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Research Article

Finite Element Analysis of linear compressor to achieve resonance condition

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***Abstract*—Resonance is a condition under which the system vibrates at natural frequency i.e. Operating frequency matches the natural frequency of the moving mass. Resonance in the vibration industry is considered to be harmful for the long life of the equipment since the amplitude of the vibration under resonance is very high, it causes damage to the structure due to increased stress levels. But there are some resonant equipment's like Linear compressor which perform with maximum efficiency under resonance condition. The present paper presents Finite Element analysis of linear compressor to achieve resonance. At resonance the amplitude of the piston is highest with minimum input power requirement. The present work discusses model of a linear compressor in CREO. FEM was used to analyze natural frequency of the linear compressor. Various parameters were optimized to achieve resonance at 50 Hz condition to meet the Indian power supply conditions**

***Keywords*—Natural frequenc, Resonance, Linear compressor**

I.INTRODUCTION

Linear compressor is a gas compressor where the piston moves along a linear track. The linear compressor is driven by a linear motor directly coupled with a piston and springs for resonant operation. In a linear compressor, a resonant spring is to obtain a piston stroke with small thrust of a linear motor. Since there is no conversion of rotary to linear motion, all the forces of the linear compressor act along a single axis i.e. the axis of piston motion. This operation along a single axis and direct coupling between the motor and piston generates minimal side loads that prevents contact between the piston and cylinder and hence reduces wear and tear of piston. This characteristic of very low side load & vibrations makes this machine very silent in operation. Tae-Won Chun et al [1] investigated the performance of linear compressors using a pulse width modulation inverter is investigated, with emphasis on the efficiency and power factor along with variations of both mechanical and electrical resonant frequencies. N Chen. et al [2] presented a study on static and dynamic characteristics of moving magnet linear compressor. A voltage stoke relationship, the effect of charging pressure on the performance and dynamic frequency response characteristics are investigated. Liang K., et al. [3] mentioned the performance of the compressor has been experimentally evaluated with nitrogen and a mathematical modal has been developed to evaluate the performance of linear compressor. Ming Xia et al [4] analyzed resonant frequency of the moving magnet linear compressor of stirlingcryocooler. Hyun Kim et al [5] investigated dynamic characteristic of linear compressor by experimental and numerical study. Fayaz H. Kharadi et al [6] investigated best geometry of flexure spring to enhance its performance and improve upon the life of the flexure of service

2. Resonance

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

$$F_n = \frac{1}{(2*\pi)} * \sqrt{(\frac{K\text{mech}+\text{Kgas}}{M})} \quad 1$$

$$K_g = \frac{(P-\bar{P})*A}{x} \quad 2$$

Where, fn = Natural frequency of the moving object, Hz.
K_{gas} = Gas spring stiffness, N/m
K_{mech}=Mechanical Spring Stiffness, N/m M = Moving mass of linear compressor, kg.

Forces acting on the piston are due to combined springs, including the gas effects and the electrodynamics driving force.
Mass of the piston includes a portion of the spring mass and the driving coil mass.

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

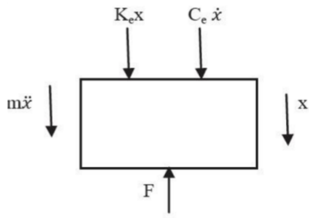

Fig 1: Free Body Diagram

Let Ke be the equivalent spring constant, Ce be the viscous damping constant and Me be the resonating mass of the system. The equation of motion that governs mechanical part of the systemis, therefore, given by:

$$M_e\frac{d^2x}{dt^2} + C_e\frac{dx}{dt} + K_e x = F \qquad 3$$

Where, Ke = KP + Kg

2.1 Parameters affecting resonance:

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

1. Moving mass (me): This includes mass of the piston, mass of the spring, mass of the magnet or coil and any other mass resonating along with the piston.

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

3. Mechanical Spring Stiffness (Kmech): The mechanical spring tries to pull the piston back to the mean position. The driving force (Motor force) should overcome all the opposing forces in order to achieve resonance.

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

3. Modelling and Analysis of linear compressor

The very first step of modeling for FEM is a creation of geometric model. For the advantages of working and competence and handling, it was decided to use CREO as geometric modeling software. The linear compressor was created using CREO 2.0.

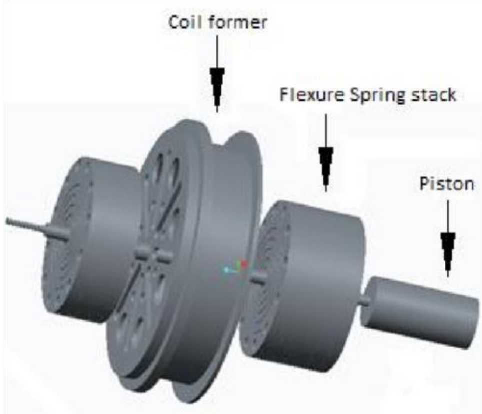

Figure 2 CREO model for linear compressor

Figure 2 shows model of linear compressor consist of piston, coil former and flexure spring. There are two states of flexures called stacks on either side of linear motor supporting a piston rod which moves the piston either side i.e. back and forth in gas displacer. In practice a single flexure spring cannot deliver the total desired stiffness. So to achieve desired stiffness a stack of flexure spring is used in parallel arrangement. The total stiffness in this arrangement is sum of individual springs arrange in parallel. The material used for piston is stainless steel, for coil former is aluminum and for the flexure spring is beryllium copper. Analysis is done for different stacks of flexure springs. Initially stiffness of 0.3mm,0.5mm 0.7mm and 1mm flexure spring are calculated. As per the analysis 0.7mm flexure spring has less stress and maximum stiffness. So 0.7mm flexure spring are used for further analysis i.e. to find natural frequency.

Table 1 -Parameters of the linear compressor

Main parameter	valve
Area of piston (m^2)	0.000397
Moving mass (Kg)	0.615
Displacement (m)	0.01
Suction pressure (bar)	2
Discharge pressure (bar)	8

3.1 Analysis result

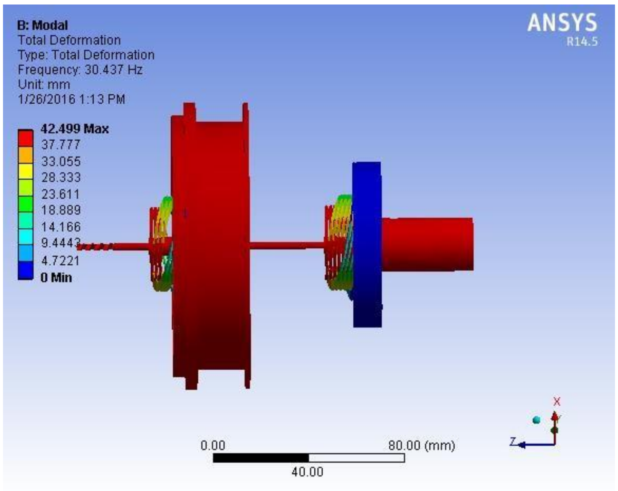

Figure 3 Analysis of 10 number of flexure spring

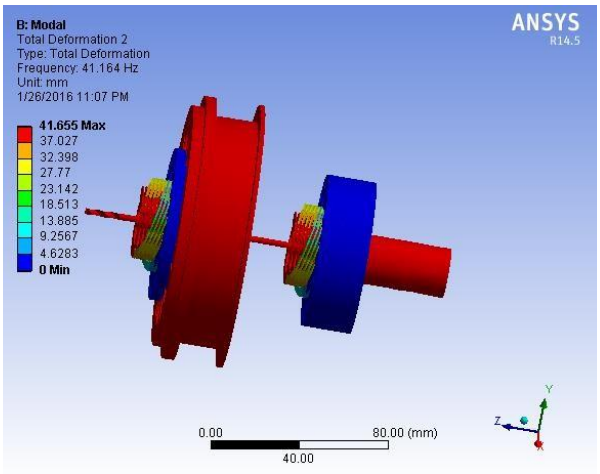

Figure 4 Analysis of 20 number of flexure spring

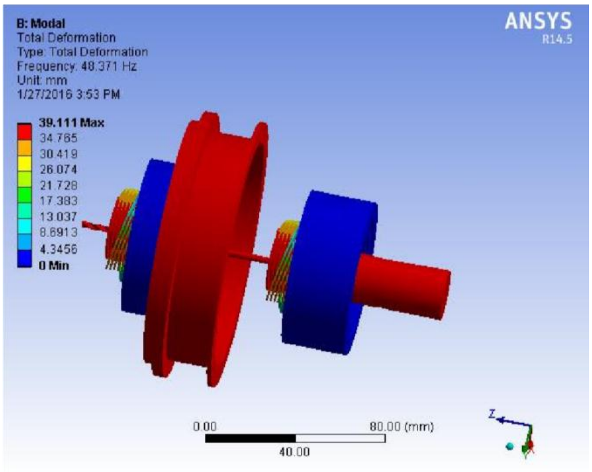

Figure 5 Analysis of 30 number of flexure spring

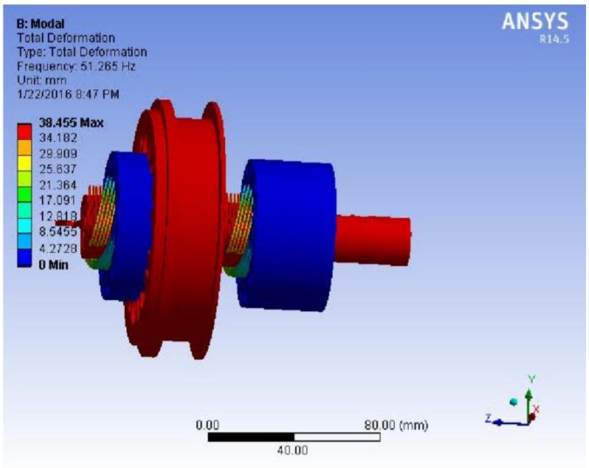

Figure 6 Analysis of 35 number of flexure spring

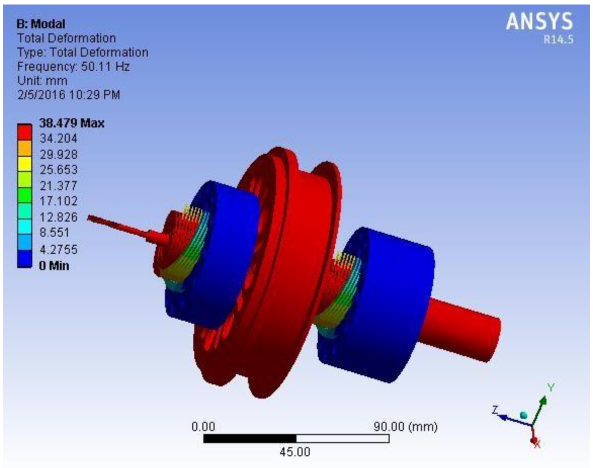

Figure 7 Analysis of 33 number of flexure spring

From the above result it is cleared that thirty-thirty flexure springs were thus required to achieve resonant frequency.

Stiffness of single flexure spring is 1676 Nm^{-1}. So total stiffness of flexure spring is 50280 Nm^{-1}.

4 Experiment

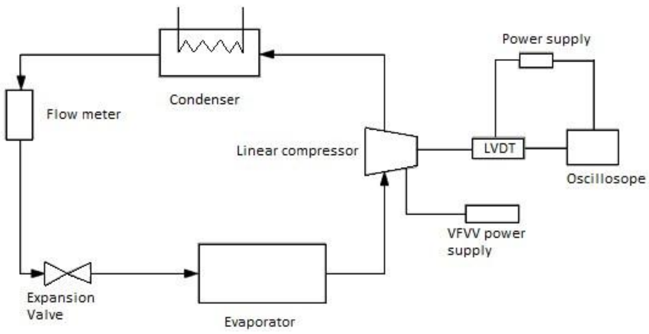

Figure 8 Experimental setup

Figure 8 shows the experimental setup of prototype linear compressor to measure the natural frequency and performance of system at resonance conditions. This setup consists of pressure gauges at inlet and outlet of the compressor, flow meter and expansion valve. Linear variable differential transformer (LVDT) and an oscilloscope is used to measure the stroke of piston and natural frequency of system. The gas used in this experiment is R134a. Linear compressor is driven by variable frequency variable voltage (VFVV) power supply. The power supply can show the voltage, current and frequency of the compressor. The mass of moving component of linear compressor is 0.615 Kg, the stiffness of spring is 50280 N/m and cross section area of piston is 0.000397 m^2. According to Eq. (2) gas stiffness can be calculated as follows,

$$K_g = \frac{(P-\bar{P})*A}{x} = \frac{(8-5)*10^5*3.97*10^{-4}}{0.01} = 11928\ Nm^{-1}$$

According to Eq. (1), the resonant frequency can be calculated as the following value, which is almost equal to the testing result,

$$F_n = \frac{1}{(2*\pi)} * \sqrt{(\frac{K}{M})} = \frac{1}{(2*\pi)} * \sqrt{(\frac{50280+11928}{0.615})}$$

F_n = 50.618 Hz.

Conclusions

In this paper finite element analysis of linear compressor is studied to achieve resonance condition. From the result is it concluded that thirty-three flexure springs are required to achieve resonance frequency.The experimental results are underway to validate the FEA results.

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