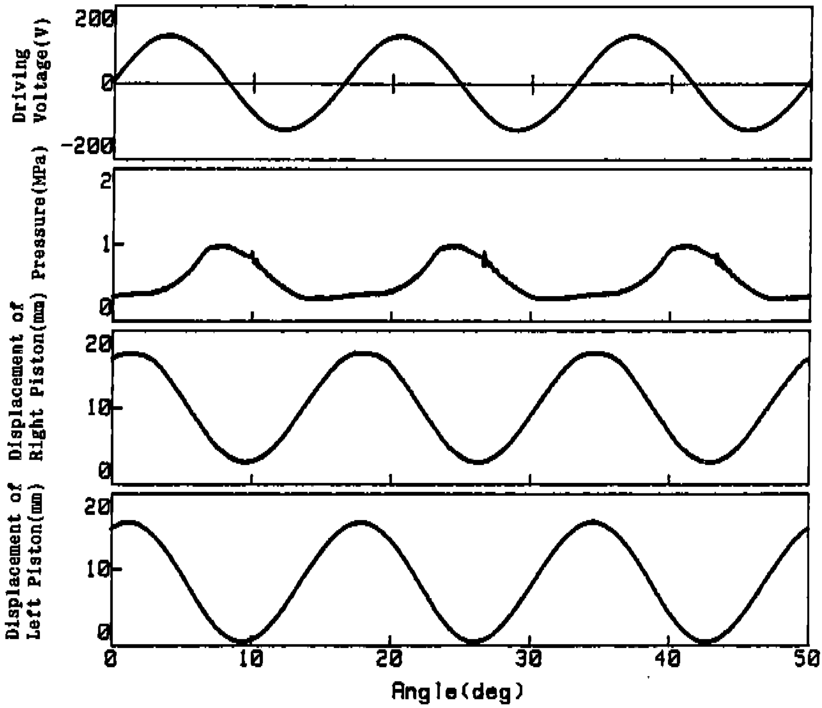

Figure 4 Measurements of E, P and X

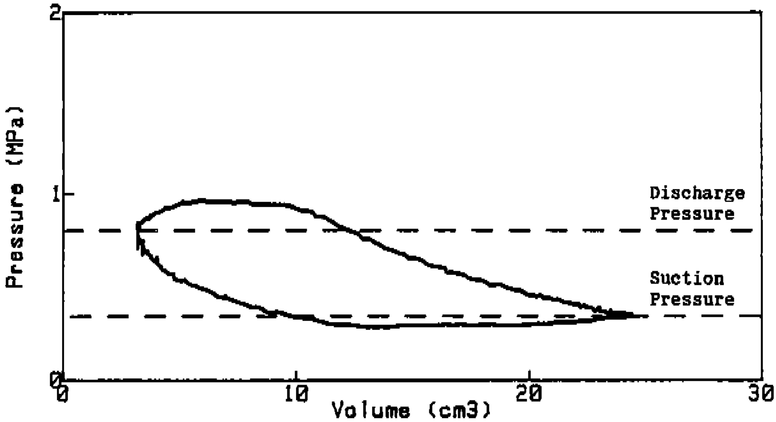

Figure 5 Measured P-V curve

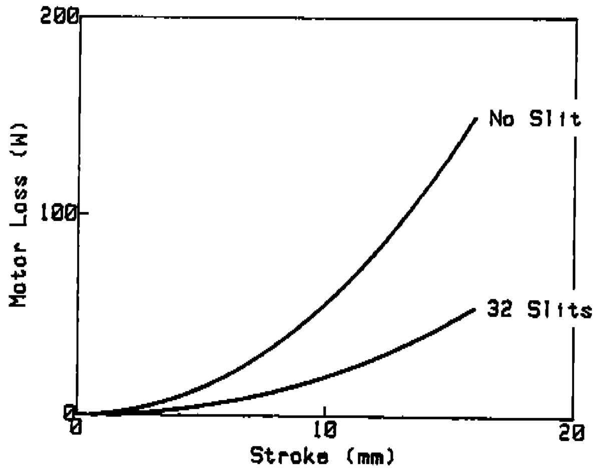

Figure 6 Motor Loss and Stroke Relation

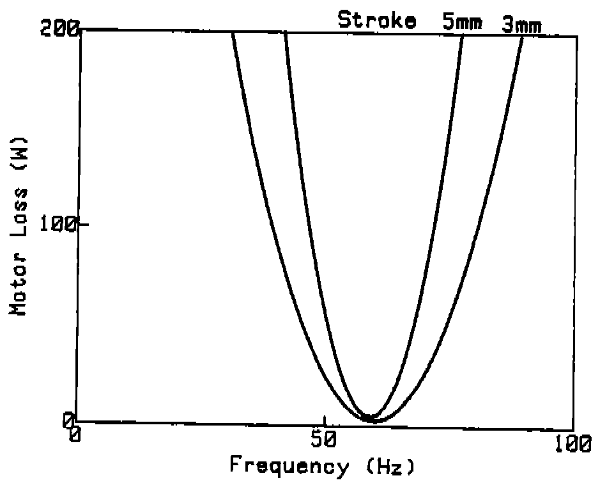

Figure 7 Motor Loss and Frequency Relation

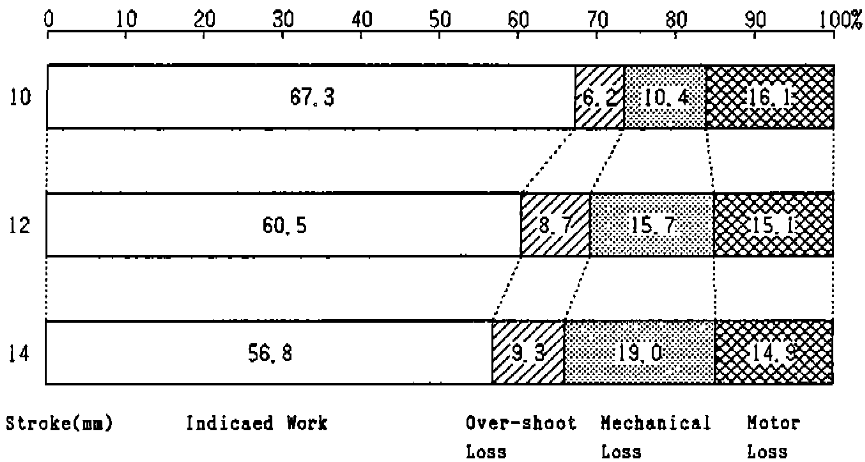

Figure 8 Loss Analysis