Review of Flexure Bearing

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Abstract— Conventional type of bearing having disadvantage of backlash, higher friction and wear, in order to overcome this limitations new concept was developed i.e. linear bearing. Linear Bearing are nothing but deformable bodies having spiral cut. They offers various advantages over conventional bearing. Now a day's technology of linear compressor uses linear motor which has very less friction. Piston motor, motor shaft is vertically supported by linear bearing. Present paper focuses on study of such linear bearing named as flexure bearing. FEA tool is used for analysis and design of bearing.
Keywords: - Linear Flexure bearing, FEA 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. 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 minimalizes 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 [1]. 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 typical flexure bearing is just one part, joining two other parts. For example, a hinge may be made by attaching a long strip of a flexible element to a door and to the door frame. The most commonly available shapes triangular, rectangular, elliptical and square are considered as different possible shapes [2]. The bearing must satisfy requirements such as it should be able to get the linear motion, it should have sufficient strength and fatigue life for a sustained period of time, it should possess linear / rotational motion accuracy at the nanometer level or better, it should be compact to fit into the limited spaces in various micro-machines and devices [3].

II. BEARINGS

In market huge variety of bearings are available such as ball bearing, roller bearings, pivot bearings, step bearings etc. such bearings offers line or point contact also friction is more, wear phenomenon is also high. Flexure bearing is one of the type having simple construction, low maintenance, low risk of damage. Flexure bearing having advantage over other bearing such as they can work in high and low temperatures, they don't make a noise when they are operating, provides high axial displacement. 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 [4].

III. ROTARY FLEXURE BEARING

Industrial products along with small feature sizes are becoming more important. These products are distributed over wild range of industries, including medicine, automotive, machine tools, electronics, optics, pharmaceutics, and communications [4]. They can be micro-machines (μ-machines) and m-devices which are usually characterized by their small size, light weight, high energy-conversion efficiency and low energy consumption, quick response, high reliability, low cost, high integration, high intelligence level, etc. Typical examples are μ-robotics, μ-machine tools, μ-submarines, μ-actuators, μ-aircrafts, μ-gears, μ-pumps, μ-valves, μ-sensors, and medical μ-instruments [5]. Structures are getting more and more complex and are often three-dimensional (3-D) are common feature to most of the μ-machines and μ-devices while their sizes are becoming smaller, hence their manufacturing is challenging task. Therefore, an important and challenging research topic has been to design μ-machines or μ-devices that are capable of 3-D m-manufacturing at the nanometric accuracy level.

Therefore, H.P. Luo et al [5] studied rotary flexural bearing that is capable of achieving rotational/oscillational motions of high accuracy and a design methodology for such a bearing. The bearing is targeted for use in μ-manufacturing and precision metrology, such as μ-EDM [6], μ-ECM [7], ultrasonic μ-machining [8], laser μ-machining, and coordinate measuring machines. The design of the bearing is based on the principle of flexural mechanisms that realizes rotational/oscillational motions of one complete revolution through the elastic deformation of the elastic flexures.

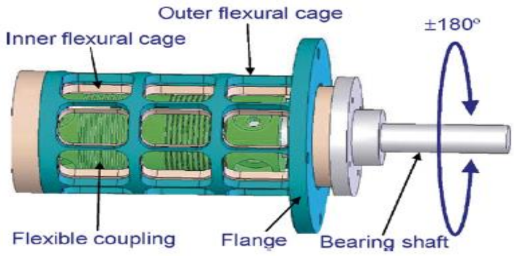

Fig. 1: Schematic vies of bearing configured as a μ-spindle

Here design point of view inner and outer bearing cages are connected at one end. By axis-symmetrically arranging the elastic flexures in the inner and outer cages, the bearing is flexible in the circumferential direction, but stiff in the other directions. The rotational oscillation of 360º (one complete revolution) or larger can be obtained. If a larger angular displacement (e.g., >360º) is desirable, more bearing sections can be added to the design although to do so makes the bearing longer and less stiff. Otherwise, the bearing can have a compact and relatively stiff design [5].

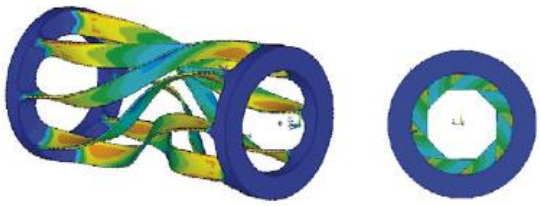

Fig. 2: Schematic vies of bearing configured as a µ-spindle

Perfect axis symmetry of elastic flexures is practically difficult due to the fact that there exist geometric errors in the flexural bearing during the fabrication and assembly processes. Error in motion of the bearing occurs due to errors in the symmetric distribution of the elastic flexures. Use of even number of bearing in design reduces the geometric errors in the fabrication and assembly processes. When the wire electric discharge machining (WEDM) method is used to machine the elastic flexures, for example, two opposing flexures can be simultaneously cut. The simultaneous machining of the two opposing flexures not only minimizes the geometric difference between the two flexures, but also relaxes the machining tolerance of the entire bearing.

For a complete revolution of rotation, the bearing needs to have at least 360º angular displacement. It is impossible for a single-section bearing to achieve such a large deflection. This is because too large deflection in a single bearing section could over stress the elastic flexures, resulting in permanent (plastic) deformation or even fracture. Over deflection could also cause the so-called ''necking'' and ''cross interference'' phenomenon, as demonstrated in Fig. 2. To obtain a large oscillation range without such a problem, the bearing is designed using multiple sections in series.

IV. LINEAR FLEXURE BEARING

The flexural bearing is used for micro-machining and precision applications where low displacement is involved. It offers the advantage of almost frictionless, vibration free and maintenance free operation. The bearing element is deformed to provide desire relative motion between the surfaces. They are made up of deformable bodies called flexure. These flexures are to be designed for required displacement. However the analytical procedure for analysis of the flexure is not available. Hence, an alternative approach of using FEA is applied for design of flexure analysis. In this work flexure having different size and shape such as triangular, square, rectangular and elliptical are analyzed. The analysis of all the above shapes with various thicknesses for least axial, maximum radial stiffness and equivalent stresses is made. Later the results have been analyzed to choose optimum design of flexure [2].

The most commonly available shapes triangular, rectangular, elliptical and square are considered as different possible shapes. For triangular three flexural cuts and for all other shapes four flexure cuts have been chosen for analysis.

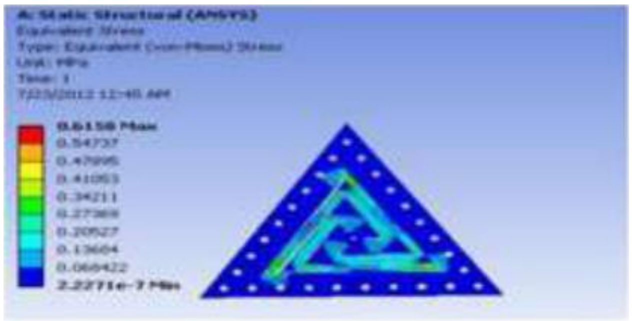

Fig. 3: Von-Mises stresses in triangular bearing [2]

Each of the FE model prepared above was analyzed using ANSYS workbench and results of displacement in axial and lateral direction and Von Misses stresses were noted. It was found that all the flexures have similar pattern as the thickness drops axial deformation increases.

Fig. 3 & 4 shows schematic view of Von Misses stresses and axial deflection of triangular flexure with and without fillet respectively.

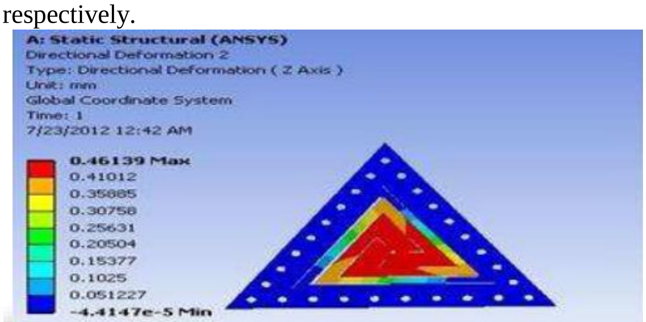

Fig. 4: Directional deformation in triangular bearing [2]

The Fig. 5 & 6 shows the Von Misses stresses distribution within the flexure. It should be noted that at the sharp corners of flexural cuts the Von Misses stresses are high due to stress concentration factor. This phenomenon is found to be present in all the shapes of flexural without fillet.

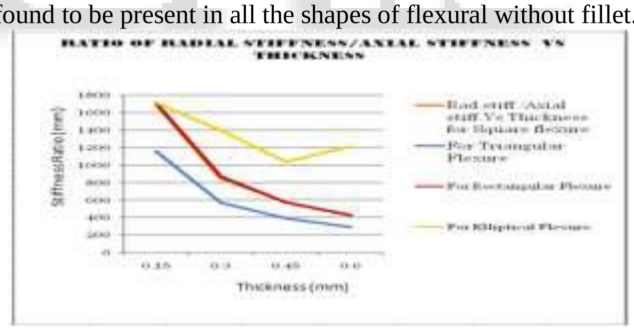

Fig. 5: Ratio of Lateral stiffness to Axial stiffness Vs Thickness

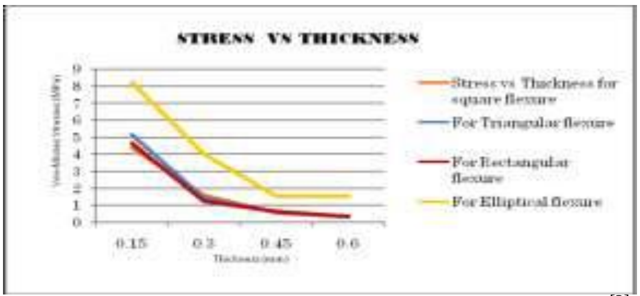

Fig. 6: Von-Misses stress Vs Thickness for all Flexures [2]

Analysis of elliptical Flexure Bearing are done by Saurabh Malpani et al. [3]. They calculate maximum principal stress, maximum shear stress, and equivalent stress for axial loading for force 100 N. Following are the results taken from

Ansys which are generated by solver for axial loading. Similarly, they are calculated results for radial loading.

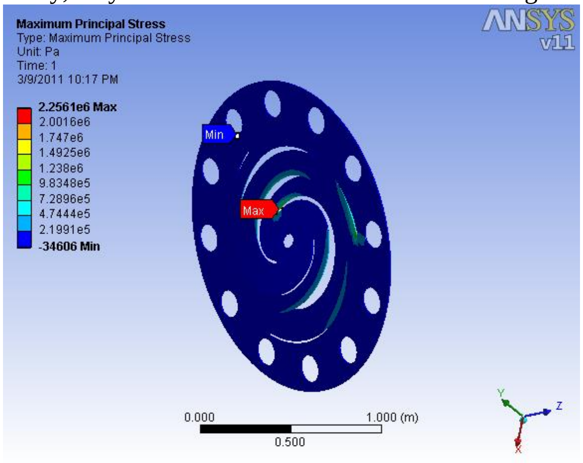

Fig. 7: Axial loading for 100N force [9]

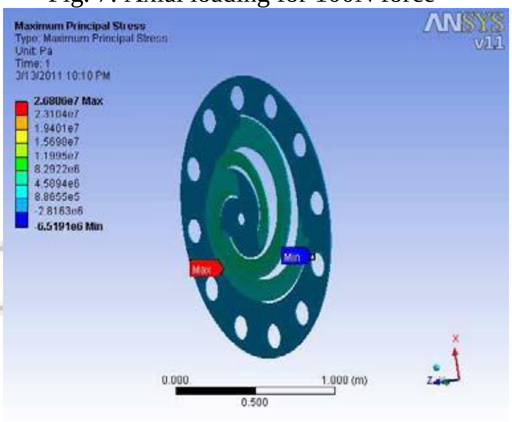

Fig. 8:Radial loading for 100N force [9]

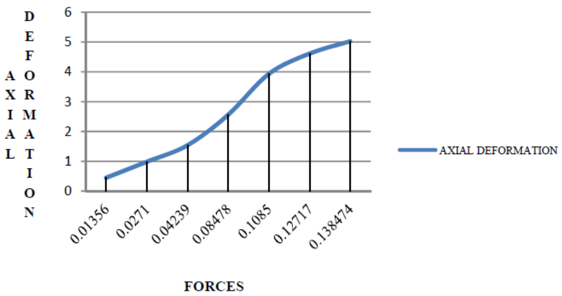

Fig. 9: Axial deformation for varying force

The axial deformation for applied force has been plotted in fig. 9 which indicates nonlinear variation of the deflection for the applied force. Initially the rate of deflection is high which further increases. When the flexure opens more. However, ones it has opened, the rate of deformation falls almost exponentially. Dropping the axial deformation par unit force applied for the higher loads as shown in fig 9. Beyond 0.1085 N, there is significant drop in the axial deformation for the increment in applied load [9].

The table 1 shows the FE results for different shapes and thicknesses at 5N force and obtained axial and lateral deformation also Von-Misses stress. From the table it is evident that the elliptical flexures were found to have more axial deformation. However it was also found that the

Shape	**Thickness**	**Axial Deformation**	**Radial Deformation**	**Von-Misses stress**
	mm	mm	mm	MPa
Square	0.3	5.3772	0.00633	1.5520
	0.6	1.0239	0.00242	0.3164
Triangular	0.3	2.9594	0.00520	1.4131
	0.6	0.6265	0.00214	0.3374
Rectangular	0.3	5.3913	0.00620	1.2230
	0.6	0.7495	0.00175	0.3112
Elliptical	0.3	35.917	0.02580	3.9785
	0.6	8.6327	0.01117	1.5052

Table 1 Results for various shapes of Flexure Bearing [2]

elliptical flexures show higher radial/lateral deformation for the applied load that the other shapes. Hence decision parameters of ratio radial stiffness to axial stiffness may be chosen as higher the stiffness ratio more the desirable flexure.

V. CONCLUSION

Use of flexural bearings gives advantages such as friction and backlash free motion, low power consumption, low weight of complete assembly. Spiral flexural bearings with spiral slot require larger amount force as compared to slotted spiral flex bearing. Comparison of analytical and F.E.M. shows good amount of matching and stress induced are within design limits.

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