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DESIGN OF XY PLANER MECHANISM USING DFM FOR PARALLEL-KINEMATIC MICRO POSITIONING XY STAGE

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Abstract

A mechanism is a mechanical system that uses certain joints to create relative movement between stiff linkages. Rolling, sliding, pin, hinge, liquid, and other joints are often used. Because of their nonlinear frictional behaviour, these joints make it challenging to regulate micro- and nanopositioning in mechanisms with great accuracy. Disadvantages like backlash and friction in the mechanism need to be addressed in order to achieve a high degree of resolution and accuracy. Flexible parts like flexural beams and hinges are used in place of these mechanical connections, providing advantages like smooth and frictionless displacement. A single DOF flexural stage, sometimes referred to as a parasitic error, is made using simple building materials like flexural hinges and beams. This stage offers little resistance to motion in the desired direction and maximum resistance in the orthogonal. The Double Flexural Mechanism (DFM), a type of beam building element, produces analytically zero parasitic error displacement with undetectable rotation of the displacement stage. This research covers experimental verification, system characterization, the design and development of DFM, as well as its mechatronic link to the dSPACE DS1104 Controller. Through static and dynamic studies, many performance characteristics like as stiffness, natural frequency, and damping factor are experimentally determined. Additionally, a cutting-edge position algorithm is created and used to the mechanism, which removes the need for expensive sensors and produces precision of 30 microns at 6.1 mm/s.

Keywords : Static, Flexural Mechanism, Optical Encoder, Precision.

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1. Introduction

Precision technology has increased as a result of advancements in manufacturing, electronics, and materials [1, 2]. Precision manipulators with higher economy and performance characteristics enhance small-scale technology. In advance technology, nano and micro positioning phases are crucial [3,4] uses in confocal microscopes, scanning probes, and micromachining. A broad range of XY mechanisms, including screw-type and precise ball recirculation mechanisms, are being developed. The previously created XY mechanism has limitations, such as poor accuracy and range performance, to create a control system that will work well for the needed performance. There has been a new way for creating mechanisms, such as flexural mechanisms, with high-speed precision applications [5, 6, 7]. Flexures are created based on the material's flexibility for use.

Anamorphisis at the molecular level causes the development of motions, which have the qualities of precision and high application speed. The flexure mechanism's benefits include frictionless, backlash-free action that is smooth. The installation and construction of the flexure mechanism are straightforward (monolithic). Effect of constraint on flexure that is not optimum. They're predictable and repeatable [8, 9]. The goal of this effort is to construct and analyse motion using a wide motion spectrum. Flexure mechanism is used to get the degrees of freedom. These are divided into two categories: hinges and beams. Beams are used for planar motion, whereas hinges are utilised for rotating motion. The purpose of the study is to create a flexure mechanism and conduct experimental research.

2. DFM System Mechanism

The practical characteristics, flexural mechanisms provide several advantages over conventional motion mechanisms [1, 2] since they do not experience frictional losses and hence no lubrication is required. Flexure mechanism have repeatable action that is smooth, steady, unbroken, and prevents backlash. The features drawn flexural mechanisms to very precise, fast movement techniques at the meso- and micro-scale, as well as to micro- and nano-positioning stages, to nano-electromechanical systems (MEMS), and other technologies. A double flexural mechanism structure with four flexural beams, main and secondary motion stages is shown in Figure 1. According to analysis, DFM provides roughly 0% parasitic error and produces precise movement in a straight line.

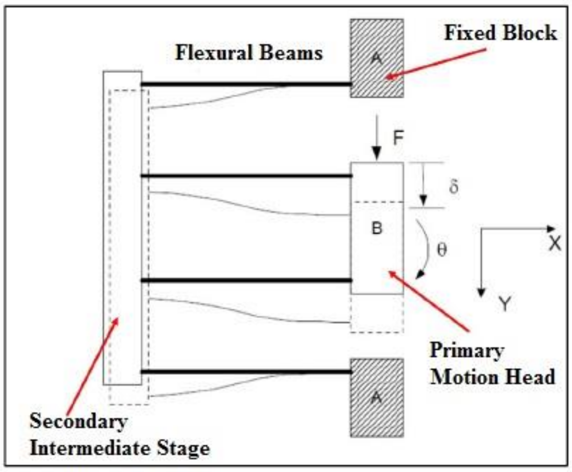

Figure 1 Double Flexure

3. Implementation of Mechatronics integration on DFM the system

Using DFM, a one DOF flexural positioning stage is built and produced. This flexural positioning stage provides a lot of benefits, including total elimination of friction and backlash, excellent repeatability, and support for a large scanning range. A constructed DFM construction with four parallel flexural beams is seen in Figure 2. An actuator called a voice coil motor (VCM) is utilised to exert force on the preliminary motion stage. This motion stage movement is detected using an optical encoder with a 50nm precision.

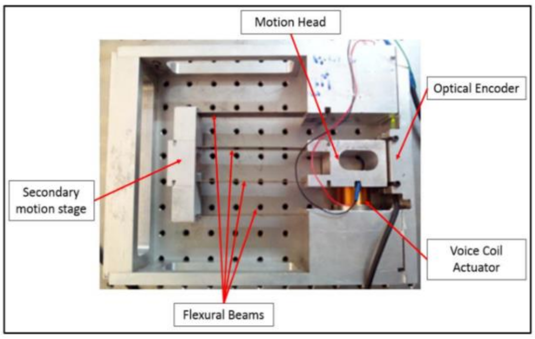

Figure 2 Setup of Experimentation

To utilise Control Desk software (the GUI programme for the dSPACE DS1104) and link the mechanism to the dSPACE DS1104 R&D controller, mechatronic integration is necessary. It has to be successively changed using DFM into the proper current-voltage signal. The DAC port on the dSPACE DS1104 has a gain of 8, therefore if we input 1.2V into the GUI, it will output 08V. The correct current-voltage signal is pushed into the DFM's motion stage. The DAC port's output current is really low. As a result, it is amplified using a Linear Current Amplifier, which converts voltage from a DAC to the necessary current using an external power supply and has a gain of 2.5A/V. As a result of the current signal being delivered to the VCM, which produces a force of 67.2 N/A, the VCM positioned on the motion head moves. When creating the system's mathematical model and control algorithm, the required measures were taken by doubling all revenues. The system's built-in linear encoder measures this displacement. The dSPACE DS1104 controller receives a position signal from the optical encoder. To connect this optical encoder feedback signal with the input reference signal and detect the false signal, a control logic is designed in MATLAB Simulink. The system integration, experimental setup, and mechatronic integration are shown in the block diagram in Figure 3.

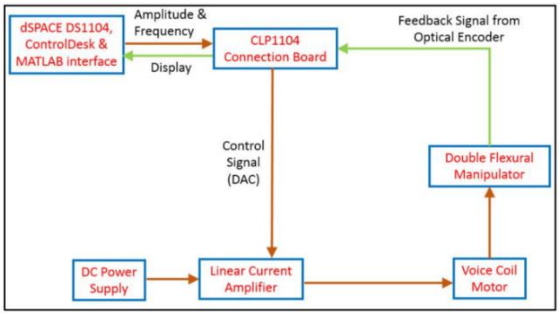

Figure 3 Integration of Flexure with dSPACE DS1104

4. Experimentation on the DFM

By using the dSPACE DS1104 controller, mechanical characteristics like stiffness and damping factor are accurately controlled for double flexure. Experimental results also reveal the mechanical system's natural frequency.

Static Characterization: The stiffness is estimated from the slope of the investigational force vs. deformation curve. To activate the VCM and precisely quantify the deformation of the primary motion head, a control system file was created in MATLAB Simulink. The displacement stage of DFM's experimental force vs. deflection behaviour is shown in Figure 4.

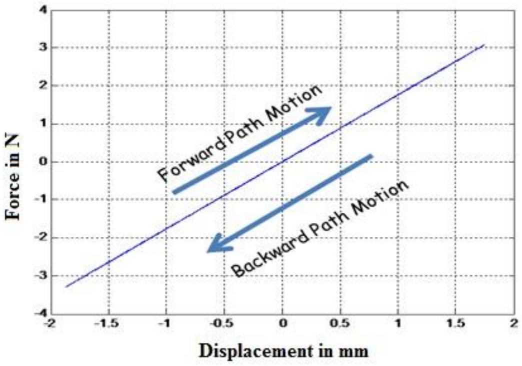

Figure 4 Force vs Displacement graph

Evaluation of investigational and theoretical stiffness for DFM is shown in Table 1.

Table 1 Comparison of Analytical & Experimental Stiffness results

Force in N	**Experimental stiffness in N/mm**	**Analytical stiffness in N/mm**	**Errorin %**
-6	0.74746212	0.75	0.338
-3	0.7464125	0.75	0.358
3	0.74354252	0.75	0.86
6	0.7429754	0.75	0.936

Dynamic Characterization: A transient force causes the primary motion stage to move initially, after which the motion stage is free to oscillate until it comes to steady. The experimental findings are plotted as a deflection vs. time graph in Figure 5. To get the damping factor, the logarithmic decrement is calculated. The formula for logarithmic decrement is,

$$\delta = \frac{1}{n}\left[log\left(\frac{X_0}{x_n}\right)\right] \qquad (1)$$

Where,

n= Successive number of peaks

x_0= First peak Amplitude

x_n= Amplitude to peak at n periods

Also damping factor is given by,

$$\xi = \frac{\delta}{\sqrt{4\pi^2-\delta^2}} \qquad (2)$$

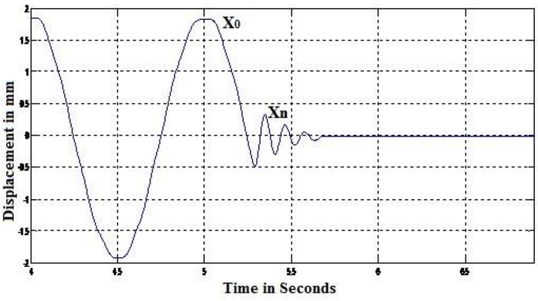

Figure 5 Step Response of Double flexure

From investigational the obtained results for the logarithmic decrement and damping factor in DFM are evaluated as below,

δ=1.197 ζ=0.1940

The linear motor, or VCM, used in this study primarily consists of permanent magnets and a current-carrying coil. The linear motor operates on a similar concept to the voice coil used in speakers. When current passes through the coil, mechanical force is generated, and the direction of the force depends on the flow of the current. A subfigure of Figure 6 displays the same circuit design as the main figure, which demonstrates the installation of a linear voice coil motor.

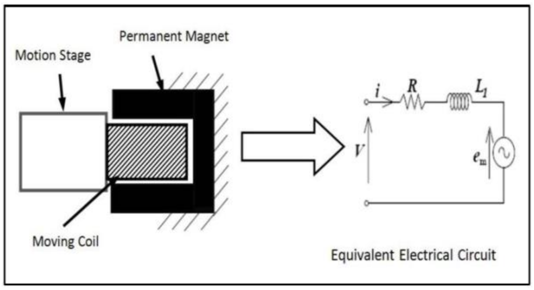

Figure 6 VCM used as Sensor

The mechatronic interface created for the location estimator method is shown in Figure 7. A second circuit is built into the VCM to sense the current and voltage the VCM draws. This idea is utilised in the current study for sensor-free positioning of the motion stage of the flexural mechanism. Utilising an appropriate sensing circuit, measurements of voltage and current across a coil are carried out experimentally before the data is further processed. A current and voltage signal are required by the position estimation method. Actual location of the motion stage is contrasted with the estimated position from the position estimator.

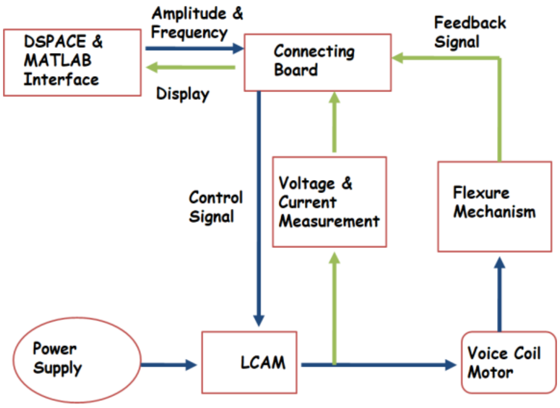

Figure 7 Voltage and Current Monitoring System

5. Results

Evaluation of Natural Frequency: To create the XY Mechanism's transfer function, which connects the input control signal to the VCM and the motion stage displacement. The sinusoidal input voltage is presented, together with displacement outputs, to obtain the frequency response. When a frequency response graph of the system is formed, as illustrated in figure 8, it may be used to analyse the system's natural frequency and phase change. A Simulink MATLAB model is created to acquire the temporal frequency response.

The system's measured peak frequency is 10.52 rad/sec. The XY Mechanism's transfer function is evaluated using this natural frequency value.

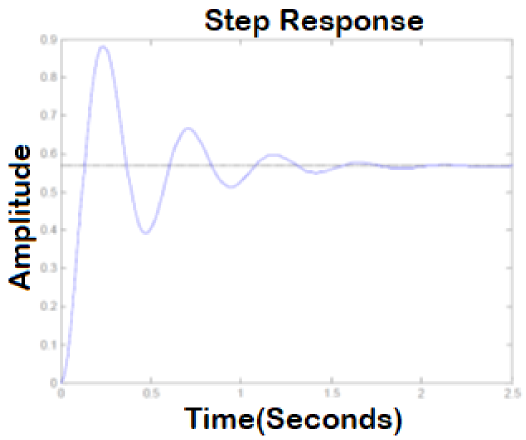

Figure 8 Frequency Response of XY Mechanism

The experiment values are used in MATLAB function tf(mum,den) to evaluate the system

$$G(s) = \frac{1}{0.090963s^2+0.05055s+1.762} \qquad (3)$$

The obtained position and error for the systems is given below

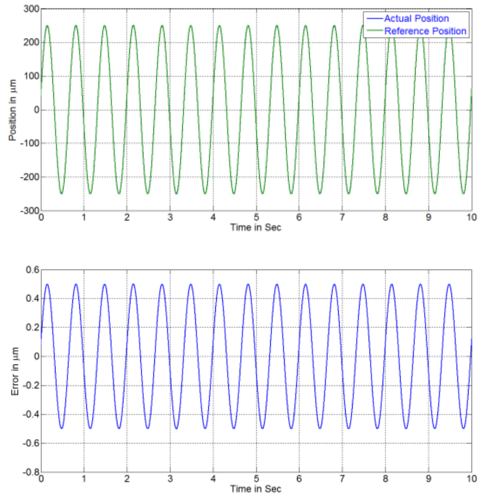

Figure 9 a, b Displacement position at Amplitude = 0.25mm Frequency = 0.8Hz

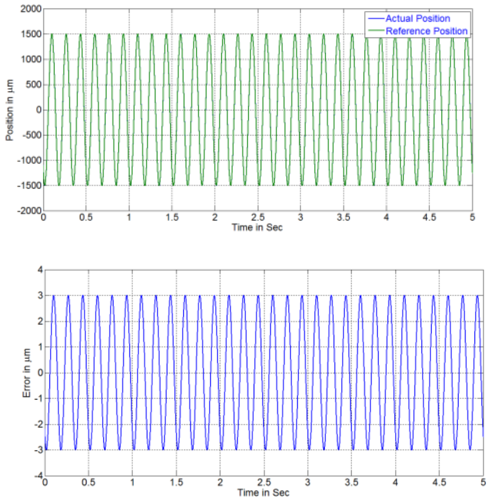

Figure 10 a, b Displacement position at Amplitude = 0.5 mm Frequency = 1.8Hz

Figures 9 and 10 show that a scanning speed of 0.4 mm/sec at a frequency of 1 Hz was attained. A 30 micro error is displayed. Any errors that are present are a result of electrical system noise.

6. Conclusion

Double Flexural Manipulator with dSPACE DS1104 controller is conceived, developed, and further integrated for high precision scanning application. To track the movement of the motion stage and gather feedback for the system, an optical encoder with a high resolution (50nm) is linked to it. There is a striking similarity between them when static and dynamic analysis is conducted, and when experimental and theoretical results are compared. Using MATLAB Simulink, a novel position estimator approach is developed to estimate the position of the motion stage without the need of a costly optical encoder. The precision is less than 30 micrometres at a scanning speed of 0.7 mm/s. The 6.1 mm/s fast scanning speed also results in the same positioning accuracy. Different control algorithms, including as PID, LQR, and LQI, can be employed to increase the system's positioning accuracy. It is also possible to create a generalised position estimator method that works with various actuators.

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