Design and Experimental Validation XY Positioning Table

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Abstract— *Flexure mechanisms have massive range in various industrial application required for high precision and frictionless motion. There are many study on concept to make precision manipulators, but only some of them can achieved to satisfy the high speed with precision. Pro-E software is used for parametric modeling of XY positioning table ANSYS is used for Static analysis and dynamic analysis. Deflection of motion is concluded by static analysis with force. The Deformation of XY mechanism is equivalent to S-shaped cantilever beam deformation. Force and deformation curve is linear. There results get compare with mathematical calculation with FEA results.*

Keywords— Flexure Mechanism, FEA, XY Positioning

I. INTRODUCTION

When Flexure mechanisms uses as bearing to provide smoothen motion. A flexure mechanism is a single-piece mechanism that transfers movement without any relative motion between joints or linkages, thus motion is wear free, energy efficient, higher resolution, and high speed device. Flexures are structure that depends on Material elasticity for their functionality. Motion is generated due to deformation at molecular level, which results in primary characteristic in flexures- smooth and precision motion for example in camera lens cap, laser scanning machine.

In this paper a flexural mechanism is designed to provide a linear motion in a compliant manner. Flexure mechanisms offer a number of advantages, such as increased precision, reduced friction and wear, simple (sometimes monolithic) construction, and reduced assembly. In many ways compliant mechanisms have developed similar functionality to rigid mechanisms. Flexure mechanisms could potentially offer an attractive choice to conventional linear motion mechanisms both in terms of improved functionality and decreased cost. Because flexure mechanisms gain some or all of their motion from deflection of the linkages, they have the potential to completely eliminate relative motion between linkages, and thus eliminate friction. As an added benefit, since mechanism members couple its energy storage with linkage motion as they deflect, stable positions can be integrated into the design. [3] [4]Several linear motion flexure mechanisms, including bi-stable mechanisms, have been developed, although they provide much less travel for their size compared to prismatic joints. Unfortunately, mechanisms that do have a longer travel often have significantly reduced off-axis stiffness due to the use of long flexural members.

II. MODELING AND ANALYSIS OF XY FLEXURE MECHANISM

Based on the designs studied we found out that the all the mechanisms were based on flexural motion. An elastic strip is made to bend or twist causing distortion in its original dimensions and producing the desired motion. After studying various existing mechanisms, we tried designing our own mechanism based on Flexural Force Transmission

A. Trial Models

1) Single Beam (Rectangular) Hinge Type Flexure Mechanism

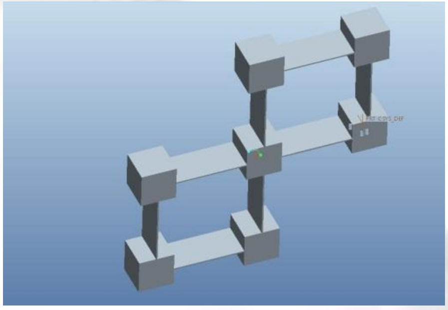

Fig. 1: Single Beam Hinge type flexure mechanism

Single beam hinge type structure, where beams were fixed to the supports and their output was linear. In this model type version the angular motion was cancelled out by connecting two beams Parallel to each other. Unfortunately, the design produced comparatively less amplification than expected and because of the weight of the mechanism it is difficult to stabilize hence this design had to be rejected. A new design was sought for that was based on the flexural bending of the links and motion transmission caused displacement amplification. The design already existed and little modifications were made hence it lacks innovation. Also the design had complex linkages causing difficulty in manufacturing. Because of these reasons the design had to be rejected thus another design need to be sought for.

2) Single Piece Based Flexure Mechanism

To eliminate the mounting difficulties we decided to take Single piece mechanism in which whole mechanism is cut from the single block using Wire cut machining processes. It provides ease in mounting and avoids unnecessary displacement of the beams (strips), which provides good stability and accuracy. The stress developing in this design is maximum. It contains the angular motion of the beams because of its design and this mechanism provides linear motion.

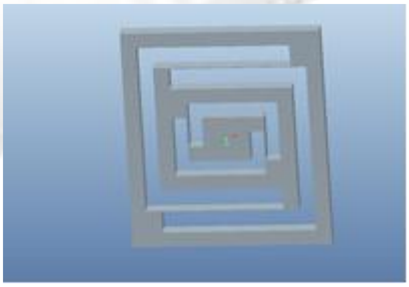

Fig. 2: Single Piece Based Flexure Mechanism

3) Design Modification

As we have seen that in the previous designs the main drawback was due to the complexity of design and less displacement. This made the manufacturing infeasible and also hampered the results drastically.

Objective is to produce linear motion. Thus in order to achieve this we have implemented this principle in two different directions in such a manner so that motion in X-direction and motion in Y-direction is nullified. These two links that are fixed are orthogonal to each other so that the motion in perpendicular direction is cancelled. The material selected is determined by the elastic modulus of the flexure strip that is required to produce the desired bending of Strips.

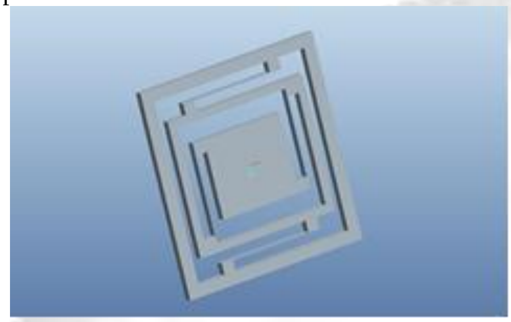

Fig. 3: Present Design of Flexure Mechanism

III. Theoretical Deflection Calculation

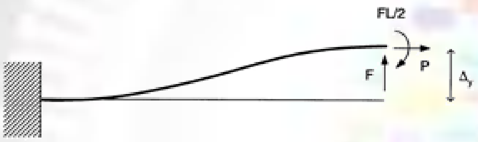

Fig. 4: Equivalent Cantilever Beam deformed n S-Shape

Buckling load of the beam is given by: [1]

$$P = \frac{\pi^2 EI}{{L_e}^2} \Rightarrow \frac{P{L_e}^2}{EI} = -9.87$$

Maximum allowable tip displacement is given by,

$$\left(\frac{\Delta y}{\mathrm{L}}\right)_{max} \leq \frac{1}{3\eta}\frac{S_y}{E}\frac{L}{T}$$

Now for any flexure mechanism, these values range as given below: Δy = 0.01L to 0.1L We will aim to obtain results for deformation value as high up to 0.1L then flexure mechanism get the linear motion.

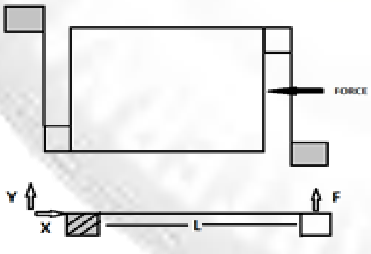

Fig. 5: Force Acting on Mechanism

For S-shaped Deformation of beam we have from ref [1]

$$\begin{bmatrix}\delta_y \\ \theta\end{bmatrix} = \begin{bmatrix}1/6 & 1/2 \\ 1/2 & 1\end{bmatrix}\begin{bmatrix}f \\ M\end{bmatrix}$$

Where,

$$\delta_y = \frac{\Delta y}{L}\ , m = \frac{ML}{EI}\ , f = \frac{FL^2}{EI}$$

Deflection of beam is given by above matrix we have,

$$\frac{\Delta y}{L} = \frac{1}{6}\frac{FL^2}{EI} + \frac{1}{2}\frac{ML}{EI}$$

Deflection of beam is given by equation,

$$\Delta y = \frac{FL^3}{6EI}$$

Where,
Δy - Deflection in beam in mm
F - Applied Force in N
L - Length of Beam in mm
E - Young's Modulus N/mm2
I - Movement Of Inertia.

To Find optimize design Considering the length variation in range 85mm to 100 mm. Thickness in Range 0.75-1.5 mm based on Design Consideration

IV. FEA Analysis

The Geometrical Modeling of the Flexure mechanism is essential for the numerical analysis and graphical representation of the model. This is done on CAD software which in this case is Pro-E Wildfire 5.0

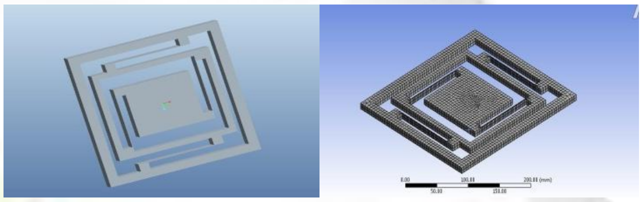

Fig. 6: CAD Model of Mechanism and Fine Meshing

A. Analysis of Mechanism

Import the model from external source (Pro-E) in parasolid (.x_t) format. Select the material for all the parts, Boundary Conditions, and Meshing.

As it is seen from the figure, the maximum stress created at the Flexure strip is 426MPa in X direction and 435MPa in Y direction. The material used for Flexure strip is Mild Steel. The Tensile Yield Strength of Mild Steel is 490MPa. Thus the maximum stress generated at the Flexure strip is within the permissible limit. Therefore the design is safe.

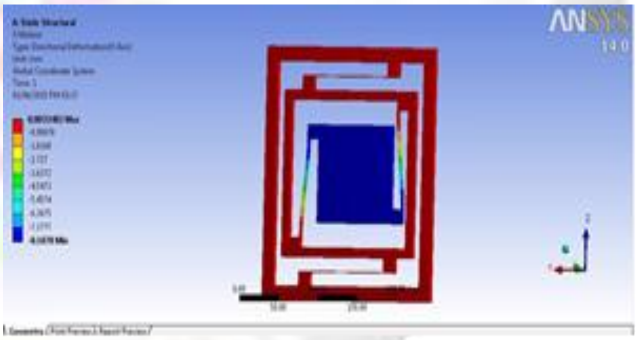

Fig. 7: Graphical results of Displacement Analysis in X-Dir

Sr. No.	*L (Length mm)*	*b (Width mm)*	*T(thickness mm)*	*Theoretical Deflection (mm)*	*FEA Stress (N/mm2)*
1	*90*	*15*	*1*	*4.2638*	*221.99*
2	*95*	*20*	*1.5*	*1.1164*	*75.85*
3	*100*	*25*	*2*	*0.44664*	*37.031*
4	*90*	*10*	*1*	*6.4807*	*403.2*
5	*95*	*10*	*1.5*	*2.7905*	*160.83*
6	*100*	*10*	*2*	*1.1435*	*84.297*
7	*85*	*15*	*0.5*	*28.316*	*819.28*
8	*95*	*15*	*1.5*	*1.5094*	*104.43*
9	*100*	*15*	*2*	*0.75501*	*61.996*
10	*85*	*20*	*0.5*	*21.053*	*604.88*
11	*90*	*20*	*1*	*3.174*	*164.77*

12	*100*	*10*	*0.85*	*1.9384*	*42.485*
13	*85*	*25*	*0.5*	*16.719*	*484.11*
14	*90*	*25*	*1*	*2.5205*	*130.57*
15	*95*	*25*	*1.5*	*0.75978*	*58.6222*

Table 1: Various Design Instances for 5N Force

Based on above table the most optimized Design for Flexure mechanism is L = 100 mm, b = 10mm and t = 0.85 mm less Stress developed.

Designed Flexure Mechanism Specification:-
Length = 100 mm.
Width = 10 mm.
Thickness = 0.85 mm.
Moment of inertia = 0.511770833
Yield Strength: = 490 MPa
Young's Modulus = 2.1 x 10^5 N/mm2

Based on this Design We calculate deflection of beam for Force Acting from 0 to 20 N force

Sr No.	*X Component*	*Y Component*	*Total Deformation*	*Maximum Equivalent Stress*
Units	*N*	*N*	*mm*	*Mpa*
1	*1*	*1*	*0.585393*	*21.66*
2	*5*	*5*	*2.926966*	*103.3*
3	*10*	*10*	*5.853933*	*216.6*
4	*15*	*15*	*8.780899*	*324.89*
5	*20*	*20*	*11.70787*	*433.19*

Table 2: Total Deformation and Max Stress by FEA

V. Manufacturing Process

In manufacturing the operations required are Drilling, Milling and Shearing. Following are the manufacturing processes employed in this job

A. Drilling

The main structural plate and pulley plate including the blocks have been drilled for the purpose of assembly. The drill of 6 mm diameter has been drilled with the help of drilling machine. For the pulley drill of 5 mm diameter has been drilled with the help of drilling machine.

B. Laser Cutting

The main structural plate has to be required to cut into precision and accuracy. Therefore Laser cutting operation is required to cut small amount of the thickness of the plate with high accuracy.

C. Wire Cutting

The linkages of structural mechanism have very low thickness. If we use laser cutting operation thermal consideration has to be taken place. Hence in order to compensate that we use wire cutting operation.

D. Surface Finish

The supporting blocks required to be finish with high accuracy for the testing as well as accurate result.

The tools required are:
1) Drilling Bit
2) Single-Point Cutting Tool
3) Laser Cutting Kit
4) EDM

VI. Experimental Setup

The experimental setup is designed in order to give the required amplification as the output result.

The materials used for the mechanism are:

A. Mild Steel

1) Fixed Block
2) Pulley Plate
3) Main Structure Plate

B. Plastic

1) Pulley
2) Weight Pan

C. Other

1) Rope
2) Clip
3) Screw

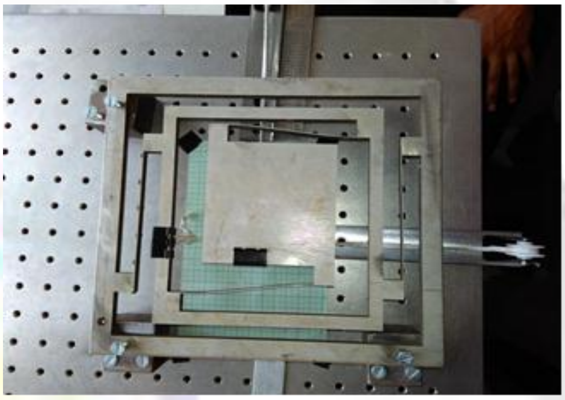

Fig. 8: Experimental Setup of Flexure Mechanism

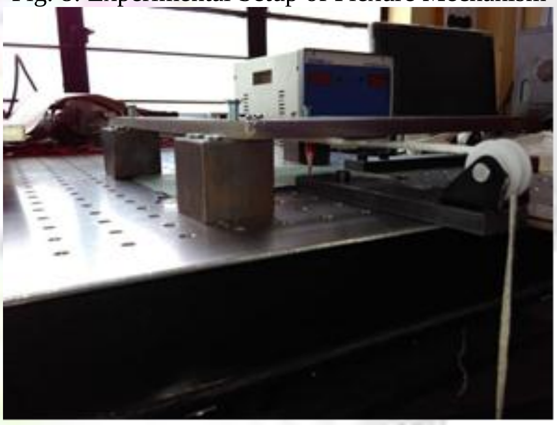

Fig. 9: Experimental Setup of Flexure Mechanism

The mechanism manufactured needed to be mounted on a fixed adjustable and vibration free base. Also the input force provided to the mechanism is given through a weight pan. Hence the weight pan shall also demand a stable and vibration free base. Lastly, the base should be adjustable to accommodate the variation in experimental setup and fix the components is different configurations.

Thus in order to fulfil the above mentioned demands, an "Optical Board" is necessary to be used for the mounting of the mechanism and assembly. Also arrangements must be made to accommodate the stylus pencil required for calibration of the output results.

In order to mount the setup on the Optical Board we use the mounting block so as to lift the model. In order to fix the Fixed Base on the board, M6 bolt is used.The model is actuated by the weights which are clamped by C-clamp that is properly positioned. Thus this setup is used to actuate the mechanism and measure the output with the help of a stylus pencil fixed at the output link.

VII. EXPERIMENTAL RESULTS

The use of XY table in traditional mechanical devices has primarily been avoided due to the increased difficulty accounting for flexibility in kinematic design. A flexure mechanism is defined as a mechanical device that contains one or more flexible members which exploits elastic deformation to achieve controlled transmission of forces and motions.

SR No	*Input Load in N*	*Experimental Output in mm*	*Analytical Output Results in mm*
X			
1	*5*	*2.1*	*2.04*
2	*10*	*4.15*	*4.09*
3	*15*	*6.15*	*6.14*
4	*20*	*8.1*	*8.18*
Y			
1	*5*	*2.1*	*1.93*
2	*10*	*4.12*	*3.87*
3	*15*	*6.01*	*5.81*
4	*20*	*8.25*	*7.75*

Table 3: Comparison for Experimental and Analytical Directional Deformation in X &Y- Direction

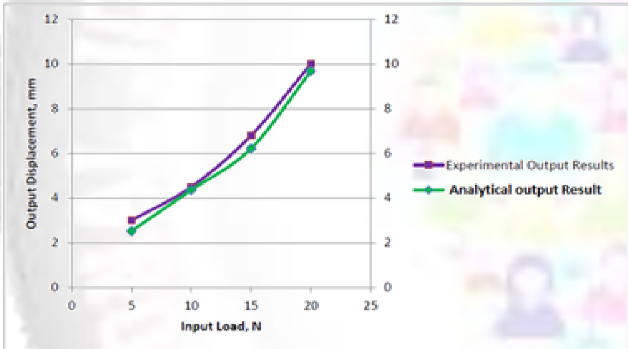

Fig. 10: Comparison between Experimental and Analytical

VIII. CONCLUSION

After analyzing the results we can observe that the Input Displacement vs. Output Displacement characteristics for the Experimental and numerical calculations remain the same. As well as stress are in permissible limit.

The mechanism fully satisfies the Flexure mechanism characteristics like linearity, no hysteresis losses, zero error, sensitivity, etc. as it is clear from the testing results mentioned above. These characteristics are the primary factors in the feasibility and applicability of the mechanism.

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