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Design and Fabrication of a Monolithic Compliant Grass Hopper Mechanism

V. Siva Ganeshan, Pithani Tarun, Peram Sukhanth, U. Sri Krishna, K. Sreenivasa Reddy

Department of Mechanical Engineering, Godavari Institute of Engineering and Technology(A), JNTUK, Kakinada.

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ABSTRACT

A monolithic compliant mechanism is a single component jointless mechanism that is extensively being used for precision applications such as biomedical, and nanotechnology applications due to the absence of friction wear lubrication,and backlash issues. Compliant mechanisms are mainly used to enhance or lower the displacement of magnification ratios. In thispaper design and analysis of the compliant Grasshopper's mechanism for the linear displacement application is presented. Finite element analysis of the mechanism was carried out using solid works to obtain the linear displacement and stresses. The results obtained for linear displacement were validated with the actual displacement obtained for the working prototype mechanism for the materials.

KEYWORDS:Compliant Mechanism, Backlash, Grass Hopper Mechanism

1. INTRODUCTION

Compliant mechanisms are flexible single-piece structures that produce the desired movement by going through elastic deformation [1]. A mechanism is a mechanical device used to transfer force, energy, and motion. But Compliant Mechanism is a monolithic structure that elastically deforms without any link and joint to produce a desired force or displacement. It is an elastic continuum that is used to transmit or transform force and motion mechanically. Rigid-body mechanisms have rigid links connected at movable joints [2]. Unlike rigid-body mechanisms, compliant mechanisms gain some of their mobility from the deflection of flexible members rather than movable joints only. Stiffness is a measure of load per unit deflection, whereas strength is how much load can be endured before failure. Despite human tendencies, it is possible to make things that are flexible and strong. Nature uses stiff structures where needed (tree trunks, bones, teeth, and claws) but in living organisms, it more often relies on flexibility. Bee wings, bird wings, tree branches, leaf stems, fish, and single-celled organisms are only a few examples of creations that use compliance to their advantage [3]. The contrast between nature and human design is easily identifiable when humans try to replace one of nature's products. For example, a human heart valve is a compliant one-way valve that is capable of sustaining billions of cycles without failure [4]. However, most current artificial heart valves use several assembled stiff parts with pin joints to obtain motion. They also have a comparatively shorter life, because of difficulty in blood flow, and often damage blood cells. Systems with concentrated compliance behave like classic rigid link mechanisms, where kinematic joints are replaced with flexible hinges, and in consequence, methods conceived to design rigid-body mechanisms can be modified and applied successfully in this case.

ADVANTAGES OF COMPLAINT MECHANISM

i. Compliant mechanisms can allow precise motion by reducing or eliminating backlash and wear
ii. The number of components required for a compliant mechanism can be considerably less than for a rigid version of the same mechanism.
iii. Because they have fewer parts and simple manufacturing processes, compliant mechanisms can be very inexpensive to manufacture [4]
iv. It is possible to significantly reduction in weight by using a compliant mechanism over their rigid-body counterparts.

LIMITATIONS

i. Energy stored in flexible elements was discussed above as an advantage since it can be used to simplify mechanisms that incorporate springs. However, in some applications having energy stored in flexible members is a disadvantage [4].

ii. It is important to design those members such that they will have sufficient fatigue life to perform their prescribed functions.[8]
iii. The motion from the deflection of compliant links is also limited by the strength of the deflecting members. [8]

2. RELATED WORK

It is required to study the basis of literature review with compliant mechanisms presented by various workers, elements, and research articles on compliant mechanisms and the relationship between the hinge configurations and the type of applications [9]. Therefore, based on an article that developed a pantograph mechanism rigid body is modified into a compliant mechanism using flexible hinges to obtain the linear displacement with the required input force. Stress evaluations and displacement synthesis of selected amplification ratio by an analytical approach using Euler-Bernoulli beam bending theory. They [9,10,11] conducted the Design and Analysis of the compliant mechanism. To confirm the range of ratios of circular flexural hinges the standard values were taken. They verify the analytical results using FEA.The Fabrication process through sheet metal and metal wires. To validate displacement of selected amplification ratio analytically, numerically, and experimentally the literature review of various compliant micro-mechanisms was carried out [12]. The micro-mechanisms have been used to provide displacement, enhance displacement, and scale down displacement [13]. Many of them [7,8,10] are based on the lever arm principle and are least capable of providing linear directional movements. The existing compliant mechanical amplifiers conclude that there are limitations such as the presence of a lateral displacement and low amplification ratio. In the present literature, fewer discussions have been observed based on amplification or reduction and corresponding replication from the micro-mechanism. Need for-compliant mechanism. There are various types of displacement amplifiers already in engineering applications, such as Lever mechanism, Scott-Russell mechanism, Pantograph mechanism, Watt straight-line mechanism, Crosby indicator, etc. Compliant mechanisms are mainly used to enhance or lower the displacement of magnification ratios. The aspect of obtaining amplification/reduction and replication of input motion from the mechanism has not been considered and needed to be addressed. Hence the compliant mechanism uses the flexible joint to product displacement and motion. We selected the Grasshopper mechanism to modify the rigid body to the complaint mechanism. The Grasshopper mechanism was designed by eliminating the turning and sliding joints to flexible joints. Hence a compliant pantograph has been proposed with the following objectives

i. To design and analyzed the linear displacement applications.

ii. To fabricate the Grasshopper's compliant mechanism and verify the results.

3. PROPOSEDWORK

In this paper, a compliant mechanism is proposed for the Grasshopper mechanism that operates as same as the traditional Grasshopper mechanism. Grasshopper mechanism dimensions were taken from a reference textbook [2]. Grasshopper mechanism with the reference dimension from fig: 1. The design process was carried out in the solid works and the analysis in the ANSYS workbench 15. The fabrication of the grasshopper mechanism was carried out by sheet metal and metal wire according to the design.

Grasshopper Mechanism

This mechanism is a derivation of the modified Scott-Russel mechanism in which the sliding pair at S is replaced by a turning pair. This is achieved by replacing the slider with a link AS perpendicularly to OS in the mean position. AS is pin jointed at A. If the length AS is large enough, S moves in an approximately straight line to AS (or in the straight line with OS) for small angular movement. P again will move in an approximately straight line if QS is proportional between OQ and QP,i.e.,

$$\frac{OQ}{QS} = \frac{QS}{QP}$$

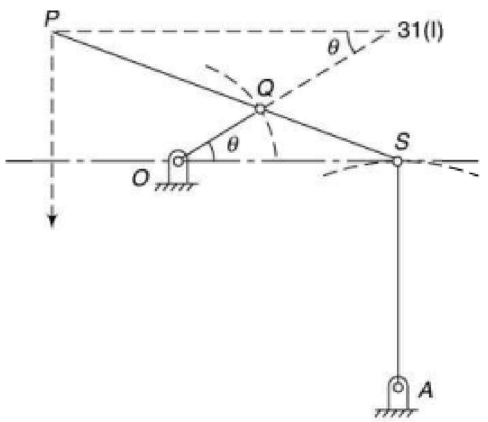

Figure 1 : GrasshopperMechanism [2]

PS = 300 mm
SA = 200 mm
OQ = 80 mm
QS = 120 mm
QP = 300-120 = 180 mm

$$\boldsymbol{\frac{OQ}{QS} = \frac{QS}{QP}, \text{ i.e., } \frac{80}{120} = \frac{120}{180}}$$

As thecondition for the dimensions of the Grasshopper mechanism is satisfied, P moves in an approximately straight line for small angles of OQ

DESIGNOFCOMPLIANT MECHANISM

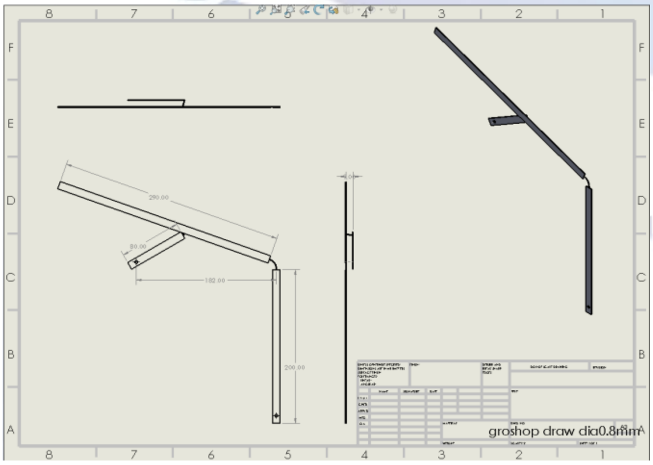

Figure 2: Design of Grasshopper mechanism

The figure shows the basic design of the Grasshopper compliant mechanism. The Monolithic compliant mechanism was designed with the values from the above fig 1. Solid works are used in the designing process. The line diagram was created using the values from the above fig by using the axis line we created a line diagram with measurements of OQ = 80, PS = 300, QS = 180, SA = 200, and OS =180.The angle at o is assumed as 30 degrees Line commend was used to create the links at PQ in a rectangular shape on the axis lines of PS with 15 mm length and height of 300 mm. With the same process the remaining links at OQ and SA were created with the length of 15mm with represented heights. Extrude tool was used to increase the thickness of the links to 1mm. The cylindrical section was created using the swept tool in the 3D model with the required circular path with the dia of 1.2 mm at joints Q and S. As shown in fig with a weld joint. The file was saved in a STEP file

Analysis procedure

The designed mechanism is transferred to ANSYS 15 in the format of the STEP file.The material properties were selected as the structural steel in ANSYS. The model geometry was directly generated from the STEP file in solid modeling. Meshing was generated with 10 mm and at the end of links “O“and “A” are fixed and the boundary conditions were restrained. The load was applied 8 N at point P vertically downwards and the Equivalent stress and direction deformation inx,y, and z directions were added

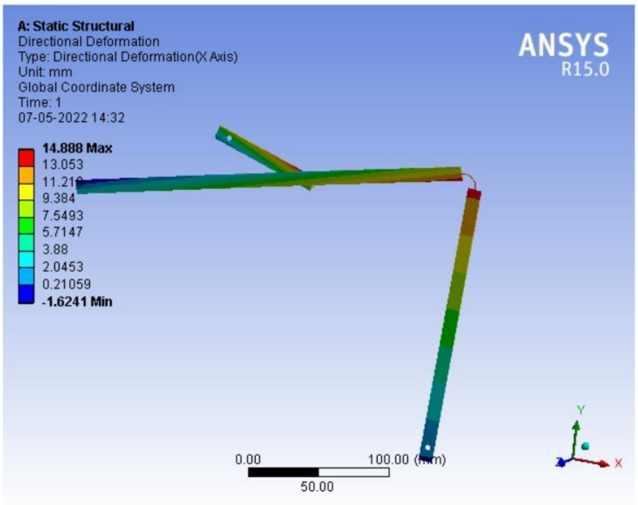

Figure 3: Directional deformation in X-axis

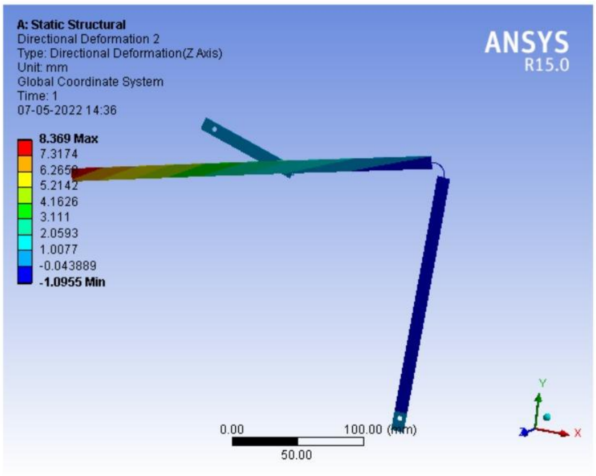

Figure4: Directional deformation in Z-axis

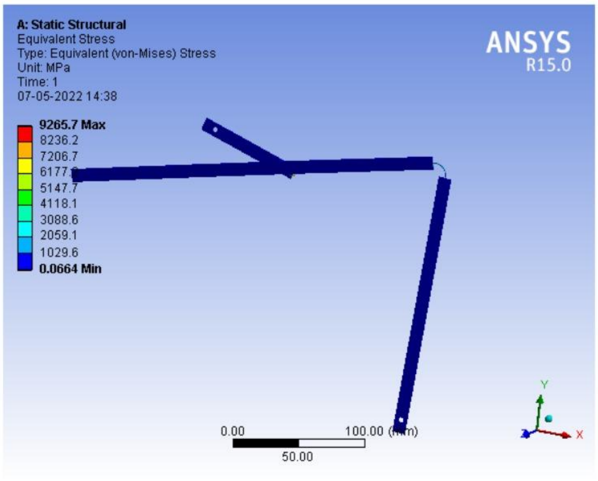

Figure 5:Equivalent stress

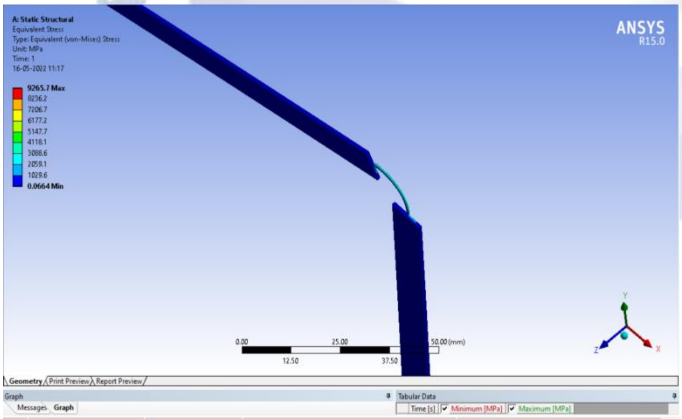

Figure 6: Equivalent Stress at joint 2

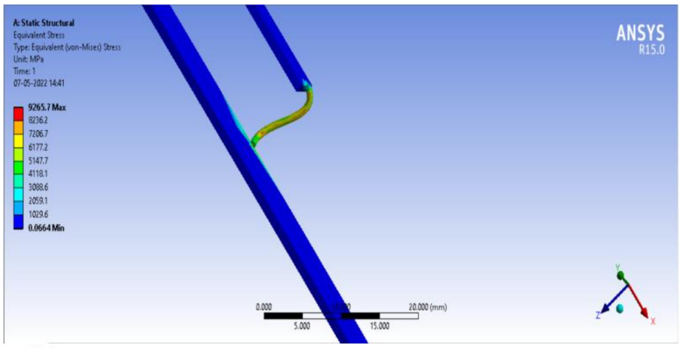

Figure 7: Equivalent Stress at joint 1

FABRICATION

The design of the grasshopper mechanism was carried out on solid works. The metal sheet was cut using the snipping tool according to its dimensions. The link PS was snipped 300*15 mm on sheet metal with a thickness of 1 mm. The link SA was snipped with the dimensions of 200*15 mm on sheet metal with a thickness of 1 mm. The link OQ was snipped with the dimensions of 80*15 mm on sheet metal with a thickness of 1 mm. A circular metal wire was used to join the links "PS" and "SA" with a length of 15 mm at the joint S with a spot welding joint. A circular metal wire was used to join the links "OQ" and "PS" with a length of 15 mm at the joint Q with a spot welding joint. the link OQ was placed at another plane with a distance of 10 mm onthe X and Y-axis. The points and Q were joined to carboard to form a turning pair. The force of 10 N was applied at point P.

4. RESULTS

This mechanism was developed to meet the requirement of many industrial applications to eliminate mechanical joints like bolt and nut joints and obtain the required motion. The compliant mechanisms are the best ones to get the motion by using the strain energy stored in the flexible material. By this, a compliant Grasshopper's mechanism had been designed and fabricated to achieve the approximate straight line. The approximate straight line based on the proposed design and fabrication process was obtained. And also the directional deformation on the x and z-axis and equivalent maximum and minimum stress at the joints and at the deformation point of different standard wire diameters of 0.80mm, 1.0mm, and 1.2mm for the material of structural steel in Ansys workbench was carried out and the the results were obtained. When the wire diameter is 0.8mm the mechanism can resist up to 8N force after that the mechanism fails at the joint as same as that the diameter of wire 1mm and 1.2mm is used the 1mm resist up to 18N force and the 1.2mm dia wire resist up to 21N. But the moment of the mechanism is good when the wire diameter of 0.8mm is used without any bending deformation of the link as compared to the other diameter wires. The maximum stress and minimum stress are placed in the tabular column is kept below. The stress ot the joints are not exerted bythe standard stress values of structural steel material. Hencethe design was safe.

Standard structural steel properties [7] were taken for the static strctural analysis of the mechanism.

Table: 01-Analysis results for dia 0.8mm

S.No	Type of deformation	Maximum value	Minimum value
1.	Directional deformation (x-axis)	14.888 mm	-1.6241mm
2.	Directional deformation (z-axis)	8.369mm	-1.0955mm
3.	Equivalent strees (von-mises)	9265.7 Mpa	0.0664 Mpa

Table: 02-Analsysis results for dia 1mm

S.No	Type of deformation	Maximum value	Minimum value
1.	Directional deformation (x-axis)	17.61 mm	-0.42471 mm
2.	Directional deformation (z-axis)	17.298 mm	-1.4193 mm
3.	Equivalent strees (von-mises)	10132 Mpa	0.17033 Mpa

Table 03: Analysis Results for dia. 1.2 mm

S.No	Type of deformation	Maximum value	Minimum value
1.	Directional deformation (x-axis)	18.26 mm	-0.12668 mm
2.	Directional deformation (z-axis)	15.424 mm	-0.40424 mm
3.	Equivalent strees (von-mises	7248.2 Mpa	0.22613 Mpa

5. CONCLUSION

(1). Displacement synthesis has been presented for the Grasshoppermechanism according to the dimensions and the wire diameters of 0.8mm,1mm, and 1.2mm.

(2). The result based on FEM for the displacement and the stress analysis of Grasshopper compliant mechanism with sheet metal of mild steel materials were found safe for the selected configuration.

(3). Due to the compliant property of this mechanism and energy storage capacity of flexible members in the form of strain energy leads to eliminate the losses due to friction in the mechanism.

(4). The mechanism configuration used in Ansys better accuracies obtained depending on the wire diameter of 0.8mm,1mm, and 1.2mm.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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