MULTIOBJECTIVE OPTIMIZATION OF FLEXURE BEARING

SAHIL SANJEEVKUMAR DOSHI
DR VITTHALRAO VIKHE PATIL COLLEGE OF ENGINEERING

AANIL V SURYAWANSHI
DR VITTHALRAO VIKHE PATIL COLLEGE OF ENGINEERING

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. This 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, modeling 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

Bearings are used to allow the relative motion between the two surfaces. A piston is to slide about the cylinder and shaft has to rotate about its casing. Both requires the relative motion for least frictional losses to be happened. A flexure bearing is a spring which allows relative motion by bending a load element. Flexure bearings have the advantage over most other bearings that they are simple and thus inexpensive. They are also often compact, lightweight, have very low friction, and are easier to repair without specialized equipment. This paper presents design, analysis and manufacturing of flexure bearing for a linear compressor which increases the efficiency of system by achieving maximum stiffness, less stresses and more fatigue life. For this, modelling is done in NX&CATIA and analysis in ANSYS with physical validation of final results by manufacturing actual prototype.

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.

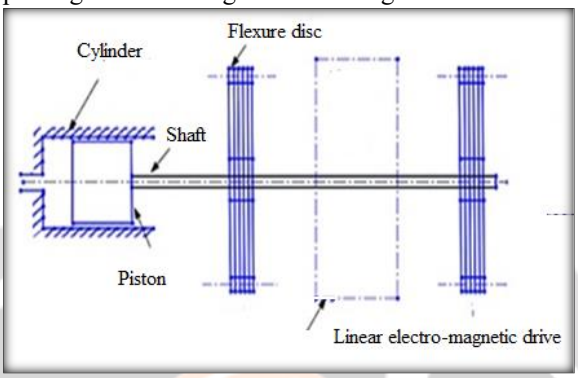

Figure 1.1 Assembly of the flexure bearing [5]

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].

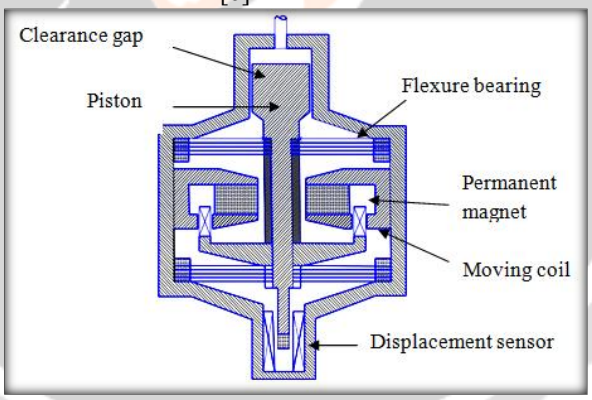

Figure 1.2 Cross section of a typical compressor [6]

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.

FINITE ELEMENT ANALYSIS

4.1 Analysis using ANSYS

Since exact analysis of the flexure element is not possible, hence the Finite Element Method (FEM) of analysis was chosen. Geometrically nonlinear static structural analysis was conducted with personal computer based ANSYS 15.0, an advanced finite element code. Table 4.1 shows that specification is used during FEM analysis.

Table 4.1 Specifications of SLC flexure bearing

Diameter	80 mm
Real constant (thickness)	0.2 mm
Material	Beryllium copper
Young's modulus (E)	130×10^3 N/mm^2
Poisson's ratio	0.3
Mesh size	0.5
Load/axial displacement	5 mm
Radial displacement	0.015 mm
Displacement at outer nodes	All degree of freedom fixed or restricted, hence displacement is zero.

4.2

Design parameters of flexure bearing

a. Geometry of flexure profile
b. Thickness of the disc
c. Axial stroke
d. Total number of discs in stack

Given the requirements of amplitude and both axial and radial stiffness, each disc of flexure bearing should operate fully within the endurance limit of the material.

The stress analysis of a linear flexure bearing is quite complex. The component experiences large deformations as a result of simultaneous shear, torsion and bending. This report outlines the design requirements linear geometry, stress, axial and radial stiffness**.** Analysis is done in ANSYS Workbench.

4.3 ANSYS result

Three types of analysis are important from the design point of view.

i) **Modal Analysis**: Modal analysis determines the natural frequencies and mode shapes. The natural frequencies and mode shapes are important parameters in the design of a structure for dynamic loading conditions.

ii) **Static Structural Analysis:** In structural analysis von misses stress, strain and total deformation are calculated.

iii) **Fatigue Analysis:** Fatigue is the phenomenon in which a repetitively load acts on structure and fracture occurs at a load level less than its ultimate static strength.

i) Modal analysis:

No of modes and their respective frequency are shown in figure 4.1.

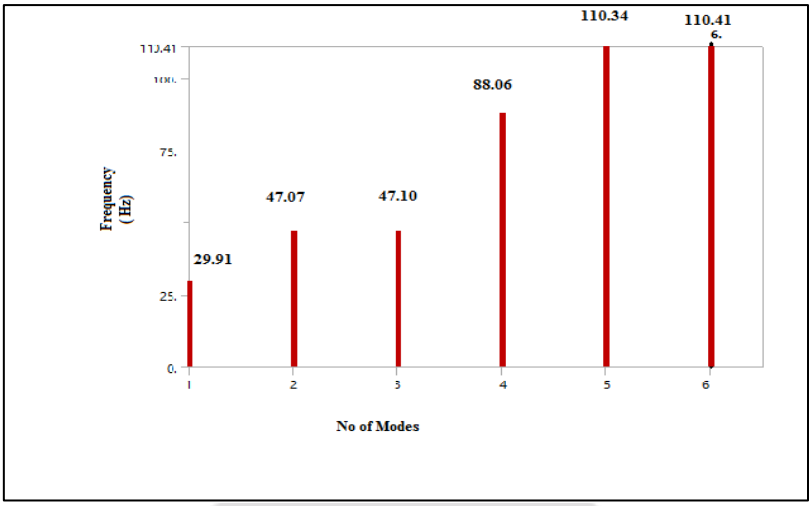

Figure 4.1 Frequencies vs. No. of Modes

ii) Structural analysis:

Spiral Linear Combination flexure bearing

Base diameter = 80mm Thickness = 0.2 mm Axial displacement = 5 mm

Radial displacement = 0.015mm. (For Sr. No 1)

Figure 4.2 and figure 4.3 shows that von misses strain and von misses stress.

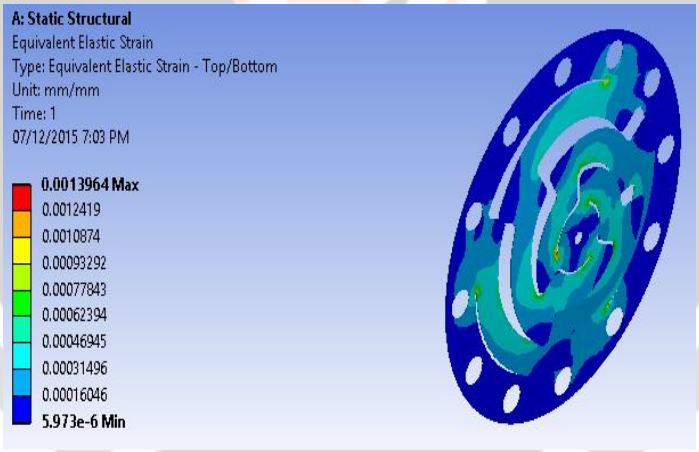

Figure 4.2 Von Misses strain

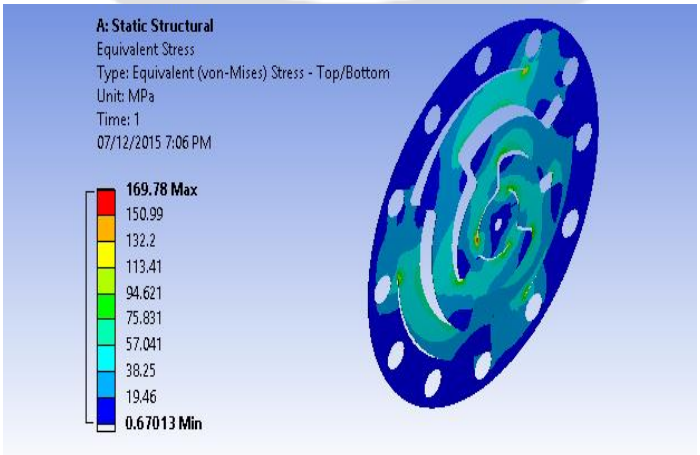

Figure 4.3 Von Misses stress

Table 4.3 shows that spiral linear combination of flexure bearing with different straight angle. Angle is varying from 0^0 to 45^0 in 15^0 steps and maximum Von Misses stress, minimum Von Misses strain, axial stiffness, radial stiffness is calculated.Here thickness is constant 0.2mm and straight angle varying from 0^0 to 45^0.

CONCLUSIONS AND FUTURE SCOPE

7.1. 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.

7.2. Future scope

1. Flexures made from photo elastic material can be tested to study the stress distribution during radial loading.
2. The flexures with different geometries like SLC can be used in the compressor and performance of compressor can be tested.

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