Modeling and Analysis of Flexural Bearing using FEA Tool

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***Abstract*— Paper presents modelling and analysis of Flexural bearing of linear compressor using FEA tool. Static structural analysis is done on Ansys and regression model is done using Mat-lab. Further regression model and FEA results are compared for various parameters.**

***Keywords*—Flexural Bearing, FEA Analysis, Regression Analysis**

I. INTRODUCTION

The traditional reciprocating-type compressor uses a crankshaft mechanism to convert the rotating motion of an electric motor into reciprocating motion to drive a piston. New way of bearings are developed which utilizes flexibility of elements to achieve desired motion objectives. Hence, Cadman and Cohen developed a linear compressor in order to eliminate the common problems of wear, vibration and noise due to the side forces exerted on the piston and cylinder wall in a reciprocating-type compressor. A linear compressor utilizes a linear motor to directly drive the piston in unidirectional motion. A well-designed linear compressor thus can greatly reduce side forces and wear, as well as vibration and noise.

II. FLEXURAL BEARING

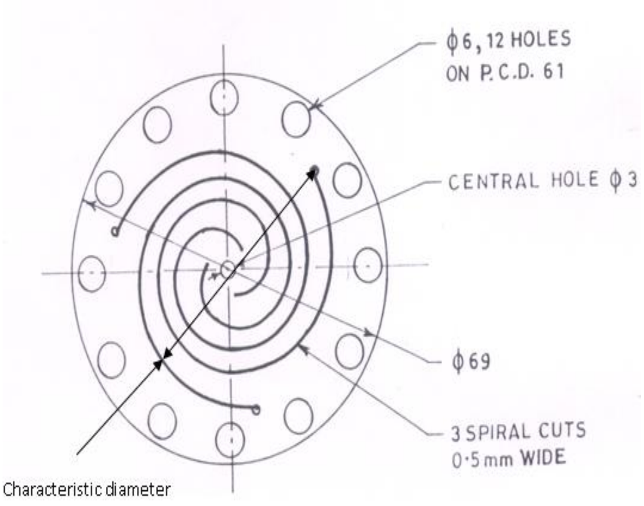
A bearing is a rotating component which is placed between two parts to allow them to move easily. A flexure bearing is just that it allows to parts to move with each other with no trouble. There are several different types of bearings and they all use a different shape to move the two parts, for example ball bearings use little balls, needle bearings use very thin needle tubes, roller bearings use tubes as well but are larger than needle size. So what type of shape is a flexure bearing and how can they help two parts move together freely? A flexure bearing allows the motion of two parts by bending a load element. It means it takes two materials and fixes them together by a flexure bearing and this bearing allows them to move. Think of a door on a hinge. The door needs to be attached the door frame but it also needs to be opened and closed and so a hinge is used. The door and door frame are the two materials and the hinge is the flexure bearing allowing it to move freely.

Flexure bearings are great because they are very simple to manufacture especially compared to some other types of bearings and they are easy and cheap to replace and so maintenance isn't a large issue. Flexure bearings have many advantages including they do not jitter or wobble as they are fixed into place, this minimalies the risk of damage to the bearing and the two rigid parts, they can operate in a vacuum, they have virtually an unlimited life span if the atmosphere is not corrosive, they can work in high and low temperatures, and they don't make a noise when they are operating. Of course these types of bearings have some limitations and downfalls for example they can only be used on materials that do not disintegrate after being repeatedly flexed, their angular excursion is limited, they are more expensive than ball bearings, and they are harder to install.

A linear flexure bearing consists of an arrangement of vertically oriented flexure elements held into place on the top and bottom by rectangular mounting blocks. It is intended to have linear travel with a spring resistance to motion which acts as a self-centering feature. As one mounting block is held stationary a horizontal force is applied to the other mounting block. The flexure elements then bend in an s-shape curve allowing a relative horizontal displacement to occur between the two mounting blocks.

The linear flexure bearing has the same advantages over traditional linear bearings as our flex pivot has over traditional roller bearings. They are frictionless, lubrication-free, self-centering, and when used within design limits have infinite life. They also have predictable hysteresis, vertical shift, and spring rate which make them useful in applications requiring limited travel.

A typical unit of a flexure suspension system is shown in fig. Each unit is in the form of a thin flat metal disc having three spiral slots, yielding three spiral arms which bear the radial and the axial loads. Each spiral sweeps an angle of 720°. In the present work, twelve peripheral holes are used to clamp the disc rigidly onto a support structure. The central hole in the flexure allows for fitting of the shaft snugly. Small holes have been provided at the end of the spiral slots to relieve stress concentration. Sufficient numbers of flexure discs are stacked together to obtain the desired axial and radial stiffness. Two such stacks are used for dynamic stability. Unlike the helical spring (low radial stiffness) which has a buckling tendency, the flexure spring has very high radial stiffness compared to the axial stiffness.



Typical flexure unit of the suspension System

DESIGN REQUIREMENTS

1. FATIGUE STRENGTH

Each arm of the flexure disc due to reciprocating movement is subjected to alternate stresses at operating frequency of the linear motor. For a given axial displacement, the location and the magnitude of the maximum stress in a disc are dependent upon the spiral profile, diameter and thickness of the disc.

2. RADIAL STIFFNESS

The radial stiffness of the flexure bearing assembly Fig 3.3 (a) should be high enough to support the clearance seal under the effect of the suspended mass which comprises mainly of the piston-shaft sub assembly, coil and coil former. In order to evaluate the radial stiffness requirement for each of the flexure discs that constitute the two stacks of the whole bearing assembly, a simplified model [11] shown in Figure 3.3 (b) has been used. Based on the model the piston tip deflection can be expressed as (Refer Figure 5.2 for the distances DF_1, DF_2 and DF_3)

$$DELP = \left[\left(\frac{DF_3}{DF_2}\right)\left(1-\frac{DF_1\left(\frac{n_f}{n_b}\right)}{DF_2-DF_1}\right)+1\right] \times \left[\frac{\left(1-\frac{DF_1}{DF_2}\right)M_p g}{n_f k_{rp}}\right]$$

where n_f and n_b are the number of flexures in the front and the back suspension stacks respectively. The value of the radial stiffness k_{rp} should be high enough to keep the radial deflection (DELP) of the piston lower than the radial clearance between the piston and the cylinder to prevent the undue rubbing between the two. Since mass of the piston at the front side is more and is closer to cylinder bore which requires the lowest radial deflection, number of flexures chosen in the front stack are greater than in the back.

3. AXIAL STIFFNESS

In order to minimize the power drawn by the linear motor of the compressor, the moving mass should resonate based on the combined effect of the gas spring above the piston and the flexure bearing below it. To an order of approximation this can be expressed as

$$M_p \omega^2 = k_g + k_p$$

where k_g and k_p are the spring stiffness for the gas and the flexures and M_p is the effective total mass of the reciprocating components.

Simple analytical methods are inadequate in predicting the operating characteristics of the flexure bearing due to the mutual coupling effect between the three flexural arms making up the bearing. Use of finite element analysis (FEA) method in tackling such a geometrically non-linear problem thus becomes indispensable. FEA has been conducted with a view to examine, apart from the stress distribution, characteristics such as axial stiffness, radial stiffness and extent of parasitic rotation as a function of axial displacement.

According to traditional design procedure the designed system may be safe. But in actual practice traditional design will not take account of stress distribution and considers on lumped mass parameter models. Such designed system may fail if proper attention towards its geometry is not taken. The present work aims at specifically for spiral flexure bearing is designed to decide the thickness of bearing and number of flexure bearings. The analysis is carried out for flexure bearing having 360° spiral slot and 720° spiral slot. Initially a Pro-E representation of flexure bearing assembly is imported to ANSYS in IGES format. By ANSYS 3-D modeling features, the object is revolved to form 3-D object. Axial force of 100N is and results are captured for directional deformation, radial and Von-Mises stresses. Analysis is carried out to decide optimum number of flexure bearings at front and rear side, also checked the effect of bearing thickness and spiral slot on stress and fatigue life.

III. FEA ANALYSIS

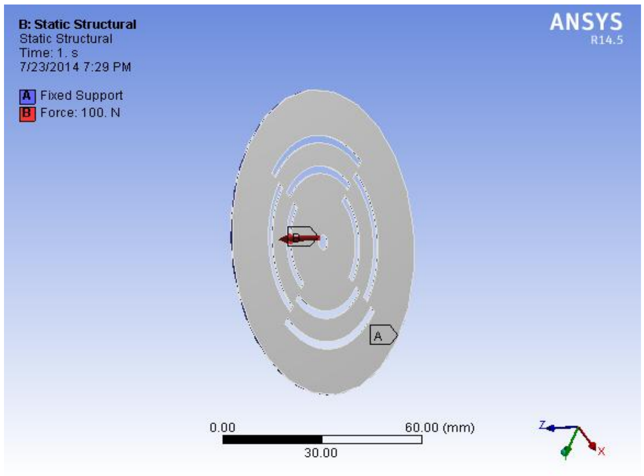
CAD Models are made for these bearing plates and these models are used for FEA analysis in Ansys. FEA analysis for radial flexural plates is carried out by varying thickness of flexural plate (in mm) as input parameters and output parameters as axial deflection (deformation), axial stiffness, radial deformation, radial stiffness, and von-misses stress. Maximum stress is developed at the end of spiral slot. Axial force of 100N is given for the analysis.

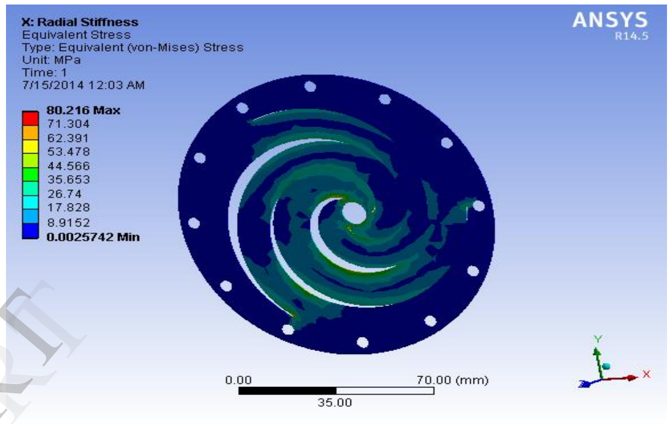
Analysis Inputs:-

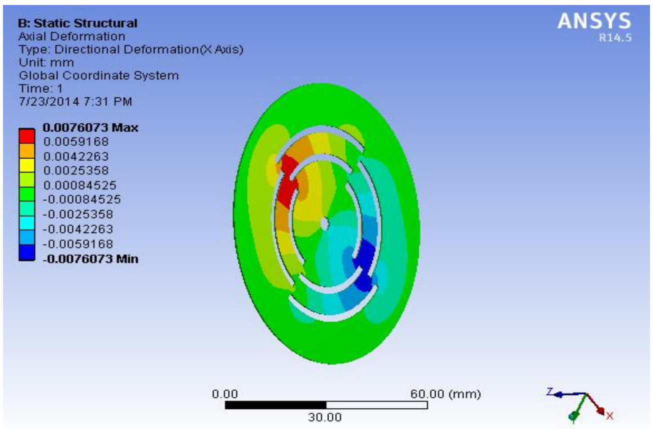
1. Flexural plate thickness varies from 0.4 -1.5mm for radial flexural bearing

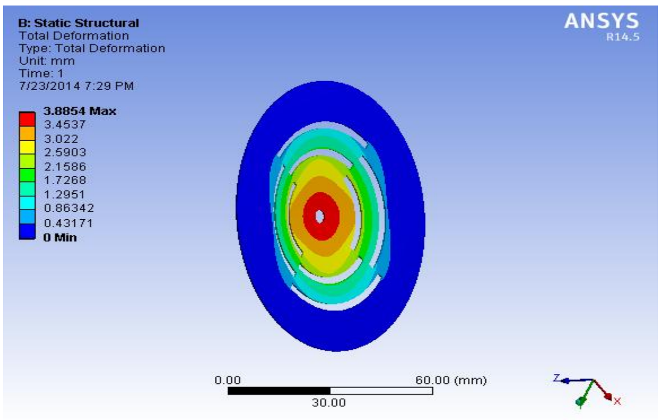
Readings Taken:-

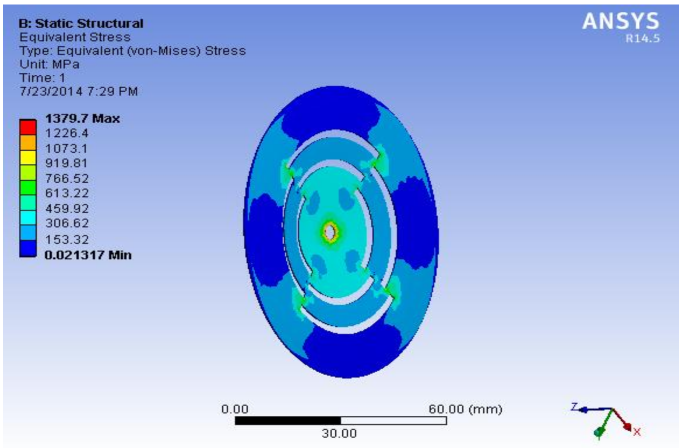
1. Axial deflection
2. Axial stiffness
3. Radial deflection
4. Radial stiffness
5. Von-misses stress











In the similar way the analysis is carried out for various plate thickness as well as for different parameters like radial stiffness, axial stiffness, radial deformation, axial deformation etc.

IV. REGRESSION ANALYSIS

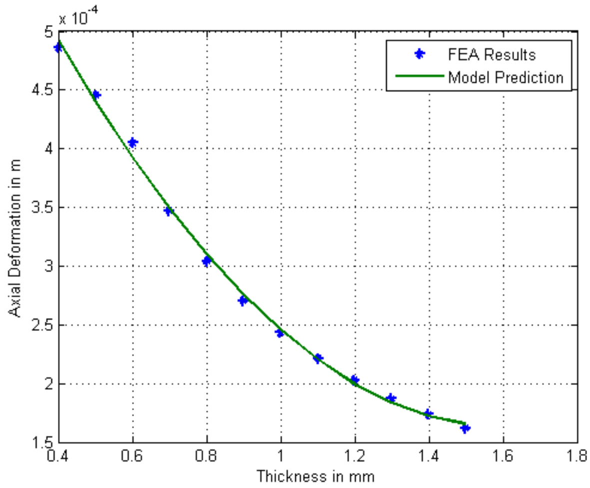
This data is used to generate regression model in Mat-Lab.Results of regression analysis and FEA analysis is listed in table below,

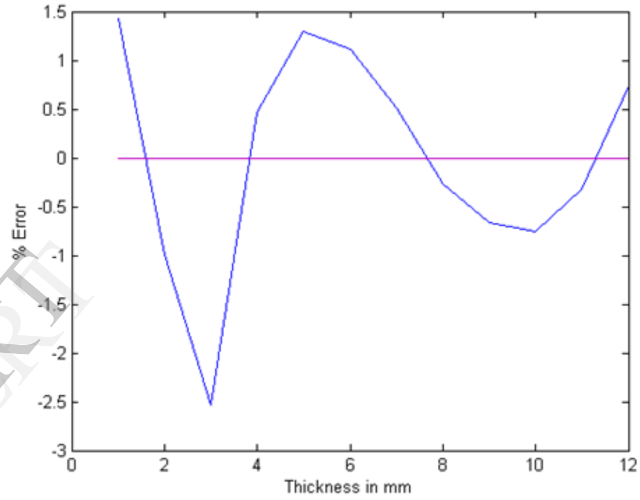
Regression Model for Radial deflection, Radial Stiffness, Von-misses stresses

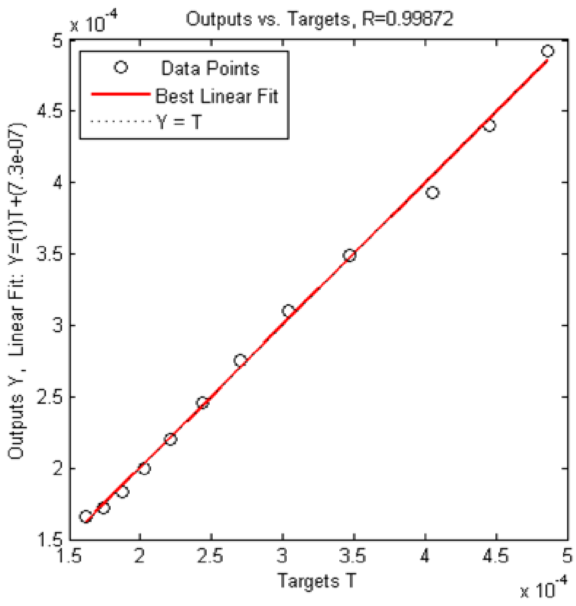
$$Output\ Parameter = a_0 + a_1 T + a_2 T^2 + a_3 T^3$$

Coefficient	a0	a1	a2	a3
Radial Deflection	0.7435 X 10^{-3}	-0.7089 X 10^{-3}	0.2015 X 10^{-3}	0.0095 X 10^{-3}
Radial Stiffness	1.8826 X 10^{4}	-1.5388 X 10^{4}	5.3928 X 10^{4}	-1.6496 X 10^{4}
Von-Misses Stress	6.6282	-6.4772	1.9706	0.03215

It is observed that % error between FEA results and regression models is not more than $\pm$ 5-8%. Further this regression model can be used directly for modeling and analysis of crane hook with circular cross section. These results are better compared using graphical method below





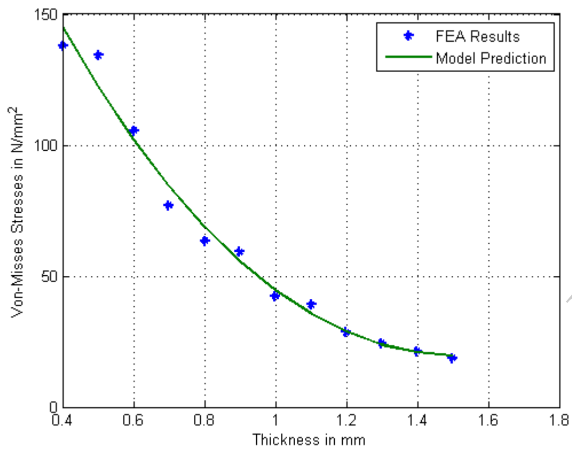


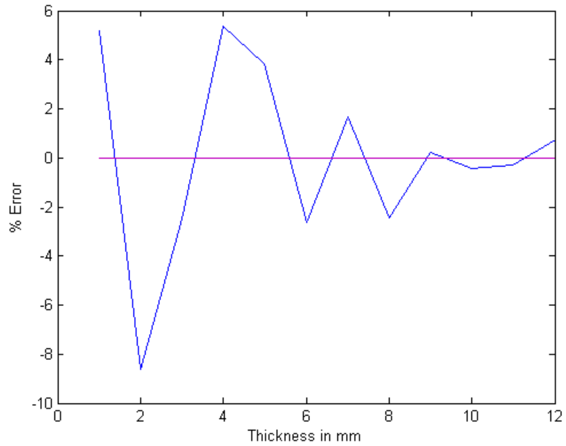
Results for radial deflection of radial flexural bearing using FEA analysis and regression model matches well. % error is less than ±2.5. Similarly, results for radial stiffness of radial flexural bearing using FEA analysis and regression model matches well. % error is less than ±0.5 and results for Von-misses stress for Radial Flexural bearing using FEA analysis and regression model matches well. % error is not more than +5 to -8%.

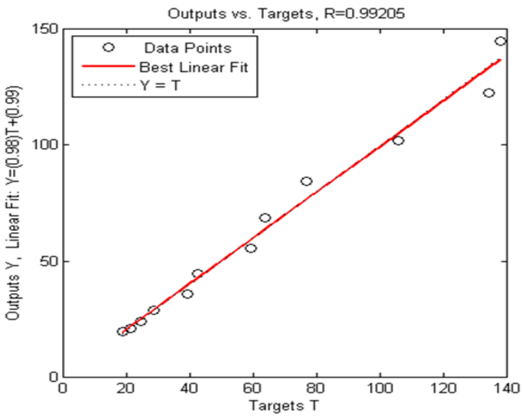
Regression model for Axial Stiffness, Axial deflection and von-misses stress is also done and results are compared with ansys.

$$Output\ Parameter = a_0 + a_1T + a_2T^2 + a_3T^3$$

Coefficient	a0	a1	a2	a3
Axial Deflection	1.0612	-2.2237	1.5951	-0.3845
Axial Stiffness	65.2183	-210.732	225.4506	121.3329







Comparison of FEA Results & Regression Model for Von-misses Stresses. Results for axial deflection of radial flexural bearing using FEA analysis and regression model matches well. % error is less than ±5, results for Axial Stiffness of radial flexural bearing using FEA analysis and regression model matches well. % error is less than ±1.5 and results for Von misses stress of radial flexural bearing using FEA analysis and regression model matches well. % error is not more than + $5\ to - 8$%.

V CONCLUSION

Use of flexural bearings gives many advantages like it has friction and backlash free motion , the complete assembly of flexural bearing has low weight and also power consumption by these bearings is very low.

The results show that value of stress is maximum at the end of spiral slots. Comparison of FEA and regression model shows good amount of matching and error is not more than ± 5%. After analysis of flexure bearing assembly, maximum equivalent stress developed at the critical point is 355.8 MPa. This value is acceptable according to acceptable limit of 400 MPa.

These regression models further can be used for directly determine deformation, stiffness and stresses in flexural bearings provided that these bearings dimensions lies in the range of experimental design.

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