Design, Analysis and Experimental Investigation of XY-Positioning Mechanism

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***Abstract*— The demand of high accuracy and precision in every walk of life. In today's fast moving and highly competitive world, everyone wants precise and accurate results. This article deals with the same aspect and positioning result so obtained are pretty satisfactory. This article deals with the mechanism Double Flexure Mechanism (DFM) and its Finite Element Analysis, based theoretical and experimental approach which helps in obtaining the results. It would not be an understatement to say that, millimeters have brought down to micrometers. In the fast growing mechanical and mechatronic world, the dire need of precision has led to the development of new types of mechanisms and these are serving the main purpose of accuracy. This new class of mechanisms is called as Flexural mechanisms which work on the virtue of stiffness and bending of a member resulting in increase in the precision without compromising the accuracy. The mechanism discussed in this paper is a Double flexure mechanism and is a simple monolithic structure. This mechanism can be further used for scanning applications like bio medical, surgical equipment, and many more places. This article presentscharacterization of the mechanism and further the mechatronic integration of the experimental setup using the LVDT and VCM. The FEA analysis is carried out to determine stiffness, parasitic motion and their characterization.Further, these results are validated via due experimental procedure. It is observed that design provides higher accuracy due to its symmetric constraint layout and analytical, FEA and experimental results demonstrate great concurrence with each other**

***Index Terms*—FEA, Double Flexure mechanism,Linear Voltage Differential Transformer , Voice Coil Motor**

I. Introduction

In modern times, due to the increase in demand of precision and accuracy, the mechanisms are designed to reduce friction and eliminate the backlash. These create inconsistency in the movement of the several links and elements in a non- precise manner this result in the loss of accuracy. In today's competitive industrial scenario, there is a need of mechanisms which reduce the error. Earlier, the industry worked in millimeters and due to the advent of the flexures (Bending members) unit of measurement has been brought down to micrometers. This insatiable need of precision is satisfied by Flexural mechanisms to some extent.

The flexures are nothing but the bending members which deform on the applications of load in a particular direction. The paper discusses the design, analysis and experimental investigation of DFM which validate the purpose of such high precision movement of the mechanism. The research further discusses the design of the experimental setup and the methods of measurements. This study is based on the fundamental properties of any ductile material of deforming on the application of loads. The mechanism using under study is aXY flexuralmechanism using DFM . This mechanism is developed using the zero stress manufacturing using wire cut EDM process it is a monolithic structure made of stainless steel alloy. The mechanism enhances the motion over the range of 20mm.

II. Background

The inspiration of this mechanism was taken based on the research conducted by Shorya Awtar[1]. The extensive work in this field is conducted by him stating the precision achieved with the help of flexures. This started with the comparison between the building blocks of the mechanism started by taking in to consideration the bending of the cantilever beam which resulted in the parasitic error in the direction which wasn't under consideration. This is overcome in the double parallelogram flexure and this helped in development of the Double flexure mechanism which provided the foundation of the development of same.

Double Flexure mechanism is an integration of double parallelogram flexure which has a minimum parasitic motion theoretically as well as practically proved. The mechanism is also called the XY scanning mechanism as the sole purpose of it is to scan. It's a planer mechanism and the motion so obtained is very precise and accuracy up to 98% can be achieved and this mechanism is developed using stainless steel of density 7850 Kg/m^3. The manufacturing of the mechanism is done using a zero stress method and it is wire cut EDM. It's a monolithic structure manufactured from the plate of dimension 300 X 300 mm.

The mechanism designed by Shorya Awtar[1] is further analyzed in detail in this article.

The mechanism in discussion is tested for the force and deflection depending upon which the stiffness and natural frequency is calculated and further the modal analysis of the same is done using ANSYS 14.5 WORKBENCH to find the first three mode shapes of the same and then the actual experimental frequency is compared with the ANSYS results and thus we find that the mechanism stands good to them.

Micro and nano-positioning stages play a very important role in modern technology. A micro-positioning stage generally refers to a system which can automatically move an end-effector with certain degrees-of-freedom (DOF) in its work space, and maintain a submicron positioning resolution. For is micro positioning stages, it is desirable to have large work space, high resolution, high bandwidth, and compact size [2]. Precision positioning is one of the most fundamental technologies for supporting the development of industrial manufacturing, and is a field of multidisciplinary engineering that includes sensors, actuators, controllers, and mechanical transmission elements [12]. Precision engineering has numerous applications and they find applications in many fields, such as micromachining and scanning probe. In precision joining processes, such as laser welding, vertical motion micro-positioning stages are used to provide large motion and high stiffness [7].

Over a period of time a lot of effort has been on improving the performance of the devices. The recent advent in the field of precision engineering and concurrent development of the advanced manufacturing processes has narrowed the manufacturing process window from micro level manufacturing to Nano scale[8]. This has forced the scientist to develop the positioning mechanisms which can prove to be very precise and accurate further increasing the accuracy in the positioning.

These mechanisms are manufactured out off single plate which defines a new class of mechanisms which possess a large range of motion with structural flexibility with several advantages like frictionless motion, elimination of backlash and wear and tear with no need of lubrication [3]. This genre of mechanisms have reduced the noise level and have made the design lighter and flexible.

Flexural mechanism basically consists of hinges and flexure beams. As presented by Shorya Awatar XY mechanism can be achieved using single cantilever beam, parallelogram flexure and double flexural manipulator (DFM) [4]. The latter unit is much closer to the idealized flexure which allows desired deflection but is stiff in off-axis direction and rotation. The flexural mechanism have inherent advantage of being frictionless, highly repeatable and flexible.

III. Building Blocks of the Mechanisms

The flexure mechanism selected for the further investigation has its origin from the use of cantilever and parallelogram flexures is shown in the figure.1 below respectively,

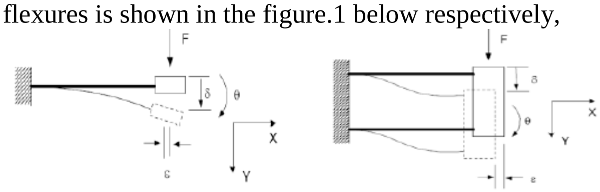

Figure.1: Building Blocks of Mechanisms

1) Double Parallelogram Flexure

The double parallelogram flexure unit is used as the building block for two-axis planar flexural mechanisms (Fig. which is also called Double Flexural Mechanism (DFM).

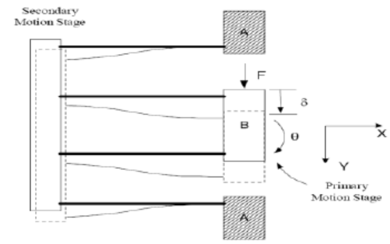

Figure.2: Parallelogram flexure

Deflection, Angular rotation and parasitic error motion is calculated by ,

$$\delta = \frac{FL^3}{12\ EI}, \theta = t^2\left[\frac{1}{b^2} + \frac{1}{b^2}\right]\frac{\delta}{l}, \varepsilon = 0 \qquad (1)$$

The use of the above analytical formulation and the building block has given rise to the development of the Double Flexure Mechanism shown in the following figure.2 [1],

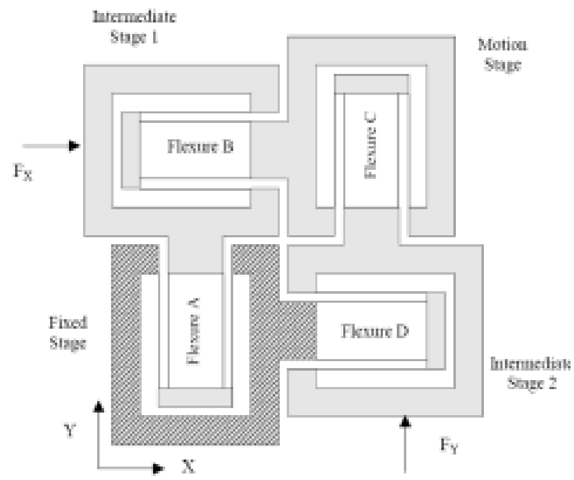

Figure.3: Double Flexure Mechanism

There exist rotational parasitic motions, which may be eliminated by appropriate location of the Y direction force (Actuator placement). Hence, body A exhibits perfect Y-translation with respect to body B on the application of a Y direction force (1). Hence the performance of the DFM is best compared to other mechanisms. The analytical comparison of the rest of the flexures and the other used flexures is shown in the following table 1.

Table 1: Analytical Comparison of Building Blocks of XY FlexuralMechanism Considering Beam Dimensions (L=100 mm, T=1 mm and W = 10 mm)

Parameter	Cantilever Beam	Parallelogram Flexure	Double Flexure Mechanism
Deformation (δ mm)	10.50	1.30	2.62
Parasitic Error (ε mm)	0.395 ***(3.76 %)***	0.005043 ***(0.387%)***	0.00532659 (***0.2032%)****
Angular Rotation (θ)	2.16 ***(20.56%)****	0.23 ***(17.66%)****	0.12 ***(4.57%)****

IV. Finite Element analysis of DFM

Fig. below shows double flexure mechanism. The mechanism has two translational degrees of freedom and has diagonally symmetric design to improve the performance of the flexural mechanism. These mechanisms are modeled using FEA Design Modeler software with same geometric properties of flexural beam (L=100mm, W=10mm and T=1.0mm). FEA results are presented in following figures. Figure shows a deformation in X-direction for double flexure mechanism; similar deformation is observed in Y-direction but not presented here due to similarity of the results. Parasitic motion is completely absent in the DFM.

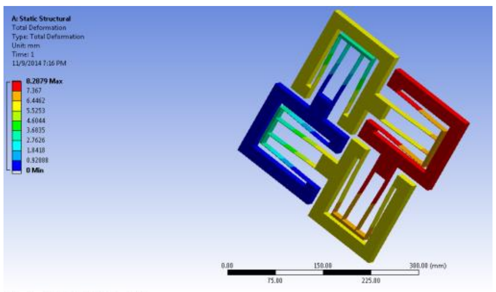

Figure 4. Deflection in X-Y Direction

Further Investigation for the parasitic error is also carried out using the FEA software ANSYS WORKBENCH 14.5.in the following figure.

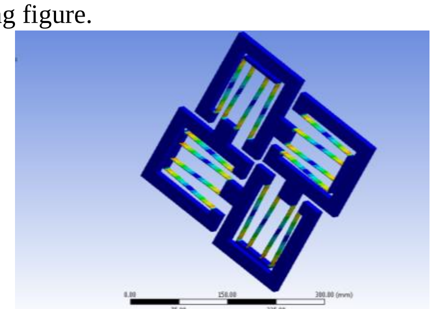

Figure 5. Parasitic motion

Table 1 shows the comparison of the results on the application of very small force ranging between 5-10N. As compared to the rest of the two mechanisms the results shows that the parasitic error in the DFM is of very less magnitude.

Furthermore, the FEA comparison of the results is shown in the table 2 below,

Table2 :FEA Comparison of XY Flexural Mechanisms

Parameter	Mechanism 1 (Cantilever)	Mechanism 2 (Parallelogram)	Mechanism 3 (DFM)
Deformation (δ mm)	0.9475	0.08627	0.2591
Parasitic Error (ε mm)	0.0391	0.0717	0.0225
Angular Rotation (θ)	2.16	0.23	0.02

Table 2 shows a comparison of three mechanisms based on deformation, parasitic error and angular rotation of motion stage. It is observed that DFM offers better performance in terms of parasitic error and angular rotation. Hence, third mechanism is fabricated and experimental setup is developed. Experimental setup and its results are presented in next section.

V. Experimental setup and results

XY flexural mechanism presented in previous section is manufactured using standard Wire EDM process. The basic EDM process is simple. An electrical spark is created between an electrode and a work piece. This electric spark produces intense heat with temperatures reaching 8000 to 12000 degrees Celsius, melting almost anything. The spark is very carefully controlled and localized so that it only affects the surface of the material. The EDM process usually does not affect the heat treat below the surface. With wire EDM the spark always takes place in the dielectric of deionized water. The conductivity of the water is carefully controlled making an excellent environment for the EDM process. The water acts as a coolant and flushes away the eroded metal particles. Fig. 5 shows a layout for XY Flexural mechanism. Thickness of each flexural beam is limited to 1 mm because of manufacturing constraints.

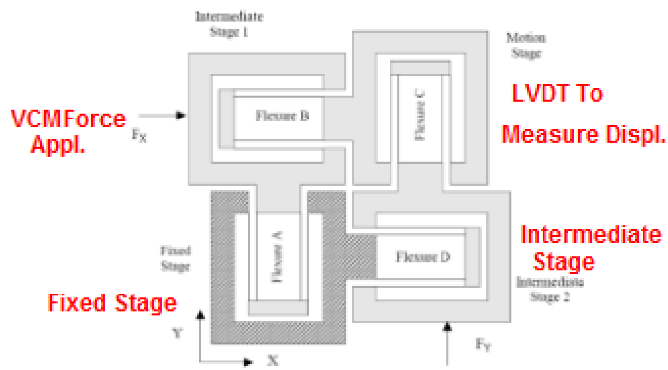

Figure.6: Layout of the experimental setup.

The mechanism is placed and fixed at the fixed stage along with voice coil motor of the gain 226 volts which actuates the mechanism in X as well as Y direction. The computer is used to give the digital input to the DSPACE. The input sinusoidal wave form of amplitude range 0.2 to 0.7 mm is given through the DSPACE to the VCM as shown in the figure6 below.

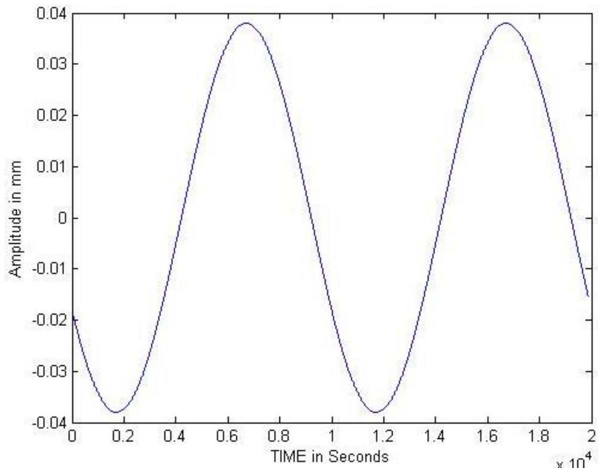

Figure.7: Input signal

The Y axcess shows the amplitude in and x axsis shows the time the out put is measured using the LVDT having a leasst count of 10µm. The LVDT generates the analog signal passing the same to the ADC port of DSPACE is reflected on the computer ouput screen.

The Block diagram for the experimental setup shows the flow of input signal and output measurement as follows

The power source DC of the input 30v is connected to the LCAM and the LCAM output is one connected to the VCM and LVDT for the voltage supply and output that is the feedback from the LVDT in analog format is given to the DSPACE to ADC port and the analog signal is further converted to the digital and is shown on the screen in the form of wave form along with the reading of displacement. The input is voltage to the LCAM having a gain of 2 and VCM as mentioned above has a gain of 22.6 these are the factors to be taken in to consideration while interpreting the results. The following figure7 shows the output wave form,

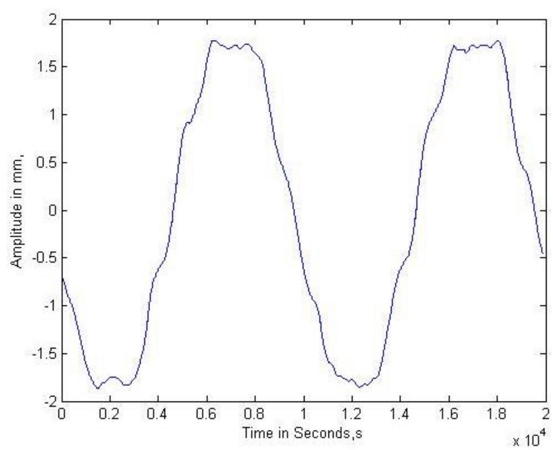

Figure.8: Output Signal Displayed

The figure8 shows the output wave form Y axis in the amplitude and x axis is the time in seconds though the wave form is sinusoidal there is a bit noise due to the instability and surface irregularites of optical table and LVDT used for the measurement of displacement.

The experimental setup is shown in the following image. Figure 9

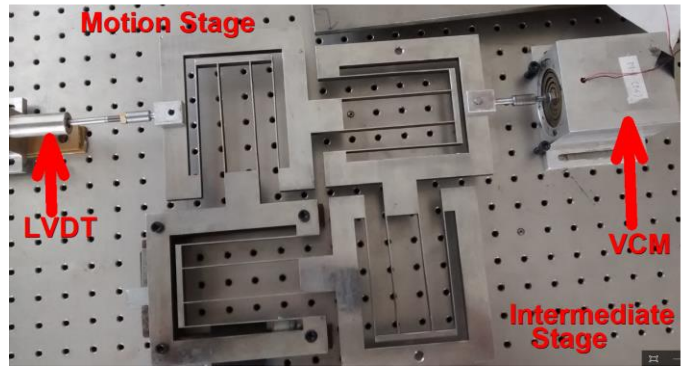

Figure.9: Experimental setup

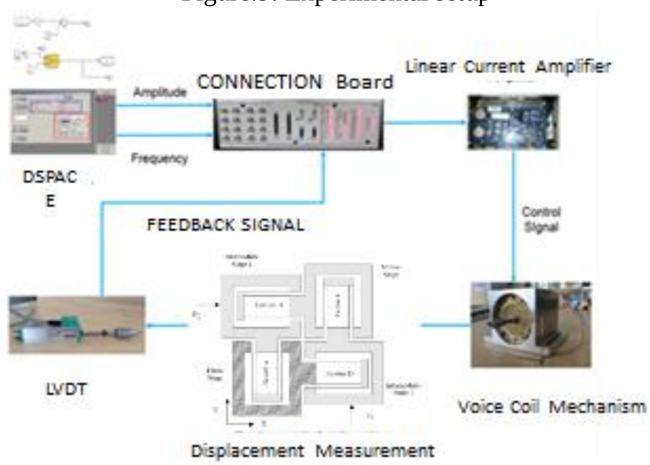

Figure 10:Block digram for the experimental setup

The flexural mechanism is aligned on optical table and LVDT are mounted for recording X and Y direction motions. Fig. 9 shows an experimental setup which consists of a LVDT which measures displacement of motion stage in X & Y directions respectively. The LVDT has a resolution of 10 µm and range of measurement is 65 mm maximum. Red color flexible wires are tied at actuator location to provide an appropriate actuation in X & Y directions. Load is applied using VCM with an increment in amplitude of 0.02mm. For each increment of load deflection of motion stage is recorded. Load applied is of maximum 31 N is given such that maximum of 7.9 mm displacement is achieved. Figure shows a comparison a close match between experimental and FEA results X-direction motion

The readings in the Y direction appeared to be the same and the linearity of both the directions along with the comparison for the parasitic error is also mentioned in the graphs.

It shows max deflection of 25 mm, and variation observed is due to surface irregularities only. Hence it is concluded that there is zero parasitic motion occurs in Y-direction when stage is moving in X-direction.

VI. RESULTS

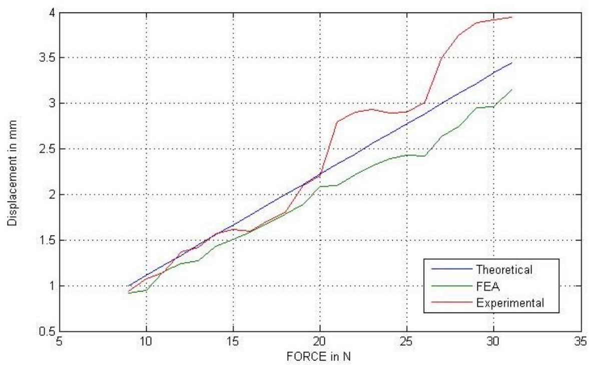

Figure.11: Comparison of Theoretical, FEA and experimental Force deflection characteristics

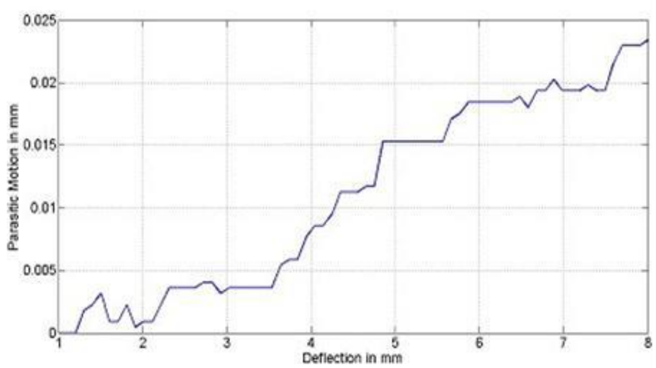

Figure.12:shows the parasitic motion in the Y direction

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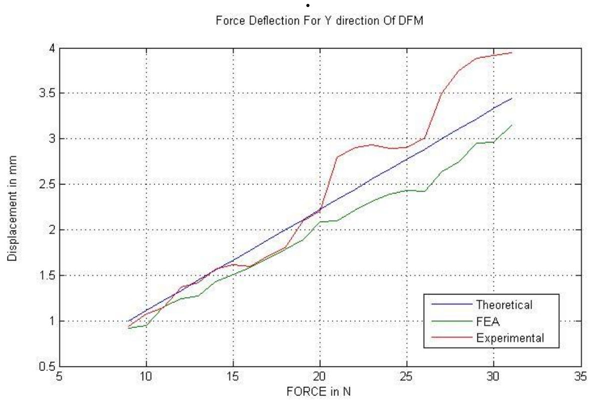

Figure.13: shows the comparison FEA, Experimental and Theoretical results in the Y direction.

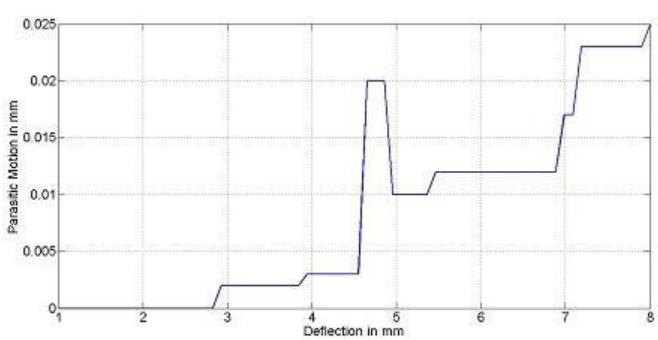

Figure.14: The parasitic error for the X direction

Comparison shows a close match between experimental and FEA results.Results of deflection in X-directions are shown in Figure 10.The results of the experiments and FEA as well as theoretical are plotted in the figure 11 which resembles the comparison in the X direction of load application. Similarly figure 12 resembles the results in the Y direction. It shows max deflection of 25µm, and variation observed is due to surface irregularities only. Hence it is concluded that there is zero parasitic motion occurs in X- direction when stage is moving in Y-direction.

VII. CONCLUSION

FEA and experimental results are compared and it clearly shows DFM based mechanism offers better performance as compared to other two mechanisms. Experimental results show slight variation in parasitic motion. Such parasitic error is due the manufacturing inaccuracies. This type of mechanisms can be further used for micro-nano precision scanning applications. The further fine tuning of the results can be achieved by using the encoder and implementing PID as well as making the mechanism sensor less this will generate more reliability in terms of the use and prove the flexibility as well as the mechanical advantage of the same.

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