A Review on Modal Analysis of Linear Compressor

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Abstract

When the system resonates or vibrates at natural frequency then it is resonance i.e. Operating or the exciting frequency matches natural frequency of considered the moving mass. Resonance in vibration industry is considered to be very harmful for the long life of most of all equipments since the amplitude of vibration under resonance condition is very high, due to the increased stress levels it may cause damage to the structure. But there few resonace equipments like linear compressor which will perform with the maximum efficiency under resonance conditions only. The present research paper presents results generated by mathematical simulation of the linear compressor to achieve resonance condition. Under resonance, amplitude of piston is highest with the minimum input power required (Maximum efficiency condition). Present work discusses the model of a prototype linear compressor in CREO. FEM was used to analyze natural frequency of linear compressor. Various parameters are studied to achieve the resonance around 50 Hz condition to meet Indian power supply conditions.

Keywords: The author can include 5-7 words like Thermal Analysis, Pre-conditioner, In-mold, Inoculant's efficiency.

1. Introduction

Linear compressor is a positive displacement compressor which is driven by linear motor. The piston is supported by the resonating spring in order to form a free piston system. A resonant spring is used to obtain a piston stroke with small thrust of the linear motor. The use of linear motor reduces mechanical linkages like connecting rod and crank necessary for converting rotary motion to linear motion. Hence this type of machine is compact, operates with less friction and noise. As there is no conversion of rotary motion to linear motion, all forces act along the axis of the piston. Chen N. studied static and dynamic characteristics of moving magnet type linear compressor. The Static characteristics were investigated by experimentation and dynamic characteristics were studied using mathematical model. Hyun Kim studied dynamic characteristics of the linear compressor. They also investigated the effect of resonance on the performance of compressor by comparing simulation results with experiment results. Ming Xia analyzed moving type magnet linear compressor of the Stirling cryocooler. The experimentation and simulation results showed effect of magnet spring on the resonance frequency of moving magnet type linear compressor. Tae-Won Chun studied PWM inverter for improving efficiency of the linear compressor. Zhengyu Lin] introduced a new technique in order to achieve resonance condition by controlling the electrical frequency to the linear motor for increasing efficiency of the linear compressor. Linear compressor has shown great potential in electronic cooling, air-conditioning, refrigeration, and cryogenics applications recently]. Present work discusses effect of operating frequency (off resonance and at resonance conditions) of the linear compressor on many parameters of the vapour compression refrigeration system. To analyze the natural frequency of linear compressor FEM is used.

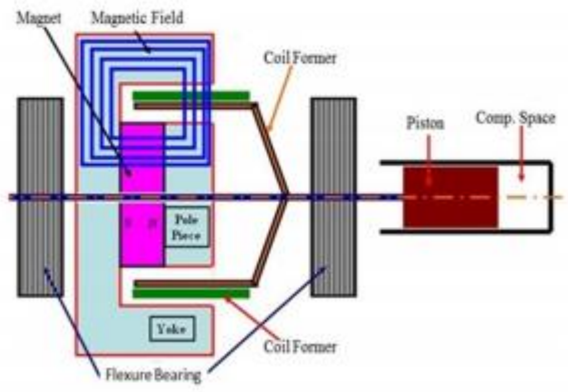

Fig. Linear Compressor [6]

2.Resonant Frequency of Linear Compressor:

Resonance is tendency at which the system oscillates with higher amplitude when the operating frequency matches with the natural frequency of the system. The linear compressor is a resonant machine. The linear compressor gives more efficiency at resonance frequency. Figure-1 shows structure of the linear compressor composed of the flexure spring, moving coil linear motor and piston. Figure-2 shows the flexure spring consist of the spiral cut. These cuts allow each of the flexure to move itself axially on application of the load in axial direction. In actual practice a single flexure spring can deliver total desired stiffness but it may restrict required displacement. To achieve desired stiffness and the displacement stack or group of flexure spring is used in parallel arrangement. Beryllium copper is used for the flexure spring as it has largest stiffness as compared to other materials like copper alloys and stainless steel. In addition, it has high fatigue strength, low magnet permeability and high corrosive resistance. Forces acting on the piston of the linear compressor such as the spring force, the damping force and the electric forces are resulted from applied current. The motion equation of the linear compressor can be described as follows.

F=m□x□+ C□x˙ + K□x (1)

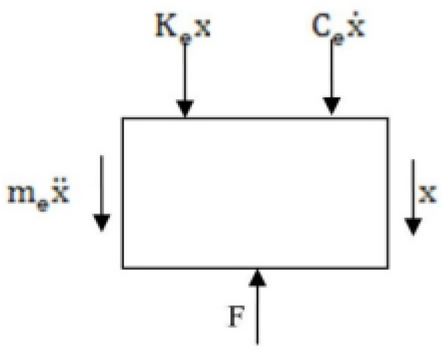

Fig. Mathematical Model [6]

Resonance is tendency of a the system to oscillate with greater amplitude at some of the frequencies than at others. Frequencies at which response amplitude is a relative maximum are known as system's resonant frequencies.

$$Fn = \frac{1}{2\pi} * \sqrt{\frac{k_e}{m_e}}$$

Where,

fn = Natural frequency of the moving object, Hz.

K_e=Kmech + Kgas

m_e = Moving mass of the piston, kg.

Parameters affecting resonance are as follows:

From the equation above for the natural frequency in order to achieve resonance, the piston should oscillate at natural frequency. Also the electrical supply frequency also should match the natural frequency. Hence linear compressor operation requires a variable frequency power supply.

1. Moving mass (m_e): This includes mass of the magnet, mass of the spring, mass of the piston or coil (Depending on type: moving coil or moving magnet) and any other mass resonating with the piston.

2. Gas spring stiffness (K_{gas}): The gas pressure inside the cylinder during compression exerts force on the piston surface. If the gas force is dominant then this force would try to push the piston towards Bottom Dead Center (BDC).

3. Mechanical Spring Stiffness (K_{mech}): The mechanical spring works to pull the piston back to the mean or original position. The driving force (Motor force) has to overcome all the opposing forces, to achieve resonance.

4. Operating frequency: The exciting frequency should match the operating frequency, to achieve the resonance.

5. Motor Force: Motor force should match all the opposing forces i.e. Spring force, gas force, damping force.

3.Modal Analysis:

The resonant frequency of free piston linear compressor is a function of moving mass and stiffness which can be represented as equation (2),

$$Fn = \frac{1}{2\pi} * \sqrt{\frac{k}{m}} \qquad (2)$$

Total stiffness K = K_m+ K_g .

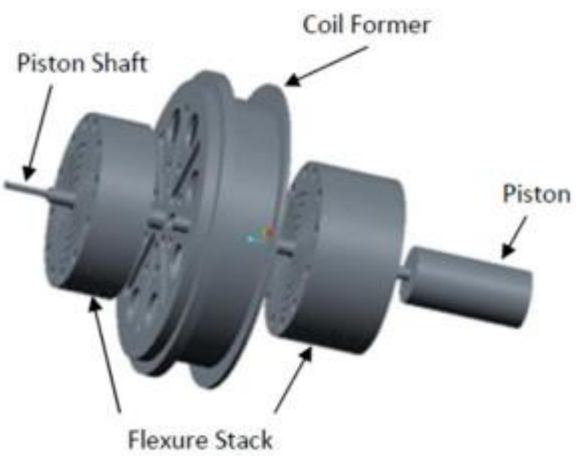

Fig. FEM Model of Linear Compressor [6]

The gas spring stiffness can be calculated as equation (3)

$$Kg = \frac{(p-p^{-})*A}{x} \qquad (3)$$

Modal analysis is used to estimate the natural frequency of the linear compressor. Figure-3 shows the creo model of linear compressor consist coil former, piston and flexure spring with same material properties as that of the prototype linear compressor. The material used for coil former is aluminium, for piston is stainless steel and for the flexure spring is beryllium copper. Analysis is done for different stacks or group of flexure springs.

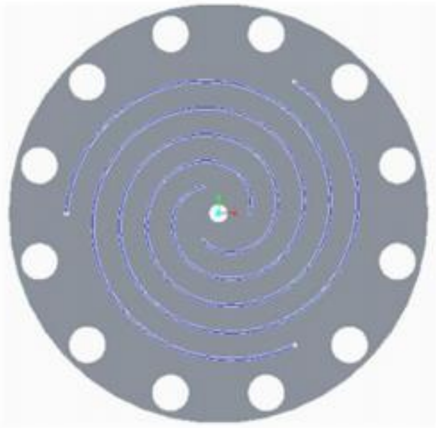

Fig. Flexural Spring [6]

Initially stiffness of 0.3mm, 0.5mm, 0.7mm and 1mm thick flexure springs were calculated. As per the analysis 0.7mm thick flexure spring has safe stress and maximum stiffness which fulfil the requirement of the experimental set-up. 0.7 mm flexure spring is used for further analysis i.e. to find natural frequency of single flexure spring with 0.7mm thickness is 1676 Nm-1 . Then modal analysis is carried out on Ansys for different stacks containing 5,10,15,20,25,30,35 flexures. The results are shown in the tables below and analysis results are also shown

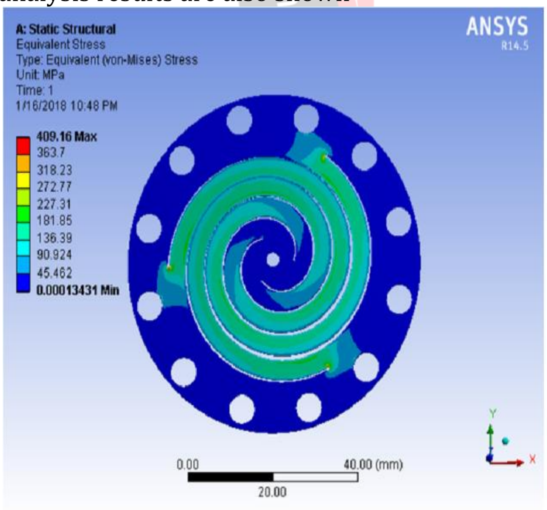

Fig . Equivalent stress in 0.70 mm thick plate

Table1: Comparison of stiffness for plate thickness

Thickness of plate (mm)	0.3	0.5	0.7	1.0
Displacement (mm)	5	5	5	5
Material	Beryllium	Beryllium	Beryllium	Beryllium

	copper	copper	copper	copper
Stress (MPa)	167.63	296.49	409.16	583.4
Yield stress (MPa)	1100	1100	1100	1100
FOS	2	2	2	2
Allowable stress	550	550	550	550
Remark	Accepted	Accepted	Accepted	Rejected

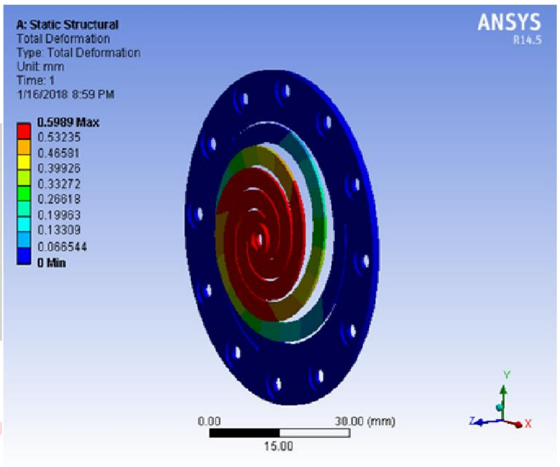

Fig. Deformation in 0.7 mm thick plate

Table2. Comparison of stiffness for plate thickness

Thickness(mm)	0.3	0.5	0.7
Applied force (N)	1	1	1
Deformation (mm)	7.1404	1.4864	0.5989
Stiffness (N/m)	140.048	672.766	1676.92

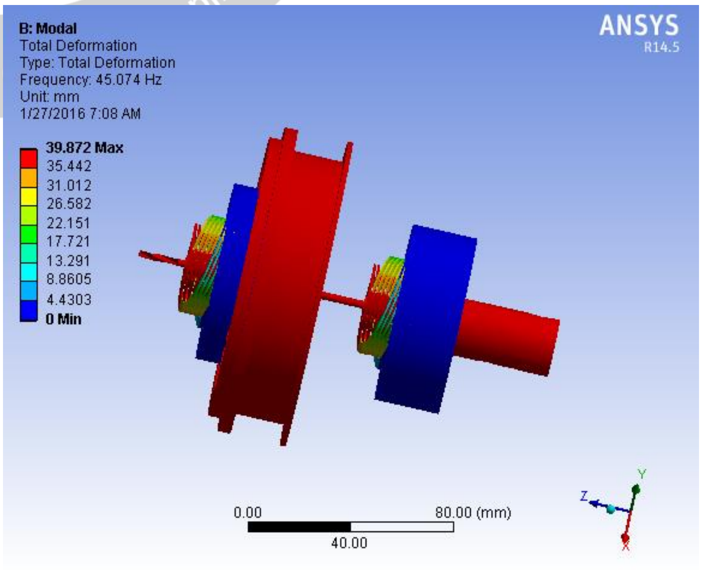

Fig . Natural frequency for 25 flexure springs

Table3: Natural frequency with and without gas stiffness

Sr. no	Number of flexure springs	Natural frequency without gas stiffness (Hz)	Natural frequency with gas stiffness (Hz)
1	5	21.97	31.67
2	10	30.437	37.767
3	15	36.167	42.392
4	20	41.164	46.284
5	25	45.075	49.586
6	30	50.06	52.636
7	35	51.265	55.02

4. Conclusion:

We have studied different parameters to improve efficiency of linear compressor and focused on changing stiffness of the spring in order to achieve resonance, In this, we have performed stress, stiffness, force analysis of the flexural spring. The results shows that 0.7 mm thick flexure is the most suitable for use. This 0.7 mm thick beryllium copper spring is used in stacks.Different stacks are analysed in order to achieve resonance and finally 30 flexure stack is selected as it give approx 50Hz (the electrical supply frequency is 50Hz) natural frequency which is the required frequency in order to achieve resonance.

5. References:

1.Patent :"**A Linear Compressor**" Inventors: Amit Jomde, Virendra Bhojwani, SuhasDeshmukh, MadhuraSevekari, 1928/MUM/2015

2.Amit Jomde, Anderson A., Virendra Bhojwani, Shreyans Kedia, NitishJangale, Kshitij Kolas, Pravin Khedkar, "Modelling and measurement of a moving coil oil-free linear compressor performance for refrigeration application using R134a", International Journal of Refrigeration, **Elsevier**, 2018

3.Amit Jomde, A. Anderson, Virendra Bhojwani, Mitali Deshmukh, "Performance predictions and parametric analysis of valved linear compressor using mathematical model", International Journal of Ambient Energy, **Taylor & Francis**, 2017

4.Amit Jomde, Virendra Bhojwani, SuhasDeshmukh, Kshitij Kolas, Pravin Khedkar, "Modeling and simulation performance of reed valve in linear compressor", Materials Today proceedings, **Elsevier**, 2017

5.Amit Jomde, A. Anderson, Virendra Bhojwani, SuhasDeshmukh ,Kharadi, "Parametric analysis of flexure bearing for linear compressor.", Materials Today proceedings, Vol.4, Issue 2, **Elsevier**,2017

6.Amit Jomde, A. Anderson, Virendra Bhojwani, SuahsDeshmukh, Paresh Shinde, SunitaPhadkule, "Resonance analysis of valved linear compressor for refrigeration application", Journal of Engineering and Applied Sciences, **ARPN**. Vol. 11 No. 23, December 2016, ISSN 1819-6608

7.Amit Jomde, SuhasDeshmukh, SourabhNaukudkar, PinakSalvekar, Hussain Raja, AjinkyaPatil,"Stress Analysis of Flexure Bearing For Linear Compressor" International Journal of Mechanical Engineering and Computer Applications, Vol 2, Issue 1, January 2014, ISSN 2320-6349

8.Ming Xia, Xiaoping Chen,"Analysis of resonant frequency of moving magnet linear compressor of stirlingcryocooler", International Journal of Refrigeration vol.33 (2010) 739 – 744.

9. Fayaz H. Kharadi, Mayur S. Jadhav, Dr. Virendra K. Bhojwani, Prof. SuneetaPhadkule, Dr. M. G. Jadhav. "Selection of high performing material in flexure bearings for linear compressor applications using FEA", International journal of scientific and technology research. Vol -4,Issue 1,January 2015.

10. Fayaz H. Kharadi, Dr. Virendra K. Bhojwani, Prof. SuneetaPhadkule, "Selection of high performing material in flexure bearings for linear compressor applications using FEA," International journal of scientific and technology research. Vol -4, Issue 1, January 2015.