Analysis of Linear And Rotary Flexural Mechanism

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Abstract- *In today's fast moving and highly competitive world, everyone wants precise and accurate results. In the fast growing mechanical and mechatronic world, the dire need of precision has led to the development of new types of mechanisms and these are serving the main purpose of accuracy. This new class of mechanisms is called as Flexural mechanisms which work on the virtue of stiffness and bending of a member resulting in increase in the precision without compromising the accuracy. In flexural mechanisms motion is generated due to deformation at the molecular level, which results in two primary characteristics of flexures – smooth motion and small range of motion. Precision scanning mechanisms is current demand of modern technologies such as micro- nano manufacturing, characterization equipments such as microscopes etc. Different flexural based mechanisms are developed for precise control/manipulation of position of object. Flexures are compliant structures that rely on elasticity for their functionality resulting in smooth motion, small range of motion, and high resolution. Such mechanisms can be used for precision applications such as micro welding, wafer alignment in lithographic micro-manufacturing. So the main purpose is to design such a flexural mechanism which can give precise motion in both linear as well as rotational direction. For this purpose three types of flexural mechanisms are studied. ANSYS Software is used to create parametric model of flexural mechanism and static analysis. Due to parametric modeling once we created model of mechanism in ANSYS and apply all constrain and load conditions will allow us to optimize flexural member.*

Keywords- Precise motion, flexural mechanisms, precise motion in linear and rotary direction, FEA.

I. INTRODUCTION

Precise control/manipulation of position of object demands the use of flexure based precision scanning mechanisms in micro-nano manufacturing, characterization equipments such as microscopes, wafer alignment in lithographic micro-manufacturing etc. Flexure joints based on elastic deformation are used in precision scanning applications as they offer the advantage of providing frictionless, backlash free, smooth and continuous motion with inherently infinite resolution. Flexures allow for very clean and precise motion. Since the displacement in flexures is an averaged consequence of molecular level deformations, the phenomena of friction, and backlash are entirely eliminated.

Flexures have been used as bearings to provide smooth and guided motion, for example in precision motion stages; as springs to provide preload, for example in a camera lens cap. Flexures are compliant structures that rely on material elasticity for their functionality. Motion is generated due to deformation at the molecular level, which results in two primary characteristics of flexures – smooth motion and small range of motion. From the perspective of precision machine design, one may think of flexures as being means for providing constraints. It is this capability of providing constraints that make flexures a specific subset of springs. In fact, all the applications listed above may be resolved in terms of constraint design. A historical background of flexures is presented in several texts. While flexure design has been traditionally based on creative thinking and engineering intuition, analytical tools can aid the design conception, evaluation and optimization process. Consequently, a systematic study and modeling of these devices has been an active area of research. Some of the existing literature deals with precision mechanisms that use flexures as replacements for conventional hinges, thus eliminating friction and backlash. Analysis and synthesis of these mechanisms is simply an extension of the theory that has already been developed for rigid link mechanisms, except that in this case the range of motion is typically small. The key aspect of these mechanisms is flexure hinge design. Unlike these cases where compliance in the system is limited to the hinges, other flexure mechanisms exist in which compliance is distributed over a larger part of the entire topology. Both these kinds of mechanisms offer a rich mine of innovative and elegant design solutions for a wide range of applications.

II. FLEXURAL MECHANISM

A mechanism is a mechanical device used to transfer or transform motion, force, or energy. Traditional rigid-body mechanisms consist of rigid links connected at movable joints. The portion of a reciprocating engine shown in Figure is an example. The linear input is transformed to an output rotation, and the input force is transformed to an output torque. As another example, consider the vice grips shown in Figure . This mechanism transfers energy from the input to the output.

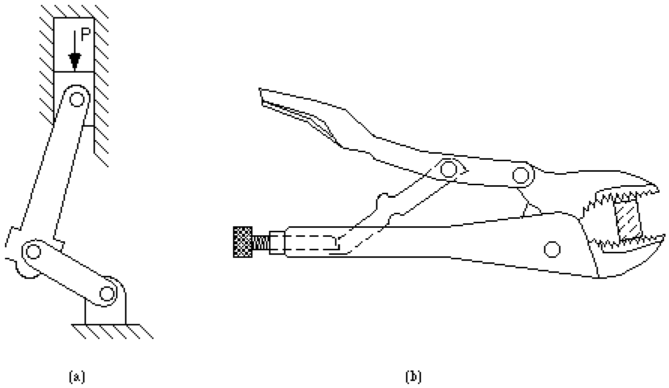
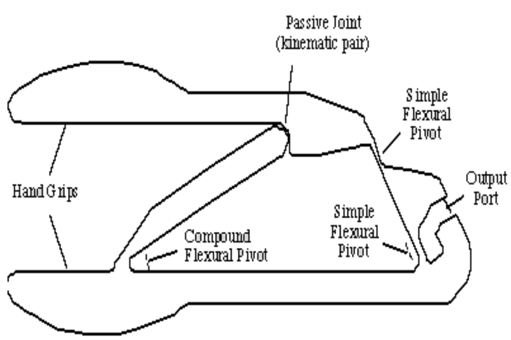
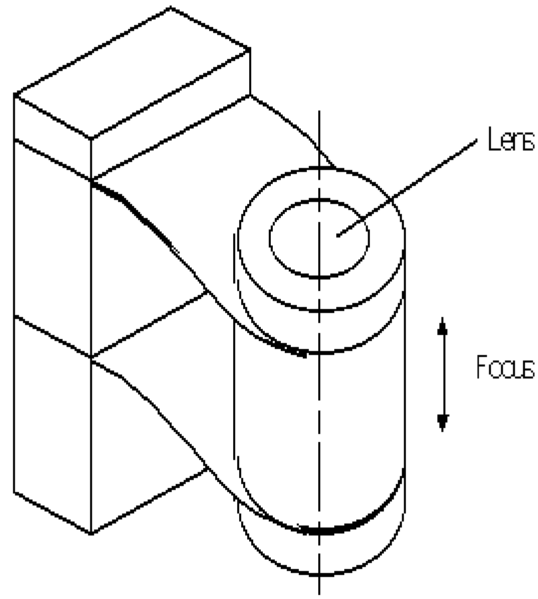


Fig.- 1: Conventional Mechanism

A compliant mechanism also transfers or transforms motion, force, or energy. Unlike rigid-link mechanisms, however, compliant mechanisms gain at least some of their mobility from the deflection of flexible members rather than from movable joints only. An example of a compliant crimping mechanism is shown in Figure 2a. The input force is transferred to the output port, much like the vice grips mechanism, only now some energy is stored in the form of strain energy in the flexible members. Note that if the entire device were rigid, it would have no mobility and it would be a structure. Figure shows a device that is used to focus a lens, and it also requires compliant members to perform its function.



(a)



(b)

Fig.- 2: Flexural Mechanism

III. MECHANISM DESCRIPTION

The Mechanism shown in FIGURE 3.consists of three linear beams which are attached to outer frame which will be fixed in this case and the motion stage which is located at the center of the mechanism. The motion stage in the middle is actuated with the help of vice coil motor. The length of the beam which is taken is 100 mm and the thickness of the beam considered is 1 mm. We can change the length as well as thickness of the beam, but as we reduce the thickness of the beam the stiffness of the beam goes on reducing and as a result of which we get lesser amount of motion. Also the selection of material of material plays a very important role in designing the flexural mechanism. As deflection of beam and young’s modulus f the beam are inversely proportional to each other ,therefore we have to select the material having low young’s modulus as much as possible. So Beryllium copper is more preferable than steel as it has low young’s modulus but the cost of BeCu is more than steel. Also care has to be taken while manufacturing it that no residual stresses are induced in the mechanism. We have tested the mechanism for force ranging from 5N to 25N. We have done the analysis by selecting BeCu material for mechanism with two and three linear beams whereas for Double Flexural Manipulator we have selected Stainless Steel Material.

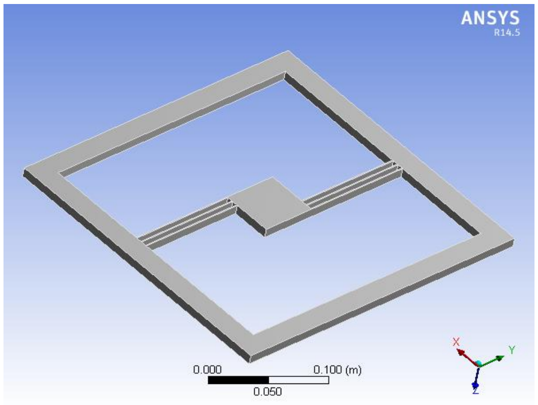


Fig.- 3: Flexural mechanism with linear beam

Now, we will consider two cases for the mechanism- one mechanism has three linear beam and second one has two linear beam on each side of motion stage and later a different flexural mechanism is explained which can move in only x direction. Further we have brought out the difference between the two mechanism by doing analysis in Ansys. The square portion in the middle is known as the motion stage which can either be used for mounting some equipment or a scale by use of which we can measure the displacement using the optical encoder.

IV. COMPARISION OF FLEXURAL MECHANISM WITH THREE AND TWO LINEAR BEAMS

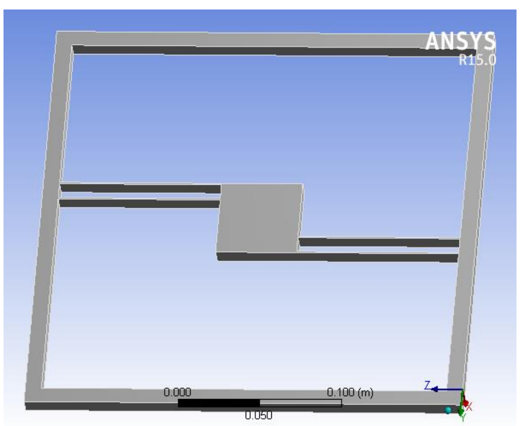


Fig.- 4: Flexural mechanism with two linear beams

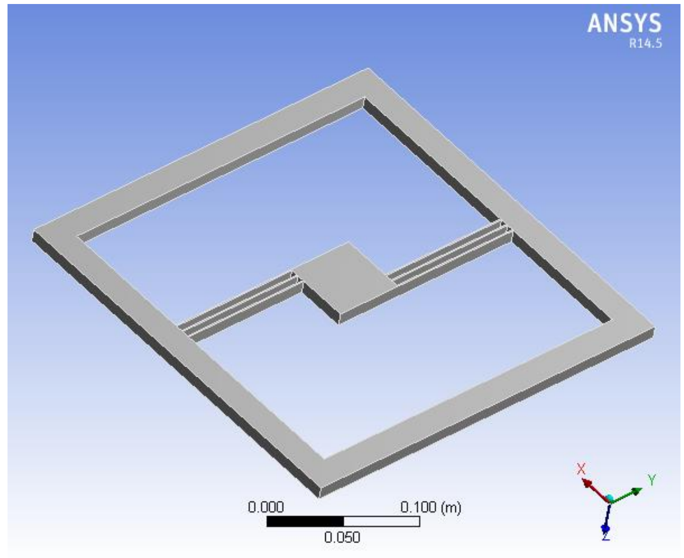


Fig.-5: Flexural mechanism with three linear beams

In this mechanism we can get both linear as well as rotational movement. By applying the force at exact center of the motion stage we can get a linear displacement. When we apply a force at a certain distance away from center we can get rotational movement. The amount of rotational movement which we can get can be varied by varying the distance of actuating force from center. But, we can get maximum rotational movement by applying force at the extreme end of the motion stage

We have considered two flexural mechanisms :

(a) Flexural mechanism with two linear beams [Mechanism 1]
(b) Flexural mechanism with three linear beams [Mechanism 2]

The analysis is done for 5N force.

4.1Total Deformation for 5N linear force:

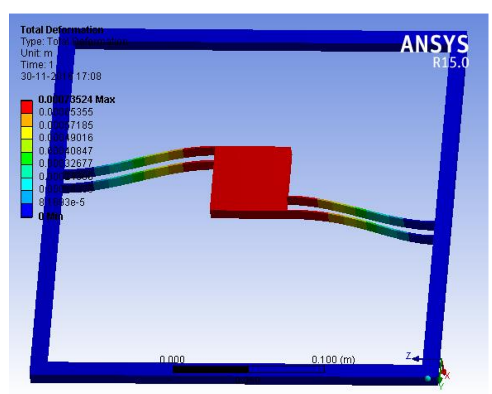


Fig.-6:Deformation forMechanism 1

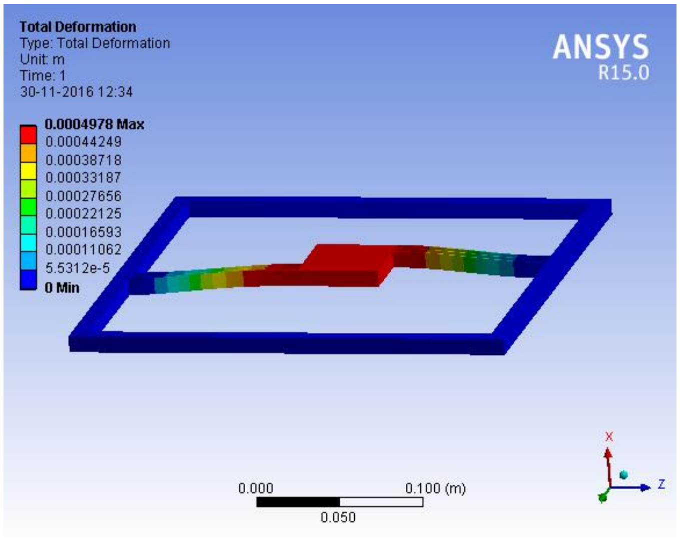


Fig.-7: Deformation for Mechanism 2

4.2Stress Intensity for 5 N linear force:

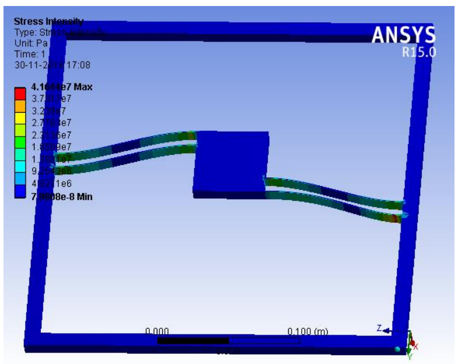


Fig.-8:Stress intensity for Mechanism 1

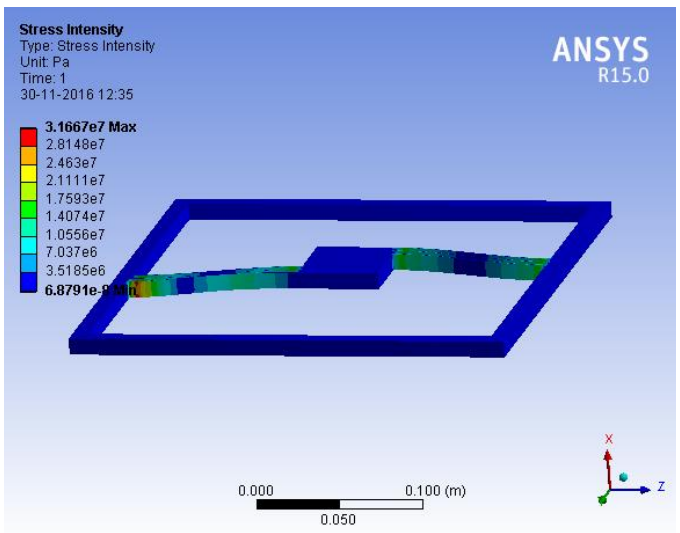


Fig.-9:Stress Intensity for Mechanism 2

Table-1:Displacement values for corresponding forces for three and two linear beams

FORCE(N)	THREE LINEAR BEAM(mm)	TWO LINEAR BEAM(mm)
5	0.49	0.73
10	0.9	1.47
15	1.49	2.2
20	1.99	2.9
25	2.48	3.67

The Stiffness provided by the beam is calculated by the formula F=kx and the values obtained are as follows:-

Table-2:Stifness values for three and two linearbeams

FORCE	THREE LINEAR BEAM	TWO LINEAR BEAM
5	10	6.84
10	10	6.80
15	10	6.84
20	10	6.89
25	10	6.81

From the graph we see that we are getting a straight line that means force is being directly proportional to displacement .Force is plotted on x axis and displacements are plotted on y axis.

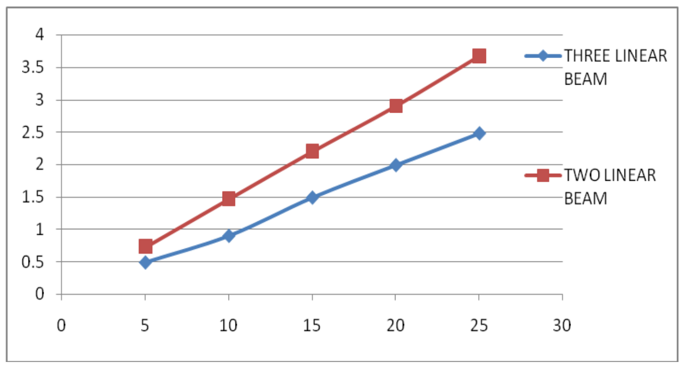


Fig.-10:Graph of Force vs displacement for linear force

4.3Total Deformation after applying couple :

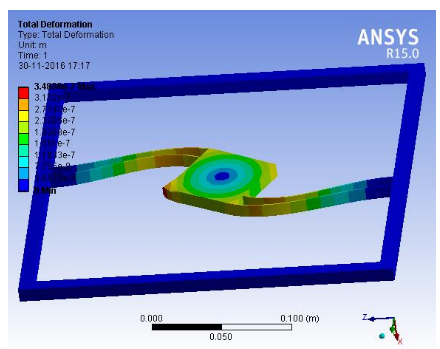


Fig.-11:Angular Displacement for Mechanism 1

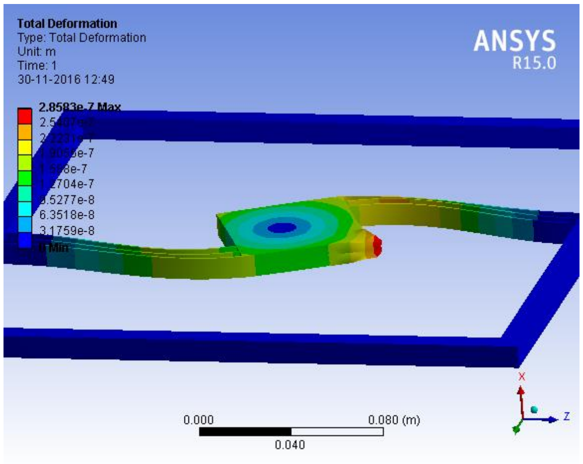


Fig.-12: Angular Displacement for Mechanism 2

4.4Stress Intensity after applying couple :

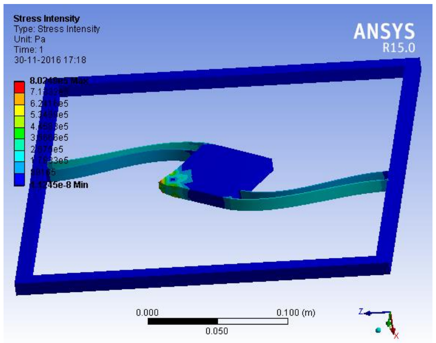


Fig.-13:Stress Intensity for Mechanism 1

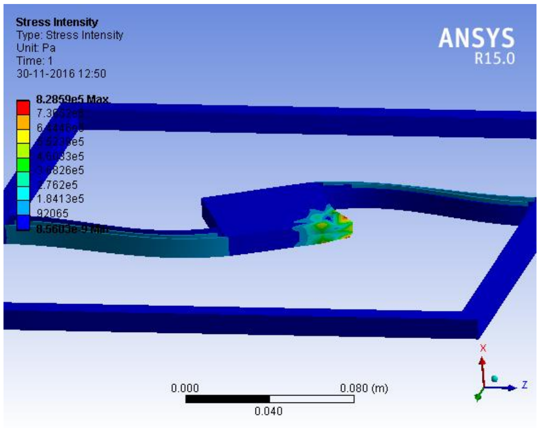


Fig.-14:Stress intensity for Mechanism 2

Table-3:Couple displacement values for three and two curvilinear beams

FORCE(N)	TWO LINEAR BEAM(mm)	THREE LINEAR BEAM(mm)
5	3.498e-7	2.858e-7
10	6.9795e-7	5.7566e-7
15	1.046e-6	8.57e-7
20	1.395e-6	1.143e-6
25	1.7449e-6	1.4292e-6

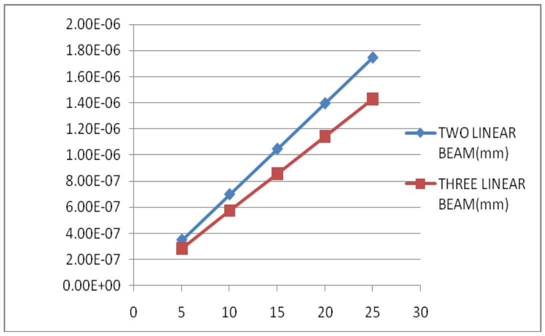


Fig.-15:Graph of Force vs angular displacement

V. FLEXURAL MECHANISM HAVING LINEAR MOTION IN ONE DIRECTION

The mechanism shown in figure can move in only one direction i.e either x -direction or y- direction.The material selected for the analysis was stainless steel .The mechanism has bee analyzed in ansys by applying force between 5N to 25N.The thickness of the beam considered in this case was 0.75 mm. The length of the beam considered was 50 mm on each side of the motion stage.

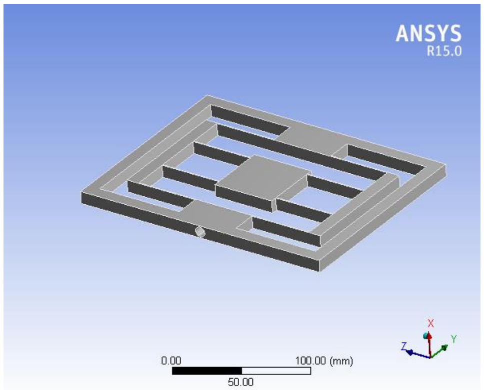


Fig.-16:Double Flexural Manipulator(DFM) moving in x-direction

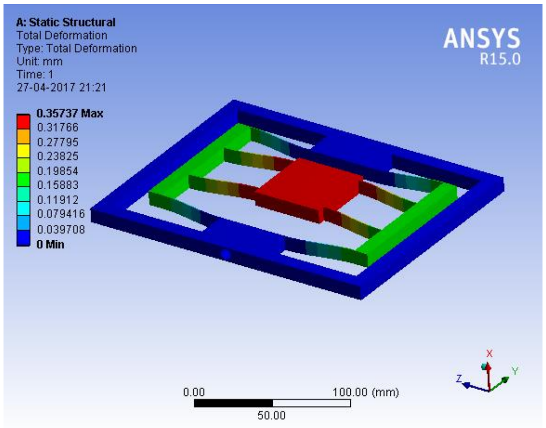


Fig.-17:Deformation of DFM

Table-4:Displacement values for DFM for corresponding forces

FORCE(N))	DISPLACEMENT(mm)	INTENSITY(MPa)
5	0.35737	32.171
10	0.71474	64.342
15	1.0721	96.514
20	1.4295	128.68
25	1.7689	160.86

The stiffness of the beam comes out to be 5/0.35737=14N/mm

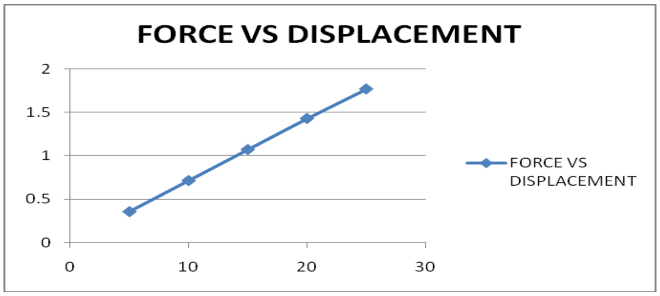


Fig.-18:Graph for force vs displacement for Double Flexural Manipulator

VI. CONCLUSION

- The characterization of linear flexural mechanism is carried out on the basis of static analysis which is executed for finding out force deflection attributes for the range of entire displacement for applied force and couple.
- The parametric modeling is done by using FEA tool ANSYS® Workbench™ 14.5 for characterizing the mechanisms presented in report.
- The results which we obtained are as follows-for mechanism with three linear beam the stiffness of the beam came out to be 10N/mm whereas for mechanism with two linear beams came out to be nearly 6.84N/mm. The stiffness obtained in DFM was 14N/mm.Thus we can conclude that for getting larger displacement by flexural mechanism the material must provide low stiffness as much as possible.
- Also, the output displacement increases with increase in effective length .Therefore, the output displacement is maximum for mechanism 2 compared to mechanism 1 since the effective length is increased.
- Flexural or Complaint mechanisms play an important role in the design of micro mechanical structures for MEMS applications. These monolithic mechanical structures can be designed to perform complex mechanical functions and fabricated within the constraints of present day micromachining processes.
- Flexural Mechanism also play an important role in atomic force microscopy where displacement required are in terms of nm.

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