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Department of CIVIL, CE, ETC, MECHNICAL, MECHNICAL SAND, IT Engg. Of Vishwabharati Academy's College of engineering, Ahmednagar, Maharastra, India.

Study of Compliant Mechanisam

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Abstract: Traditional rigid body mechanisms are designed to be strong and stiff, and the systems are usually assembled from discrete components. These rigid body mechanisms transfer motion through their rigid joints or rigid links because of which these mechanisms have several disadvantages such as backlash, wear, requirement of lubrication, low accuracy. The single piece compliant mechanisms are found to be convenient over these rigid body mechanisms. The current paper is a insight on compliant mechanisms and discussion on advantages of these mechanisms over their counterpart conventional rigid body mechanisms. This paper also focuses on compliant mechanical amplifiers and few applications of compliant mechanisms.

Keywords;- Compliant, CMA, Flexural Hinges, Piezoelectric Actuator

1. INTRODUCTION

Compliant mechanisms are single-piece flexible structures that deliver the desired motion by undergoing elastic deformation as opposed to rigid body motions of conventional mechanisms [1]. It gains some or all of its motion from the relative flexibility of its members rather than from rigid body joints alone [1]. 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 into devices may be reductions in weight, friction, noise, wear, backlash and importantly, maintenance. The absence of hinges makes compliant mechanisms attractive for many applications including the emerging areas of micro and nano-scale systems. There are many familiar examples of compliant mechanisms designed in single-piece that replaced rigid-link mechanisms, Fig. 1.1 shows complaint mechanisms used commonly [1]. Traditional rigid body mechanisms consist of rigid links connected at movable joints and are capable of transforming linear motion into rotation or force in to torque. Compliant mechanisms rely on the deflection of flexible members to store energy in the form of strain energy. This stored energy is similar to the potential energy in a deflected spring. Thus compliant mechanisms can be used to easily store and/or transform energy that can be released at a later time or in a different manner.

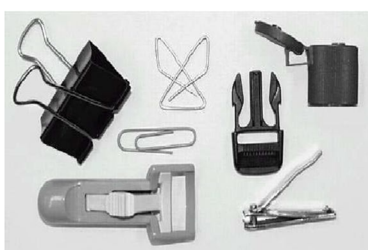

Fig. 1.1: Common compliant devices. A binder clip, paper clip, backpack latch, lid, and eyelash curler and nail clippers [1].

II.LITERATURE REVIEW

1. G.K. Anathsuresh, Laxman Saggere [2] explains the design of monolithic compliant stapler. The design in this paper gives a product with fever components, and eliminating a component assembly results in decrease of production cost considerably. In the design proposed desired functionality is achieved entirely through compliance, an emerging

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class of mechanisms which derive their mobility through elastic deformation of flexible material as opposed to rigid body motion of the conventional mechanisms.

2. Bhagesh Deshmukh, Dr. SujitPardeshi, Dr. P.K. Mishra [3] gave an insight on the design of compliant mechanisms which are free from backlash, wear and require least lubrication. They have presented an alternative mechanism for a linear slide that is required in the development of Microfactories, electronic, microscopy, medical etc in the form of a compliant pantograph.
3. P. R. Ouyang & R. C. Tjiptoprodjo &W. J. Zhang & G. S. Yang [4] have reviewed the world-wide study on micro-motion systems both from an academic and an industrial perspective. The micro-motion systems considered in this paper are classified into four kinds in terms of their motion ranges: (a) < 1 µm, (b) 1 - 100 µm, (c) 100 - 1000 µm, and (d) > 1000 µm. This paper includes study of advantages and disadvantages of various types of actuators, manipulator systems for micro motion, and compliant mechanisms for micro motion. This review concludes that the PZT actuation element integrated with the compliant mechanism is the most promising technology which can achieve high accuracy (sub-nanometer) of all four kinds of motion ranges.
4. Annem Narayana Reddy, Nandan Maheshwari, Deepak Kumar Sahu, and G. K. Ananthasuresh [5]. This paper is concerned with grasping biological cells in aqueous medium with miniature grippers that can also help estimate forces using vision-based displacement measurement and computation. This paper presents the design, fabrication, and testing of three single-piece, compliant miniature grippers with parallel and angular jaw motions.
5. P.R. Ouyang, W.J. Zhang, M.M. Gupta [6] presented a new topology that is a symmetric five bar profile for displacement amplification. A compliant mechanical amplifier (CMA) based on the new topology is designed to amplify the stroke of a piezoelectric actuator. First, three existing topologies of CMA are analyzed and evaluated, which results in the new topology of CMA. The finite element analysis for the CMA based on new topology double-beam symmetric five bar structure using the Corner-filleted hinges is done to obtain the best performance in terms of the displacement amplification and natural frequencies.
6. Sridhar Kota, Joel Hetricka, Russell Osborna, Donald Paulb, Ed Pendletonb, Peter Flick [7]. This paper presents work to design novel compliant mechanisms that efficiently morph aircraft structures in order to exploit aerodynamic benefits. This paper is focused on use of compliant mechanisms in two different types of morphing systems: (i) variable geometry wings and (ii) high-frequency vortex generators for active flow control

III.RIGID BODY MECHANISMS

Mechanism is a system of rigid elements (linkages) arranged and connected to transmit motion in a predetermined fashion. Mechanism consists of linkages and revolute joints**.**These revolute joints have an infinite range of motion in the rotational axis.Since motion is transmitted through rigid hinges and rigid links there is always presence of backlash, friction and wear which necessitates lubrication and make these mechanisms not suitable in achieving well controlled force or motion at the micro scale.It often requires space and increases costs of parts, materials and increase in labor due to complex assembly of large number of links. These mechanisms require regular maintenance and replacement of wear links or joints. Fig. 3.1(a) shows the four bar linkage rigid body mechanism in which links '2' and '4' are constrained to rotate about their revolute joints in one single plane. And fig. 3.1(b) shows pin joint pantograph [3].

IV.COMPLIANT MECHANISMS

Until mid-1960's elastic deformations of materials have been successfully utilized to generate useful motions in numerous mechanisms for certain special advantages and were compatible with then applications. The flexure generated mobility was largely confined to small angular rotations between stiff members by means of flexure hinge (a short and thin metallic strip or a small "necked" down region of a thick blank of material); that provides a rotational degree of freedom (DOF) similar to that of a conventional pin joint. The mechanisms that are designed to derive mobility from elastic deformations in some elements; (a flexural hinge and/or a relatively long flexible segment of a mechanism) can be broadly referred to as compliant mechanisms. Compliant mechanisms are flexible structures which use strain energy to transform input energy components into a desired output force or displacement. Compliant

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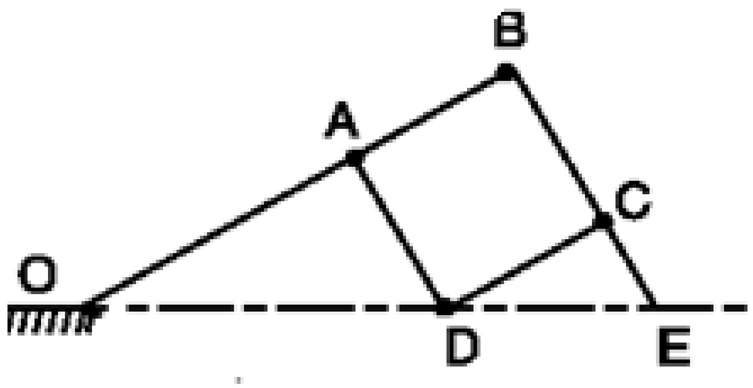
mechanisms provide a joint less alternative to conventional rigid body mechanisms eliminating issues such as friction, wear, lubrication, and backlash. They are monolithic structures and require no assembly.Compliant mechanisms are particularly suited for applications with a small range of motions, as their unitized construction without joints makes their manufacture extremely simple, eliminating assembly operations altogether. The compliant stapler shown in Fig. 4.1 illustrates this paradigm of no assembly [2].

Compliant mechanism consists of a flexural hinge and relatively long flexible segments or beam section. One such mechanism known as compliant pantograph is shown in Fig. 4.2 [3]. This compliant pantograph when actuated by a PZT can be used as an alternative mechanism for a linear slide that is required in the development of Microfactories, electronic, microscopy, medical etc [3].

IV.1.1 Flexure Hinges

These are short and thin metallic strip or a small "necked" down region of a thick blank of material [3]. Flexure hinges provides rotational degrees of freedom similar to those in conventional mechanisms. Flexure hinges are not fully fixed in all directions except at rotational axis. Thus flexure hinge will twist when subjected to torsional loads and exhibit shear deformation when subjected to shear loads [4]. Fig. 4.3 shows the flexure hinge [3].



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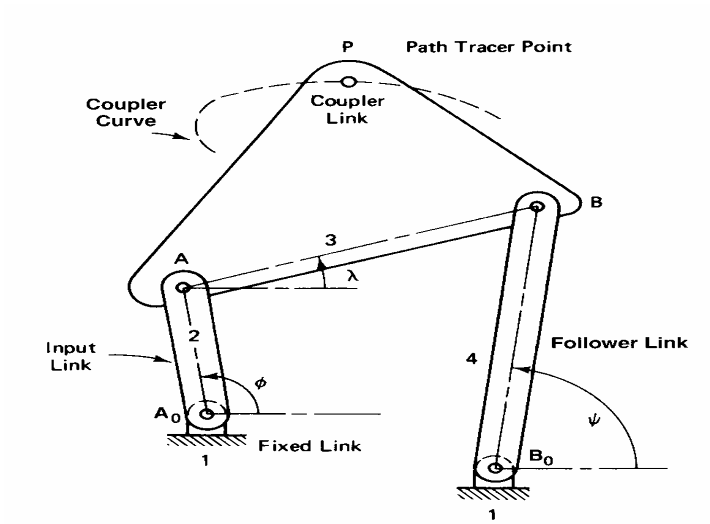
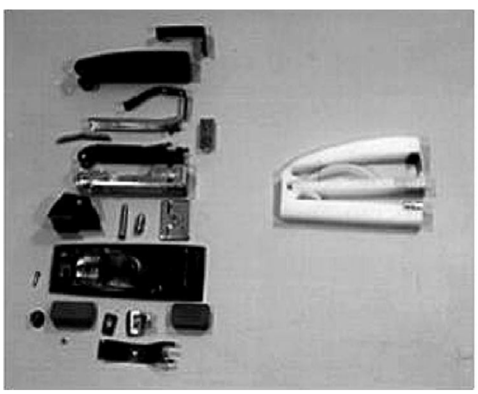


(b)

Fig. 3.1 (a) Four bar linkage, (b) Pin Joint Pantograph [3].



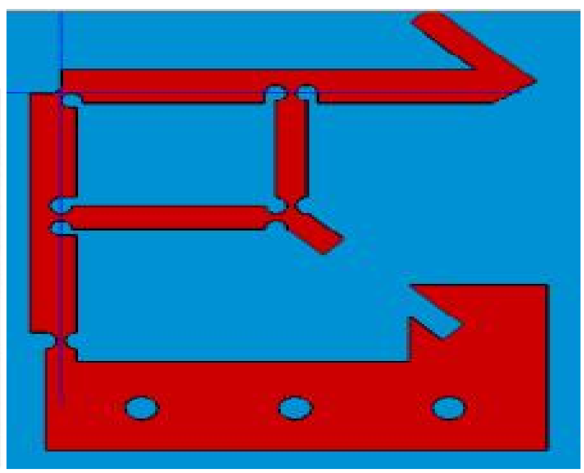


Fig. 4.1: A single-piece compliant stapler [2] **Fig. 4.2: Complaint Pantograph [3].**

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

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

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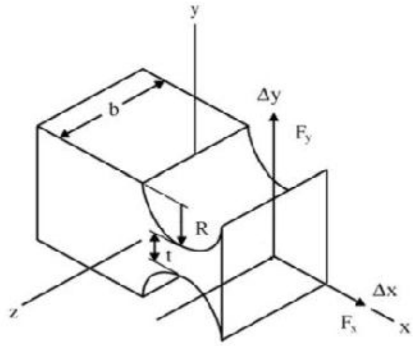

Fig. 4.3: Flexure Hinge [3].

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

IV.1.2 Manufacturing Of Complaint Mechanisms.

Complaint mechanisms made of spring steel material can be fabricated using drilling or milling, or nonconventional machining processes such as EDM, wire-EDM, electron/ion beam machining, water jet machining, and laser machining. The miniature complaint grippers made of Polydimethylsiloxane (PDMS) are fabricated using vacuum casting [5]. PDMS is preferred for grippers because of its optical clarity, biocompatibility, and low stiffness as compared with those of spring steel. The stiffness of the PDMS gripper is 0.024 N/m as compared with the stiffness of spring-steel grippers which is 80.5 N/m. Therefore PDMS material most suitable for fabricating micro complaint mechanisms compared to spring steel material [5]. Spring steel is suitable for moderate scale mechanisms due to the higher spring stiffness.

IV.1.3Complaint Mechanical Amplifiers (CMA)

When unconventional actuators are tailored along with compliant mechanisms to achieve amplification or modification in force or displacement characteristics are known as complaint mechanical amplifiers (CMA).
Displacement amplification is known as geometric advantage (GA) whereas force amplification is known as mechanical advantage (MA).
Unconventional actuator such as piezoelectric actuator has advantages as follows [4],
– Sub-nanometer resolution
– Large force generation
– Sub-millisecond response
– No magnetic fields
– Extremely low steady state power consumption

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– No wear and tear
– Vacuum and clean room compatibility.

But piezoelectric actuator has its disadvantages as follows, highly nonlinear input/output behavior, creep, and hysteresis. Another major disadvantage with the PZT actuator is that it has a very small motion range (typically ~ 15 – 20 μm) [4]. There are many ways to amplify the displacement by stacking multiple piezoactuators in different configurations. Although modest motion amplification can be achieved through such means, many of such arrangements are cumbersome and impose a heavy penalty of voltage requirements. The length of a piezo stack is limited due to the position error generated at the end of the stack. The stacking is also limited due to the stress generated in the piezo slice [4]. Due to the fewer number of interfaces with the design concept of an integrated PZT and compliant mechanism amplifier, the absolute accuracy of such a system will very likely be higher than that of the stack PZT actuator.These disadvantages can be overcome by having an amplification mechanism that is assembled with PZT actuators.The promising principle for the amplification mechanism is the compliant mechanism [4]. The amplification mechanism based on the compliant mechanism is a special type of compliant mechanism with a proper design of topology and geometry [6].

The CMA can convert the motion generated by a PZT actuator with a large amplification ratio (24.4) in a very compact size, and it has a high natural frequency (573 Hz) and no lateral displacement [6]. Figure4.4 shows a compliant mechanism amplifier [4]. This amplifier is based on a five-bar topology and has shown its superior performance (the amplification ratio and system natural frequency) over the other systems.

V. APPLICATIONS OF COMPLIANT MECHANISMS

Complaint mechanisms have both macro-scales as well as micro-scale applications. These mechanisms find enormous applications in the field of components in transportations, hand-held tools, micro scale devices in electronics industry and medical.

V.1 Components in transportation

Properly designed compliant mechanisms are well suited for shape morphing applications such as variable geometry leading and trailing edge surfaces, engine inlets, and other aircraft components [7].

There are two general applications for compliant mechanism technologies in air-crafts: (i) variable geometry wings – specifically for leading and trailing edge flaps and (ii) high-frequency vortex generators for active flow control.

V.1.1 Variable geometry wings

Change of the shape of an airfoil can offer significant benefits in terms of reduced drag, enhanced lift, and reduced radar cross-section. Compliant mechanism technology can be applied to the wing morphing problem.Adaptive Compliant Wing with an embedded compliant mechanism provided 6-degree leading edge camber change on demand. Wind tunnel test results showed a 51% increase in lift-to-drag ratio and a 25% increase in the lift coefficient for the 6-deg, variable geometry TE wind tunnel model shown in Figure 5.2 [7] .

V.1.2 High-frequency vortex generators for active flow control

Mixing high energy air in the outer regions of the boundary layer with low energy air near the surface has been shown to improve flow attachment of airfoils with slope discontinuities and/or operating at heightened angles of attack. In our concept, a vortex generator blade is mechanically oscillated at the surface to "pulse" vortex production. The blade in effect produces a coherent helical vortex structure that moves high momentum air towards the surface replacing the retarded low energy air and produce strong, coherent vortex structures that trail downstream. The advantage of this concept is that the vortex generator blade produces a stronger vortex as Mach numbers increase [7]

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(a)

(b)

Fig. 5.2 Variable geometry wings- TE wind tunnel model shown in -10 degrees (fig a) and +10degrees (fig. b) positions [7] .

Techniques to actuate the vortex generator are limited due to the achievable power density available from actuation sources (pneumatic, electromagnetic, ferroelectric, etc.) in addition to inertia, friction, thermal, and structural limitations. By utilizing compliant mechanisms to amplify the displacement of piezoelectric stack actuators (trade force for displacement), it is possible to develop a compact, energy-efficient actuator that can meet the displacements and frequencies needed for active flow control applications. It was desirable to create a mechanical (blade) vortex generating system effective at both subsonic and transonic flow conditions, since many of the current pneumatic systems are inefficient when used to control flow separation in a transonic flow environment. Figure 4.3 Figure 9 shows a High Frequency Micro Vortex Generator (HiMVG) device [7].

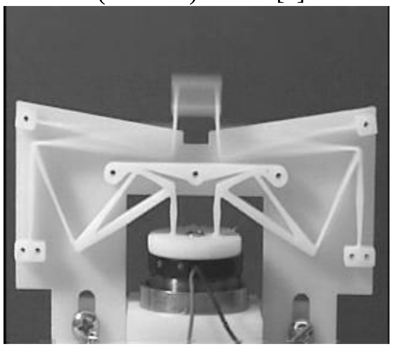

Fig.5.3 The High-frequency Mechanical Vortex Generator (HiMVG) running at 150Hz with 5mm displacement due to a compliant motion amplifier integrated with a voice-coil motor [7].

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V.2 Hand-held tools.

Compliant mechanisms can be used for making hand-held tools such as one piece stapler, binder clip, paper clip, backpack latch, lid, eyelash curler and nail clippers.A one piece stapler is shown in Figure 4.1. The principal advantage of all these tools is that there is enormous saving in manufacturing cost besides their light weight and aesthetic looks [2].

V.3 Micro Scale Devices

Microelectromechanical Systems (MEMS) are small, compliant devices for mechanical and electrical applications. Examples of MEMS application are medical instruments for in-body surgery, hearing aids, air-bag sensors, micro pumps and optics and tilting mirrors for projection devices. Mechanical manipulation of individual biologicalcells which is useful in sperm injection, cellular reconstruction, mechanical characterization, etc. can be done using miniature grippers. Figure 5.4 shows compliant gripper used to grip the coin.

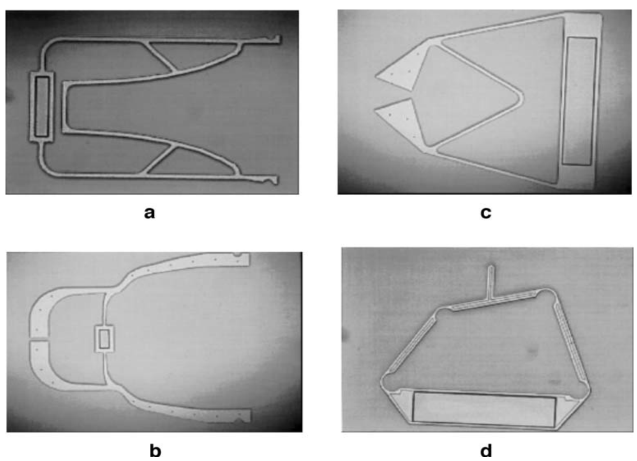

Fig. 4.4 Examples of micro compliant mechanisms [4] . (a) Crimping Mechanism, (b) & (c) Compliant grippers, (d) Micro four bar mechanism.

VII. CONCLUSION

The compliant mechanisms are monolithic mechanisms which do not possess any backlash, friction, wear and lubrication. So therefore these mechanisms give sub- nanometer resolution, high repeatability unlike their counterpart rigid link mechanisms. Due to these reasons compliant mechanisms are most suitable for micro scale motions which are frequently seen in electronics, robotics and medical.

Compliant mechanisms with unconventional actuators are used to modify force or displacement characteristics of these actuators. Such motion amplification is achieved in air-craft industry for morphing of aerofoil shapes.

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