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Design and Analysis of Micro/Nano X-Y Positioning Stages for Evaluation of Stiffness of Suspension Beams

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***Abstract*—Now a days, in-precision manipulation systems stiffness are plays an important role to predict precise performance of a suspension beam, due to the high precision control of motion the Nano-position are widely used in industrial and research applications which requires super resolution, such as microscopy, nanofabrication, Nano-patterning and interferometer. Finite Element method which helps to determine stiffness of folded suspension beams with present research trends. This work proposes to calculation of stiffness which is an important parameter to analyze performance of suspension beam for large displacements in positioning stages. Also using various governing equations for straight beams in stages are chose and the analysis is carried out the defined value of stress with deformation and comparing with numerical and analytical data.**

Keywords—Nanofabrication, Interferometer, Micro/Nano x-y Positioning, Suspension beams

I. INTRODUCTION

A Nano position is a high precision positioning device used to manipulate an object to a target position at a nanometer resolution. Due to the high precision control of motion, Nano position are widely used in industrial and research applications which require super resolution, such as microscopy, nanofabrication, Nano patterning and interferometer. The design tools of Nano position can speed up computation, increase modelling accuracy, and hence improve quality of the designs. Nano position are actuated to manipulate an object to a target position. As scientists and engineers depend more and more on nanotechnologies, there is a great need for Nano position of a higher performance. Here the new model is designed and fabricated for both analysis and experimental testing is done. Thus, a significant amount of research has been done to improve the design process. PRBM model is used to create simple models and is based on envelop and inputs/outputs. And the parameterization of the results is also been done. And the error values between experimental and analysis part is calculated. The XY stage is designed and tested for the application Nano position like robotics, etc... It is widely used for optimization of the structure mechanism and results in a distributed compliance structure. Compliant mechanisms have attracted widespread attention in a variety of scientific and industrial applications owing to their high precision and compact size without wear, friction, and backlash or need little assembly. However, one limitation of compliant mechanisms in comparison with their rigid-body counterparts is that the design and analysis of compliant mechanisms require simultaneous consideration of kinematic and elastic-mechanical behaviors. The research goal of this paper is to develop a new XY model positioning stage using folded beams by validating stiffness and computational model for the design of compliant mechanisms with the applications to Nano position.

A. *Objectives*

- To develop generalized methodology for designing a compliant mechanism.
- To develop a folded beam by increasing number of folds which are straight by validation of stiffness?
- To develop a new design of XY positioning stage with folded beams.
- To analyzing the loads and stresses acting on the optimized structure.
- To illustrate the effectiveness of the developed design , several novel compliant mechanism designs are created using the FEM.

B. *Research background*

The most common approach to beat this vary limitation is to mount a 'fine' flexure- based Nano positioning system by incorporating folded beams in validation of stiffness which is a novel approach on high of a 'coarse' large-range ancient motion system. We have a tendency to define the physical challenges related to Flexural elements incorporated in folded beam , and present a physical system construct for an oversized vary XY positioning system.

C. *Research Support*

To find the stiffness of XY position stage using complaint mechanism it is more useful in industry propose and in robotics field also. The study of complaint mechanism is interesting because there is more hope in future for the complaint mechanism, because it reduces the work, cost and time. And the implement of folded beam is done in the research work for more precision. The XY stage is designed because all the movement is done with the single stage so it is planned accordingly and designed.

II. LITERATURE RIVEW

Micro positioning stage plays important role in Precision and engineering applications. These positioning stages based on flexure hinges provide output movement with properties such as vacuum compatibility, repeatable motion, backlash, friction and low cost [1]. The most important component which play a major role in flexible compliant mechanisms and design of positioning stages are Flexure Hinges [2]. These flexures are the mechanical elements which provides rotation between the rigid members of the body through bending instead of conventional joints [3].Many flexural geometries are introduced based on their compliance characteristics and analytical equations for flexures been derived[4]. Compliant mechanism based flexures in positioning stage using modified topology optimization techniques is shown [5,6].

These compliant mechanism based flexures are widely used in design of positioning stages and suspension beams such as folded beam, serpentine springs, Taper, Sinusoidal, Curved beams by considering their parameters such as stiffness coefficient and effective mass[7]. The stiffness of flexible cantilever beams is to identify their sensitivity of geometry and natural frequency by combining physical and geometrical parameters, material properties etc[8]. Suspension stiffness assumed to be linear for electro static comb drive actuator for positioning stage is studied by [9]. Large transverse stiffness of totally decoupled flexure-based XYZ parallel-kinematics micro positioning stage with piezoelectric actuation has been developed [10].Stiffness modeling of novel flexure-based 3-degree-of-freedom elliptical micro/nano-positioning motion stage was developed to obtain translation motions [11]. Stiffness along the three rotational directions of a novel parallel kinematic flexure mechanism that provides highly decoupled motions along the three translational directions (X, Y, and Z) has been developed [12]. Flexure-based compliant rotary micro positioning stage with a large rotational on multistage compound radial flexures for stiffness has also been studied [13]. Compact XYZ flexure manipulator with relatively large-stroke and high-frequency Z-motion is designed for fast scanning ion-conductance microscopy of large scale specimen, such as the biologic cell or other tens of microns rough surface [14]. Novel design method to restrict the parasitic rotation by means of reducing in-plane moment, but without increasing rotational stiffness has been proposed [15]. Monolithic mechanism with capability of working in three translational axes and having a high resonant frequency of being precise in rotation is developed [16] large deflection behavior of clamped–clamped beams and a folded flexure design is modeled and comparison of several suspension designs is presented at low driving voltages [17]. Governing equations to calculate stiffness is derived from castgliano's theorem, rayleigh energy principle and strain energy for serpentine folded beams [18]. A flexure-based differential XY micro positioning stage driven by piezoelectric actuators was proposed in this study with finite element analysis method and experiments to validate its performance [19].

III. DESIGN AND ANALYSIS

Design has been carried by this methodology and it analyzed with an analytical approach in order to simplify the analysis and design of compliant mechanisms, certain design considerations are required to be presented in the initial section. Based on these considerations, a design is obtained such that it meets the specified design objectives. It may be further refined using methods such as finite element analysis, and then it can be prototyped and tested. The above deformation and vonmises various force reactions are carried out from analytical and FEM

A. Modeling

The design considerations of pantograph compliant mechanism are presented with its benefits. Also, displacement synthesis is carried out for selected folded beams. The configuration of mechanism (its size and sectional details) has to be evaluated analytically and is required to verify using FEA tool. The design of folded flexural hinge is proposed on basis of results obtained earlier and design of experiment is used to promote the straight suspension flexural hinge.

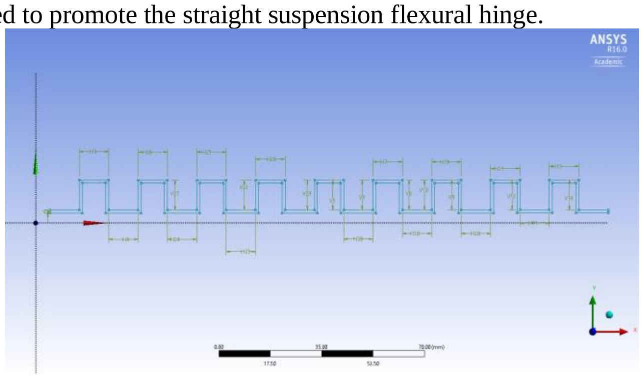

Fig. 1. Modeling of 10 folds

For analytical stiffness is given by

$$K=f/\delta \quad (1)$$

TABLE I. STIFFNESS FOR VARIOUS FORCE REACTIONS FROM FEM AND ANALYTICAL WITH E=200000 AND I=0.08

Folds	*Force (N)*	*Deformation (mm)*	*Stiffness*	*Length*	*Total Deformation*	*S Eq*
1	0.625	0.011	56.81818182	30	0.042356928	14.75555556
2	0.049055	0.0318	1.542610063	50	0.015391253	3.1872
3	0.0329	0.0434	0.758064516	70	0.02832505	1.161516035
4	0.027115	0.0554	0.489440433	90	0.04961555	0.546502058
5	0.02055	0.0669	0.307174888	110	0.068654744	0.299323817
6	0.01667	0.0788	0.211548223	130	0.091927686	0.181338188
7	0.0147	0.090029	0.163280721	150	0.124529367	0.118044444
8	0.0128	0.1035	0.123671498	170	0.15784739	0.081090983
9	0.011146	0.1145	0.097344978	190	0.191893609	0.058084269
10	0.009811	0.1257	0.078050915	210	0.228061423	0.043019112

B. Analysis

The maximum stress at straight fold suspension beam by increasing number of folds and calculated by using Euler's bending equation and the results are verified with FEA results.

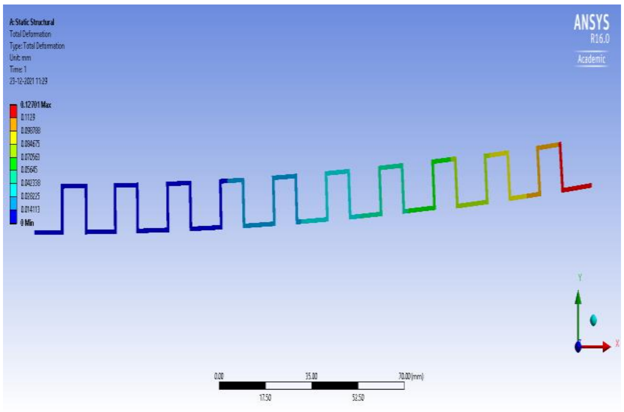

Fig. 2. Total deformation of folds

1) The pseudo-rigid-body model is employed to simplify the analysis and design of compliant mechanisms. The pseudo-rigid-body model, on the opposite hand, may be used to get a preliminary design which can then be optimized.

a) Design of XY Stage: An XY suspension single folded flexure-based positioning stage was developed for Nano manipulation tasks in our work. The overall mechanical design of the planned XY Nano positioning stage with complaint mechanisms and decoupling modules is shown in Fig by incorporating single folded suspension beam so as to accumulate XY Nano positioning, two identical actuation mechanisms are orthogonally organized, with every of the intermediate stage being connected to the output end-effector through 2 parallel leaf sort flexure hinges. The design model and the meshing and loads for various conditions are shown in the below mentioned results To more limit the lateral parasitic motion induced by the displacement output which are symmetrically connected to the end of micrometer input. The design of XY compliant positioning stage subjected to various dimension parameters are studied from SOLIDWORKS platform and the design is pre and post processed by importing its parameters into ANSYS

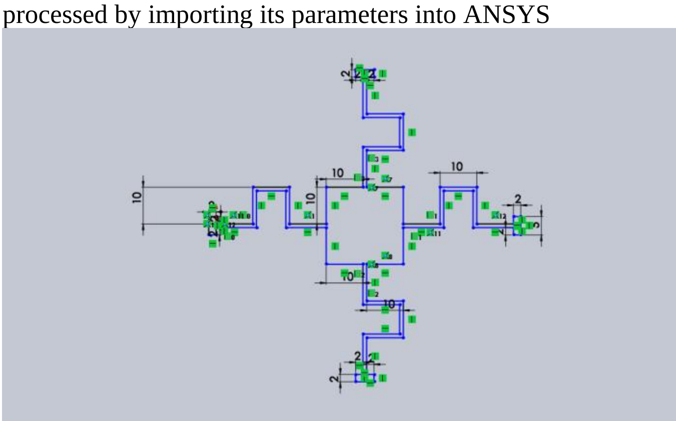

Fig. 3. XY-Positioing and Dimensioningstage

b) Loading Conditions: A horizontal beam is designed with dimensions of 20mm in length and 1 mm in width. An analysis to study deflection of this has been carried out for various input forces and displacement . The results are shown below for meshing of size 0.1mm meshing of cantilever beam (0.1mm) various pre loading conditions for the cantilever beams are given in the below shown horizontal force and displacement conditions to study deflection

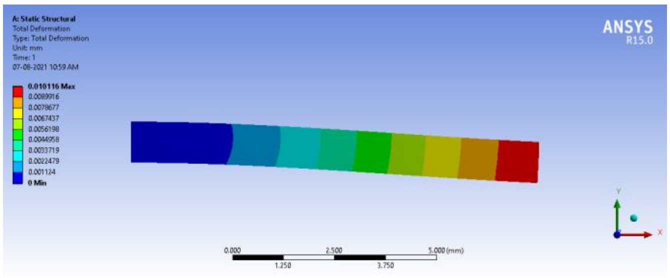

Fig. 4. Static defromation

2) Analaysis of XY Stage: FEA for comparison with the analytical models, and to more study the behavior of the XY stage underneath large displacements. Various dimensions of the entire model of compliant XY stage are chosen to be 20X20 mm length for centre stage and 1 mm in thickness.

a) Selection: The impact of the length and dimension on the stiffness of the beams will be evaluated to verify the established analytical model and performance characteristics of the proposed compliant mechanism. Parameters such as youngs modulus,poisson's ratio and surface creation has been chosen for the design. Static analysis is conducted by defining the structural parameters for various input displacements and vonmises stress for X and Y input loadings are presented

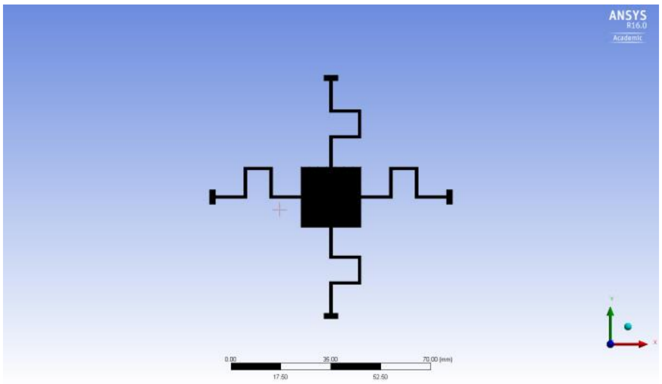

Fig. 5. Static defromation

b) Static Analysis: The static analysis consists in applying a load on the stage to check the displacement and stress engendered. The material properties listed for the analysis is aluminium 7075-T6 as a result of its wide utilized in the literature. it's a Young's modulus of 2*10^5 Mpa; a Poisson's ratio of 0.33; a density of 2810kg/m3; and yield strength of 503MPa. The loading conditions for the design are listed below in the designs for X loading and Y loading to analyze the displacement test

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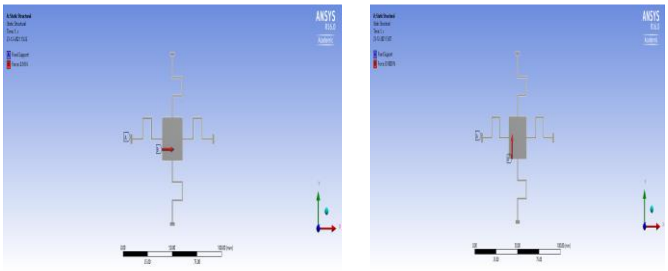

Fig. 6. X-Y Loading input displacemnt

c) Force-Displacement Analysis: To more study the force-displacement relationship, a force is step by step applied and also the displacement on the direction of motion is recorded. The results are then compared with analytical models to validate stiffness of compliant XY single folded positioning stage These parameters are going to be taken into consideration for improvement of the final design while fabrication study. The results of input displacements for total deformation is presented

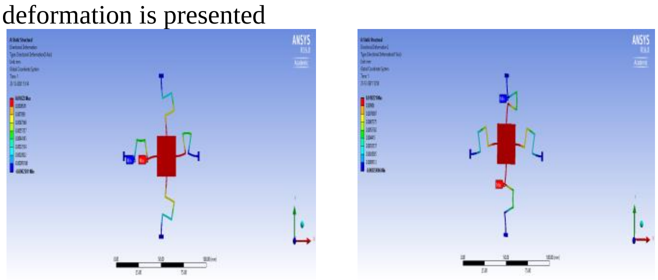

Fig. 7. X-Y Force and displacemnt

Stress Analysis: A stress analysis is employed to outline the utmost allowable displacement, restricted in perform of the yield strength of the fabric. The results of the stress analysis linear FEA model for various input displacements of X and Y and input forces are presented below . As for the force-displacement analysis, it's clearly shown that the analytical linear model deviates from the linear FEA model. The stress concentration factor of the designed XY single folded motion stage, obtained by linear interpolation, is suitable for fabrication with aluminum as a material to furnish further results and the results are presented.

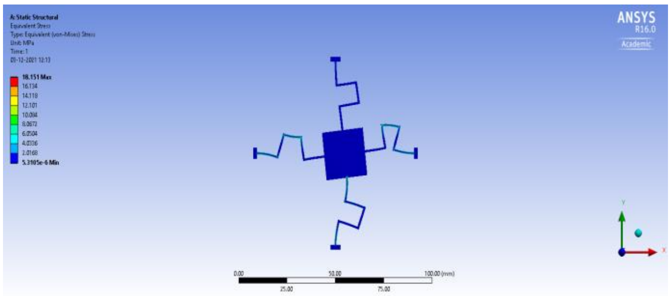

Fig. 8. Vonmises stress for input force

From the resultants above the values of vonmises and total deformation are calculated for a simply supported cantilever beam from theory of beam bending as shown in our analytical equation and study to identify thickness is also defined the variation of a cantilever beam approach from input displacement to force for finding total deformation and equivalent vonmises stress. The input parameters for FEA are: material properties, which are mentioned, based on the above DOE the geometries are prepared and simulations were carried out on these geometries in ANSYS. The four corners are fixed and input forces and input displacement given (range 0.01 mm) as displacement and input force of (0.52N) for the corresponding towards X and Y direction. After all consideration analysis is done on the model of compliant mechanism. The results furnished above shows feasible to validate stiffness for Compliant XY folded positioning stage

The above resultants of horizontal and single folded beams shows how to incorporate suspension folded beams in XY positioning stages to achieve large displacements by variation in stiffness calculation from numerical and analytical. The findings are presented above and values of total deformation ,meshing model, validation of vonmises stress are presented in forth coming chapters of current study. These findings incorporate a line diagram for Single fold XY positioning stage as shown.

IV. RESULTS AND DISCUSSIONS

The parameterization is done for the XY folded suspension beam stage designed to know the thickness of the centre stage and the thickness of beam.

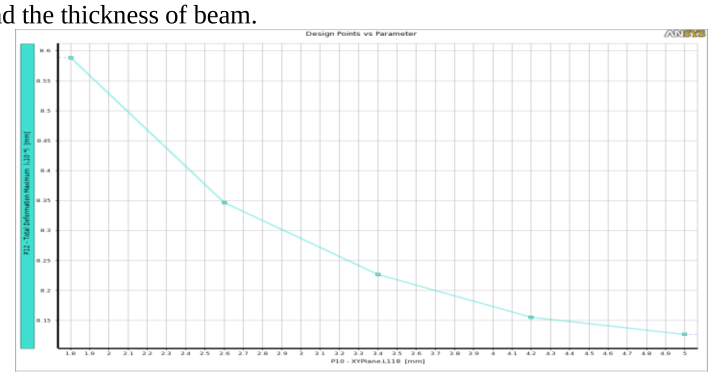

Fig. 9. Deformation of beam thickenss

The self-weight analysis done to find the better results of the stage design the optimum range for the self-weight analysis is 1 to 2 mm thickness.

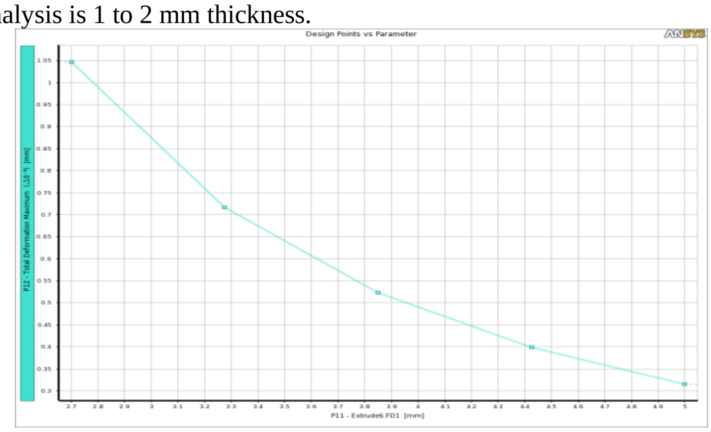

Fig. 10. Deformation of X-Y stage thickenss

And the parameterized optimum value of the beam is 1 to 1.2mm thickness. The candidate points results are taken in ANSYS DOE and it show in graphical format are presented from the above findings the values of various parameterized

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results are published and stiffness constant values are provided to validate with FEM.

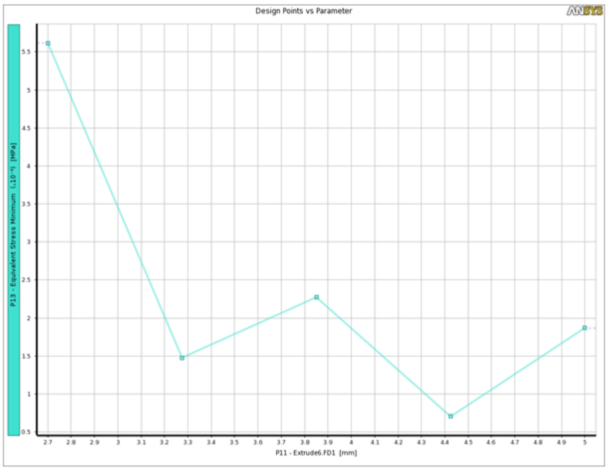

Fig. 11. Deformation of X-Y stress

The obtained results are feasible in comparisons and the proposed single fold XY positioning stage is fabricated with Al material in near future for further comparisons of Experiment and Numerical. The values of stiffness calculated from FEM and analytical is presented.

CONCLUSION

The analytical derivations of calculation of stiffness of a folded beam in compliant XY micro/ nano positioning stages are proposed in this study for various folds by increasing the length. The governing equations are derived using Castigliano's displacement theorem and beam theory. FE analysis is carried out for the design by increasing number of folds for both straight folded suspension beam. The results obtained from the proposed equation estimates stiffness variation of 8% for straight folded suspension with FEA results. These findings show the equation referred here is suitable better for prediction of deflection and general equation of stiffness constant for compliant XYmicro folded positioning stages. In future, experiment study for the above will be carried to predict stiffness performance of positioning stages and the results will be verified with the proposed equation.

FUTURE WORK

Our on-going research is aimed at achieving better stiffness performance which is a novel parameter in existing research. The proposed XY single folded positioning stage is initially fabricated and tested with FEM through our analytical equation and a comparison of percentage of variation has to be studied. Further, the number of folds increased is incorporated into XY single folded positioning stage for stiffness validations

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