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EXPERIMENTAL INVESTIGATION OF HIGH PRECISION XY MECHANISM

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ABSTRACT

This paper discusses static, dynamic characteristics of the XY Mechanism. It offers zero backlash, friction free motion and high order repeatability. Flexure mechanisms are used in high precision applications for compact design in nature. The merit of using flexure mechanism is single monolith. The paper discusses different design of flexure mechanism using DFM. XY Mechanism consists of actuator (VCM), optical encoder, DAQ dSPACE DS1104 R & D Controller Board. XY Mechanism is manufacture on Wire EDM machine and integrates with dSPACE DS1104. Experimentation is carried out on mechanism and parameters are estimated which have close match with FEA analysis. Frequency response of the system and experimental transfer function is identified.

Keywords: Monolith model, VCM, Flexure Mechanism, System identification, EDM, dSpace DS1104, Encoder.

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1. INTRODUCTION

The development of the advance manufacturing has raised the ultra-fidelity techniques [1]. The XY flexure provides large range of motion in the application of scanning interferometry [3]. Despite of the different design exist in literature [6] motion ranges lacks in stages of flexure. In the design of large scanning range of XY mechanism arise between Degree of Freedom (DOF) and Degree of Constraint (DOC) [1]. For micro-positioning stages, it is suitable to have workspace of larger area, higher resolution, size in compact and higher bandwidth. XY Scanner developed till now has limitations they are range, performance characteristics, accuracy, backlash and many more [7]. The mechanism is XY Flexure Mechanism using Double Flexure mechanism.

Micro positioning stages play important in the modern world of technology. These are used in micromachining and scanning probe. In performance mirco or nano-positioning to get high resolution positioning. In such design the kinematic pair are supersede by flexure monolithic to abolish the friction and backlash. There are advantages of these types of XY mechanism like motion with zero friction, high scanning speed etc. the inauspicious effects as stiction, friction, backlash are eliminate or suppress. The displacement in few orders of better magnitudes, non-ideal quality of constraint. The monolithic construction also simplifies production enabling low cost fabrication.

The work aims at development, design and experimental setup on XY Flexure Mechanism for high precision and high speeds. Marked enumeration like stress, stiffness, frequency response and damping factors are investigated. The paper is arranged as follows initial part explains design of XY Mechanism and theoretical procedure to evaluate stiffness, parasitic motion and rotation of the mechanism. In the second part gives the mechatronics integration with dSPACE DS1104 Controller. Final part of the paper gives the identification of parameters of static and dynamic as ω_n, ξ.

2. FLEXURE MECHANISM

The double parallelogram flexure as shown in figure 1 as the building blocks for two axis planar flexure mechanism. The unit is also referred as folded beam flexure or crab leg flexure

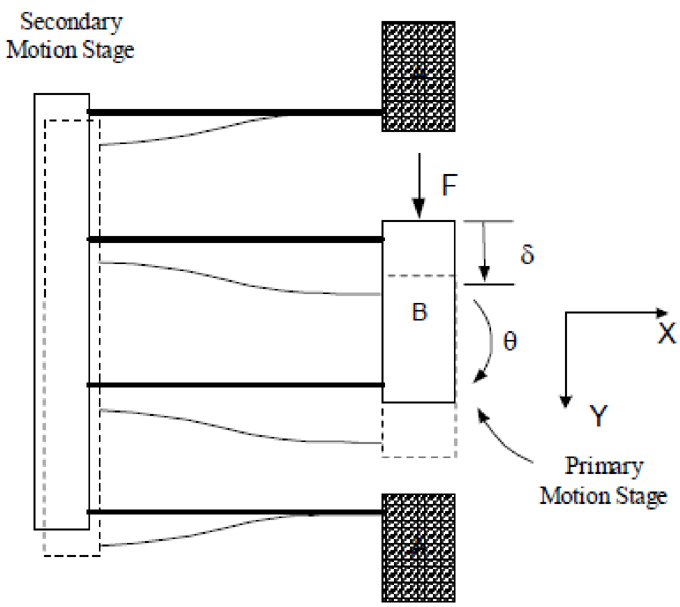

Figure 1 Double Flexure Parallelogram

The deformation, rotation and parasitic error motion in case of DFM unit is calculated by

$$\delta = \frac{FL^3}{12EI} \qquad \theta = t^2\left[\frac{1}{b_1^2} + \frac{1}{b_2^2}\right] \times \frac{\delta}{L} \quad \varepsilon = 0 \tag{1.1}$$

Where

F= Force Applied in N

L=Flexural Beam Length in mm

E= Modulus of Elasticity of beam Material in N/mm^2

I=Mass Moment of Inertia mm^4

t=thickness of the beam in mm

b=width of the beam in mm

The use of the above equation and building blocks to give rise to the outgrowth of double Flexure mechanism as shown in below figure

Figure 2 XY Mechanism

Table 1 Comprasion of the blocks of XY Mechanism using the dimenaions Length L=100mm, Width b=10mm thickness t=1mm

Parameters	Single Beam	Parallel Flexure	XY Mechanism
Deformation δ	7.599	0.6184	1.83
Parasitic Error ϵ	0.3464	0.00299	0.0200
Angular Rotation θ	0.0015	0.000123	0.000360

Double Flexure mechanism is shown above. X and Y direction FEA results are plotted below in table 2

Force in N	FEA Output in X-Direction in mm	FEA Output in Y-Direction in mm
01	0.4048	0.4101
06	2.0238	2.0610
10	4.0475	4.1312
15	6.0713	6.1901
20	8.1950	8.6424

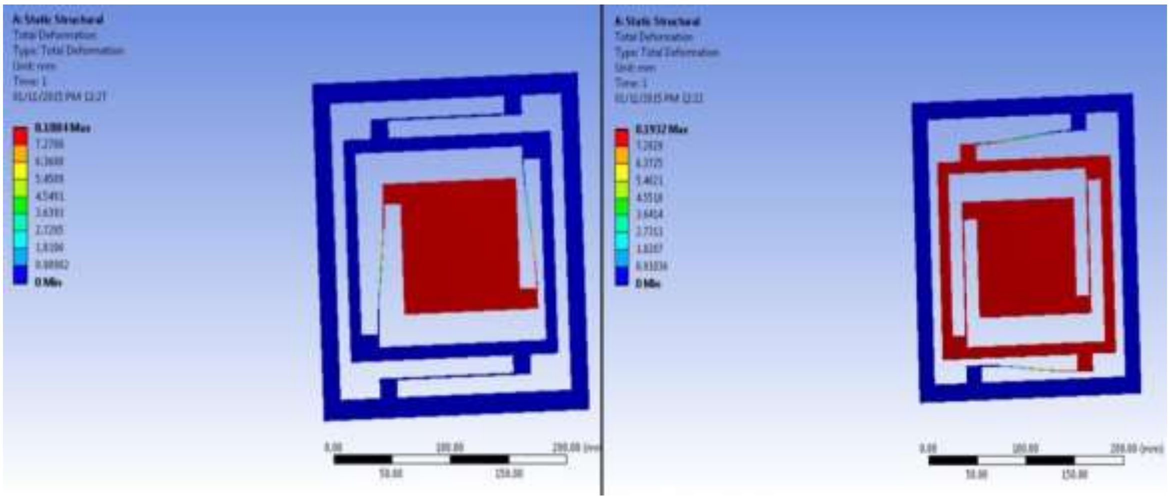

Figure 3 FEA results in X Y Direction

3. INTEGRATION OF MECHATRONICS SYSTEM

Integration of the system with dSPACE DS1104 controller and actuate with control desk as shown in figure 4

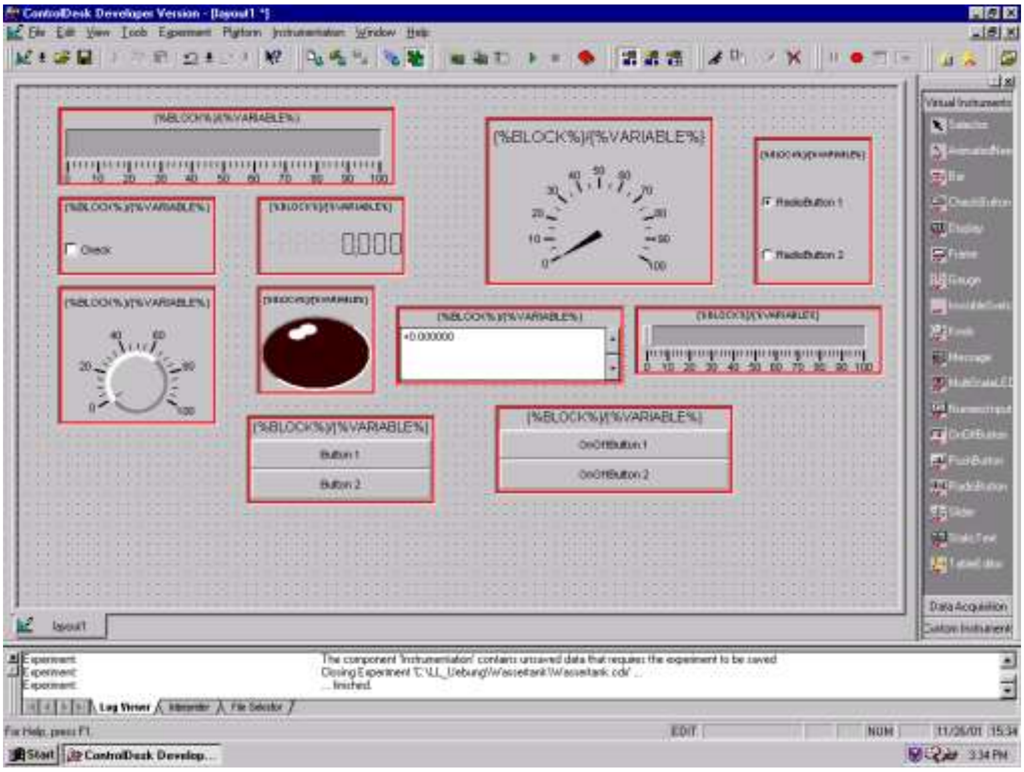

Figure 4 GUI Control Desk

The dSPACE port DAC has amplification factor 1:10. The conversion of 1V in control desk is output of 10V in DAC port. The force is applied to the XY mechanism converting appropriate current voltage signal. The current output is very low magnitude and therefore it is amplified using LCAM (Linear Current Amplifier). The force moves the motion head, output gain is 2A/v. the corrective care has been considered and all the gains are added while preparing the simulink model.

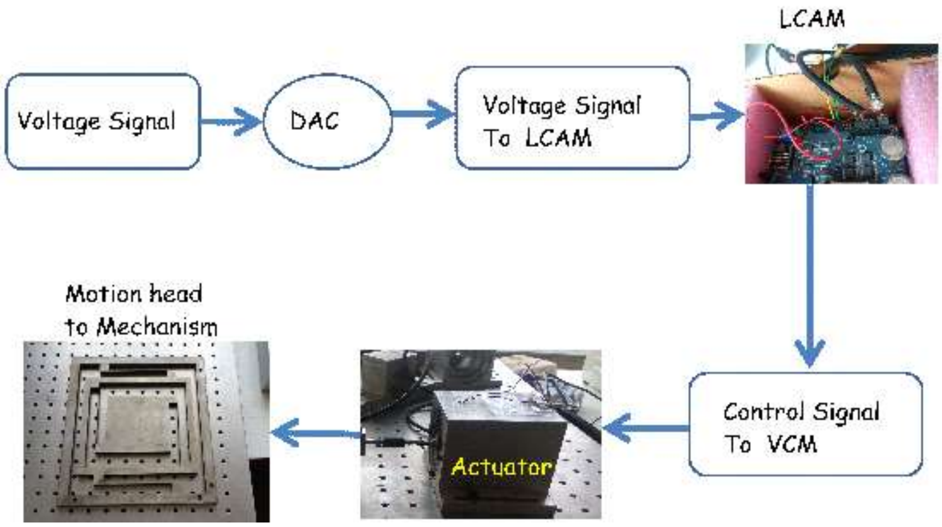

Figure 5 Force applied to the XY Mechanism using Control Logic

The setup is ready for experiments. The control logic is build in MATLAB Simulink and the VCM (Voice Coil Motor) generates signal and actuates the actuator. The encoder evaluates the position of the motion stage. The linear encoder signal is displayed on the control desk. The Electronics and Experimental setup is shown in figure below

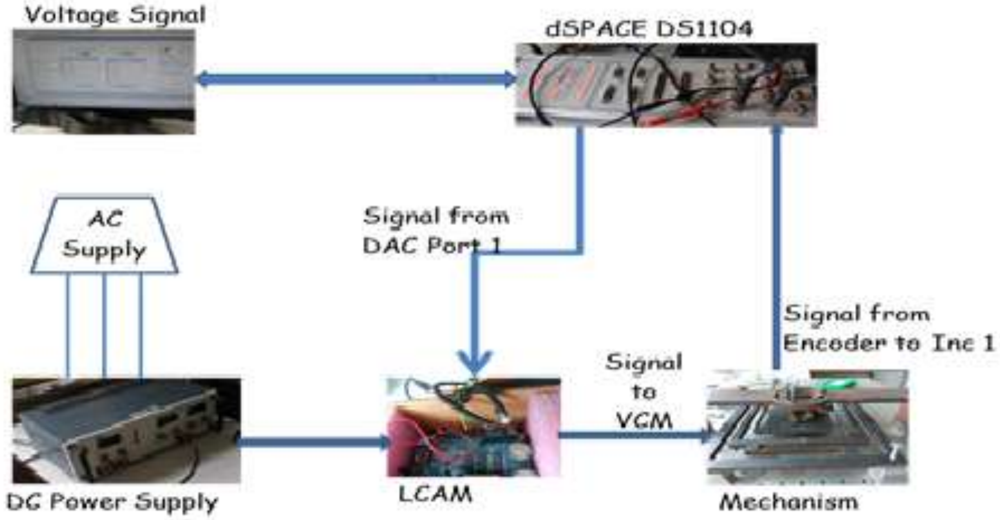

Figure 6 Experimental Setup with integration of XY Mechanism with dSPACE DS1104

Various Mechanical properties like stiffness, damping factor etc. are evaluated with the help of XY Mechanism in Mechatronic integration with dSPACE DS1104. The system Natural Frequency is also evaluated for the present system

4. DETERMINATION OF PARAMETERS STATIC AND DYNAMIC CHARACTERISTICS

4.1. Estimation of Stiffness:

Stiffness the rigidity of an object i.e slope of the force deflection plot is calculated. Simulink code in MATLAB is developed to control and actuate the actuator using VCM. Position of motion stage is sensed by optical encoder. Experimentation is done to evaluate the stiffness in both forward and backward direction of motion. Figure 7 shows the displacement and applied force plot of the XY Mechanism

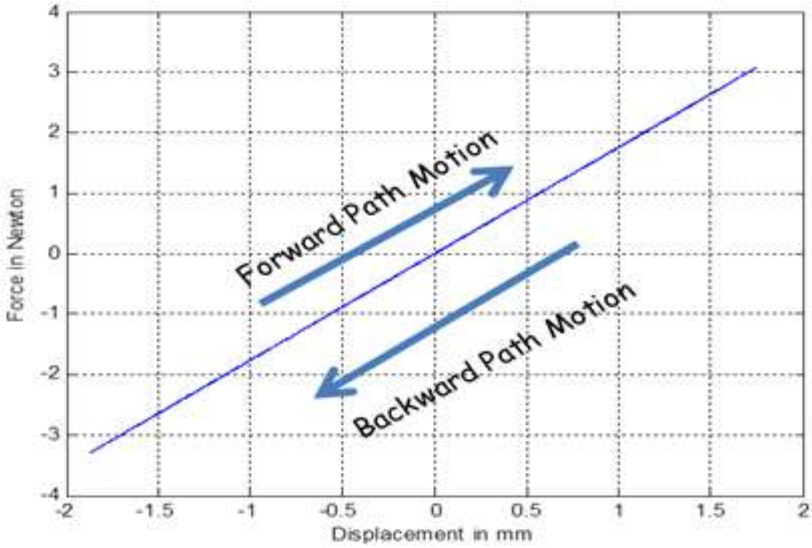

Figure 7 Force vs Displacement

4.2. Damping Factor:

Motion stage is given with the initial displacement by fugitive force and it oscillates freely until it comes to rest as shown figure 8 below

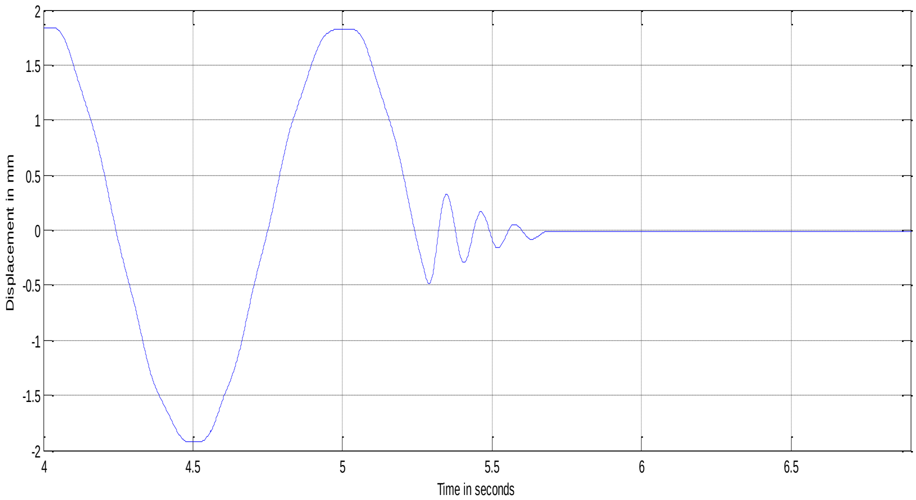

Figure 8 Transient Response of the XY Mechanism

The logarithmic decrement is applied to evaluate the damping factor. It is given by

$$\delta = \frac{1}{n}\left[log\left(\frac{X_0}{X_n}\right)\right] \quad (4.1)$$

Where

n= Successive number of peaks

X_0= First peak Amplitude

X_n= Amplitude to peak at n periods

4.3. Damping Factor

$$\xi = \frac{\delta}{\sqrt{4\pi^2 - \delta^2}} \tag{4.2}$$

From the experimentation the obtained values are

$$\delta = 1.197 \qquad \xi = 0.1940 \tag{4.3}$$

4.4. Evaluation of Natural Frequency:

To develop the transfer function of the XY Mechanism that connects between input control signal to VCM and motion stage displacement. To get the frequency response the sinusoidal input voltage is given and displacement outputs. Simulink MATLAB model is developed to obtain the time frequency response when the Amplitude of 1amp was provided a frequency response graph of the system is generated to analyze the natural frequency and phase change.

The obtained peak frequency for the system is 13.52 rad/sec. this value of natural frequency is used to evaluate the transfer function of the XY Mechanism.

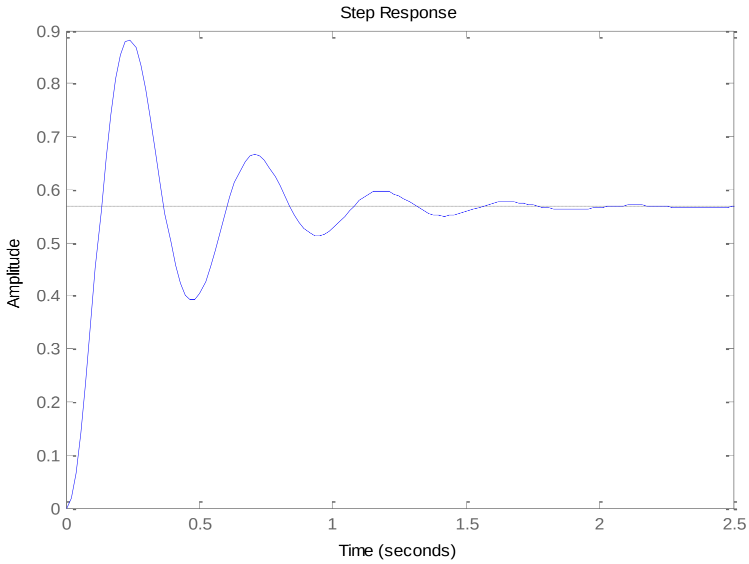

Figure 9 Frequency Response of XY Mechanism

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

$$G(S) = \frac{1}{0.00963s^2 + 0.05055s + 1.762} \tag{4.4}$$

5. CONCLUSION

Motion Stage successfully moves in X and Y direction with precise motion. XY Mechanism is developed with mechatronic integration of dSPACE DS1104 R & D Controllers. The static and dynamic characteristics are experimentally carried out and also theoretically. The results show good agreement to the both. Constrained minimization approach is used to find the frequency response of the model. FM gives repeatable and smooth motions, used for precision applications as laser printing and laser scanning, microscopy, micro-nano fabrication systems.

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