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A REVIEW ARTICLE ON DISPLACEMENT AND FORCE COMPLIANT MECHANISM AMPLIFIER

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Abstract

This review paper consists of various emerging technologies in compliant mechanisms amplifier. The force amplification and deformation amplification is feasible in a compliant mechanism. The displacement amplification mechanism consisting of the compliant structure is getting more response in MEMS application where accuracy, precision, compactness, and reliability are required. We can use various types of force and displacement amplification of the compliant mechanism. The different types of displacement mechanisms likes' bistable, hybrid, Scott-Russell, self-guided, proportion, Orthogonal, Ratchet, compliant mechanism and force compliant mechanism has briefly discussed. The force amplification of compliant mechanisms such as High-Efficiency Compressive Mode Energy Harvester and Piezoelectric Energy Harvester is briefly studied. The application of various types of compliant mechanisms has reported in the article.

***KEYWORDS**: Compliant Mechanism Amplifier, Force Amplification, Bistable Mechanism, Hybrid Mechanism, Energy Harvester.*

I. INTRODUCTION

The compliant mechanisms performs various unique functions with minimum invasive therapy (M. I. Frecker, Dziedzic, and Haluck 2002). The displacement amplification mechanism has the primary role in sensitivity and performance analysis of micro-devices (Iqbal and Malik 2019). The commonly used displacement amplification compliant mechanism has plenty of categories of bridge-type mechanisms, lever mechanisms, Scott–Russell mechanisms, and many more (Xu and Li 2011). In these types of optical instruments, the quality of image and software required for processing of the image is a very important aspect and in this non-contact type of measuring instrument category, the laser sensor is also grouped in a particular order to process data (Daniel 2018). The examples show the capabilities of the design procedure, the result of the direction of the output deflection requirements on the solution, as well as the effect of the starting point and effect of the material resource constraint (Arunkumar and Srinivasan 2006; M. Frecker, Kikuchi, and Kota 1999). It gains some or all of its motion from the relative flexibility of its members rather than from rigid body joints alone (Howell, Magleby, and Olsen 2019).

The recently developed bridge-type displacement amplification compliant mechanism is compact, also having substantial displacement amplification factors and can be used in high frequency applications. The bridge type compliant mechanism with a flexural hinge is a classic displacement amplification compliant mechanism (Ma et al. 2006). A bistable mechanism has two stable states and this mechanism does not require power input to remain in position, and it will return to its stable position after giving small disturbances (Jensen and Salmon 1999). It has three locations where no input power is required (Wilcox and Howell 2005). Different actuation technologies have been developed for MEMS devices in various applications, including piezoelectric, electrostatic, thermo pneumatic, electrochemical, and electromagnetic principles (Bolzmacher et al. 2010).
The energy requirements in the twentieth century have motivated us in green energy sources such as bio-energy, thermal energy, and vibration energy than traditional energy sources. Due to these various types of energy-harvesters are developed to novitiate these energy sources into electricity. Human motion gives a continuous energy source to accomplish sovereign power supply for electronics and wearable sensors (Qian, Xu, and Zuo 2019). The force amplification of compliant mechanism has very considerable progress in the past few decades because of low power electronics; therefore, vibration-based energy harvester technologies are developing so fast. All researchers are working toward the energy harvester, and their focus is on enhancing efficiency by various methods such as material optimization, non-linear mechanism, matching of impedance (Yang and Zu 2014).

II. DISPLACEMENT AMPLIFICATIONS MECHANISM

The displacement amplification compliant mechanisms such as bistable, hybrid, Scott-Russell, self-guided, proportion, Orthogonal, Ratchet compliant mechanism has briefly discussed in this sections.

1. Bistable Compliant Mechanisms

The bistable compliant mechanism driven by an electromagnetic actuator for dynamic switching, as shown in figure 1, was refined (Wang, Pham, and Hsieh 2009). The bistable mechanism is having a combination of bending and tensile beam structure. For evaluating the static behavior of a bistable compliant mechanism, the finite element method had used. The mathematical model had developed, and the behavior of a bistable compliant mechanism had compared with a prototype made for experimentation and testing.

The extended study on the bistable compliant mechanism, as shown in figure 2 was developed. (Han et al. 2017). In this paper, they have proposed a new fully complaint bistable mechanism which had called "tensural-compresural bistable mechanisms (TCBMs)". This mechanism consists of the pair segments, i.e. tensural segment and compresural segment. The tensural segments were subjected to bending and tensile force while the compresural segment had subjected to bending and compressive force. In TCBMs (i.e. tensural-compresural bistable mechanisms) consist of the pair tensural segment and compresural segment.

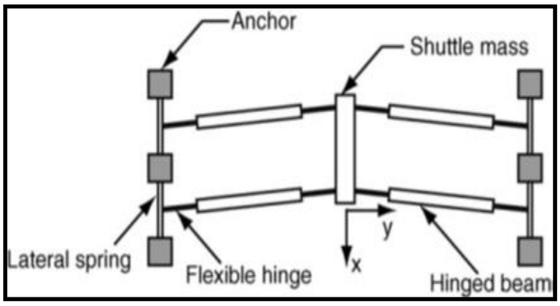

Figure 1: A Schematic of Bistable Compliant Mechanism (Wang, Pham, and Hsieh 2009)

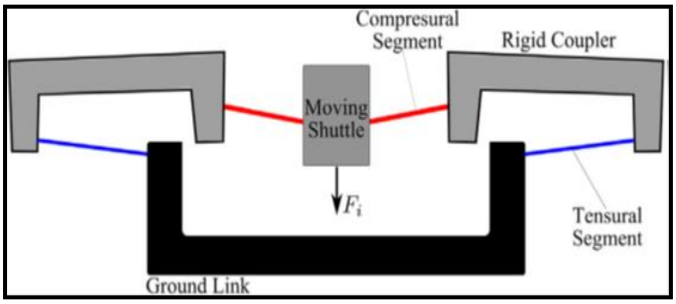

Figure 2: A Schematic fully compliant tensural-compresural bistable mechanism (Han et al. 2017)

2. Hybrid Compliant Mechanisms

The new design of hybrid compliant mechanism-based micro-gripper driven by the piezoelectric actuator, as shown in figure 3, had refined (Zubir, Shirinzadeh, and Tian 2009). In this paper, the two mathematical modeling technique had used, and they are Finite Element Analysis (i.e. FEA) and PRBM (i.e. Pseudo Rigid Body Model). For the manufacturing of a hybrid compliant mechanism-based micro-gripper, a wire Electro Discharge Machining (EDM) had used. The experimentation had carried out for model and prototype, and high amplification characteristics had achieved. The FEA, PRBM and experimental results are very close to each other.

3. Scott–Russell Compliant Mechanisms

The flexural based Scott–Russell Complaint Mechanism, as shown in figure 4, was developed (Tian et al. 2009). In this paper, the dynamic model and design of flexural based Scott–Russell Complaint Mechanism for nano-manipulation had developed. This flexural based Scott–Russell Complaint Mechanism is having excellent accuracy and repeatability characteristics. The Finite Element Analysis, Numerical analysis, and experimentation had carried out for the developed model, and the dynamic response had found.

4. Self-guided Compliant Mechanisms

A new design of the Self-guided displacement amplification mechanism had developed (Kim et al. 2012). In this article, a new design of Self-guided displacement amplification mechanism with flexure based single axis, nano-positioning stage were developed. This mechanism has a compact stage size and having two compound parallelogram structure which gives displacement amplification by eliminating serial connections. This mechanism improves the positional accuracy due to its symmetry in structure, by eliminating thermal deformation and parasitic motion error. They have designed the optimistic mathematical miniature of self-guided displacement amplification compliant mechanism, and it had verified by using experimentation.

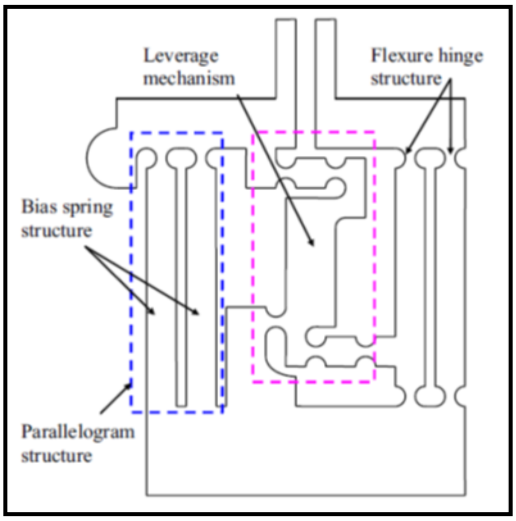

Figure 3: Basic Model of Hybrid complaint Mechanism Micro-gripper (Zubir, Shirinzadeh, and Tian 2009)

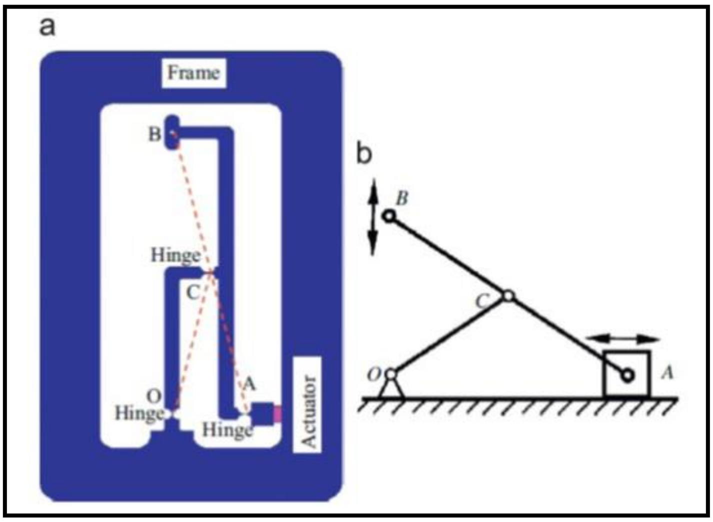

Figure 4: A Schematic of Scott–Russell Compliant Mechanism (Tian et al. 2009)

5. Proportion Compliant Mechanisms

A Proportion Complaint Mechanism, as shown in figure 5, was developed (Meng, Li, and Xu 2014). In this paper, for designing the analytical model principle of pseudo rigid body model (PRBM) and virtual work were used, and it is flexural based Complaint Mechanism. By using the new proposed design equation by author and stiffness equation, a new Proportion Complaint Mechanism had developed. In this mechanism, the least square method had used for designing of corner filleted flexural hinge. A Proportion Ratio equation had developed for four slider-crank mechanisms, and it had verified by using the finite element analysis method.

6. Orthogonal Compliant Mechanisms

A novel Orthogonal Displacement Amplification Complaint Mechanism driven by the piezoelectric actuator, as shown in figure 6, had developed (W. Chen et al. 2017). In this paper, optimum design and non-linear analysis had executed on the Orthogonal Displacement Amplification Complaint Mechanism without using any traditional, compliant mechanism. The design of the proposed micro-gripper based on the Orthogonal Displacement Amplification Complaint Mechanism had developed.

The extended study on a compression based Orthogonal Displacement Amplification Complaint Mechanism used in micro-grasping, had developed (Weilin et al. 2019). In this paper, the proposed mechanism not only depends on displacement amplification and orthogonal movement transformation but also with an increase in force, it was increasing the displacement amplification ratio. The design of a compression-based Orthogonal Displacement Amplification Complaint Mechanism used in micro-grasping had presented, and the feasibility of mechanism was also discussed based on Euler–Bernoulli beam theory and finite difference method.

7. Ratchet Compliant Mechanisms

The novel design of the Ratchet Complaint Mechanism, as shown in figure 7, was developed (Sakhaei et al. 2018). In this paper, multi-material additive production technology had used in Ratchet Complaint Mechanism. This mechanism had eliminated movement of gear or pawl and spring which exists in a traditional Ratchet mechanism. Finite element analysis had done on this mechanism, and its results had verified by using tangible results. The authors demonstrate a parametric study material and geometric properties in this new design of the Ratchet Complaint Mechanism.

8. Planar Compliant Mechanisms

The design and analysis of planar compliant mechanisms through two port dynamic stiffness model, as shown in figure 8 had developed (Ling, Cao, and Pehrson 2019). In this paper, Serial-parallel configurations had used for designed planar compliant mechanisms. To develop this mechanism model, the combination of Alembert's principle and transfer matrix method for kinematic static and dynamic analysis with Serial-parallel configurations were employed. By using commonplace serial-parallel sub-structures in planer compliant mechanisms, the two types of improved transfer matrix and relationship between output force-displacement and frequency-dependent input were derived. Based on this numerical approach, the model was demonstrated by calculating input and output stiffness, natural frequency, forced dynamic response and displacement amplification factor. In this paper, no finite element analysis and experimentation had executed.

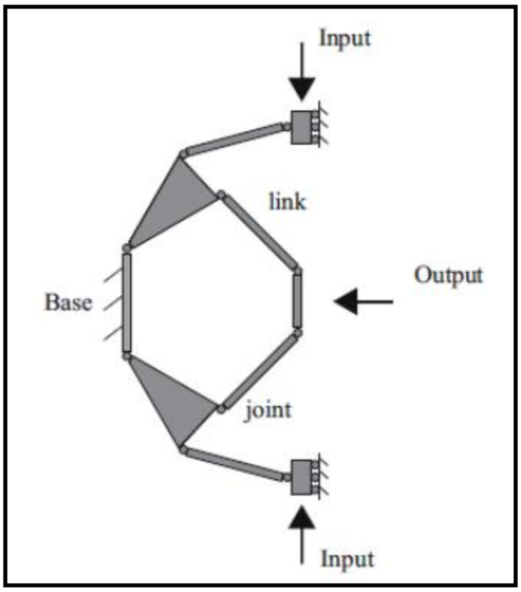

Figure 5: A Schematic of Proportion Compliant Mechanism (Meng, Li, and Xu 2014)

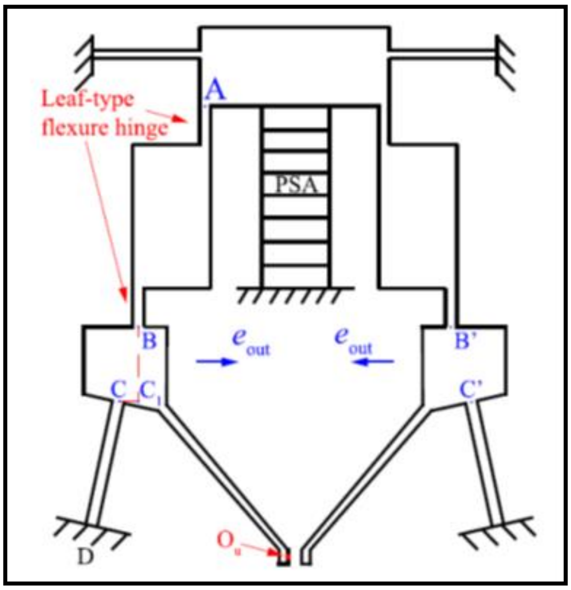

Figure 6: A Schematic novel compliant orthogonal DAM (W. Chen et al. 2017)

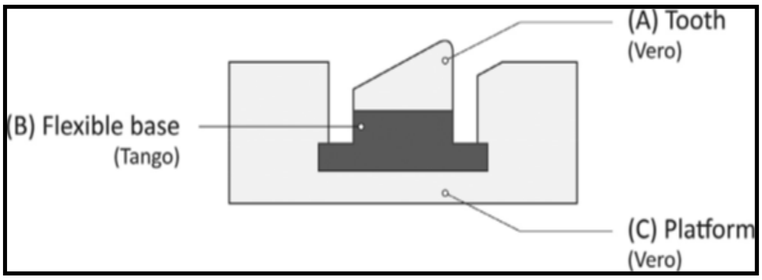

Figure 7: A Schematic of compliant ratchet mechanism (Sakhaei et al. 2018)

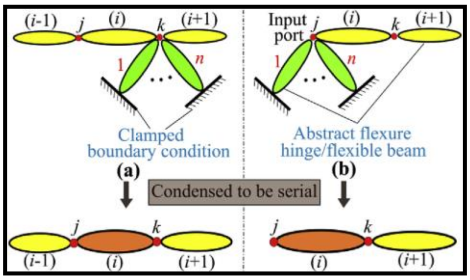

Figure 8: A Schematic of two type of serial configurations with parallel sub-chains (Ling, Cao, and Pehrson 2019)

III. FORCE AMPLIFICATIONS MECHANISM

The multi-stage force amplification compliant mechanism for HE-CEH (i.e. High Efficiency Compressive Mode Energy Harvester), developed (Yang and Zu 2014). In this paper, an innovative harvester, i.e. HC-PEH, was presented. This HC-PEH contains a pair of compressive flex-center and elastic beam. In this, a compressive mode had considered as tensile and bending mode because of piezo-ceramics have the superior compressive load carrying capacity.

The external force calculation of a piezoelectric actuated mechanical compliant mechanism depends on the hysteresis model, was developed (Zhu et al. 2018). In this paper, compared with practically measure deformation or displacement with the calculated free one when it had subjected to actuating voltage, the force estimation was proposed. The experimental tests had carried out on the two hysteresis models on the piezoelectric actuated bridge-type compliant mechanism, and the result obtained had compared.

A force amplification compliant mechanism, PEH (i.e. Piezoelectric Energy Harvester) with a two stage, was developed (Qian, Xu, and Zuo 2019). In this paper, design, modeling and analysis had carried out on developed PEH (i.e. Piezoelectric Energy Harvester). The Piezoelectric Energy Harvester (PEH) consists of four components of two-stage piezoelectric transducers combined between two plates having a shape like a heel. The high power had developed with the help of a dynamic reaction force that had amplified two times using two-stage force amplification frames before use 33-mode piezoelectric stacks. The prototype of Piezoelectric Energy Harvester (PEH) had manufactured, and experimentation had carried out over different frequencies and load levels.

IV. DESIGN APPROACHES IN COMPLIANT MECHANISM

We have tabulated compliant mechanism associated with application and design method in displacement amplification, as shown in table 1. There are two basic approaches used in design of compliant mechanism viz. topology optimization and kinematic based approach. In the kinematics-based approach has been used successfully in designing compliant mechanisms. This approach requires a good involvement on the part of the designers. The compliant mechanisms which are designed using this approach have lumped compliance.

For designing the devices which are suitable for MEMS applications, the second method of design i.e. topology optimization methods are used because of distributed compliant mechanisms. A distributed compliant mechanism is capable of producing distributed compliance through the elastic deformation.

Table 1: Compliant mechanism associated with application and design method

Type of Compliant Mechanism	Design Method	Application Area
Distributed Compliant Mechanism	Topology Optimization Method	MEMS Devices
Lumped Compliant Mechanism	Pseudo Rigid-Body Method (PRBM)	Precision Positioning

V. APPLICATIONS OF DISPLACEMENT & FORCE AMPLIFICATIONSMECHANISM

The micro-motion stage has various applications in the field of optical device tuning, ultra-precision machining, analysis of structure in material surface, semiconductor industry (Hsiao and Lin 2001). There are various application of microleverage mechanism likes electrostatic actuation, thermal actuation, Jet Propulsion Laboratory, micro-valve (Su and Yang 2001). A piezoelectric driven micro-positioning stage used in pulsed laser welding, diamond turning, and micro-lithographic processes (Jouaneh and Yang 2003). The MEMS-based accelerometer has many engineering applications such as consumer electronics, digital cameras, cell phones, computer games, airbags system, navigation and guiding system in defense (Cao et al. 2018). Compliant based micro-grippers have a very vital role in micromanipulation likes cell manipulation, micro-particle handling, optical fiber assembly such application consists of parallel grasping for stable micro-manipulation (S. Chen, Ling, and Zhang 2018). Bistable mechanisms have various applications in the field of nonvolatile shock detecting, meta-materials construction, overload protection, vibration energy harvester, and mechanical memory (Han et al. 2017). Piezoelectric actuator has high frequency response, output displacement and very high resolution. It is used in high precision positioning, energy harvesting (Ling et al. 2016), vibration control etc.

Many application of compliant mechanism requires large workspace such as adaptive adjustment mechanism in an astronomical telescope, binary optical processing equipment, micro-coordinate measuring machines and MEMS processing systems (Wan and Xu 2016). Flexural based compliant mechanism had widely used in aerospace, automotive, medical, optical, computer and telecommunication industries (Lobontiu and Garcia 2003). Flexural based compliant mechanism is extensively used in aerospace and instrumental fields like control of fluid in servo valves, shape active control in aircraft, fatigue tests for micro-structures (Ling et al. 2016). Flexure-based compliant mechanisms had used in Microelectronics Mechanical Systems, aerospace technology, modern precision engineering, biomedical engineering, and piezoelectric actuators because of fast response and high precision characteristics. The piezoelectric actuators had used in vibration control, energy harvester, ultra-precision positioning because of high-frequency response, large output force and high displacement resolution (Lin et al. 2018).

VI. CONCLUSION

The force amplification and deformation amplification is feasible in a compliant mechanism. The displacement amplification mechanism consisting of the compliant structure is getting more response in MEMS application where accuracy, precision, compactness, and reliability are required. We can use various types of force and displacement amplification of the compliant mechanism. The displacement amplification is possible in various compliant mechanisms such as bistable, hybrid, Scott-Russell, self-guided, proportion, Multi-stage, Orthogonal, Ratchet compliant mechanism. The force amplification is possible in various compliant mechanisms such as HCPEH (i.e. High-Efficiency Compressive Mode Energy Harvester) and force amplification compliant mechanism of PEH (i.e. Piezoelectric Energy Harvester) with two-stage. The application has mentioned all these displacement and force amplification of the compliant mechanism.

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