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Study of characteristics of linear motor compressor for different clearances between pistons and cylinder

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ABSTRACT

This paper work is concerned with study of different properties of moving coil compressor. Study of different properties has been done by changing the clearances between piston and cylinder. Available system of moving coil compressor is used for further study of properties. Theoretical and experimental calculations are the major work. For experimental calculations Dynamic pressure sensor and DeweFRF set up is used. With the help of this calculation we have to conclude the better combination of clearance between piston and cylinder.

Keywords: Cryocooler, Linear motor compressor, Dynamic pressure sensor and DeweFRF set up.

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INTRODUCTION

The piston diameter has the biggest impact on the natural frequency however the moving mass is the most effective way of adjusting it without affecting the thermodynamic performance of the cooler.For the calculation of different input and output parameters of linear motor compressor some measurement devises has been used. An AC power supply is used to supply and control the operating frequency of linear compressor, input currents and input voltage. A linear variable differential transformer is set on the top of piston to measure stroke of pistons. A piezoelectric pressure sensor is installed on top of the expander to measure pressure waves and input currents, electric powers, and voltages from power supply are measured simultaneously. Software needs to calculate the input power, amplitude and phase of each wave from measured data.

Some forces are loaded on the piston of linear compressor such as

(1) Inertia forces due to reciprocating motion

(2) Damping forces due to friction between piston and cylinder

(3) Forces from coil spring

(4) Forces induced by pressure difference between compression and expansion of working fluids inside of compression and buffer space of cylinder

(5) Electric forces resulted from applied current.

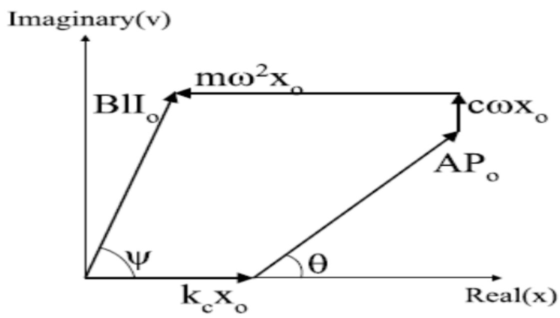

Fig.1 Force diagram of piston

PAPER CONTAIN

Gas stiffness value is always depends on the value of pressure. As the value of pressure changes it shows effect

on the values of gas stiffness. Here we find out the change in the value of gas stiffness for different clearances (10, 15, and 20) and we compare the analytical and practical results with the help of graph. With the help of graphs we will estimate dynamic performance of linear motor compressor.
Under this estimation we have found out the different characteristics for linear motor compressor for ranges of clearances between piston and cylinder. Under dynamic performance we are going to consider the efficiency of the linear motor compressor. In the first objective we have found out the natural frequency and efficiency of linear motor compressor. So we have to found out practical values of it and compare the results.
Gawali B. S. has developed single coil linear motor driven dual opposed piston compressor with 300 W power output for Pulse Tube cryocooler of 15 W at 70 K. He has used spiral flexure bearings in this compressor. Selection of bearings was made using the design charts developed by Gaunekar.

Gyu-sik Kim reported the researching status and developing trend of linear compressor. The structure, the operation principle and the characteristics of the moving-coil and moving-magnet type linear compressor are analysed in details. The features of linear switched reluctance actuator are investigated, and it is recommended to be a competitive candidate for linear compressor.

$$k_{gas\ spring} = \frac{(P - P_{avg})A}{s}$$

Zhu Zhang has reported the study of Linear Motor for Linear Compressor .It studies the performance of the linear compressor and parameters for high efficiency.

$$\eta = \frac{W_{motor} - W_{clearance} - W_{damp}}{W_{motor}}$$

The mechanical power generated by the linear motor at resonance condition is given by,

$$W_{motor} = \frac{1}{2} fs\pi\alpha I \sin\theta_m$$

Power dissipated by the damping force is given by,

$$W_{damp} = \frac{1}{2}\pi^2 f^2 s^2 C$$

The clearance loss in compressor is described in the following expression,

$$W_{clearance} = \frac{\pi D t_c{}^3 P_{avg}}{96 * \mu * L_{seal}}$$

K Park has studied result from the geometry of the reciprocating mechanism and is revealed by detailed kinematic and dynamic analyses. It also shows that torsional vibration also affected by piston-to-cylinder friction.

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k_{m/c\,spring} + k_{gas\,spring}}{m}}$$

PLANT MODEL

It consists of dual opposed piston linear motor compressor to produce the pressure pulsations. The moving coil type linear motor gives to and fro motion to piston. The assembly of piston and piston rod is an integral part resting on two stacks of flexure bearings. The flexures are having low stiffness in axial direction so allow the piston to move freely forward and backward in the cylinder. The flexures are radially stiff so that the piston remains concentric within cylinder. The clearance of 10 to 20 microns between the piston and cylinder provides the gas clearance seal.

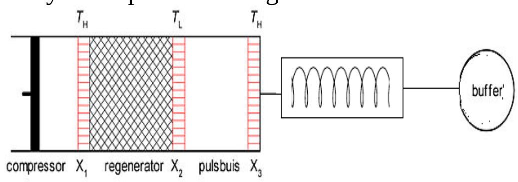

Fig. 2 Pulse-Tube Refrigerator

The parameters to be measured are stroke of the piston, static pressure and pressure variation during the operation, input power measurement to the compressor and frequency. The system is dwell opposed. This system having two motors. Power supply is given to both motors with help of power meter. One LVDT is installed to measure the displacement of the compressor piston. LVDT arrangement is provided at the end of end cover. One pressure sensor with the range (0 – 25 bar) is installed at the outlet of the compressor to measure the dynamic pressure and thereby evaluating the pressure ratio developed by the compressor. All the signals are given to signal conditioners where the small signals developed by the sensors are amplified. The LVDT is calibrated manually such that the oscilloscope output equals the piston displacement of 5 mm. the output signal from LVDT and pressure transducer is given to computer which displays the waveforms.

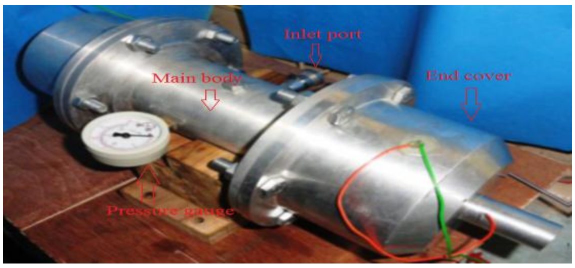

Fig. 3 Linear motor compressor assembly

CALCULATIONS

Pressure Ratio

Pressure ratio is important factor for any type of compressor. For linear motor compressor pressure ratio may vary from 1.2 to 1.4.Here we consider the effect of pressure ratio on different properties of linear motor compressor. Mainly we consider the natural frequency and efficiency.

TABLE 1 PRESSURE RATIO

Time	Pressure ratio (10μ)	Pressure ratio (15μ)	Pressure ratio (20μ)
0	1.140	1.137	1.117
0.1	1.143	1.139	1.130
0.2	1.110	1.105	1.101
0.3	1.141	1.138	1.132
0.4	1.109	1.108	1.103
0.5	1.142	1.139	1.133
0.6	1.109	1.105	1.102
0.7	1.143	1.137	1.131
0.8	1.108	1.106	1.101

For analytical values of natural frequency and efficiency of linear motor compressor we have used different formulae. In the formulae, pressure ratio was the important value. Pressure ratio is the important factor for calculation of different properties of linear motor compressor. During the theoretical analysis of linear motor compressor we have found out analytical values of natural frequency and efficiency.

NATURAL FREQUENCY

Impact Hammer Testing is an experimental method of finding the natural frequencies of a system. The FRF module is used for analysis of mechanical structures or electrical systems to determine the transfer characteristic (amplitude and phase) over a certain frequency range. The instruments used for measurement of natural frequencies are Fast Fourier Transform (FFT) analyzer, accelerometer, impact hammer and related accessories. The accelerometer is mounted on the system.

TABLE 2 NATURAL FREQUENCIES

Natural frequency		
(10μ)	(15μ)	(20μ)
44.382	41.785	42.143
46.826	41.433	43.121
45.122	41.392	42.565
46.715	42.321	42.849
45.89	43.11	44.45

RESULT AND DISCUSSION

Gas stiffness

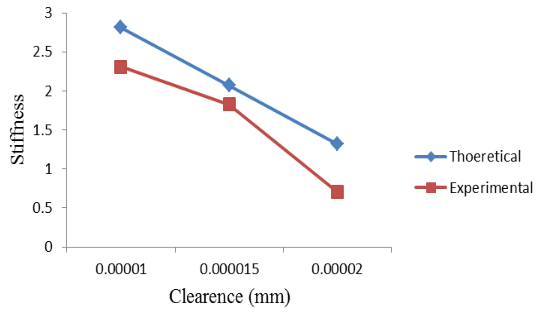

Fig. 4 comparisons for gas stiffness

Fig .shows variation in experimental and theoretical values. In fig 8.2 we have taken gas stiffness on X axis and clearance is on Y axis. The clearance value is changes from 10 microns to 20 microns.

EFFICIENCY

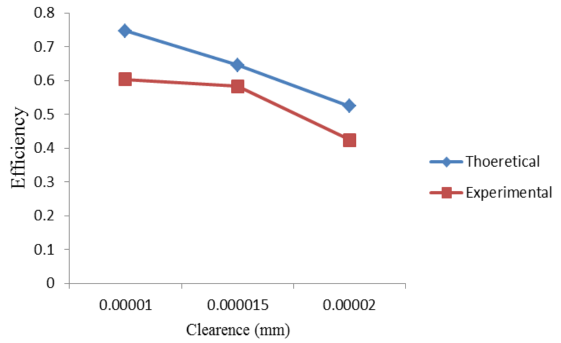

Fig. 5 comparisons for efficiency

It shows variation in experimental and theoretical values. In fig 8.3 we have taken gas stiffness on X axis and clearance is on Y axis. The clearance value is changes from 10 microns to 20 microns.

DISPLACEMENT

For measuring the displacement accurately, LVDT is used as the displacement sensor.

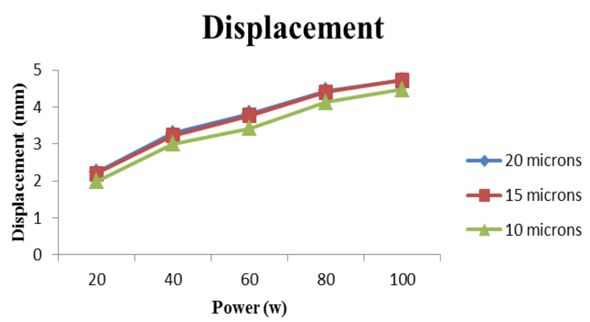

Fig. 6 Displacement for different clearances

The LVDT inductive transducer constructed using a static transformer (primary winding) and two secondary windings.

RATE OF COOLING

Fig shows the graph for the cooling rate of the system. In this the time is on Y axis and temperature is on X axis. Variation is shows for three differences clearances between piston and cylinder.

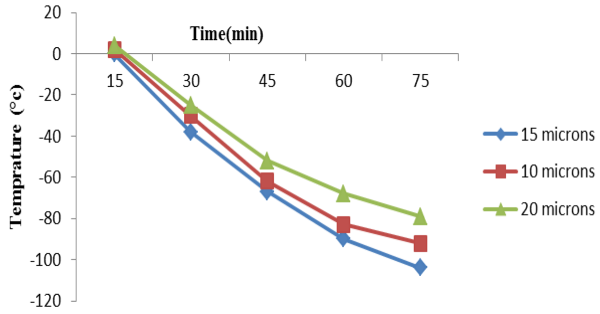

Fig. 7 cooling rate for different clearances

CONCLUSION

We consider the behaviour of linear motor compressor for ranges of clearances between piston and cylinder. For the clearance of 20 microns, the results which we have discussed are not satisfactory. Cooling capacity and efficiency of linear motor compressor decreases as the clearance increases. So it is not desirable to use higher clearance. For 10 micron clearance and for 15 micron clearance, the output results which we have got are almost same Cooling capacity and efficiency for both clearance values doesn't show much difference. But as the clearance decreases the friction forces increases. This increase in friction forces affects the displacement of a piston. Farther decrease of clearance will increase wear of coating material due to higher friction forces so for long life and for better performance, 15 micron clearance is best option.

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