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Design Analysis & Experimental Set Up Of Flexure Bearing

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Abstract
Flexure bearing is a new concept and used for precision applications such as Programmable focusing mechanism (PFM), linear compressor etc. These bearings are compact and inexpensive. A flexure bearing is designed for specific applications. These design can usually be done with the advanced design tool like FEA. With the advent of computers FEA has become the most suitable tool for the engineering analysis where the conventional approach is not suitable, geometric complexity are involved etc. This paper deals with the study of flexure bearings in linear compressor and makes FEA analysis on it to calculate equivalent stress and tries to optimize it. Using software's like CATIA and PROE ,modelling of flexure bearing is done. Also make FEM analysis on it by using Ansys software. Gaunekar have made design calculation for flexure bearing to make appropriate model. This bearing contains three spiral slots having 120° apart and 12 peripheral holes are used to clamp the disc rigidly onto a support structure. One central hole made for movement of shaft.

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I. INTRODUCTION

1.1 Background

The satellite based electronic sensors, infra-red detector system, thermal imaging cameras, Superconducting Quantum Interference Devices (SQUIDs) and vast variety of circuits requires cryogenic cooling. Such type of applications demand very high reliability, low specific power consumption, long maintenance free life, small size, low weight and low vibration levels. Now a day's linear compressors are commonly used in miniature cryo-coolers instead of rotary and reciprocating compressors. Linear compressor also eliminates radial forces and lubrication problem. The bearing requirement of linear compressor can be achieved with the help of flexural bearing instead of conventional bearings. These bearings tremendously increased the reliability and life of cryo-coolers as compared to those of contact type bearing [1].

In general the flexure bearing assembly consists of a stack of axially flexible cut diaphragms with outer rim fixed. An ideal flexure bearing should have the characteristics of very large radial or in plane stiffness, minimal axial or out of plane stiffness and low stresses when deflected. The radial stiffness is needed to maintain the extremely tight clearance between the piston and cylinder to form a gas "clearance seal". The axial stiffness needs to be kept low to avoid affecting the natural frequency of the spring mass system composed of piston and compressible gas. The low stresses are required to assure that the bearing will not fail due to fatigue stress [2].

Advanced engineering applications such as μ-manufacturing and precision metrology requires bearings with low friction, high accuracy, repeatability, smooth motion almost no mechanical wear with no lubrication requirements. In addition they are required to be compact, lightweight and in expensive. Flexure bearing offers these advantages. A Simplest flexure bearing is a hinge made by attaching a long strip of a flexible element to a door and to the door frame. Another example is typical turbines are often supported on flexible shafts so an imperfectly-balanced turbine can find its own centre and run with reduced vibration. Basic ideas of the finite element method originated from advances in aircraft structural analysis [3].

The Flexural bearing is new concept and there are very precision applications to understand concept of flexural bearing, few of them are explain as follows:

1. Novel Rotary Flexural Bearing.
2. Linear Bearing for linear Compressor.
3. Programmable Focussing Mechanism (PFM) [4].

A typical flexure supported system is shown in Figure 1.1 its principle of operation is similar to that of an electromagnetic vibrator.

It consists of electric coils fixed to the piston drive shaft, free to reciprocate in annular working gap formed by a stationary assembly of an axially magnetized permanent magnet and pole pieces. The required oscillatory motion is governed by passing an alternating current through the coils.

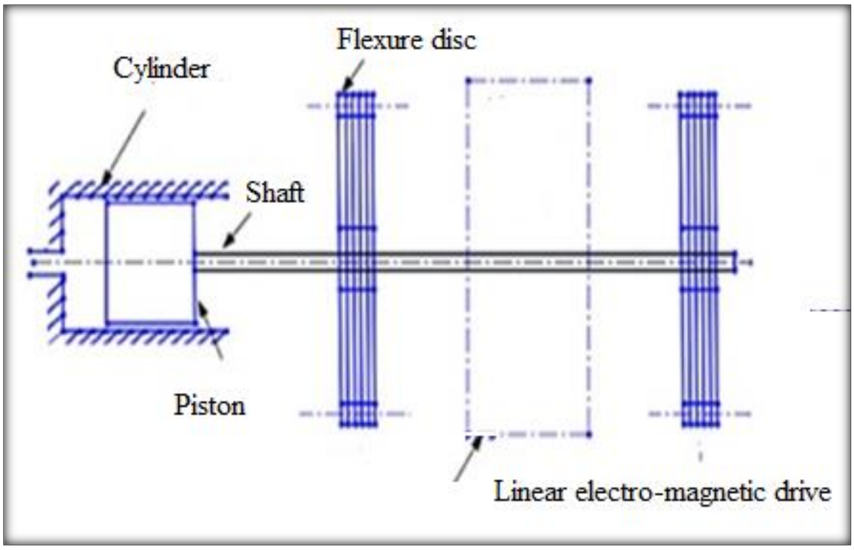

Figure 1.1 Assembly of the flexure bearing [5]

The most common technique for eliminating rubbing contact uses flexure bearing to support the piston inside the cylinder without any contact. A clearance gap of 10 to 20 μm provides the necessary flow of impedance to serve as dynamic seal. Figure 1.2 shows a simplified cross section of compressor with flexure bearings. The flexure bearings provide a stiff support in the radial direction [6].

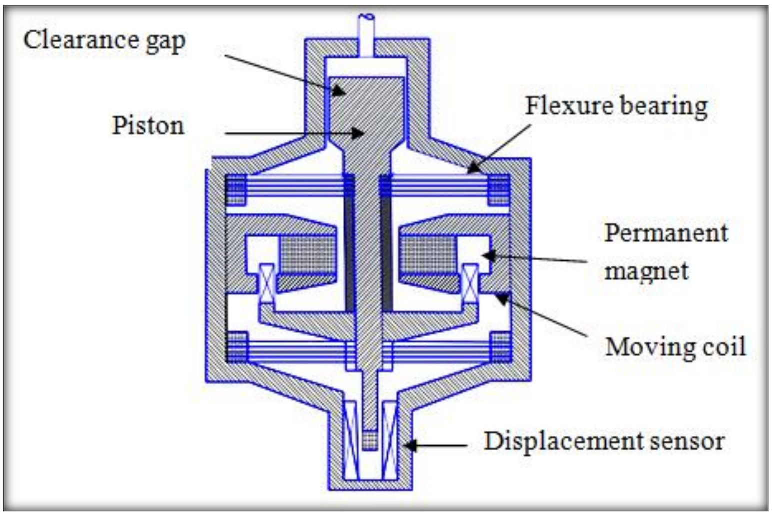

Figure 1.2 Cross section of a typical compressor [6]

Flexure bearing is a new concept and used for precision applications such as Programmable focusing mechanism (PFM), linear compressor etc. These bearings are compact and inexpensive. A flexure bearing is designed for specific applications. Flexure bearings are used in cryo-cooler compressors and expanders to maintain integrity of the clearance seal between piston and cylinder. This study proposes a design methodology for a flexural bearing used in linear compressor that is based on the motion principles of elastic flexures. The bearing is capable of providing rotational oscillations of one complete revolution and is characterized by potentially high repeatability, smooth motions, no mechanical wear and no lubrication requirements, zero maintenance, in addition to its compactness [7].

Flexure bearing is manufactured by Photo Chemical Machine (PCM). Photo-Chemical Machining process is non-conventional machining process. It is used for the fabrication of very complex part on flat plate. It produces burr free parts at economical rate.

DESIGN OF FLEXURE BEARING

3.1 Modeling of spiral linear combination flexure bearing

The model is drawn in CATIA V5 R19 created as IGS file and imported in ANSYS Workbench for analysis. The outer age is fixed and inner hole surface is given axial and radial displacements. Radial displacement is 15μm

because radial clearance is of about 15μm between the piston and the cylinder serves as a clearance seal, and hence it is expected that any disc in the flexure bearing assembly would not deviate radially more than the clearance. Since the axial displacements are much higher than the thickness of the model, nonlinear structural analysis is done for a range of thickness and axial displacement.
Figure 3.1 shows a flexure bearing which has three spirals cut are provided having distance is 120^0. Thickness of these spiral cut is 0.5 mm. Spiral is not continuous at 45^{0} it has straight lines are connected to another spiral. Spiral curve start at 5 mm distance at centre hole and end at 20 mm distance at centre hole.

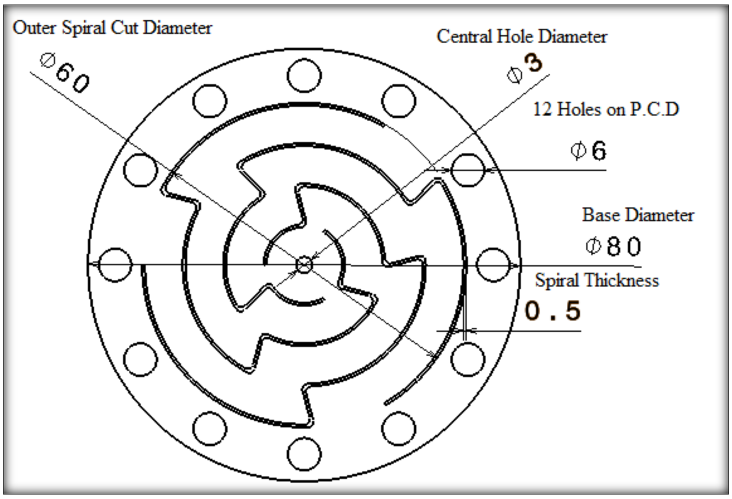

Figure 3.1 Spiral Linear Combination (SLC) Flexure bearing

Dimensions: Base diameter = 80 mm
Central hole = 3 mm
Pitch circle diameter (PCD) = 60 mm

Design point of view Flexure bearing has three different parameter are important
1) Fatigue strength
2) Radial stiffness
3) Axial stiffness

1) Fatigue strength : Each flexure disc is subjected to alternating stresses at a frequency equal to the operating frequency of the linear motor (50 Hz). For a given axial displacement, the location and magnitude of the maximum stress in a disc are dependent upon the spiral profile, diameter and thickness of the disc. This maximum stress value should fall well below the endurance limit of the material selected in order that the disc has virtually infinite life.
2) Radial stiffness: The radial stiffness of the flexure bearing assembly should be high enough to support the clearance seal under the weight of the suspended mass which consists mainly of the piston-shaft sub-assembly, coil and coil support.
3) Axial stiffness: In order to minimize the power drawn by the linear motor of the compressor, the moving mass should resonate on the combined spring effect of the gas spring above the piston and the flexure bearing below it. The axial stiffness of the flexure bearing is normally kept substantially low compared to the stiffness of the gas spring above the piston so as to minimize the moving mass which determines the level of vibrations in the unit.

Table 3.1 Parameters for FE analysis of flexure bearing

Sr. No	Parameter	Variation	No. of Levels
1	Effective diameter	50-80 mm	4
2	Inner diameter	30-60 mm	4
3	Thickness	0.2-0.5	4

Table 3.1 shows parameters which can be varied for the flexure bearing used for analysis. Number of possible combinations for linear flexure bearing considering four parameters and four levels are 64. But to study the effect of geometric parameters on the response variables and to arrives at the most suitable geometry, we need not analyse all 64 geometries. Hence Design of Experiments (DOE) theory needs to be used. From various methods available, Taguchi method is selected for present application.

II. CONCLUSIONS

1. It is observed that in case of SLC flexure bearing as the thickness increases von misses stress, strain, axial stiffness and radial stiffness increases.
2. As diameter increases von misses stress, strain, and axial stiffness decreases. As diameter increases radial stiffness increases.
3. As straight angle increases von misses stress, strain, axial and radial stiffness decreases.
4. Linear and SLC flexures are compared and it is observed that SLC flexure bearing is suitable for compact size and long life application for longer axial stroke.
5. FEM and experimental testing results are compare it is found that axial stiffness value obtained in FEM is 0.38075 N/mm and experimental testing is 0.4 N/mm therefore 4.82 percentage variation between FEM and experimental result.
6. FEM and experimental testing results are compared it is found that in von misses strain value maximum percentage variation is 5.65 and minimum percentage variation is 3.15 between experimental testing and FEM results.