A Review Paper on Flexure

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Abstract- *Flexure mechanisms are a designer's delight. A Flexural mechanism uses flexibility of material for desired motion objectives. As compared rigid-body mechanisms where actuations are applied at the joints connecting rigid links, the manipulation of the Flexural mechanism relies on the deflection of internal flexible members. Flexural mechanisms have no relative moving parts are relatively compact in design as compared to rigid link mechanism. Flexures have been used as bearings to provide smooth and guided motion. Flexural joints are widely used in precision motion stages and micro robotic mechanisms due to their monolithic construction. It is difficult and expensive to make such compact mechanism using traditional machining methods. In addition, the traditional mechanisms machining methods are limited to simple design. To reduce the cost of fabrication and also to allow more complex designs, object i.e. a rapid prototyping machine is proposed to be used to build the mechanism. Traditional motors, gears, and revolute joints are not able to meet the requirements due to existence of backlash between moving parts. Hence, the flexure joints are more popularly used. One of the primary applications of flexures is in the design of motion stages. It strives to bridge the gap between intuition and mathematical analysis in flexure mechanism design. This paper presents design and analysis of flexure mechanism.*

Keywords- Flexure hinges, compliant mechanisms, backlash, actuator-cross sensitivity, parasitic coupling, precision motion

I. INTRODUCTION

A flexural mechanism can be defined as single piece flexible structure, which uses elastic deformation to achieve force and motion transmission. It gains some or all of its motion from the relative flexibility of its members rather than from rigid body joints alone. Such mechanism, with built-in flexible segments, is simpler and replaces multiple rigid parts, pin joints and add-on springs. Hence, it can often save space and reduce costs of parts, materials and assembly labor. Other possible benefits of designing compliance (flexibility) into devices may be reductions in weight, friction, noise, wear, backlash and importantly, maintenance. Flexure mechanisms have immense scope in their use for applications involving high precision motion. There are many concepts to build high speed or high precision manipulators, but only a few of them can serve to obtain high speed together with high precision.

Flexure jointed mechanism have been widely utilized in precision instruments such as watches & clocks for hundreds of years, and continued to be used today in applications such as optical systems, micro robots, and clean equipment. Flexural mechanisms are colossal structures which provide desired motion with the help of flexural hinges. Due to their smooth operation flexural joints have little friction losses and also does not require lubrication. They generate smooth and continuous displacement without backlash.

The importance of properly constrained design is well known to the engineering community. The objective of an ideal constraining element, mechanism, or device is to provide infinite stiffness and zero displacements along certain directions, and allow infinite motion and zero stiffness along all other directions. The directions that are constrained are known as Degrees of Constraint (DOC), whereas the directions that are unconstrained are referred to as Degrees of Freedom (DOF). While designing a machine or a mechanism so that it has appropriate constraints, the designer faces a choice between various kinds of constraining elements, two of which are considered for comparison: ball bearings and flexures. Clearly, ball bearings meet the definition of a constraint quite well, since they are very stiff in one direction, and provide very low resistance to motion in other directions. Nevertheless, motion in the direction of DOF is associated with undesirable effects such as friction, stiction and backlash that typically arise at the interface of two surfaces. These effects are non-deterministic in nature, and limit the motion quality. Flexures, on the other hand, allow for very clean and precise motion. Since the displacement in flexures is an averaged consequence of molecular level deformations, the phenomena of friction, stiction and backlash are entirely eliminated.

II. LITERATURE SURVEY

Yeonge- jun Choi et al. 1] worked on kinematic design of large 1displacement precision X-Y positioning stage by using cross strip flexure joints and over constrained mechanism. For the design of a large displacement precision XY positioning stage, a cross strip flexure joints were used. And to achieve a good kinematic design advanced kinematic techniques such screw system theory are used. The weight support mechanism of the motion stage was made of links and flexure joints, and a linear motor was used as the actuator. Crossed strip type flexure joints that provide large rotation were used. To eliminate the effects of center shifting in large-motion flexures an over-constrained mechanism was used to incorporate symmetry.

Byounge Hun Kang et al.2] carried out the analysis and design of general platform type parallel mechanisms contanining flexure joints. They considered static performance measures such as task space stiffness and manipulability. Based on these performance measures they obtained the multi-objective optimization approach. Firstly they obtained Pareto-frontier. Lumped approximation of flexure joints in the pseudo rigid body are considered for simplification. They established the key difference between flexure mechanism and parallel mechanism with conventional joints and is that kinematic stability is no longer a design consideration. Instead ofthat, important design parameter is task space stiffness which needs to be carefully designed to avoid undesired motion in the presence of external loads.

Zettle et.al. 3] worked on equivalent beam methodology. In this paper they presented a methodology which is accurate and efficient finite elements method (FEM) simulations of planar compliant mechanisms with flexure hinges. In this method one-eighth of a single hinge is simulated to determine its true stress/stiffness characteristics by using symmetry/antisymmetry boundary conditions and 3D elements. A set of fictitious beams is derived, which have the identical characteristics. This set is used in conjunction with other beams that model relatively stiff links to generate an equivalent model of an entire mechanism consisting of the beam elements only. The research work shows that the static and dynamic characteristics of the whole 3RRR mechanism can be simulated with high precision with a model that has a very small number of DOF. The numerical efficiency of the EBM model is very high. Therefore it becomes conceivable to apply it for other purposes such as mathematical optimization, simulating complex dynamic responses, or even for real time applications to control and handling of compliance mechanisms.

Yangmin Li et al.4] represented the modeling and evaluation of a nearly uncoupled XY micromanipulator designed for micro-positioning uses. The manipulator features are monolithic parallel-kinematic architecture, flexure hinge-based joints, and piezoelectric actuation. The evaluation is carried out analytically in terms of parasitic motion, cross-talk, lost motion, workspace, and resonant frequency. The mathematical models for the kinematics and dynamics of the XY stage are derived in closed-forms, which are verified by resorting to finite element analysis (FEA) based on pseudo rigid-body (PRB) simplification and lumped model methods. They established a nonlinear kinematics model, which is based on the deformation of the entire manipulator since the above simplified models fail to predict its kinematic performances. And the validation of effectiveness of non linear model is done by both FEA and experimental studies on the prototype. Results obtained from validation shows that the nonlinear model can predict the manipulator kinematics accurately, and the reason why simplified models fail is discovered.

SollapurShrishail B et al.5] Worked on mathematical modeling of simple XY manipulator is carried out XY manipulator uses typical Double Flexural configurations. Static and dynamic analysis is carried out using MATLAB. Static analysis is carried out to determine static deflection of motion stage with force. It is observed that force deflection curve is linear. Dynamic analysis is carried out to determine frequencies and mode shapes of flexural manipulator. Further, Finite Element software ANSYS is used to carry out static and dynamic analysis of basic DFM configuration and few XY mechanisms. It is observed that close matching of FEM results with model developed.

Shunli Xiao et. al. 6] has worked out the design and analysis of a novel compliant flexure-based totally decoupled XY micropositioning stage which is driven by electromagnetic actuators. They constructed the stage with a very simple structure by employing double parallelogram flexures and four contactless electromagnetic force actuators. Compliance and stiffness analysis based on matrix method, and analytical models for electromagnetic forces is done by using the kinematics and dynamic modeling of the mechanical system of the stage. Both mechanical structure and electromagnetic model are validated by finite element analysis(FEA) via ANSYS. The stage designed possesses a totally XY decoupled character, simple symmetrical structure, easy controlling strategy, and large range of motion. The kinematics and dynamics modeling of the mechanical structure is done by using compliance based matrix method.

Sharad S. Muliket. al. 7] discussed about the design of flexural mechanism using double flexural manipulator (DFM). Here, DFM is designed using classical as well as numerical approach to achieve straight line motion. DFM consists flexural manipulator, actuator (VCM i.e. Voice Coil Motor), optical encoder and high speed data acquisition microcontroller dSPACE DS1104 R and D Controller Board. Further, DFM is manufactured and integrated with dSPACE DS1104. Experimental investigation is conducted and experimental parameters are estimated which are having close match with theory as well as numerical FEA analysis. Frequency response system identification is conducted and experimental transfer function is identified and validated with due experimentations. Further, PID control strategy is implemented on DFM and numerous experiments are conducted to test its precision positioning at high speed of the scanning. It is observed a positioning accuracy of less than 2 microns at scanning speed of 2 mm per second (low speed scanning) and precision position of less than 5 microns at 60mm per second (high speed scanning).

Y.Tianet. Al.8] presented the mechanical design and dynamics of a 3-DOF (degree of freedom) flexure-based parallel mechanism. They utilized three piezoelectric actuators to drive active links of the flexure-based mechanism. The inverse dynamics of the proposed mechanism is established by simplifying flexure hinges into ideal revolute joints with constant torsional stiffness. For the validation of the performance of the proposed 3-DOF flexure-based parallel mechanism he used finite element analysis. The interaction between the actuators and the flexure-based mechanism is extensively investigated based on the established model. He carried out experiments to verify the dynamic performance of the 3-DOF flexure-based mechanism.

Suhas P. Deshmukhet. al. 9] presented the static and dynamic model of double parallelogram flexural manipulator. Static model and dynamic model is derived from basic classical mechanics theory. Forth order vibration wave equation is used for mathematical modeling of DFM. Differential equation is solved using assumed modes method and its performance is determined for step input and sinusoidal forced input. Results of simulation are investigated and it is observed that natural frequency of DFM is 4.95Hz. DFM model is further experimental investigated. Different components of DFM is manufactured and assembled to achieve a desired motion objective. Here, Voice Coil Motor is used as Actuator and optical encoder is used for positioning sensing of motion stage. DFM module with actuator and sensor is interfaced to PC using dSPACE DS1104 microcontroller with ControlDesk software module. DFM is characterized in two different domains (1) Static characterization is carried out to determine its stiffness and force deflection characteristics over the entire motion range; (2) Dynamic characteristics is carried out using Transient response and Frequency response. Transient response is determined using step input to DFM which gives system properties such as damping, rise time and settling time. These parameters are further compared with theoretical model presented previously. It is observed that theoretical model is having close agreement with experimental results within 5 % accuracy. Frequency response of DFM system gives characteristics of system with different frequency inputs. This frequency response is further used for experimental modeling of DFM device. Experimental model (transfer function of DFM with input: voltage signal output:displacement of motion stage) using frequency response is determined using constrained minimization approach. Experimental model is further compared with theoretical model developed using fourth order wave equation and it is observed that results of simulations and experiments are in good agreements. Developed experimental model is further used for PID control implementation. PID parameters (i.e. proportional gain, derivative gain and integral gains) are tuned using Zeigler Nichols Method. Experimental model was initially tested offline and accuracy of less than 1 micron is achieved. PID control is implemented experimentally using dSPACE DS1104 microcontroller and Control Desk software. There is slight deviation from theoretical results is due to assumptions made during modeling process. During modeling noise is not taken into consideration. Experimentally positioning accuracy of less than 5 microns is achieved.

HrishikeshZambareet. al. 10] theyillustrate the design, development and system integration of flexural motion stage for precision applications. Parametric Modelling and analysis of flexural stage is carried out using FEA package ANSYS. Developed flexural stage is integrated with desktop PC via dSAPCE DS1104 micro-controller. Further experimental system parameters are estimated (such as stiffness, damping factor, natural frequency) which are having close match with FEA results.

U. Bhagat et.al. 11] focused a research work on the computational analysis of a miniature flexure-based mechanism. This novel flexure-based mechanism is capable of delivering planar motion with three degrees of freedom (3-DOF). He studied the stress distribution at all flexure joints, modal analysis and the workspace envelop of the mechanism. And this mechanism is used for three piezoelectric actuators to achieve desired displacement in X, Y and Θ. He designed a miniature 3 DOF micro/nano mechanism and analysis is done by using ANSYS. The FEA study and the collected data confirm the performance of the mechanism and the displacement of the TCP in the X-, Y- and Θ- direction. Stress levels in the hinges are found to be well below the yield point of the material.

III. CONCLUSION

In this study, the designs to be presented make unique use of known flexural units and novel geometric symmetry to minimize or even completely eliminate actuator-cross sensitivity, and parasitic coupling between the two axes. Future work is aimed at producing the algorithm to produce an efficient synthesis algorithm that would enable the determination of design parameters of a mechanism that satisfy a set of given constraints. The method presented is accurate and efficient finite elements method (FEM) simulations of planar compliant mechanisms with flexure hinges. In all literatures the validation is by using finite element analysis.

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