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Design and Development of A Pulse Tube Cryocooler

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Abstract: *NASA planned few Mars missions in between 2012 to 2018. This mission requires very compact maintenance free, long life cryocooler for production and storage of cryogenic fluid on Mars. The main moving component of cryocooler is linear motor and we have to design it very precisely to give good overall efficiency and long maintenance free life. So an attempt is made to carry out parametric analysis of motor available in lab. It was shown that the linear motor efficiency for available design increases by 4% approx. Based on this outcome, a new linear motor compressor is manufactured for different capacity pulse tube cryocooler with enhanced operational efficiency and similarly by playing with different parameters of pulse tube and regenerator we developed a cold head also to suit for the compressor.*

***Keywords** -Linear motor compressor, moving coil linear motor, cryocooler, pulse tube, regenerator*

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I. INTRODUCTION

Cryocoolers are used in space related applications like space surveillance, Thermal imaging cameras, X-ray astronomy and satellite cooling system etc. Also nowadays pulse tube Cryocoolers are beneficial than stirling Cryocoolers as they have no moving parts in cold region and high reliability and stability of temperature at cold end.

Nowadays linear motors are used in cryocooler due to following advantages:

- No large number of moving parts
- Less friction and noise,
- No lubrication problem and
- Minimum vibrations.

In designing the motor and cold head we have used a FORTRAN code prepared by using method proposed by Gaunekar et al [1], [2],[3]. During designing selection of proper magnet material of high flux density and direction of magnetization to suit application is selected. Also by using code, magnet dimensions, coil dimensions, pole piece dimensions, magnet flux, gap flux,pulse tube and regenerator dimensions are decided.

II. DESIGN OF LINEAR MOTOR

Linear motor (LM) compressors use a current carrying wire within a magnetic field (Fig.1) to impart a linear force in the axial direction to the piston while conventional rotary compressors use a crankshaft to provide this force. Rotary compressors apply large radial forces to the piston, which provide no useful work, cause a large amount of wear and usually require lubrication. Lubrication is a major problem in Cryocoolers since contaminant can often migrate to the cold end of the cryocooler and liquefy or freeze. Linear motors eliminate radial forces completely since the force created in the wire is perpendicular to both the magnetic field and the direction of the current in the wire. A linear motor compressor can operate at any frequency but is most efficient operating at a unique resonant frequency.

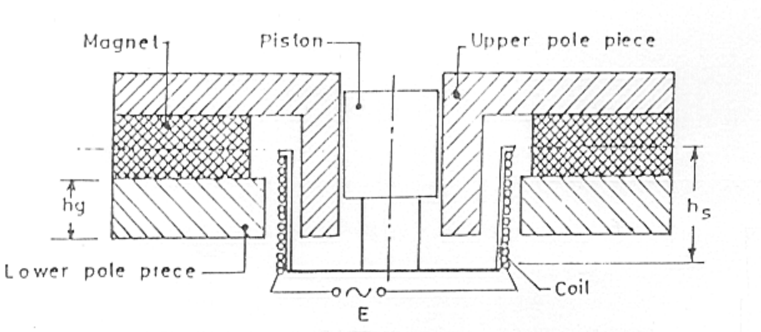
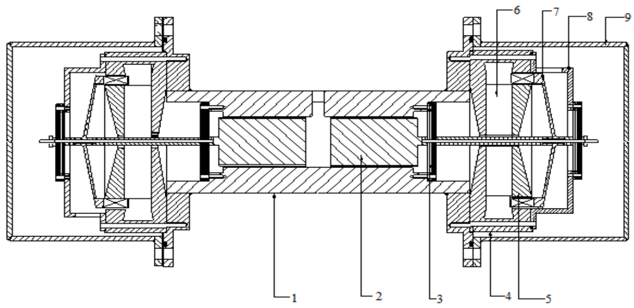


Fig. 1 Moving coil linear motor [3]

To minimize the vibration of reciprocating compressors a balanced opposed piston compressor is selected, in which the pistons are counter balanced in-line, 180^0 out of phase (Fig.2). The traditional problem of reciprocating compressor is the seal between the piston and cylinder, which has been accomplished by using piston rings and is another source of wear in the compressor and hence increase in power input. To achieve the same effect while eliminating contact between the piston and cylinder wall, thus eliminating wear clearance seals is selected. A gap of 15 μm is considered as will allow only a small percentage of the working fluid to pass through during a half



1-Main body
4- Inner Pole piece
7- Coil
2- Piston
5- Outer pole piece
8-Flexure support ring
3- Flexures
6- Magnet
9- End cover

Fig. 2 Linear motor compressor [3]

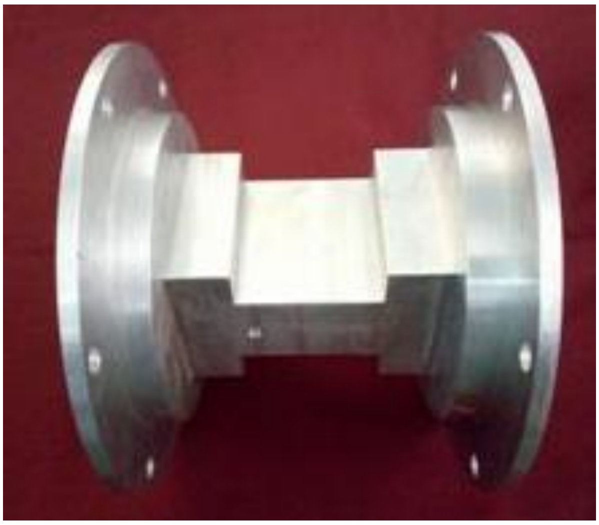
cycle thus minimum loss of power. As the gas pressure on the backside of the piston is the average of that in the compression space, so it considered that there is no loss of gas from the compression space when averaged over one cycle. Clearance seals require very good alignment between the piston and cylinder over the entire stroke.

By using LM design code and making parametric analysis,new compressor is designed with 8cc displacement volume. For this compressor, optimized geometrical parameters are summarized in following Table 1 and some actual photographs of parts of compressor are shown in Fig.3

Table 1 Summary of new linear compressor design

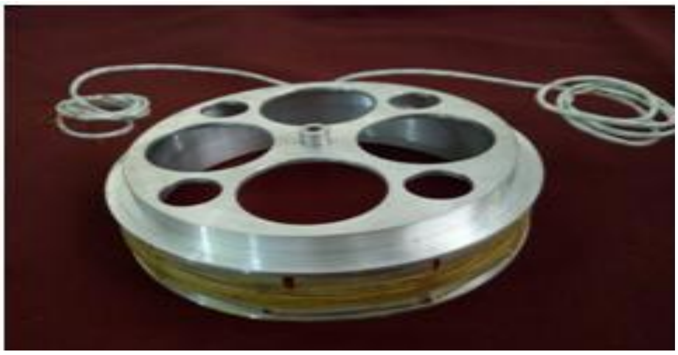
Components /parameters	**Unit**	**Size /specification**
Compressor swept volume	cm^3	8 cc
Compressor piston diameter	mm	22.5
Motor type	--	Single coil opposed piston
Magnet	--	VACODYAM 655 HR
Magnet inner diameter	mm	10
Magnet outer diameter	mm	100
Magnet height	mm	20
Gap inner diameter	mm	100
Gap outer diameter	mm	118
Gap height	mm	15
Coil wire gauge	SWG	27
Number of Coil radial layers	--	18
Number of Coil axial layers	--	44
Wire length	M	254

Gap flux density	T	0.6
Total stroke	mm	10
Efficiency	%	87
RMS voltage	V	194
RMS current	Amp	0.795



a. Main body

b. Piston and piston rod assembly



c. Coil former

Fig. 3 Different parts of newly fabricated compressor

III. DESIGN OF PULSE TUBE AND REGENERATOR UNIT (COLD HEAD)

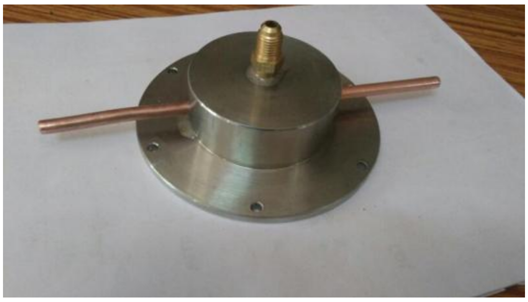
By using PTdesign code and making parametric analysis,we have the dimensions for pulse tube and regenerator unit for a newly designed compressorwith 8cc displacement volume. For this cold head, optimized geometrical parameters are summarized in following Table 2 and some actual photographs of parts of cold head are shown in Fig.4

Table 2 Summary of cold head design

Component/ parameter	**Units**	**Values**
Pulse tube diameter	mm	10
Compressor swept volume	cm^3	08
Operating frequency	Hz	50
Regenerator OD	mm	16
Regenerator length	mm	40
Regenerator mesh (49 gauge)	Mesh / in.	400
Pulse tube length	cm	50
Reservoir volume	cm^3	500
Average pressure	bar	16
Heat rejection temperature	K	300
Refrigeration temperature	K	80
Gross Refrigerating effect	W	12.27
Loss due to regenerator Inefficiency	W	2.2
Temperature swing loss	W	1.72
Conduction loss	W	0.921
PV loss	W	2.81
Shuttle loss	W	0.865
Pumping loss	W	0.40
Conduction loss through gas piston	W	0.921
Compressor power (Ideal)	W	47.8
Regenerator pressure drop	W	8.56
Heat exchanger pressure drop	W	22.83
Net refrigerating effect	W	3.27
PV power	W	98.98
Net power input (87 % motor efficiency)	W	113.7

a. Pulse tube and regenerator

b. Cold head unit



c. Hot end exchanger body

Fig. 4 Different parts of newly fabricated cold head.

IV. CONCLUSIONS

Based on the design methodology proposed by Gaunekar et al[1], a computer program was developed and by playing with different parameters, we have tried to increase efficiency of available linear motor compressor. Using same code, a new 8cc compressor is designed .Similarly based on design methodology proposed by Narayankhedkar K.G. et al [2],[3]a computer program was developed and by playing with different parameters,We design pulse tube and regenerator unit suitable for 8cc compressor.

FUTURE ENHANCEMENT

While analyzing new compressor design more powerful magnet strength can be used and perform further parametric study for improving efficiency and to reduce the size of compressor. Research can also be carried out with different materials so as to see effect on compressor performance.

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