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Design of Flexure Mechanism using FEA and Experimental Method

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A B S T R A C T

This paper presents the design of jointless mechanisms with distributed compliance, specifically tailored for Micro-Electro-Mechanical Systems (MEMS) applications. Flexure mechanisms play a crucial role across various industrial applications, demanding high precision and frictionless motion. While numerous studies focus on the conceptualization of precision manipulators, only a subset successfully attains both high speed and precision. In this work, Pro-E software is utilized for the modeling of the flexure mechanism, while ANSYS is employed for both static and dynamic analyses. Static analysis, involving force-induced deflection, is conducted to assess the motion. The deflection of the XY mechanism mirrors the deformation of a Cross-shaped cantilever beam. Comparative analyses are performed with experimental results, enhancing the validation through Finite Element Analysis (FEA).

Keywords: FEA, MEMS, ANSYS, Flexure, Static

Introduction

This paper explores the utilization of flexure mechanisms as bearings to enable smooth motion. A flexure mechanism, being a single-piece structure, facilitates movement without any relative motion between joints or linkages, resulting in wear-free, energy-efficient, highly precise, and rapid devices [1-5]. These mechanisms leverage material elasticity for their functionality, generating motion through molecular-level deformation [6-7]. Notably, flexure mechanisms find applications in various products, such as camera lens caps and laser scanning machines, emphasizing their significance in achieving smooth and precise motion [8-12]. Flexure mechanisms represent a recent advancement in MEMS design, offering advantages like frictionless and hysteresis-free operation. The design principles involving flexural bending at linkages have spurred their application in diverse products, ranging from macro-scale components like clutches and switches to micro-electromechanical systems (MEMS) [13-16]. Compliant mechanisms, known for increased precision, reduced friction, and simplified construction, exhibit functionalities similar to rigid mechanisms while eliminating relative motion between linkages, thereby eliminating friction [17-21].

The paper focuses on the mathematical modeling of a simple XY manipulator using typical double flexural configurations [22]. MATLAB is employed for static and dynamic analyses, with static analysis determining the static deflection of the motion stage under force [23-27]. Dynamic analysis aims to identify frequencies and mode shapes of the flexural manipulator. ANSYS is utilized for static and dynamic analyses of basic double flexural mechanism configurations and a few XY mechanisms [28-30]. The modeling of the XY flexure mechanism is based on the characteristics of the building blocks used in its construction. The paper presents a comparison of linear and non-linear closed-form analyses, and the analytical results are compared with finite element analysis (FEA) and experimental outcomes [31-34]. For the design of a large displacement precision XY positioning stage, the paper employs cross strip flexure joints. The analysis and design of general platform-type parallel mechanisms containing flexure joints highlight a key difference from conventional parallel mechanisms – kinematic stability is no longer a design consideration [35-36]. Finally, the paper delves into the design and analysis of a flexure-based XY micro-positioning stage. Compliance and stiffness analyses based on matrix methods are conducted, and both the mechanical structure and electromagnetic model are validated through finite element analysis (FEA) using ANSYS.

Development of the XY model

The paper focuses on the design of a flexure mechanism, drawing inspiration from various existing designs that predominantly rely on flexural motion. In these mechanisms, an elastic strip is manipulated to bend or twist, inducing distortion in its original dimensions to achieve the desired motion. In contrast, the proposed design centers around Flexural Force Transmission [37-38]. To address mounting challenges, the decision was made to adopt a single-piece mechanism, fabricated by laser and wire cut machining processes. This approach streamlines the mounting process, preventing unnecessary displacement of strips and enhancing overall stability and accuracy. However, it leads to maximum stress development in the design. The mechanism incorporates angular motion of the beams in its design while providing linear motion. The Geometrical Modelling of the proposed mechanism is crucial for both numerical analysis and graphical representation. For this purpose, Computer-Aided Design (CAD) software is employed, and imported in ANSYS being the chosen platform as shown in figure 1. This software aids in visualizing and analysing the intricate details of the mechanism, facilitating a comprehensive understanding of its behaviour and performance characteristics.

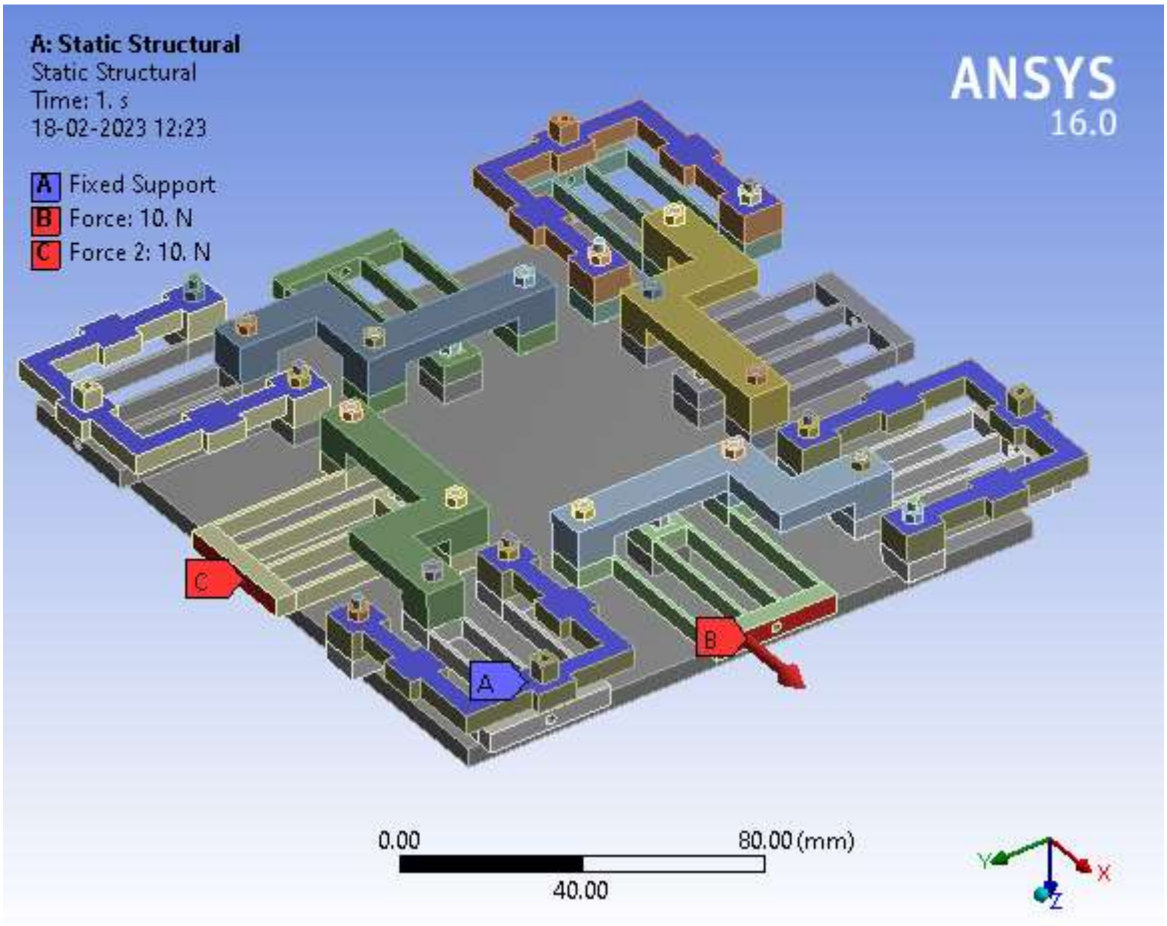

Fig. 1 - CAD model in ANSYS of the Cross Flexure Mechanism

Experimental Setup of the Mechanism

The experimental setup comprises several components: a mechanism, graph paper, pencil, C-clamp, string, weight pan, a vibration-free base (i.e., Optical Bread Board), and four metal mounting blocks as shown in figure 2. The primary objective is to mount the manufactured mechanism on a fixed, adjustable, and vibration-free base. Additionally, the input force for the mechanism is provided through a weight pan, requiring a stable and vibration-free base for the weight pan as well. The base should also be adjustable to accommodate variations in the experimental setup and fix components in different configurations. To meet these requirements, the use of an "Optical Board" is essential for mounting the mechanism and assembly. Arrangements must also be made to incorporate the stylus pencil necessary for calibrating the output results. Mounting blocks are employed to lift the model and fix it on the Optical Board. To secure the fixed base on the board, an M6 bolt is utilized. The model is actuated by weights clamped using a C-clamp, which is properly positioned. This setup serves to actuate the mechanism and measure the output by employing a stylus pencil fixed at the output link. Overall, the experimental setup is carefully designed to ensure stability, adjustability, and precision in conducting experiments with the flexure mechanism.

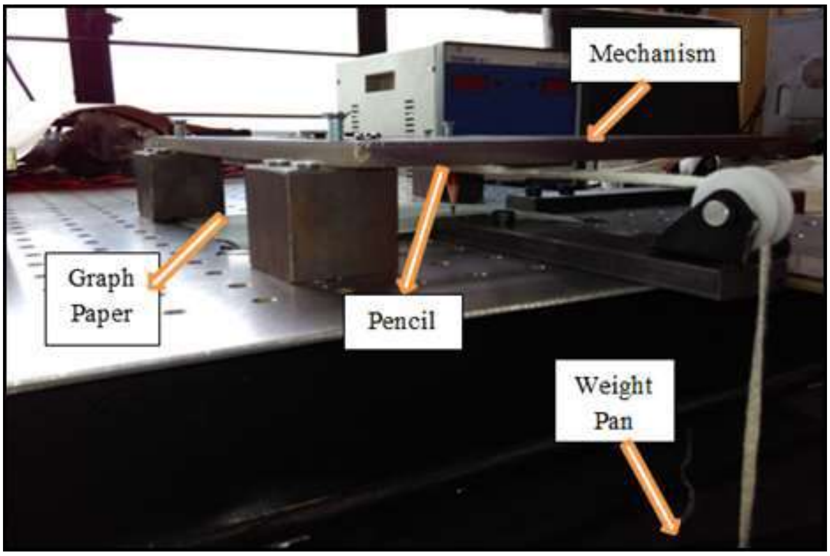

Fig. 2 - Experimental set for the Mechanism

After experimental testing the observations are shown in following table 1.

Table 1 - Results of the Experiment

Trail No	Applied Force (N)	Output Results	
		X- Direction	Y Direction
1	5	1.78	1.89
2	10	3.99	4.01
3	20	6.78	6.89
4	25	8.12	8.21

4. FEA Analysis of the Model

When we apply the maximum force of 25 N in X-direction and in Y-direction in Ansys software then we get the maximum deformation in X and Y direction, also the maximum stresses occurs in X and Y direction respectively.

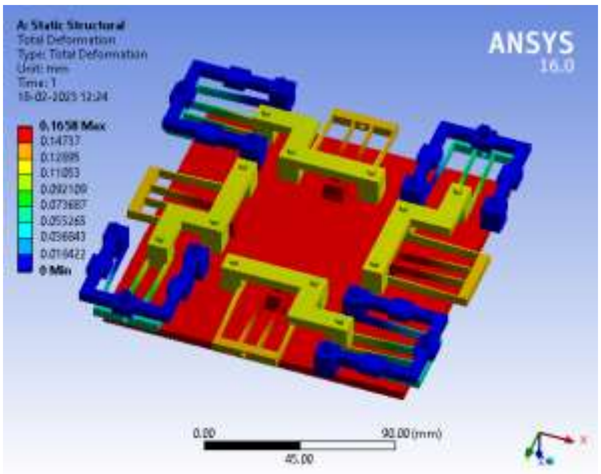

Fig. 3 - Deformation in X Direction

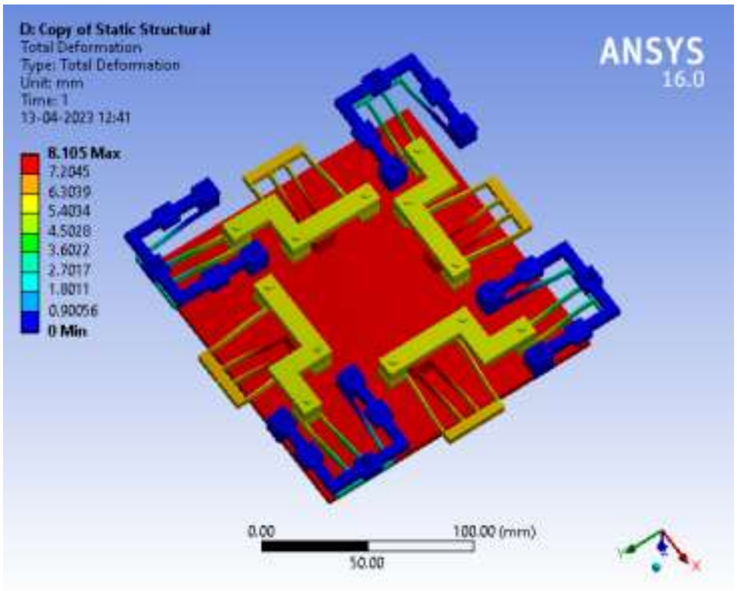

Fig. 4 - Deformation in Y Direction

After experimental testing the results are shown in following table,

Table 2 - Analytical results of X and Y direction

Trail No	Applied Force (N)	Output Results	
		X- Direction	Y Direction
1	5	2.11	2.18
2	10	4.46	4.71
3	20	6.78	6.89
4	25	8.78	9.45

5. Result and Discussion

Now we can compare the experimental output results and Analytical output results of mechanism for X & Y direction as given in table 3.

Table 3 - Results of comparison for Experimental and Analytical Directional Deformation in X &Y- Direction

Test	Applied Force (N)	Experimental Result	Analytical Results
X Direction			
1	5	1.78	2.11
2	10	3.99	4.46
3	20	6.78	6.78
4	25	8.12	8.78
Y Direction			
1	5	1.89	2.18
2	10	4.01	4.71
3	20	6.89	6.89
4	25	8.21	9.45

From the above table 3 the graph has been plotted which they are having a close match as shown in fig 5 and fig 6.

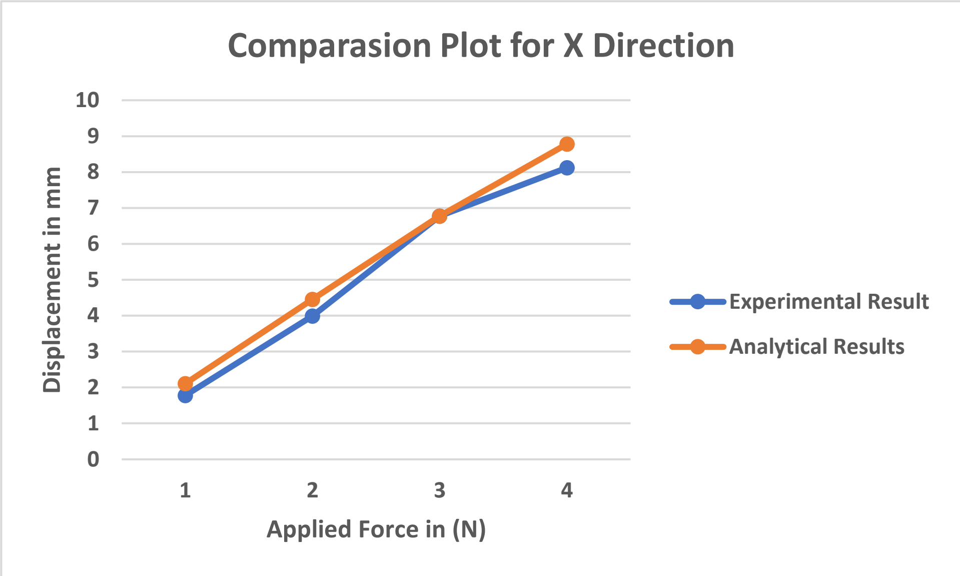

Fig. 5 - Comparison plot of Experimental and Analytical in X direction

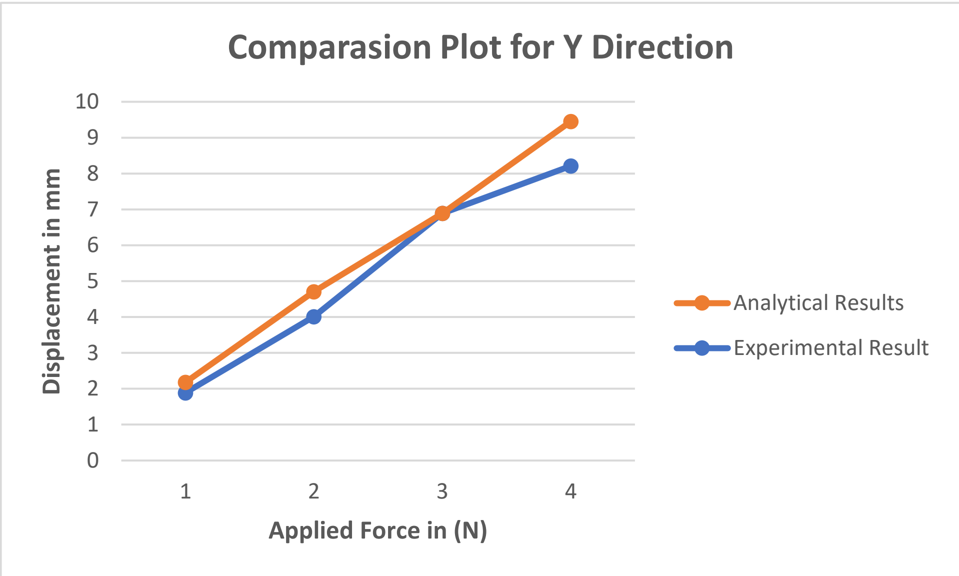

Fig. 6 - Comparison plot of Experimental and Analytical in Y direction

6. Conclusion

The results, it is evident that the Input Displacement vs. Output Displacement characteristics in both the experimental and numerical calculations align closely. Furthermore, the stress levels observed are within permissible limits. The mechanism successfully exhibits key Flexure mechanism characteristics, including linearity, absence of hysteresis losses, zero error, and sensitivity. These observed characteristics are crucial factors determining the feasibility and applicability of the mechanism. The testing results underscore the mechanism's ability to meet essential performance criteria, reinforcing its suitability for intended applications.

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