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Design Modeling and Experimentation of Linear Motion Transducer by Using Flexural Bearing.

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***Abstract*— The availability and wide range of applications of low cost sensors have encouraged a demand for improved sensor performance. Smart sensors are becoming integral parts of system and are performing the functions that previously could not be performed. Displacement can be measured by using precise measuring instruments such as LVDT, laser instruments which offers high speed, high resolution and highly accurate laser sensors (non-contact linear position sensor) for measuring displacement and position. But all these instruments are very costly and require high maintenance and they are very complex in design. So there is need to develop a system which gives high accuracy as that of existing measuring instruments and should also have low manufacturing and running cost. Proposed system consists of unique design of flexural bearing which is highly sensitive to axial movement. Deflection of bearing is recorded by the strain gauges in the form of resistance. This resistance is converted into the voltage form using strain gauge module. This voltage is given to ARDUINO microcontroller and using MATLAB program the results are generated.**

***Index Terms*— Flexural bearing, FEA, Strain gauge, MATLAB, ARDUINO.**

I. INTRODUCTION

THE flexure hinge is a mechanical member that substitutes a conventional rotational joint in order to produce a limited angular motion about one axis. Flexural mechanisms are colossal structures which provide desired motion with the help of flexural hinges. Due to their smooth operation flexural joints have little friction losses and also does not require lubrication. They generate smooth and continuous displacement without backlash. Flexure jointed mechanism have been widely utilized in precision instruments such as watches & clocks for hundreds of years, and continued to be used today in applications such as optical systems, micro robots, and clean room equipment.

Metal rollers meet the meaning of a requirement entirely well, since they are firm in one heading, and give low imperviousness to movement in different bearings. By the by, movement toward DOF is connected with undesirable impacts, for example, erosion, stiction and backfire that ordinarily emerge at the interface of two surfaces. These impacts are non-deterministic in nature, and breaking point the movement quality.

A. Flexural mechanism and significance

Flexure direction has the point of preference over most different heading that they are straightforward and therefore reasonable. They are likewise regularly smaller, lightweight, have low contact, and are less demanding to repair without particular gear. Flexure direction has the impediments that the scope of movement is restricted, and frequently exceptionally constrained for orientation that bolster high loads. Flexure course can give low erosion furthermore give extremely unsurprising rubbing. Numerous different heading depend on sliding or moving movements, which are fundamentally uneven in light of the fact that the bearing surfaces are never consummately level. A flexure bearing works by bowing of materials, which causes movement at tiny level, so grinding is extremely uniform. Consequently, flexure direction is regularly utilized as a part of touchy accuracy measuring hardware.

Flexure jointed instrument have been generally used On precision instruments for example, such that watches & tickers to hundreds about years,, and continued to be used today in applications such as optical systems, micro robots.

B. Types of flexural

a) Flexural Hinge

Flexure hinges hold several advantages over classical rotational joints, including

a. No friction losses
b. No need for lubrication
c. No hysteresis
d. No clearance
e. No wear.
f. Low stiffness (bending, torsion)
g. limited movement

Applications:- micro and nano-scale mechanisms in precision engineering.

b) Flexural Beam

A beam is define as a member whose length is relatively larger than its thickness and depth, and which is loaded with a transverse load that produce significant bending effect as oppose to twisting and axial load. Flexural characterizes the behavior of slender structural element subjected to an external load applied perpendicularly to the longitudinal axis of the beam.

II. LITERATURE REVIEW

S. C. Saxena, et al [1] "A self-compensated smart LVDT transducer," Presents a new technique of dual secondary coils for self-compensation of a linear variable differential transformer (LVDT) transducer for variations in excitation current and frequency and changes in ambient and coil temperatures. Linear variable differential transformer (LVDT) transducers LVDT is influenced by transducer geometry, arrangement variations in excitation current and frequency, and changes in ambient and winding temperatures. experimental results that the compensated dual secondary The dual winding compensation technique introduces a technique makes the transducer & quot; smart& quot; enough to provide self-compensation without circuits, or transducer assembly and also on its placement for a self-compensated smart LVDT transducer It is evident from the theoretical relationships and the experimental results that the compensated dual secondary winding LVDT has better performance than a conventional type. The compensated LVDT is highly insensitive to variations in excitation current, excitation frequency and changes in temperature.

F. N. Toth, et al [2] "A Low-Cost, Smart Capacitive Position Sensor" describes a novel high-performance, low-cost, capacitive displacement measuring system. The basic sensing element consists of two simple electrodes is surrounded by a guard electrode. Electrodes, an inexpensive microcontroller and a linear provided with an accurate reference capacitor, a low-cost, high-performance displacement sensor has provided with an accurate reference capacitor.

Subir Das, et al [3] "A New Method of Linear Displacement Measurement Utilizing Grayscale Image" here linear displacement measured in the range of millimeter or less by applying very small force, capacitive displacement sensors are useful for that. The strain gauge based displacement sensor has introduced mechanical error in terms of ruggedness and acoustic displacement sensor suffering from the environmental noise and self-oscillating detector by means of reflected sound energy. To measure the linear displacement here a designed a sensor module which consists of a plate with laminated gradient grayscale image and an optical sensor. Hence as the target displaced, the plate as well as the grayscale image shifted accordingly due to the coupling between plate and target through a shaft.

M. V. Karateet, et al [4] "Optimization of Flexure Bearing Using FEA for Linear Compressor" states that stringent demands on the repeatability of lens position and orientation call for the use of flexure bearings. Flexures offer incomparably high repeatability of motion since motion is enabled through elastic deformation of the material. Absence of relative motion between two contacting parts leads to frictionless, wear-free operation. Thus, if designed adequately to withstand fatigue, flexure bearings can easily outlast rolling element bearings and slider bearings. They are relatively inexpensive to produce and simple to assemble.

H.P. Luo, et al, [5] "A rotary flexural bearing for micro manufacturing", provides a design analysis on the various aspects of the bearing, including material selection, stress analysis and calculations (such as nonlinear finite element analysis, static and fatigue strength designs), This study proposes a novel rotary flexural bearing that is that is capable of achieving rotational/oscillation motions of high accuracy and a design methodology for such a bearing. Bearing subjected to cyclic stress condition, the fatigue problem must be taken into consideration at the design stage in order to have bearing a long lifetime. Generally titanium or beryllium copper is used as material of bearing. In the design calculations, finite element method (FEM) was used on a single bearing section for the respective inner and outer bearing cages which were formed by the serial connection of the individual bearing sections.

III DESIGN METHODOLOGY

3.1 Material Selection for Flexural Bearing

Material Selected: for manufacturing of flexural bearing Beryllium Copper (Be Cu) is selected. The Beryllium Copper alloys are the most versatile of all copper alloys. Beryllium copper has highest strength and high Young's modulus of elasticity in copper alloys. They combine a wide range of properties that make our alloys the ideal materials to meet the exacting requirements of many products demanding high specifications that are used in the most diverse markets.

The alloys offer a wide combination of mechanical and electrical properties, combining with excellent formability which is unique for copper alloys. The mechanical strength achieved after a simple heat treatment, at low temperature, ranks highest amongst all the copper-based alloys, and combined with a high electrical conductivity outperforms any bronze alloys. Beryllium Copper exhibit a wide range of desired properties such as high fatigue strength, excellent corrosion, wear and abrasion resistance. They are also non-magnetic and non-sparking.

Properties of Beryllium Copper.

Sr. No	Properties	Value	Unit
1	Density	8.36	g/cub.cm
2	Elastic Modulus	130	GPa
3	Tensile Strength Ultimate	410-700	GPa
4	Tensile Yield Strength	190-400	GPa

IV. FEA ANALYSIS

From analysis of flexural bearing following meshing data is obtained. Material and Element Selection For the required case of ANSYS copper was chosen and the element chosen was 20 nodes solid 186. The ISO of copper and copper alloy is ISO 1190-1:1982. The geometric model is meshed in ANSYS 14.5 workbench. Hence, it was decided to create maximum possible elements as offered by the default assistant ANSYS. Table shows the no. of

nodes of element
Type of element: Tetra-hedral mesh
Number of nodes: 47232
Number of elements: 21549
Element size = 2 mm

A. Design of Bearing

a) Model No. 1

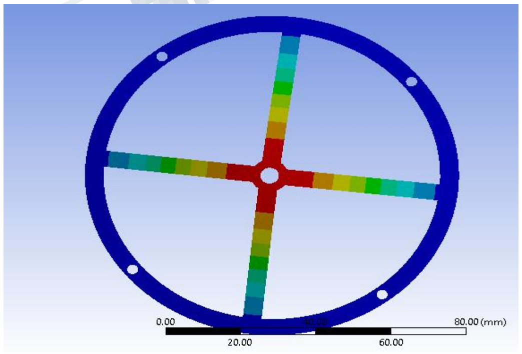


Figure IV 1 Model 1

Diameter (mm)	100
Thickness (mm)	0.3
Force (N)	1
Deflection(mm)	2.19
Stress (MPa)	146.818
Strain	0.001142

Table no.1

We required maximum deflection by applying minimum force but in this case even after applying high force we are getting very less deflection. That's why we are not using this model.

b) Model No. 2

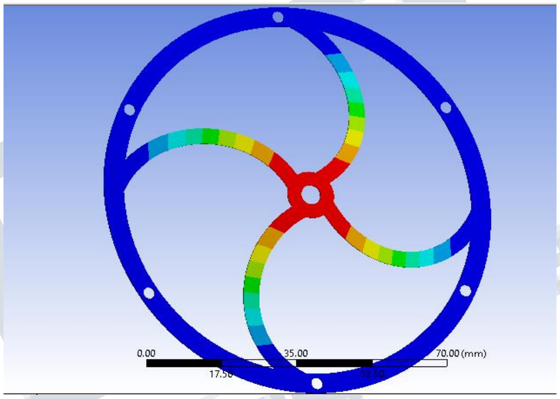


Figure IV 2 Model 2

Diameter (mm)	100
Thickness (mm)	0.3
Force (N)	1
Deflection(mm)	2.0566
Stress (MPa)	110.7
Strain	0.001

Table 3

Due to unsatisfactory result in straight rib, we have designed a new flexural ring with helical rib. We increased the effective length of the rib, because of that we got more deflection by applying minimum force.

c) Model No. 3

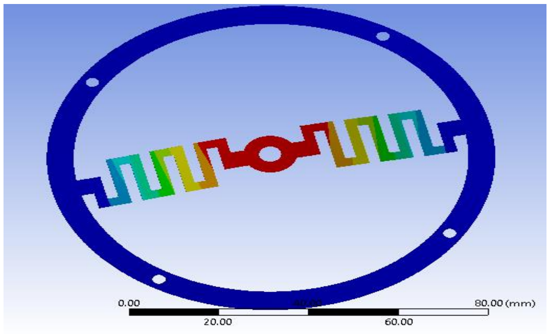


Figure IV 3 Model 3

Diameter (mm)	100
Thickness (mm)	0.3
Force (N)	1
Deflection(mm)	7.2708
Stress (MPa)	344.62
Strain	0.00279

Results with helical rib are not that much satisfactory in our project point of view. Therefore we tried to increase the effective length of rib for getting maximum deflection. But in this case the stress is much more than tensile yield strength of the material; therefore there are maximum chances of failure.

d) Model No. 4

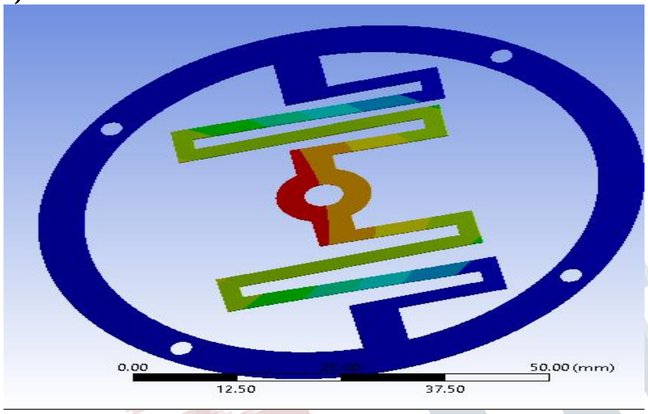


Figure IV 4 Model 4

In this model we have again increased the effective length of the rib and it turns out into maximum deflection. But the main drawback in this design is that the stresses induced in ring are very high. So it cannot sustain it.

Diameter (mm)	100
Thickness (mm)	0.3
Force (N)	1
Deflection(mm)	10.357
Stress (MPa)	415.45
Strain	0.003

Table 5

e) Model No. 5

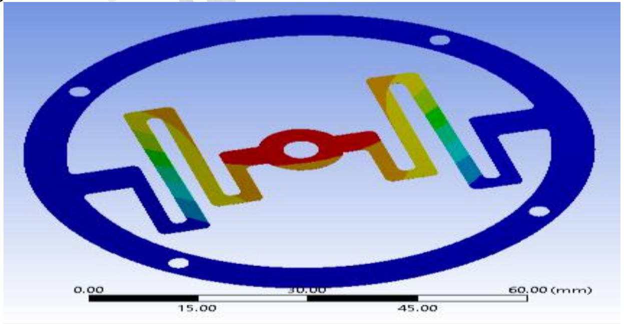


Figure IV 5 Model 5

Diameter (mm)	100
Thickness (mm)	0.3
Force (N)	1
Deflection(mm)	7.7684
Stress (MPa)	364
Strain	0.00279

Table 6

For overcoming the drawbacks of the 4th model, we have filleted the sharp corners into the smooth ones. It has reduced the stress but along with that the deflection also got reduced.

f) Model No. 6

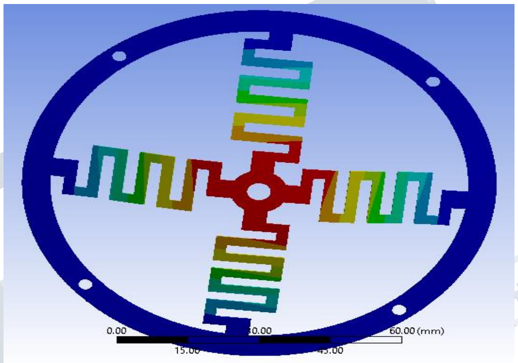


Figure IV 6 Model 6

Diameter (mm)	100
Thickness (mm)	0.3
Force (N)	1
Deflection(mm)	3.568
Stress (MPa)	171.38364
Strain	0.00139

Table 7

Model No.	Deflection (mm)	Stress (Mpa)	Strain
1	2.19	146.818	0.001142
2	2.0566	110.7	0.001
3	7.2708	344.62	0.0027
4	10.357	415.45	0.003
5	7.7684	364	0.00279
6	3.568	171.38	0.00139

Table No.8 Summery of FEA results

V. EXPERIMENTATION LAYOUT

The experiment was carried out by using two displacement measurement methods; one is most known LVDT and another one by using stain gauge transducer.

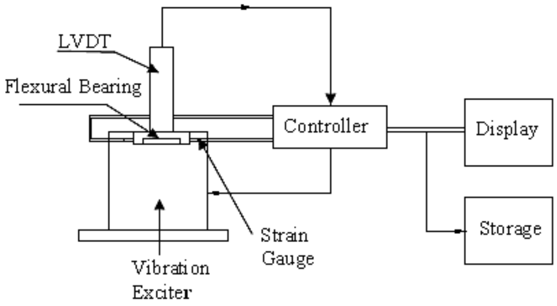


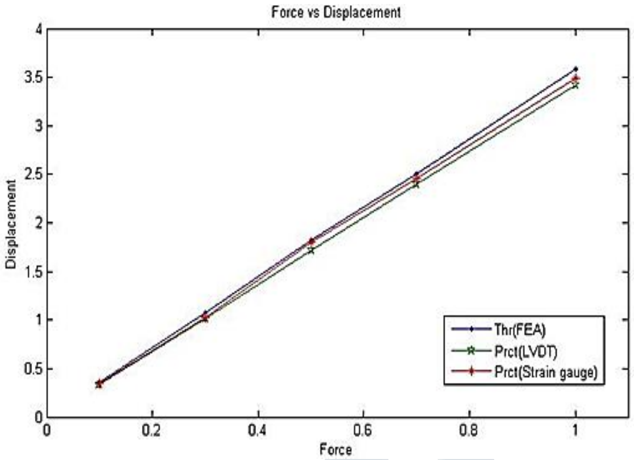
Fig. No. 5.1 Experimentation layout

Fig. shows the experimental setup. It consists of vibration exciter, LVDT, flexural bearing, strain gauge circuit, controller and display. Flexural bearing mounted on vibration exciter with supporting plate and supporting ring, four strain gauges glued on surface of flexural bearing where maximum strain is obtained during FEA analysis, these strain gauges further connected to strain gauge module for signal transmission purpose. Vertical position of LVDT measures the axial displacement of flexural bearing. System integration will be needed to connect the mechanism to the dSPACE controller and finally operate it with the computer installed Graphical User Interface software control desk with MATLAB Simulink. Actuating force is given to the mechanism after converting it to corresponding current voltage. Due to application of force flexural bearing displace and this displacement measure by LVDT and Strain gauge circuit.

VI. RESULTS AND DISCUSSION

During experimentation it is observed that reading taken by LVDT and by strain gauges are differ from each other. This results are compare and plotting error in MATLAB Simulink . Results of Bearing

Force (N)	Theoretical (By ANSYS) (mm)	Experimental Value (By LVDT) (mm)	Experimental value (by Strain Gauge) (mm)	Displacement error in %
1	3.58	3.42	3.49	2
0.7	2.506	2.40	2.46	2.43
0.5	1.82	1.72	1.80	4.34
0.3	1.074	1.02	1.03	0.9
0.1	0.358	0.3391	0.351	3.39



Graph. Force Vs Displacement.

Graph shows the response of therotical and experimental displacement with force. The response of LVDT and strain ggauge is verysensitive to changes in excitation parameters.

VII. CONCLUSION

1. According to material data beryllium copper is an age-hardening alloy which attains the highest strength of any copper base alloy. Presently the bearings are design by the Aluminum, and in this project we design the bearing by using copper material.

2. Different configurations of flexural bearing models are prepared in CAD. These models are analyzed by FEA software by applying 1 N force at the centre periphery of the flexural bearing. We calculate maximum stress, strain and deflection for axial loading force. After analysis, we conclude that axial displacement of model no 6 is high (3.568mm) with minimum principle stresses (171.38364 N/mm2) at 1 N force.

3. By using strain gauge we developed a mechatronic integration circuit which measures the axial deflection of flexural bearing. Compared the results which are getting from LVDT and strain gauge.

4.By doing the experimental and theoretical analysis we have got the accuracy up to 98%.

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