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# Finite Element Analysis of Various Shapes of Flexures

Sunil Girde[1], Prof. Y. L. Yanarkar[2]
*[1,2]Department of Mechanical Engineering Rajiv Gandhi College of Engineering, Research and Technology, Chandrapur (M.S.) India*

***Abstract:*** *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.*

***Key Words:*** *Flexural Bearing, Stress Analysis, Deformation, Finite Element Analysis*

## I. Introduction

For micro-machining and precision applications where low displacement are involved the frictionless, vibration-free flexural bearing are advantageous to the conventional bearings that involves friction. The nature of application demands that the least energy be wasted in the bearing function. Hence, maintenance free flexural bearings are the most suitable options. These are made-up of deformable bodies called flexure, which deform on application of load retrieved their position removal of it. The flexural bearing is unconventional and use in specific applications. It does not have standardized conventional design procedure. The relations for standard design are not available. Hence, FEM is the tool in designing flexural bearings. Malpani [1], Gaunekar et.al [2] have presented the FE analysis approach using the circular shape flexure with spiral cuts.

The present study is on different shapes of flexures and thicknesses. 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 this analysis. The thicknesses for all the flexure are varied from 0.15 to 0.6mm in the steps of 0.15 mm. The FE models of all the combination of shapes and thickness were made with periphery fixed and load applied at the center hole in the steps of 0.5N from 0.5N to 5N. Each of flexure for with and without fillet flexural cuts was analyzed. Fig. 1.1 shows the discretization of elliptical shapes flexure. The table 1.1 shows the discretization details of flexures of various shapes.

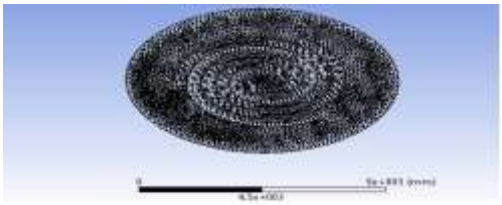

Fig. 1.1: Discritization of Elliptical Flexural Bearing

1.1: Detail of Discritization of Various Flexures

| Sr. No. | Shape | Thickness (mm) | With Fillet | | Without Fillet | |
|---|---|---|---|---|---|---|
| | | | No. of Nodes | No. of | No. of Nodes | No. of |
| 1 | Elliptical | 0.15 | 4057 | 1800 | NA | NA |
| | | 0.3 | 3349 | 1468 | NA | NA |
| | | 0.45 | 16070 | 7672 | NA | NA |
| | | 0.6 | 9042 | 4219 | NA | NA |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2 | Rectangular | 0.15 | 1610 | 200 | 13848 | 1885 |
| | | 0.3 | 1329 | 163 | 31383 | 5992 |
| | | 0.45 | 10717 | 1803 | 14159 | 6693 |
| | | 0.6 | 7479 | 1236 | 30099 | 5736 |
| 3 | Triangula | 0.15 | 3435 | 446 | 11630 | 2116 |
| | | 0.3 | 3444 | 1546 | 13820 | 2380 |
| | | 0.45 | 3885 | 609 | 16925 | 3328 |
| | | 0.6 | 2835 | 432 | 19606 | 3720 |
| 4 | Square | 0.15 | 7460 | 991 | 7016 | 928 |
| | | 0.3 | 1333 | 163 | 30521 | 5819 |
| | | 0.45 | 10966 | 1843 | 30567 | 5829 |
| | | 0.6 | 7421 | 1223 | 29836 | 5682 |

## II. Analysis Results

Each of the FE model prepared above was analyzed using ANSYS(TM) 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.

The FE results for the triangular case with and without fillet are tabulated in table 1.2 and 1.3 respectively.

Fig. 1.2, 1.3 and 1.4, 1.5 shows schematic view of Von Misses stresses and axial deflection of triangular flexure with and without fillet respectively.

1.2: Triangular Shape Flexure 0.6mm thickness without fillet

| Sr. No. | Force (N) | Lateral Deformation (mm) | | Axial Deformation (mm) | Von Misses Stress (MPa) | Axial Stiffness (N/mm) | Radial/Lateral Stiffness (N/mm) |
|---|---|---|---|---|---|---|---|
| | | X | Y | Z | | | |
| 1 | 0.5 | 0.0002782 | 0.000138082 | 0.041543 | 0.006328 | 12.03563 | 1796.881 |
| 2 | 1 | 0.0004174 | 0.000276169 | 0.083086 | 0.126556 | 12.03572 | 2395.783 |
| 3 | 1.5 | 0.0004174 | 0.000414251 | 0.12463 | 0.189829 | 12.03563 | 3593.667 |
| 4 | 2 | 0.0005565 | 0.000552322 | 0.166177 | 0.253116 | 12.03536 | 3593.664 |
| 5 | 2.5 | 0.0004632 | 0.000690433 | 0.2077 | 0.316386 | 12.03659 | 5396.456 |
| 6 | 3 | 0.0008348 | 0.000828503 | 0.24926 | 0.379673 | 12.03563 | 3593.662 |
| 7 | 3.5 | 0.0009739 | 0.000966574 | 0.29081 | 0.442944 | 12.03535 | 3593.662 |
| 8 | 4 | 0.0011130 | 0.001104685 | 0.33235 | 0.506216 | 12.0355 | 3593.664 |
| 9 | 4.5 | 0.0012522 | 0.001243543 | 0.3738 | 0.569502 | 12.03852 | 3593.664 |
| 10 | 5 | 0.0013913 | 0.001380866 | 0.46139 | 0.6158 | 10.83682 | 3593.663 |

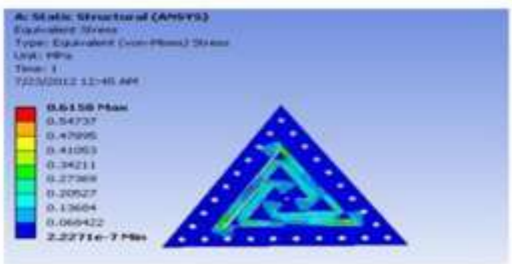

Fig. 1.2: Von Misses Stresses Developed in Triangular Type Flexural Bearing without fillet at 5N force

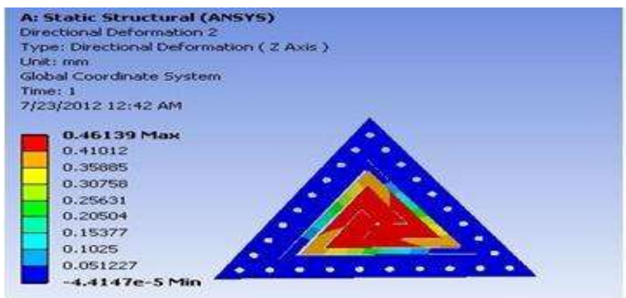


Fig. 1.3: Axial Deflection Developed in Triangular Type Flexural Bearing without fillet at 5N force

1.3: Triangular Shape Flexure 0.6mm thickness with fillet

| Sr. No. | Force (N) | Lateral Deformation (mm) | | Axial Deformation (mm) | Von Misses Stress (MPa) | Axial Stiffness (N/mm) | Radial/ Lateral Stiffness (N/mm) |
|---|---|---|---|---|---|---|---|
| 1 | 0.5 | 0.0002 | 0.0002 | 0.0626 | 0.0337 | 7.98 | 2500 |
| 2 | 1 | 0.0004 | 0.0004 | 0.12531 | 0.0675 | 7.98 | 2500 |
| 3 | 1.5 | 0.00064 | 0.00065 | 0.1879 | 0.1012 | 7.98 | 2343.75 |
| 4 | 2 | 0.00085 | 0.00085 | 0.2506 | 0.135 | 7.98 | 2352.94 |
| 5 | 2.5 | 0.00107 | 0.00108 | 0.3132 | 0.1687 | 7.98 | 2329.92 |
| 6 | 3 | 0.00128 | 0.0013 | 0.3759 | 0.2025 | 7.98 | 2343.75 |
| 7 | 3.5 | 0.0015 | 0.00151 | 0.4386 | 0.2362 | 7.98 | 2333.33 |
| 8 | 4 | 0.00171 | 0.00173 | 0.5012 | 0.2699 | 7.98 | 2339.181 |
| 9 | 4.5 | 0.00193 | 0.00195 | 0.5639 | 0.3037 | 7.98 | 2331.606 |
| 10 | 5 | 0.00214 | 0.00216 | 0.6265 | 0.3374 | 7.98 | 2336.448 |
| | | | | | | | |

Fig. 1.4: Axial Deflection Developed in Triangular Type Flexural Bearing with fillet at 5N force

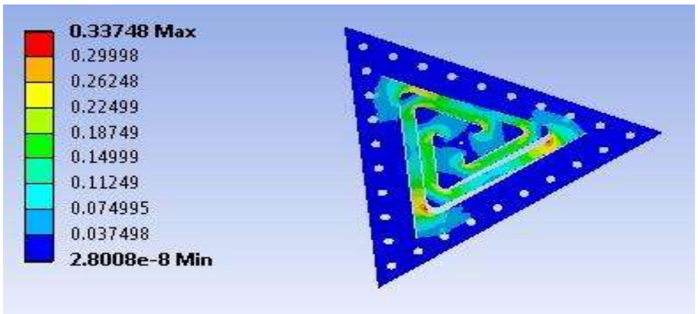


Fig. 1.5: Von misses Stresses Developed in Triangular Type Flexural Bearing with at 5N force fillet

The Fig. 1.6 to 1.8 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.

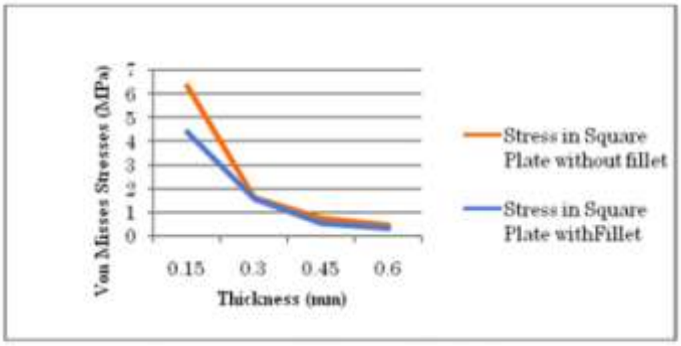


Fig. 1.6: Von Misses Stress Vs Thickness for Square Flexure

Fig. 1.6: Von Misses Stress Vs Thickness for Square Flexure

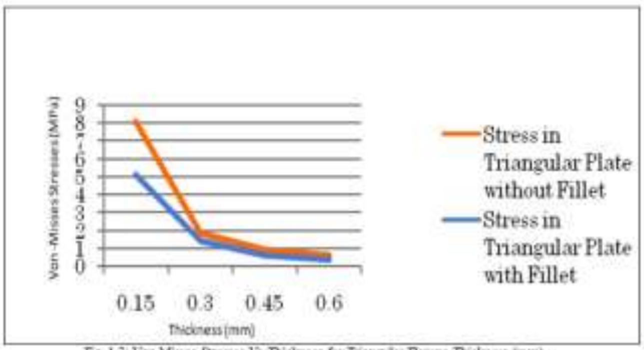


Fig. 1.7: Von Misses Stresses Vs Thickness for Triangular Flexure Thickness (mm)

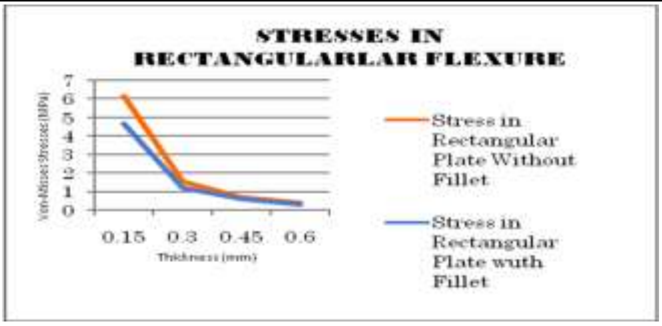


Fig. 1.8: Von Misses Stresses Vs Thickness for Rectangular Flexure

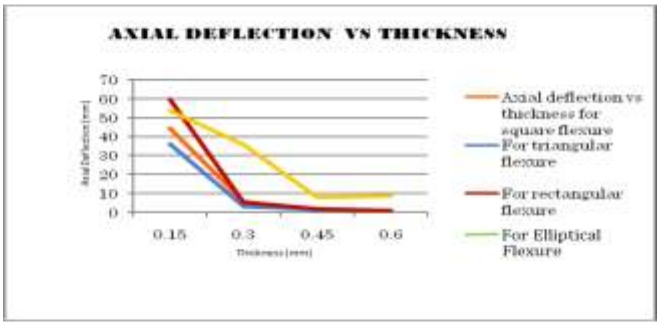


Fig. 1.9: Axial deflection Vs Thickness for Flexures

Fig. 1.9 shows the variation of axial deflection verses thickness that for all flexures. Since too thin flexures tend to have more stresses and more lateral deformation, the flexures with 0.15 mm thickness were found to be not suitable. Among rest of the thicknesses, the elliptical flexures were found to have more axial displacement for applied load applied load.

The table 1.4 shows the FE results for different shapes and thicknesses at 5N force and obtained axial and lateral deformation. From the table it is evident that the elliptical flexures were found to have more axial deformation. The Fig. 1.9 shows the variation of axial deformation against thickness for various shapes, Hence it may be stated that for higher axial deformation as required by design, elliptical flexures are most suitable.

However it was also found that the 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. Fig. 1.10 depicts the relationship between stiffness ration and thickness for various shapes. Further it should also be noted that the maximum Von Misses stresses for elliptical flexures were found to be higher than stresses for other shapes. Therefore it can be said that when the radial/ lateral deformation and stresses in the flexure are to be limited the shapes other than elliptical shapes offer better choice. Fig. 1.11 shows the stress variation among different shapes for 5N applied load.

1.4 : Optimization Of Various Shapes Of Flexure Bearing With Fillet

| Shape | Thickness (mm) | Force (N) | Von Misses Stress (MPa) | Axial Deflection (mm) | Radial Deflection (mm) | Axial Stiffness (N/mm) | Radial Stiffness (N/mm) | Radial /Lateral Stiffness/Axial Stiffness(N/mm |
|---|---|---|---|---|---|---|---|---|
| Square | 0.15 | 5 N | 4.386 | 44.423 | 0.02621 | 0.11255 | 190.8396 | 1695.5984 |
| | 0.3 | | 1.552 | 5.3772 | 0.00633 | 0.9298 | 789.8894 | 849.5261 |
| | 0.45 | | 0.543 | 1.7212 | 0.0030 | 2.9049 | 1666.67 | 573.7443 |
| | 0.6 | | 0.3164 | 1.0239 | 0.00242 | 6.707 | 2840.9091 | 423.57374 |
| Triangular | 0.15 | 5 N | 5.129 | 36.287 | 0.03147 | 0.13779 | 159.0482 | 1154.2797 |
| | 0.3 | | 1.4131 | 2.9594 | 0.0052 | 1.6895 | 963.5974 | 570.3447 |
| | 0.45 | | 0.6081 | 1.4452 | 0.0037 | 3.45972 | 1351.3514 | 390.59559 |
| | 0.6 | | 0.3374 | 0.6265 | 0.00214 | 7.9808 | 2336.4486 | 292.7586 |
| Rectangular | 0.15 | 5 N | 4.6569 | 59.812 | 0.03489 | 0.1148 | 196.07 | 1707.9268 |
| | 0.3 | | 1.223 | 5.3913 | 0.0062 | 0.9274 | 806.4516 | 869.5816 |
| | 0.45 | | 0.6091 | 1.7306 | 0.00302 | 2.8891 | 1655.6291 | 573.0605 |
| | 0.6 | | 0.3112 | 0.7495 | 0.00175 | 6.67111 | 2857.1428 | 428.2859 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Elliptical | 0.15 | 5 N | 8.1969 | 53.875 | 0.0387 | 0.09281 | 129.198 | 1713.6968 |
| | 0.3 | | 3.9785 | 35.917 | 0.0258 | 0.1392 | 193.7984 | 1392.2298 |
| | 0.45 | | 1.5228 | 8.0241 | 0.00773 | 0.6231 | 646.6101 | 1037.73086 |
| | 0.6 | | 1.5052 | 8.6327 | 0.01117 | 0.7955 | 614.7717 | 772.81169 |

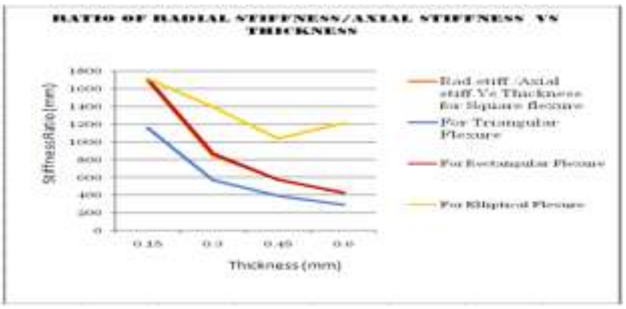


Fig. 1.10 : Ratio of Lateral Stiffness to Axial Stiffness Vs Thickness

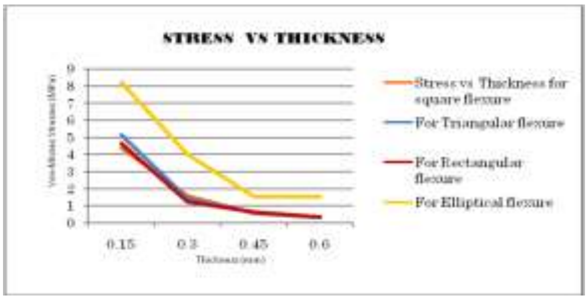


Fig. 1.11: Von Misses Stresses Vs Thickness for All Shape Flexures

## III. Conclusion:

From the analysis results it may be concluded that the flexures with fillet have better distribution of stresses that flexures without fillet. Furthers the different shapes of flexures with fillet were investigated using FEA and it was found that they offers almost the similar behavior with comparable stresses when loaded. Though the elliptical flexures offer more axial deformation and hence could be a better choice. This advantage is negated by the more lateral/ radial deflection and the higher stresses in the flexure. Hence it may be concluded that the exact choice of flexure may be made depending on acceptable stresses levels, shape and space requirement of the application for which the flexural is to be used.

## Reference


[1]. Saurabh Anand Malpani, Yogesh Yenarkar, Suhas Deshmukh, FE Analysis of flexural bearing for linear compressor, *International Journal of applied research in Mechanical Engg. Vol. I, issue-I,* 2011. S. Gaunekar, T. Goddenhenrich, C. Heiden, Finite element analysis & testing of flexure-bearing elements, *Cryogenics-1996, Vol. 36, No. 5,* pp. 359-364.

[2]. W. E. Kepple, Dave W. Read, Fouad Y. Zeidan, Christian Paraskevakos, Matthew P. Dawson, *proceedings of the 15th International pump users symposium.*

[3]. M. Mai, I. Ruchlich, C.Rosenhagen & Th. Wiedmann, Development of the miniature flexure bearing cryocoolers, SFO70, *International Cryocoolers Conference, INC, Boulder Co*, 2009.

[4]. C. Rosenhagen & Th. Wiedmann, Flexure Bearing Compressor in the One Watt Linear (OWL) Envelope, *Electrodynamic oscillating compressor Part- 1,* pp.656-663 and *Part-2,* pp.664-670.

[5]. Shorya Awtar, Alexander H., Slocum, Parasitic Error-free Symmetric Diaphragm Flexure, and a set of precision compliant mechanisms based it: Three and Five DOF flexible torque couplings, Five DOF motion stage, single DOF linear/axial bearing, *Paper publish in precission in Engg. Research Group, Massachusetts Institute of Technology.*

[6]. Willem Van de Groep, Tony Benschop, Wordragen, The development of a new generation of miniature long – life linear coolers, *Conference ICC16,* p.1 of 10 year 2010, *Thals publication*.

[7]. T.R. Chandrupatla. A.D. Belagundu, *Finite elements in engineering* (Pearsons Education)

[8]. Practical finite element analysis finite to infinite publications, Pune By Nitin Gokhale, Sanjay Deshpande.

[9]. Timoshenko, *Theory of plates and shells* (McGraw Hill publication), second edition, pp.62, 63