ISSN 2395-1621

Design and Analysis of Compliant Mechanical Amplifier

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ABSTRACT

The device in precision engineering and biomechanics applications also micro-electro mechanical system (MEMS) and nanotechnology applications, special standards are necessary regarding the drive and motion system. This requirement can be realized with conventional rigid body mechanism with great constructional effort. When designing on a high precision positioning stage with micro-scale (micrometer or nanometer) resolution, the backlash problem becomes a more significant issue. The flexure hinges are relatively new strategy for providing zero backlash rotation. Therefore, due to their advantages compliant mechanisms are found to be more convenient over these rigid body mechanisms. A compliant mechanism is a single-piece flexible structure where the structural deformation is utilized to transmit force or deliver motion due to an input actuation. Compliant mechanism provide a joint less mechanisms eliminating issues of friction, wear, lubrication, backlash and all its associated issues are eliminated. Therefore they are very well suited for micro fabrication. The purpose of this research is to investigate the use of compliant mechanism in linear displacement applications. Therefore pantograph mechanism are very well suited for positioning resolution by scale down the motion of linear stage and design, analyze and test a pantograph compliant mechanism.

Keywords— **Compliant mechanism, Micro-scale resolution, Pantograph mechanism, Single piece structure.**

ARTICLE INFO

Article History

Received :18th November 2015

Received in revised form :

19th November 2015

Accepted : 21st November , 2015

Published online :

22nd November 2015

I. INTRODUCTION

A. Rigid Body Mechanism

A mechanism is a mechanical device which is used to transfer or transform motion, energy or force. A rigid body mechanism consists of joints and rigid links. Conventional rigid body mechanisms are designed to be strong and stiff and systems are usually assembled from discrete components. These rigid body mechanisms transfer motion through their rigid joints or rigid links because of which mechanisms have several disadvantages such as backlash, wear, requirement of lubrication, low accuracy. The mechanism shown in Fig. 1 consists of four rigid links joined with pin joints or revolute joints that result in the transfer of motion and energy.

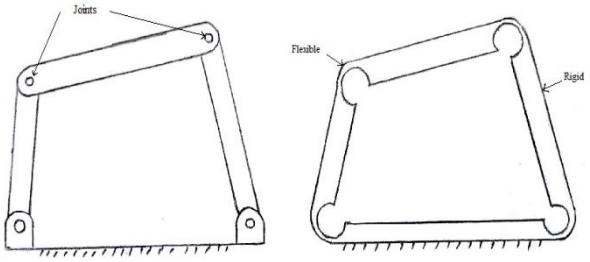

Fig.1 a) Rigid link mechanism b) compliant mechanism [1]

B. Compliant Mechanism

A mechanism with flexible segments is simpler and replaces multiple rigid parts, pin joints as shown in Fig. 2. Compliant mechanisms [1] provide a joint less alternative to conventional rigid body mechanisms eliminating issues of

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friction, wear, weight, noise, lubrication and backlash and important maintenance. Due to the limitations of micro fabrication methods, structures in precision applications have to be monolithic and assembly must be avoided. Hence it can often safe space and reduces cost of parts, material and assembly. The absence of hinges or joints makes compliant mechanism attractive for many emerging applications like precision application, micro-electro mechanical system (MEMS) so mechanical displacement amplifier is used to increase the output displacement. Therefore they are very well suited for micro fabrication.

II. LITERATURE REVIEW

In a precision positioning system, compliant mechanisms play a vital role. The literature is to be studied to gather knowledge about compliant mechanism. The important issues such as Design of Flexural Hinges for Compliant Mechanisms, existing compliant mechanisms and the methodology of analysis, means of actuations, topology and Finite Element Analysis of compliant mechanisms need to be considered.

J. Chen, C. Zhang [2], proposes rhombic micro-displacement amplifier (RMDA) for piezoelectric actuator (PA). First, the geometric amplification relations are analyzed and linear model is built to analyze the mechanical and electrical properties of this amplifier then accurate modeling method of amplifier is studied for important application.

Bharti and Frecker [3], discusses a methodology for designing CM with piezoelectric actuation to obtain maximized deflection and force at output. The focus is on design of CM with multiple optimally placed and sized piezoelectric actuators.

P. R. Ouyang et al. [4], Proposed new topology that is a symmetric five bar mechanism for displacement amplification and compliant mechanical amplifier (CMA) based on new topology is designed to amplify the stroke of a PA.

J. M. Acob et al. [5], previously proposed compliant mechanical amplifier based on a symmetric five bar structure was studied for performance optimization. The amplifier was optimized based on its most significant design parameters with goals of large amplification ratio and high natural frequency also optimized for various load cases and over a range of input displacements.

Xiao-Ping S. and Henry S. Yang [6], presents the design theory and synthesis of compliant microleverage mechanisms including single-stage and multistage microlevers. The analysis of a single-stage microleverage mechanism is presented as the building block for the multistage microleverage mechanisms.

S. K. Singh et al.[7], discusses motion analysis of 1 degree of freedom pantograph based micro-nano scratching machine has been performed to ensure transferring of actuated micro-nano scale linear motion to the tool tip in a single axis to have better control over depth of cut. Also it shows potential reduction of linear motion by up to 1/4th of the riving point displacement.

Baker S. And Howell L advocated use of pseudo rigid body model (PRBM) for designing compliant mechanism. The PRBM is a method of analysis that allows the large deflection to be modelled using rigid body kinematics greatly simplifying the design of compliant mechanism.

III. DESIGN CONSIDERATION OF COMPLIANT MECHANISM

A. Pseudo-Rigid-Body Models

The pseudo-rigid-body model is used to simplify the analysis and design of compliant mechanisms. The pseudo-rigid-body model, on the other hand, may be used to obtain a preliminary design which may then be optimized. Once a design is obtained such that it meets the specified design objectives, it may be further refined using methods such as nonlinear finite element analysis, and it may then be prototyped and tested. Since the lengths of the flexural members are small relative to the lengths of the rigid segments. Torsional springs are used to represent the member stiffness. The accuracy of this method decreases as the relative length of the flexural member increases, and a different approach is required for compliant mechanisms containing longer flexural pivots.

There are many different kinds of compliant segment types that can be modeled using pseudo rigid body model. But, especially two of them are very useful for compliant four-bar synthesis:

1. Small length flexural pivots
2. Fixed-pinned links

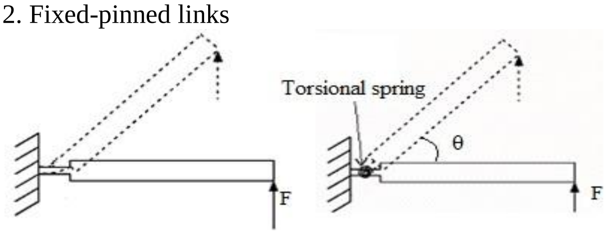

Fig.2 a) A small length flexural pivot b) and its pseudo rigid-Body model [8]

The torsional spring is positioned at the middle point of the small length flexural pivot. It is a good assumption and gives enough accuracy in the calculations.
The torsional spring constant, K, is found as

$$K = \frac{E * I}{l}$$

Where: E: elasticity modulus, I: moment of inertia

B. Types of Flexural Hinges

Flexure hinges are the most important components in the flexural compliant mechanisms. A flexure hinge is a mechanical element that provides the relative rotation between adjacent rigid members through flexing (bending) instead of a conventional rotational joint. They can be used in a number of applications due to their advantages over traditional rotational joints.

The geometry of the thinning is usually a pair of opposed cylindrical grooves. A leaf hinge has historically been created by clamping a thin plate between two rigid bodies. The result is a thinned out piece of material connecting two rigid bodies formed of the same material. Notch hinges are created by machining symmetrical circular patterns from each side of a solid body creating a thin path between two rigid bodies. A notched flexure has the additional advantage

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over a simple leaf flexure, because it can be assembled with almost 100% efficiency.

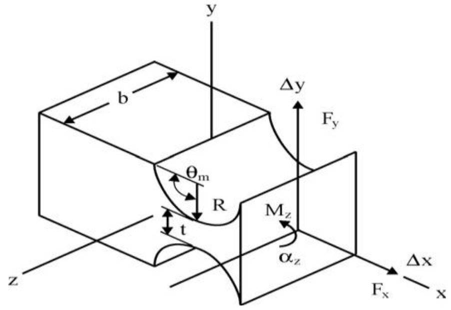

Fig. 3 a circular flexure Hinge [9]

The stiffness of the flexure hinges determines the elastic deformation achieved by the complaint mechanisms. Then stiffness for the hinge is taken as

$$K = 2Ebt^{2.5}/9\pi R^{0.5}$$

Where,
K = Torsional stiffness of the spring
E = Young’s Modulus of material used
b = Thickness of the plate used
t = Hinge Thickness
R = Hinge radius

These methods provide better accuracies than the others depending on the wide range of t/R ratios ($0.05 \leq t/R \leq 0.8$) of circular flexure hinges.

C. Pantograph Mechanism Synthesis

A **pantograph** is a **mechanical linkage** connected in a manner based on **parallelogram.** It is a geometrical instrument used in drawing offices for reproducing given geometrical figures or plane areas of any shape, on an enlarged or reduced scale. It is also used for guiding cutting tools. Its mechanism is utilized as an indicator rig for reproducing the displacement of cross-head of a reciprocating engine which, in effect, gives the position of displacement.

Design of pantograph mechanism to be used in straight line mechanism which represents six times amplification ratio (R) of given input value. This pantograph mechanism design over100 to 100 mm scanning area. Therefore we consider the distance between fixed point (O) and end point (E) of pantograph mechanism is 75mm.

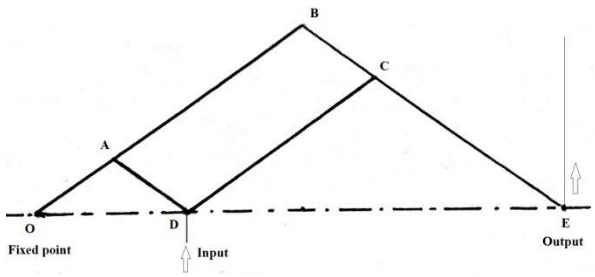

Fig. 4 Pantograph mechanism [10]

$$R = \frac{OE}{OD} = \frac{OB}{OA} = \frac{BE}{AD} \qquad (1)$$

$$6 = \frac{75}{OD}$$

$$OD = 12.5\,mm$$

Δ OBE,

$$OB + BE > OE$$

Δ OBE is isosceles triangle, should satisfy the following condition

$$OB > \frac{OE}{2} > \frac{75}{2} > 37.5mm$$

Assume OB = 40 > 37.5 mm
From (1) OA = 6.667 mm
Therefore,
AB = OB – OA = 40 – 6.667 = 33.3 mm
Again from (1) AD = 6.667 mm
Because, OB = BE as Δ OBE is isosceles triangle.
Therefore AD = BC = 33.3 mm

IV. KINEMATIC ANALYSIS OF PANTOGRAPH MECHAISM

A. MSC ADAMS

ADAMS can be used for flexible body simulation of a mechanical design. ADAMS is useful for early simulation of the effects of flexibility in mechanical systems when detailed finite element representations aren’t available. Using ADAMS [11], one can build a parametric flexible body representation of a component, analyze the system, make changes to the flexible body and evaluate the effect of the changes.

Benefits:

- The Adams simulation dramatically reduced the time required to design the child safety lock mechanism to only about three weeks.
- The performance of proposed design iterations using engineering simulation prior to the prototyping phase.
- Using Adams flexible body, they precisely captured the deformation of the plastic levers and how that affects the system performance.

B. Position Analysis of Pantograph Mechanism

The position analysis is done on the CATIA Software and the image translation characteristic of the pantograph linkage is the result of the parallelogram formed by points A, B, C, and D. The ABCD parallelogram creates two similar straight lines which are proportional to each other by the specified magnification ratio. These similar straight lines provide identical movements at points D and E due to the parallel relationship between each of the links as shown in fig.5.

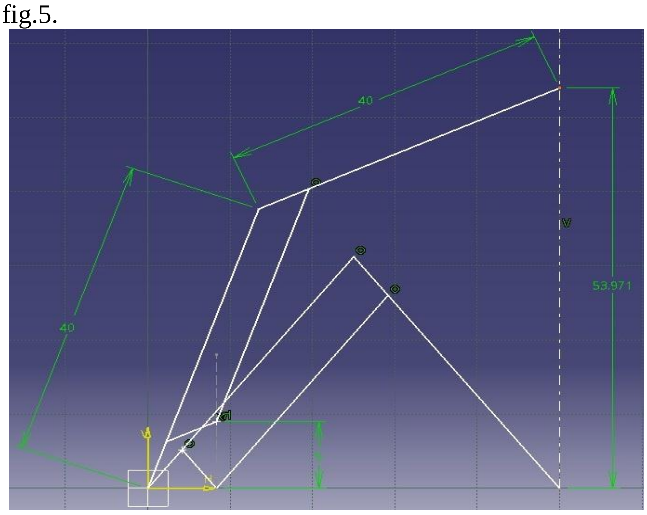

Fig.5 CATIA sketch showing pantograph linkage configured for magnification ratio of 1:6.

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C. Numerical Analysis of Pantograph Mechanism

The kinematic analysis of pantograph mechanism is to be done on ADAMS Software. The initial position of pantograph mechanism shown in fig.6. The input value given at D point and output will come from E point vice versa.

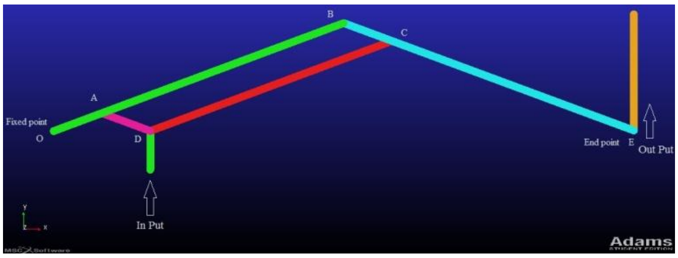

Fig.6 Initial position of pantograph mechanism in ADAMS

Comparison between response of input and output value of pantograph rigid body mechanism (RBM), with zero lateral displacement and magnification ratio is 1:6 achieve continuously as shown in fig. 7. Also compare velocity response of input and output point of RBM achieves 1:6 ratios as shown in fig. 8. Also verify the results between the steel and aluminium materials compliant mechanism (CM) as shown in below graphs.

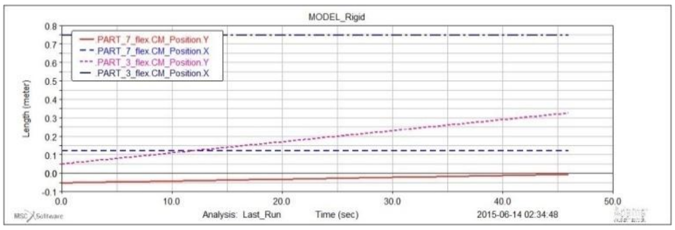

Fig.7 Comparison between response of input and output value of RBM for lateral displacement and magnification ratio

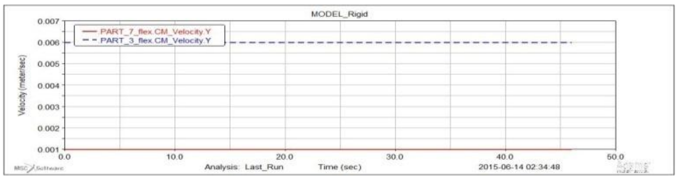

Fig.8 Comparison between response of input and output value of RBM with velocity

Compare the response of input and output value of pantograph compliant mechanism (CM) using steel material, with 0.4mm lateral displacement and magnification ratio goes linearly up to 0.3231m after that for some extend constant beyond that decreases as shown in fig. 9. Also compare velocity response of input and output point of steel CM achieves 1:6 ratios up to 45.3 sec as shown in fig. 10.

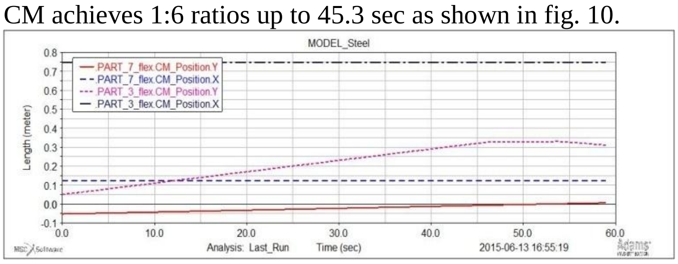

Fig.9 Comparison between response of input and output value of Steel CM for lateral displacement and magnification ratio

Fig.10 Comparison between response of input and output value of Steel CM with velocity

Compare the response of input and output value of pantograph compliant mechanism (CM) using aluminium material, with 0.9mm lateral displacement and magnification ratio goes linearly up to 0.3225m after that follows constant path as shown in fig. 11. Also compare velocity response of input and output point of aluminium CM achieves 1:6 ratios up to 45.3 sec as shown in fig. 12.

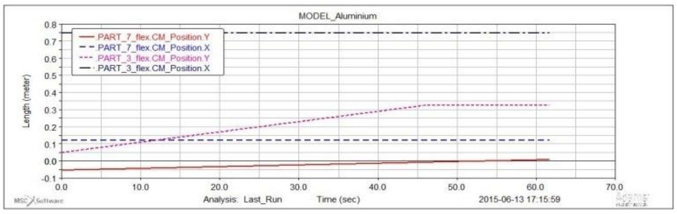

Fig.11 Comparison between response of input and output value of Aluminium CM for lateral displacement and magnification ratio

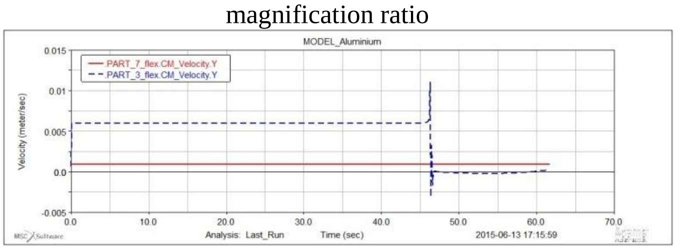

Fig.12 Comparison between response of input and output value of Aluminium CM with velocity

V. CONCLUSION

Compliant mechanism is used for magnifies the displacement in precision applications, micro-electro mechanical system (MEMS), etc. Synthesis of pantograph mechanism over a scanning area 100 to 100 mm displacement is to be design and it is used for enlarged or reduced scale. Displacement analysis of pantograph mechanism with rigid links and pantograph compliant mechanism with steel and aluminium material is done on the ADAMS Software and results shows that very less lateral displacement present in the output of pantograph mechanism. Due to compliant mechanism property and flexible member stores energy in the form of strain energy so that amplification ratio reduces.

REFERENCES

[1] Larry L. Howell, Compliant Mechanisms, 2009, New York: John Wiley & Sons.

[2] Jinglong Chen, ChunlinZhang, MinglongXu, YanyangZi and Xinong Zhang., Rhombic Micro-displacement Amplifier For Piezoelectric Actuator and Its Linear And Hybrid Model, Mechanical Systems and Signal Processing,2014, pp.1-14

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[3] Smita Bharti and Mary Frecker., Compliant Mechanical Amplifier Design Using Multiple Optimally Placed Actuators, ASME International Mechanical Engineering Congress, 2003, pp. 1-8

[4] Ouyang P. R., Zhang W. J. and Gupta M.M., Design Of A New Compliant Mechanical Amplifier, ASME International Design Engineering Technical Conferences, 2005, pp. 1-10

[5] John Michael Acob, Vangjel Pano and Ouyang, P. R., Optimization of a Compliant Mechanical Amplifier Based on a Symmetric Five-Bar Topology, 2012, pp. 323–332

[6] Xiao-Ping S. Su, and Henry S. Yang., Design of Compliant Micro leverage Mechanisms, Sensors and Actuators, 2001, (A 87), pp.146-156

[7] Shishir Kumar Singh, Soumen Mandal and Nagahanumaiah., Motion and Force Analysis in Pantograph Mechanism for Micro-Nano Patterning, Procedia Engineering, 2013,(64), pp. 1445-1453, International Conference On Design and Manufacturing, 2013 FLEXChip Signal Processor (MC68175/D), Motorola, 1996.

[8] Nicolae Lobontiu, Compliant Mechanisms Design of Flexure Hinges, 2002

[9] Y. K. Yong and et al., Review of circular flexure hinge design equations and derivation of empirical formulations, Precision Engineering, 2008,(32), pp.63–70

[10] C. S. Sharma, K. Purohit, Theory Of Mechanisms And Machines, Technology & Engineering, 2006, pp. 119-120

[11] MSC Software, ADAMS/Autoflex, http://www.mscsoftware.com/student-editions,2014