

Modelling and Analysis of Flexure based Compliant Microgripper

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Abstract : In the world of miniaturisation, Micro-systems Technology has proven their usefulness in the various fields, such as biomedical, material science, automotive etc. Typical micro system requires precise microgripper to achieve safe transport/handling of micro-sized objects. Handling of the components needs to consider the correct gripping force in order to protect the micro part from excessive gripping force. Here, a need of a device for measurement of gripping force is raised. Researchers have mentioned various tools however simple, low cost and compact tool is missing. An attempt is hence presented in this paper to design a microgripper which is capable of measuring the gripping force. Pseudo Rigid Body Model (PRBM) of a compliant microgripper is developed and is validated through numerical simulation. The results obtained are satisfactory.

Keywords -Compliant Microgripper, Gripping Force, PRBM

I.INTRODUCTION

In recent years, Micro-Electro-Mechanical System(MEMS) has proven their usefulness in the various fields, such as biomedical, material science, automotive, consumer electronics, information technology etc. Gripping and manipulation of micro-sized objects is obvious in typical microsystem to perform micro-assembly task. Micro-objects such as MEMS parts, biological tissues/cells are often delicate and get damaged if applied gripping force exceeds the strength of the component to be manipulated. Requirement of a tool to achieve safe manipulation of micro-objects has led to broad research on micro-manipulators.

II. LITERATURE REVIEW

Nikoobin and Niaki[1], in their paper reviewed and compared sixteen different types of micro-grippers. They derived effective parameters such as material specification, displacement amplification factor, gripping range and stroke etc. on the performance and designing of micro-gripper. They also proposed an overall algorithm to design the micro-gripper.

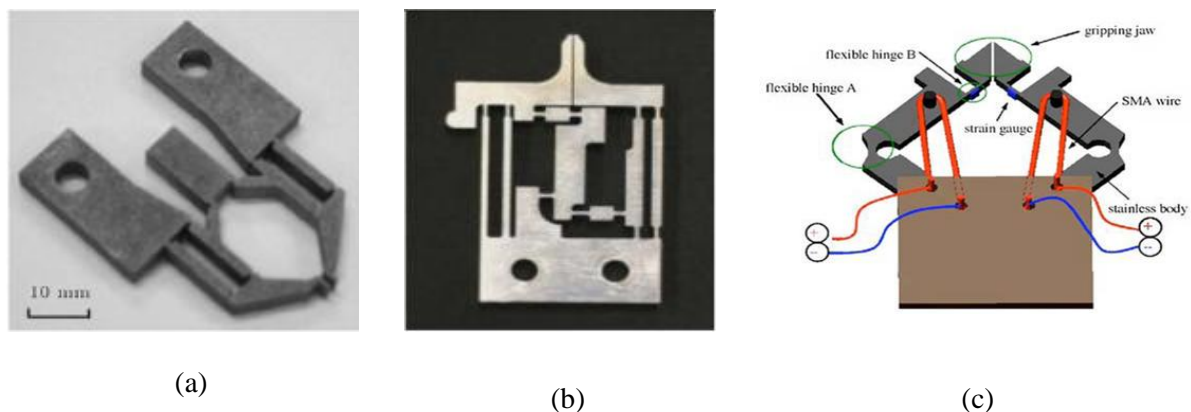


Fig.1(a,b,c). Different Micro-grippers[1]

Larry L.Howell in[2],have explained the usefulness of PRBM.He says that Pseudo-rigid-body models are helpful for understanding the behaviour of flexible parts and compliant mechanisms because they allow flexible bodies to be modelled as rigid bodies, thus allowing application of analysis and synthesis methods from rigid body mechanisms. Author has also defined PRBM as a set of diagrams and equation that describe a correspondence between the motion and force of an elastic member and a rigid-body mechanism.Author has

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considered a typical case of a planer beam whose one end is fixed and force is applied to other free end. Fig.2(a) shows fixed-free compliant beam and Fig.2(b) shows PRBM form of the fixed-free beam.

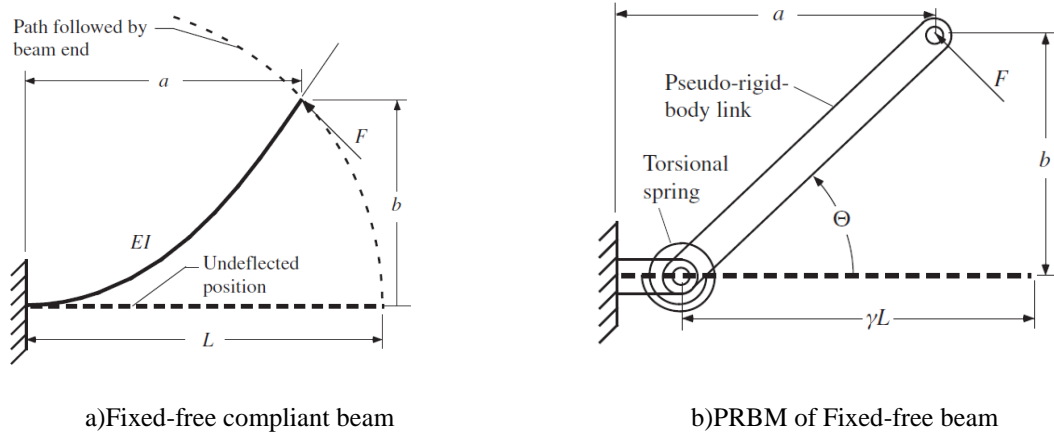


Fig.2 Formulation of PRBM for Cantilever Segment[2]

MohdNashrulMohdZubiret.al[3],developed a high precision flexure based microgripper as shown in Fig.3. They have adopted kinematic approach under the utilisation of Pseudo Rigid Body Model(PRBM) to design the microgripper. Authors have utilised a combination of flexure hinges and bias spring mechanism with appropriate mechanical transmission, while developing a microgripper mechanism capable of generating parallel motion.

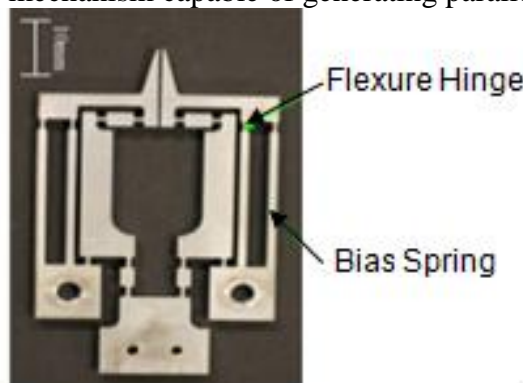
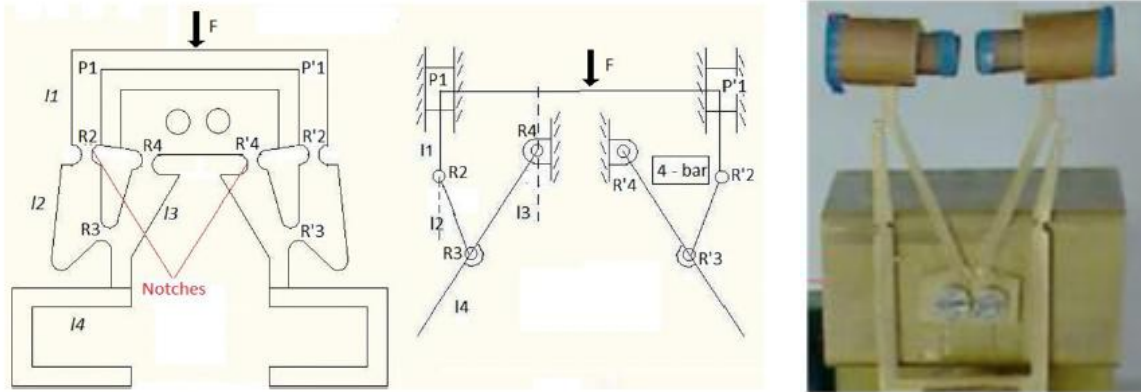


Fig.3 Microgripper Prototype[3]

K. Jayram and S. S. Joshi [4], in their paper presented the design of a flexure-based microgripperhaving a real time, vision-based force sensing system. Authors have obtained initial microgripper design using simulation-based design methodology which is further optimized using theoretical modeling.For easy measurement and control of the gripping forces a spring system has been integrated into the microgripper. For the theoretical design,gripper is considered as the combination of two 4-bar mechanisms as shown in Fig.4(b)



a) Gripper Design

b) Double 4-bar mechanism microgripper model

c) Microgripper Prototype

Fig.4 Compliant Microgripper[4]

2.1 Findings on Literature Survey:

Lumped design mechanisms are designed using kinematic synthesis approach based on PRBM. Out of various actuation systems and sensors piezoelectric actuator is preferred over other types of actuators such as electrostatic, electromagnetic etc. Right circular flexure hinges are usually used to design compliant mechanism for microgripper as the position accuracy and repeatability of the gripping arms with right circular hinge is good. Micro-objects are usually fragile and can get damaged if the gripping force exceeds the strength of object to be manipulated. In recognition of this issue, a need of a device for measurement of gripping force is raised. Researchers have mentioned various tools however simple, low cost and compact tool is not communicated. Hence there is a need to design a microgripper which is capable of measuring the gripping force.

III. DESIGN METHODOLOGY AND ANALYTICAL SOLUTIONS

3.1 Design Approaches:

Kinematic synthesis approach and Continuum synthesis approach are used to design lumped and distributed compliant mechanism respectively.

Kinematic Synthesis Approach:

Kinematic synthesis approach is also called as design approach of pseudo-rigid-body mechanism, where the design is firstly performed by synthesizing a rigid-body mechanism, and then the flexibility is introduced to redesign the hinged joints of rigid-body parts as flexible hinges. The performance of the resulting compliant mechanism is roughly like a pseudo-rigid-body mechanism when compared to that of a rigid-body mechanism[5].

As stated in [2], for small length flexural pivot spring constant K is given by equation (i),

$$K = \frac{(EI)l}{l} \dots\dots(i)$$

Where,

K =Spring constant,

E =Young's Modulus

l = length of flexible segment

I =Beam moment of inertia

While designing the compliant mechanism, the flexures are replaced by torsional spring as shown in Fig.5 having equivalent stiffness given by equation (ii), as stated in [3]

$$k_{\theta} = \frac{2Ebt^{2.5}}{9\pi r^{0.5}} \dots\dots\dots(ii)$$

Where,

E=Young's Modulus

b=Thickness of plate used

t=Thickness of flexure hinge

r=Radius of flexure hinge

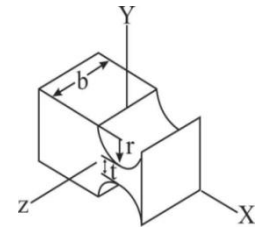


Fig.6 Flexure Hinge[6]

Continuum Synthesis Approach:

Distributed compliant mechanisms are designed using continuum synthesis approach also known as structural optimization approach. In this type of mechanism flexibility is distributed throughout the segment. Such mechanisms are considered as flexible continua and treated as such in their analysis and synthesis[7].

3.2 Modelling And Analysis

In present work kinematic synthesis approach is used to design compliant microgripper. Modeling and analysis of a flexure based microgripper is carried out in order to formulate relation between input displacement and gripping force.

Theoretical Calculation for Displacement of Compliant Microgripper:

As stated earlier, PRBM is an effective method to devise relationship between force and displacement. The Pseudo Rigid Body Model (PRBM) concept is used to perform basic modeling of compliant microgripper. Use of classical cantilever beam theory along with PRBM simplifies the model in order to predict the mechanism response under prescribed input motion.

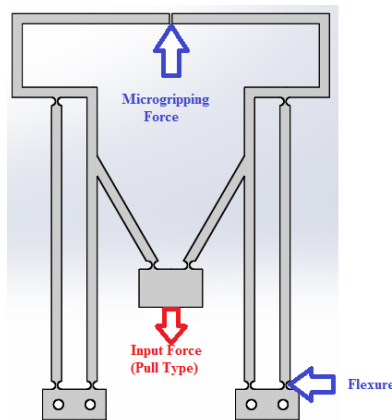


Fig. 7 Compliant Microgripper

Fig.7 shows the basic model of compliant microgripper. A pull type input force make this device acts as a gripper as shown in Fig.7

$$Y = \frac{Fl^2}{4k_{\theta}} \dots\dots\dots(iii)$$

Equation(iii), provide the displacement of a compliant microgripper.

Input force and input displacement is calculated by PRBM and is tabulated in Table.1


Table.1 Force Vs. Displacement of A Compliant Microgripper

Input Force F (N)	Input Displacement(mm)
	Gripper thickness(1.60mm)
1	0.0043
2	0.0086
3	0.0130
4	0.0173
5	0.0216
6	0.0259
7	0.0303
8	0.0346
9	0.0389
10	0.0432

Numerical Simulation:

Once formulating the relationship between input force and displacement analytically i.e. using Pseudo Rigid Body Modeling method, the same models are then compared by using numerical method software SolidWorks.

Finite Element Model

Total Nodes	91048
Total Elements	50641
Maximum Aspect Ratio	3.8046
	
Fig.9 Meshed Model	

In this study only planar compliant mechanisms are considered and it has been ensured that the Compliant Mechanisms are made from material sufficiently thick to support the x-directional load such that out of plane displacements are trivial. Therefore, out of plane displacements can be ignored so that only translations x-y plane has to be considered[8].

Steps in FEM:

Following are the general steps undertaken in the Finite Element Analysis of a compliant microgripper.

- a) Pre-processor-Model generation

- b) Solution-Application of load and boundary condition followed by the solution of the problem
- c) Post-Processor-Display results

a) Pre-processor:

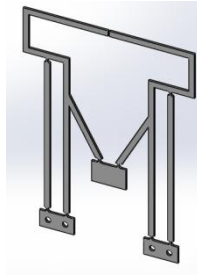


Fig.8 Model of microgripper

A solid model is generated using SolidWorks as shown in Fig.8

b) Solution:

Boundary conditions and load is imposed to the meshed model. To accomplish microdisplacement with reduction in stress concentration is the key objective of the present work. In tune with this objective, 'static structural analysis' module of SolidWorks is considered for analysis. Fig.10 shows application of boundary conditions to the model. After specifying boundary conditions, solution is carried out for resulting deformation and induced stress.

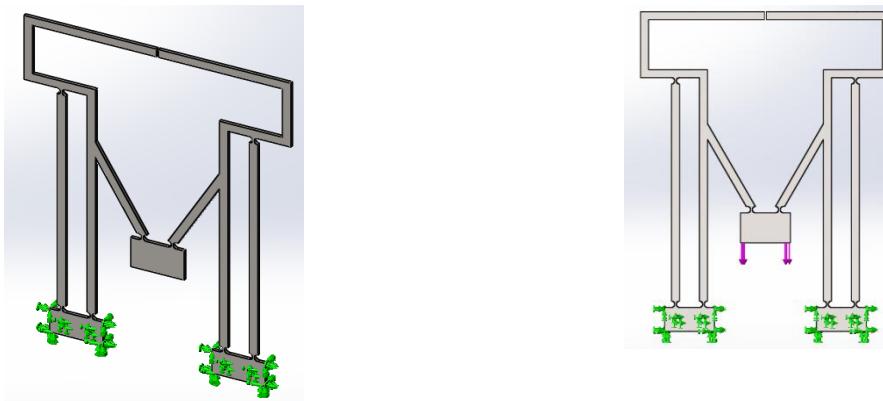


Fig.10 Application of Boundary Conditions

c) Post Processor:

The solution obtained by the solution process is a general solution. The displacement plot is obtained for the particular load condition and is represented in Fig.11. The displacement analysis is carried out over a range of input force (1 N to 10 N) and the corresponding values are represented in Table.2. From the displacement obtained, reverse methodology is followed to validate the results obtained to find out relation between force and displacement. From the Table.2, a relation between input force-input displacement, output displacement-input displacement and finally gripping force-output displacement can be established.

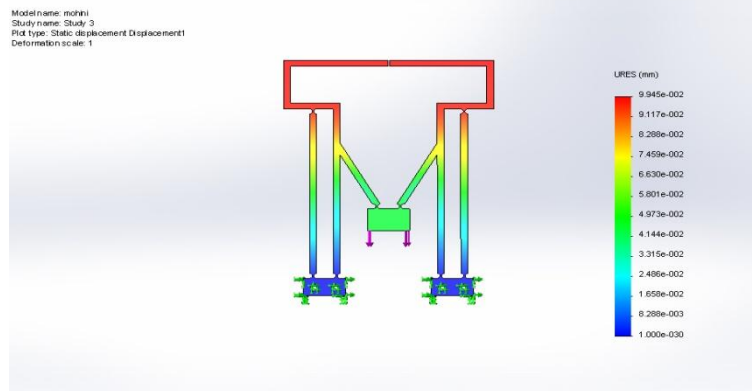


Fig.11 Displacement plot

Output displacement(Y_{out}) =0.1478 Input displacement(Y_{input})

From the above relation obtained,output displacement can be calculated by measuring the input displacement and vice versa.

By PRBM, the relation between input force and input displacement is

$F_{input}=231.0294Y_{input}$

Table 2. Corresponding Force and displacement

Input force (Gripping Force)	Input displacement(Gripping Displacement)	Output displacement	Output force	Input force/output displacement
1	0.0636	0.0094	2.1737	106.2812
2	0.1273	0.0188	4.3503	106.2135
3	0.1909	0.0282	6.5220	106.2700
4	0.2544	0.0376	8.6959	106.2699
5	0.3182	0.04705	10.8699	106.2699
6	0.3818	0.05646	13.0439	106.2699
7	0.4454	0.0659	15.2179	106.2699
8	0.509	0.0753	17.3919	106.2699
9	0.5726	0.0847	19.5659	106.2700
10	0.6362	0.0941	21.7376	106.2812

From the Table.2 the relation between Gripping Force and gripping displacement is established as

$$\text{Gripping Displacement}(Y_{\text{input}})=0.0636\text{Gripping Force}(F_{\text{grip}})$$

The prime objective is to measure gripping force of a microgripper. From the PRBM and numerical solution relation between gripping force and output displacement is established and is tabulated in Table.2

From Table.2 Gripping force and output displacement are related as below.

$$\text{Gripping Force}=106.2665 \text{ Output Displacement}$$

This is the relation to find the gripper force by measuring output displacement of microgripper. The results are validated by calculating displacement at input, output and input and output force.

IV. CONCLUSION

Pseudo Rigid Body modeling is useful for analytical calculations of Lumped compliant mechanism. The results obtained authenticate the importance of PRBM for analysis of lumped compliant mechanism. A relation between gripping force and metered output displacement is established.

$$\text{Gripping Force}=106.2665 \text{ Output Displacement}$$

So with the help of this relation it is possible to calculate the safe value of gripping force in order to avoid damage of fragile micro-objects during its manipulation.

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