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Research Article

Development of 'XY' Flexural Mechanism

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Abstract

The main requirement of a flexural mechanism for Nano-positioning as well as micro-positioning stage used in various nanotechnology equipment is to have minimum parasitic motion or cross axis motion and large range in the direction of force. This paper presents the design and analysis of 2-DOF flexure mechanism for a Nano-positioning stage. This paper motivated by the problem of designing Nano-positioning equipment for two dimensional (2-D) motion stages for micro-nano manipulation of objects. A flexural parallel mechanism for two translations is proposed and applied to XY fine motion stage driven by the weight with the help of pulley (alternative of the piezo electric actuator). Due to the active joint chains for motion, the mechanism has more compact structure than the other which have the separated mechanism of motion guide and the displacement amplification. The flexural mechanism is designed, considering related design constraints using finite element analysis and experimentally tested for validation of FEA results. Both the theoretical and FEA results confirm the mechanism meeting the large range requirement for Nano-micro-positioning stages.

Keywords: *FEA, Flexure Mechanism, XY positioning Stage.*

1. Introduction

The Nano positioning system is gaining more importance and finds its application in various areas of nanotechnology. The need for higher resonant frequency Nano positioning stage is growing in many fields like fabrication, Nano metrology and in cell-biology .In order to obtain the high resonant frequency many research works have been carried out (S. Awtar *et al*, 2007). Since the scanning probe microscope (SPM) was invented by Binning and Rohrer at the IBM Zürich Laboratory in the early 1980s, a new window has been opened into the Nano world and has been a major driving force in the current development of Nano science and engineering. Nanotechnology that aims at the ideal miniaturization of devices and machines down to atomic and molecular sizes has been a recent hot topic as a promising high technology for the new century, which results in an explosion of activities surrounding the design of Nanoelectromechanical systems (NEMS), sensors, and devices (T. Fukuda *et al*, Nov.2003). Different from the macro scale, inertial forces become negligible going down to the nanometre scale, and adhesive forces become larger and dominant. Nano manipulation can be defined as the manipulation of nanometre size objects using an end effector with (sub) nanometre precision (M. Sitti *et al*, 2001).Nowadays, compliant positioning stages with ultrahigh precision play more and more important roles in applications where a high-resolution motion over a micro range is expected in the cases of microelectromechanical system (MEMS) sensors and actuators, optical fibre alignment, biological cell manipulation, and scanning probe microscope. An XY translational stage is needed in an atomic force microscope (AFM) (D. Kim *et al*, 2007) for scanning of the probe over samples to get information such as surface profile of the canned materials. A great number of compliant stages proposed for the pertinent applications can be found in the literature (E. Pemette *et al*, 1997).

Compliant stages based on flexure hinges transmit motions by resorting to elastic deformation of the material (Y. M. Moon *et al*, 2002).The flexures instead of conventional mechanical joints endow a mechanism with several advantages including no backlash, no friction, vacuum compatibility, and easy to manufacture (Y. Li *et al*, 2006). As the increasing of activities around the research and development in micro- and Nano-scales technology, micromanipulators with ultrahigh precision play more and more important roles in such applications as biological cell manipulation, optical fibres alignment, micro component assembly, and scanning probe microscope (*e.g.* Atomic Force Microscope (AFM)). Due to a parallel mechanism usually owns a greater stiffness and lower inertia than a serial one (J. Dong *et al*, 2008).

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2. Parametric Modeling and FEA Analysis of Flexural Mechanism

The Conceptual design of 2 degree of freedom kinematic motion stage of the flexure mechanism used to develop the mechanism model is as shown in figure1.This kinematic design has four individual kinematic chains connected to the motion stage in a series configuration. The kinematic chains consist of a central motion stage. When the mechanism is displaced in one direction, the resulting motion of the motion stage is accommodated by the other kinematic chains. The link is replaced by beam fixed at both end and a symmetrical single parallelogram mechanism. Parallelogram mechanism has flexure beam and one end of the beam that is connected to the sample platform. The flexure beams provide high structural stiffness and also have high natural frequency.

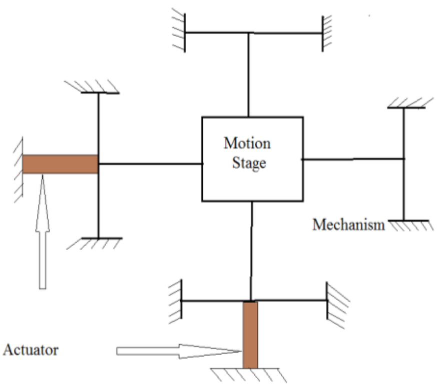

Fig.1 Conceptual design of flexural mechanism

3. Stages in development of mechanism

3.1 Stage 1

First model of mechanism developed using the conceptual design is shown in Fig. 2. The model was analysed for static load simulations by varying geometrical parameters mentioned in table 1. Where Lb = length of beam attached to motion stage, tb = thickness of all beams, tf = thickness of frame, Lf = length of frame, LP = half-length of plate flexure, Fe = clearance between plate flexure and frame, Ls = size of stage, CL = chamfer length and Hp = horizontal length of plate.

3.2 Analysis settings

All outside frame of mechanism is fixed and force is given at open end of mechanism shown in fig.2. Force value is varied from 5 N to 25 N and value of displacement is measured at both ends of motion stage i.e. in x and y direction for all the parametric models.Aluminium 6061-T6 with yield strength of 276 Mpa, Poisson's ratio of 0.33 was selected as the flexure material because of its good strength-to-modulus ratio, lack of cold working stresses, low cost and ease of availability. Its only drawback is relatively high coefficient of thermal expansion. Finite element model for the first run of simulation was meshed with default meshing data which resulted in 11460 Number of Nodes and 1292Number of Elements.

By using the parameter range defined in table 1 extensive static load simulations were run on the parametric model in an attempt to attain maximum deflection in motion direction. Figure 2 shows the maximum displacement of 2.75 mm in the actuation direction for a load of 30N applied in either one direction (either in x or y).

Table 1 Geometrical parameters of mechanism

PM	IV	R
lb mm	50	50-100
tb mm	1	0.2-1
tf mm	10	10-50
lf mm	30	50-110
lp mm	50	50-110
fe mm	120	60-100
F N	30	10-50
ls mm	50	10-50
cl mm	70	50-80

Where,
PM= Parameters mentioned in stage 1
IV=Initial value
R= Range

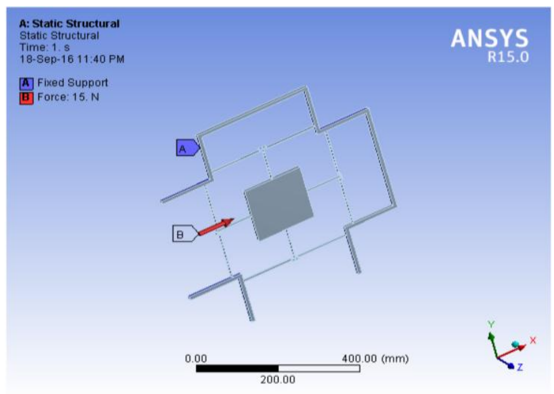

Fig.2 Model 1

3.3 Stage 2

In the second stage of development geometry of motion stage was altered to octagon and the model was checked for displacement and stress in range of parameters mentioned in table 1.The displacement of 2.76 mm in the actuation direction as shown in Fig 3 was obtained for a load of 30N applied in one direction (either x or y).

3.4 Stage 3

In the third stage of development the plate flexure connecting beams were modified symmetrically to add one additional plate in parallel to existing one. Static load simulations run over a range of parameters defining new plate provided a maximum displacement of 5.04 mm. This large range of motion was achieved at cost of mechanism size.

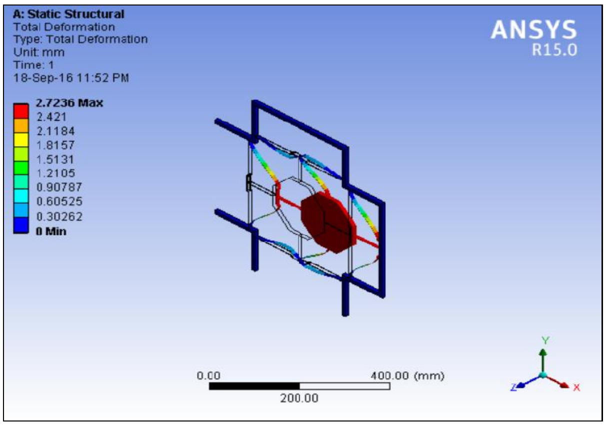

Fig.3 Model 2 displacement

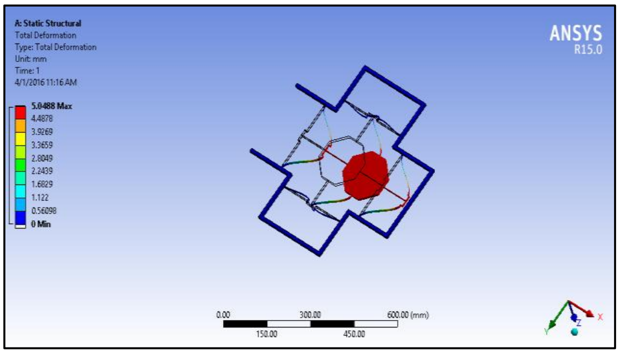

Fig.4 Model 3displacement

3.5 Stage 4

In order to reduce the size of mechanism shape of motion stage was altered as a square. Static load simulations run over a range of parameters defining new motion stage provided a maximum displacement of 3.96 mm in actuation direction at maximum stress 193.57 MPa. FEA results are depicted in Fig. 5 and Fig. 6 respectively. The geometry giving the desired range is detailed in table 2.

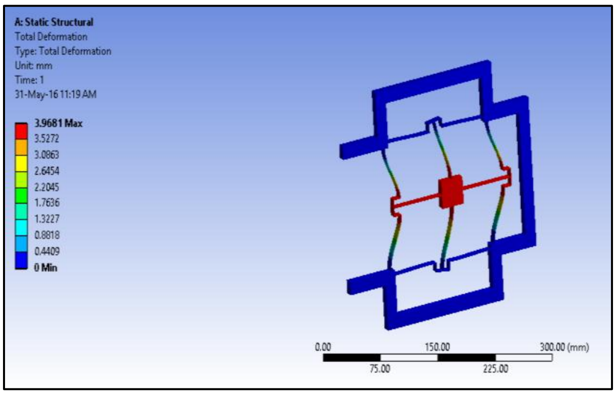

Fig.5 Model 4 displacement

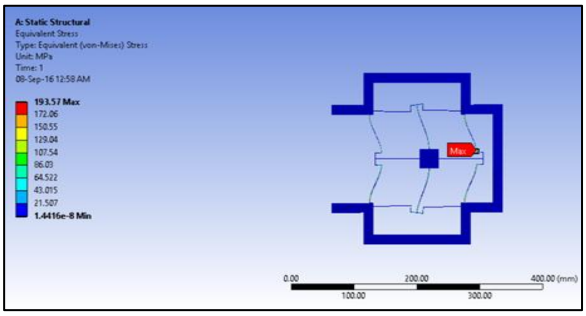

Fig.6 Model 4 max stress

Table 2 Geometric parameters of mechanism model 4

Fe	50
Lb	70
Lf	20
Lp	60
Ls	15
Tb	0.65
Wf	10
F N	30
Ex	193.9
Def.	3.96

All Dimensions in mm

4. Experimental validation

Monolithic Mechanism giving range of 4.99mm was fabricated using wire EDM from aluminum alloy plate of 3 mm thickness in one set up. Wire EDM was preferred over laser cutting due to absence of thermal stresses in the former. Experimental test set up was developed as shown in Fig. 7 to validate the results of FEA analysis. Mechanism was loaded in one direction using dead weight and pan arrangement as shown. Dial gauge of least count 0.01mm was installed to record the displacement of motion stage in parasitic direction and digital vernier with least count of 0.02mm was installed to measure the motion direction displacement. Displacement Readings in X and Y directions were recorded for different values of weight to plot the load displacement characteristics of mechanism and determine the guiding accuracy.

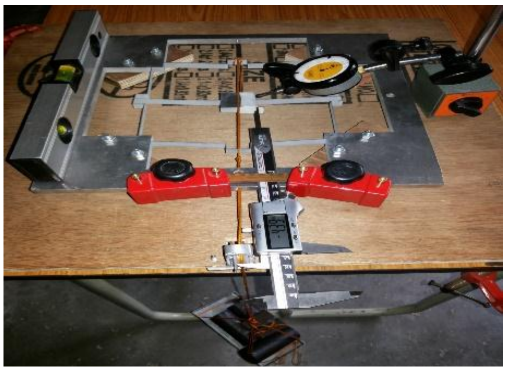

Fig.7 experimental setup

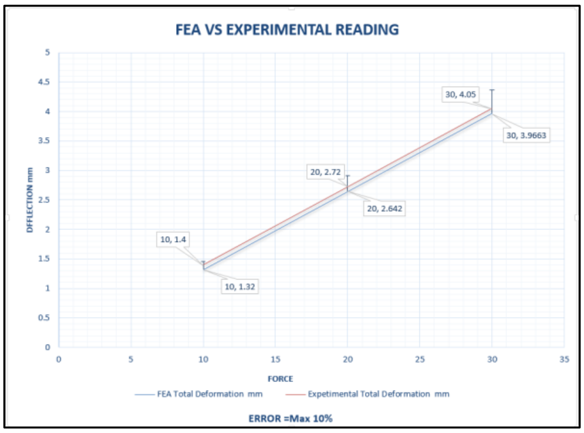

Fig.8 Load deflection characteristics

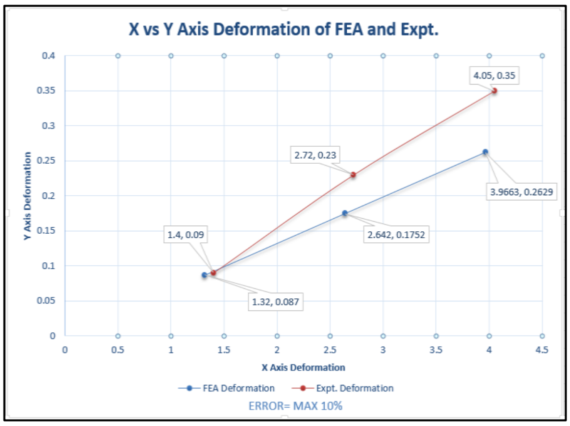

Fig.9 Guiding accuracy comparison

The range of motion is determined as the amount of deflection which causes yielding in the material. It was observed that maximum deflection in experimentation was 4.39 mm as compared to FEA maximum deflection of 3.99 mm. Maximum error in FEA and experimental readings for load displacement characteristics of the mechanism is less than 10%. Maximum deflection occurs in the flexure mechanism when the thickness of beam is minimum and length of beam is maximum. Guiding accuracy of mechanism is the measure of deviation from the axis of straight-line motion.

While generating translation in motion direction flexure stage also shifts in undesired directions due to flexure bending. This is undesirable for the purpose of generating precise motion. Larger the ratio of motion direction deflection to deflection in other direction more precise is the mechanism. Guiding accuracy of mechanism was evaluated using FEA and compared with experimental readings and the corresponding error was less than 15%. Use of precise equipment like actuator, potentiometer *etc.* in measurements may further reduce the errors in result comparisons.

Conclusions

By using ANSYS workbench 15.0 analysis software parametric analysis is done for mechanism geometry which resulted in 300mm*300mm*10mm size flexural mechanism giving 4.39 mm displacement in motion direction. The proposed mechanism can be used in applications likeScanning probe microscopy, metrology, nanolithography *etc.*Future work aims at dynamic analysis of mechanism to determine its mode shapes and natural frequencies.

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