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Development & Analysis of XY Stage Mechanism

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ABSTRACT

The XY Flexure is well-known for its exceptional positioning precision. When combined with ordinary stages, it produces dual-range positioning devices with remarkable accuracy within a working range of a few centimetres. These systems, however, may be costly and provide a wide range of versatility. This study presents an inexpensive and small XY flexure device developed for single-range manipulation that not only saves workspace but also improves mechanical precision. In this study, a large range/Arduino controller and an IR sensor are used to detect the stage's location, followed by the implementation of an XY Motion Stage equipped with short-range/high-resolution capacitive sensors to correct positioning errors using Wire Electric Discharge Machining.

Keywords: Complaint mechanism for low range, IR Sensor, XY flexure, VCM

1. Introduction

A flexure is a flexible element designed to be compliant in specified degrees of freedom. Unlike rigid body motions in a typical mechanism, this compliant XY mechanism is a single flexible design that provides the required motion by elastic deformation. It is designed to be flexible enough to communicate motion while remaining sturdy enough to withstand external forces [1-2]. The changeless design of the XY Flexure mechanism minimises backlash errors and efficiently reduces production and maintenance costs associated with complaint mechanism construction [4-5]. Flexure joints are frequently constructed as a single component to reduce assembly errors. In certain directions, a perfect limiting mechanism and device give infinite stiffness and zero displacements while allowing limitless motion and zero displacements in others [6-8]. Flexure behaviour is geometry sensitive, hence enough dimensional accuracy is necessary during manufacture. As a result, the model is built as a single unit. When none of the active joints have degrees of freedom, i.e. there is no uncontrolled motion under any external force, the mechanism is kinematically stable. Kinematic stability, on the other hand, should be substituted by a stiffness criteria, because joint stiffness may be employed to avoid undesired motion [9-11]. The force-displacement parameters of the stage are initially studied in this study utilising Finite Element Analysis[12-15]. The constructed stage is next reviewed and the findings are compared to FEA.

2. Literature Review

Li demonstrated fresh approaches for developing and building a revolutionary XY micromanipulator optimised for micro-scale positioning applications, focusing on a decoupled approach [16-19]. The manipulator's parallel-kinematic architecture, use of flexure hinge-based joints, and piezoelectric actuation set it apart. Efficient models for the kinematics, statics, and dynamics of the XY stage were created and then validated using finite element analysis (FEA) software[20]. To improve the stage's dimensions, an optimisation approach based on particle optimisation was used, culminating in the production of a high-performance manipulator[21-23]. A manipulator prototype was also built using the Wire EDM method. The established complaint mechanism is planned to be used in real-world applications. Within the setting of Shorya, Awtar denotes a certain type of avatar[3,24-25]. This article digs into an in-depth analysis of performance features in XY mechanisms, spanning topics such as mobility, axis coupling, drive stiffness, lost motion, parasitic errors, actuator isolation, and geometric sensitivity, in accordance with Alexander H. Slocum's research. During construction, the typical double parallelogram flexure module is used as a constraint element, with its force-displacement properties crucial in evaluating the performance of two suggested XY flexure mechanism designs.

The research offers insight on critical performance trade-offs within flexure processes, notably those caused by nonlinear load stiffening and elasto-kinematic effects, exposing the limits of linear assessments in comparison to nonlinear equivalents [25-26]. The addition of geometric symmetry to the constraint reduces design trade-offs, resulting in improved performance[27]. The nonlinear analytical findings' validity is verified using a mix of ANSYS simulations and experimental validation. Significantly, it is demonstrated that the influence of elastokinematic and load-stiffening effects on stiffness fluctuations and coordinate coupling has a significant impact on the dynamic characteristics of the proposed designs [28-30]. To produce a high-precision, high-bandwidth motion system, an accurate dynamic model that accounts for these impacts is required. Furthermore, the analytical methodology given here recognises the significance of assessing thermal sensitivity, which is crucial in high-precision applications.

3. Theory

3.1 Design and Modeling

Compact XY flexure stages with a wide range of motion are useful in high-density memory storage, atomic force microscope scanning, micro-manipulation, micro-assembly, MEMS sensors and actuators, and semiconductor mask fabrication. However, these XY flexure phases are often restricted in motion. Flexures are defined by a trade-off between degrees of freedom (DOF) and degrees of constraint (DOC), which presents unique design issues when building long-range systems. As constraint factors, balancing motion range within DOF while preserving stiffness and minimising erroneous movements within DOC is a difficult challenge in the creation of flexure-based systems.

3.2 Material Selection and Design Details

This study's stage serves as the foundation for the compliant XY motion stage under consideration. The beam is constructed with precise specifications to optimise its performance: it is 300mm long to give a wide range of motion, 2mm tall to provide rigidity along the Z-axis, and 1mm thick to reduce the force required for input. This stage, like the majority of compliant stages documented in the literature, is made of stainless steel 202, a material recognised for its high reversible strain properties.

4. FEA Analysis

Project model is made in CREO 2.1 by solid modeling. Spring, magnet and holding assembly is created to analyze in ANSYS for modal and harmonic response.

XY Flexure are designed and simulated. Fig. 1 shows PRO-E model of a Mechanism.

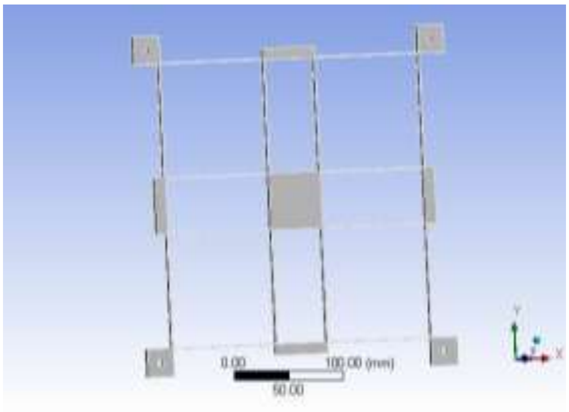

Figure. 1 - CREO 2.1 model of XY flexure

4.1 XY Flexure Fabrication

Wire Electric Discharge Machining is used to create the XY flexure mechanism. This approach enables precise tolerances and flawless surface polishing. It is, however, expensive. Despite the fact that laser cutting and CNC machining have been investigated, they are insufficient for milling 1mm thick beams. The first would melt the beams, while the second would bend them due to the cutting force used. The stage was constructed of 202 stainless steel.

4.2 Equivalent Stress Analysis (Von -Mises Stress)

Buckling occurs at the beams in this example when the load at the centre suddenly increases and the difference between the input and output displacement of the stage grows considerably in figure 2, figure 3 and figure 4 shows the stress analysis, directional deformation and total defromation.

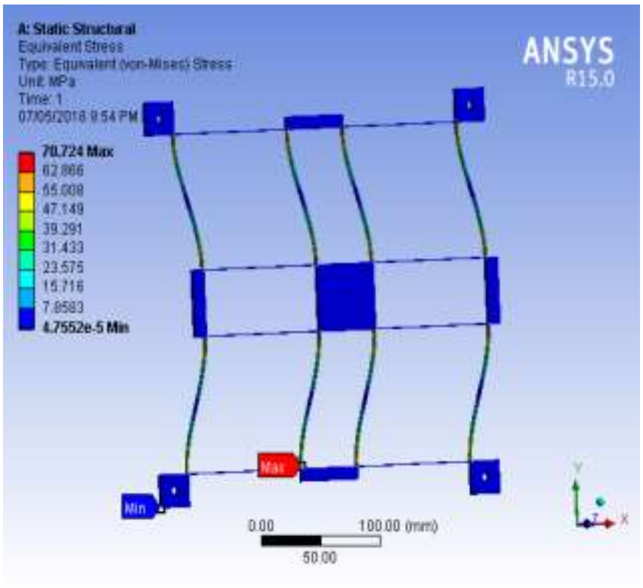

Figure. 2 - Equivalent (von- mises) stress

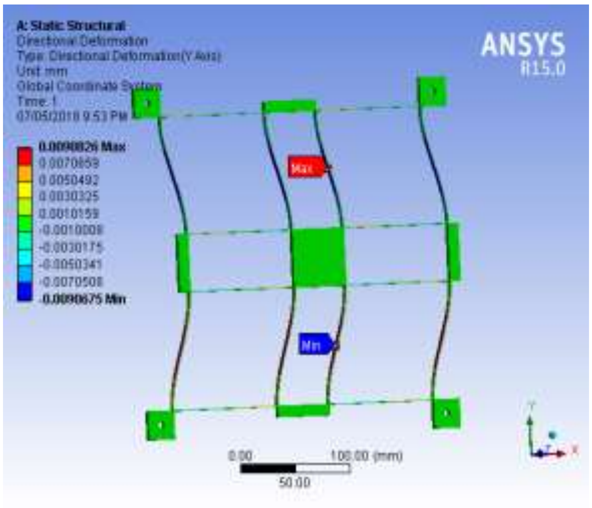

Figure. 3 - Directional Deformation (Y-Axis)

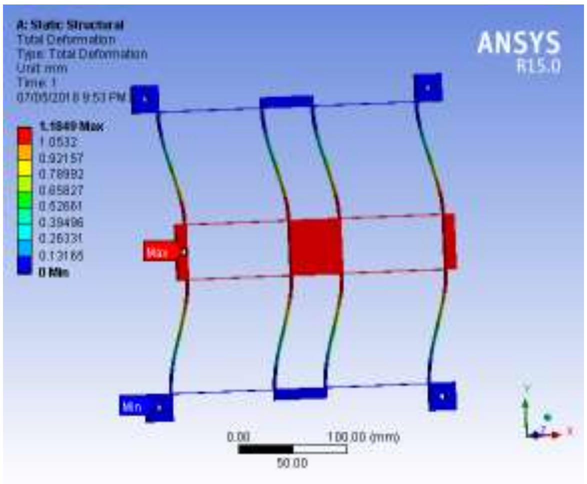

Figure. 4 - Total Deformation

5. Experimental Setup

Figure 5 depicts the experimental setup for XY Flexure. The Ardiuno controller sent various programming outputs to the IR sensor, which activated it and provided specified deformation and equivalent displacement over a range of up to 2 m. This sensor met the output voltage and input programming specifications of up to 5 amps.

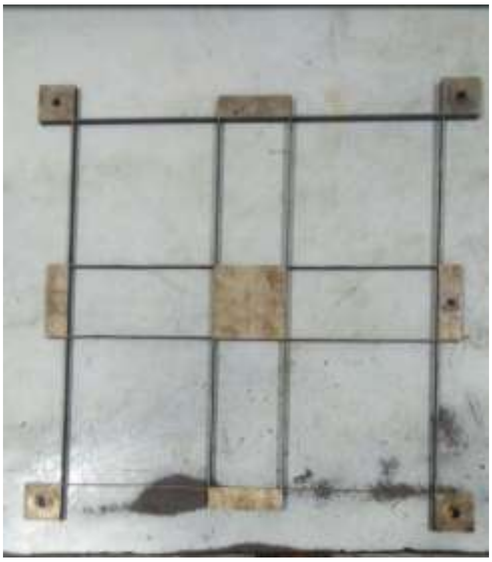

Fig. 5 - Fabricated Compliant XY Micro-Motion Stage

6. Results and Discussion

To begin, a one-way displacement test along the Y-axis is performed, encompassing a range of 0mm to 1mm. The acquired data show a 2µm difference between the input and output displacements, coupled by a 100µm lateral translation. The experiment is subsequently repeated twice in two orthogonal orientations. Keeping the previously applied 1mm input displacement along the Y-axis, an incremental 1mm input displacement along the X-axis is introduced.

The first notable discovery is the agreement of these results with Finite Element Analysis (FEA), which shows a maximum error of less than 4µm for a 2.5mm input displacement. The second notable finding is the biggest parasitic displacement, which measures 100µ m. As a consequence, the total distortion in the analytical data is 2 mm. Figures 2, 3, and 4 depict these analytical results visually.

7. Conclusion

The investigation focuses on the XY Flexure mechanism, which is intended for high-precision applications. It includes high-resolution motor controllers and sensors for Mechatronics integration, as well as Arduino and long-range IR sensors. As a result, this configuration has a high potential for attaining accurate, cost-effective micro-motion in a dual-range environment. The experimental setup should yield data for comparison with analytical results.

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