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To cite this article: Sheng Lin and Shiqi Song 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **569** 022028

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Hybrid curved beam compliant mechanism with six degrees of freedom and large working space

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Abstract. Compliant mechanism has the advantages of compact structure, high precision and easy miniaturization. It has been widely used in the fields of robotics, precision engineering, bio-engineering and so on. In this work, a six degrees of freedom hybrid curved beam spatial compliance mechanism is proposed. The spatial six degrees of freedom are realized by means of series-parallel combination of curved beam compliant elements. The structure consists of an outer base, an inner base, a worktable, driving frame, curved beam compliance elements and piezoelectric ceramic actuators. The working principle of motion in six degrees of freedom is analysed, and statics analysis is carried out to verify the feasibility of the structure.

1. Introduction

Compliant mechanism is a new type of mechanism that transmits and transforms motion, force or energy through elastic deformation^[1]. The compliant mechanism has the advantages of low cost, no lubrication, high motion sensitivity, and easy to manufacture^[2]. The compliant has been widely used in different fields.

Burns presented the concept of compliant mechanism for the first time^[3]. After years of development, the form of compliant mechanism has become more and more diversified. Culpepper et al. designed a new type of six-degree-of-freedom fretting platform. The platform is driven by an electromagnetic actuator with lower cost than a piezoelectric ceramic actuator. And the displacement sensor is integrated into the fabrication process^[4]. Naves presented a three-degree-of-freedom spherical bending joint with a large stroke^[5]. Chen proposed a method for analyzing large deformation of curved beams in a compliant mechanism using a chain-constrained beam model^[6].

In this work, a hybrid curved beam compliant mechanism with 6 DOF and large working space is designed, and the compliant mechanism uses curved beams as compliant element to avoid stress concentration. The structure overcomes the disadvantages of series or parallel connection. The spatial structure and the working principle of the six-degree-of-freedom motion is described in detail. Finally, the ANSYS Workbench is used to perform the static analysis to obtain the deformation and stress of the mechanism.

2. Structure and composition

As shown in Figure 1, the structure consists of an outer base, an inner base, a worktable, C-type driving frames, L-type driving frames, curved beam compliance elements and piezoelectric ceramic actuators. The inner base, the out base and the worktable are connected by the curved beam compliant elements.



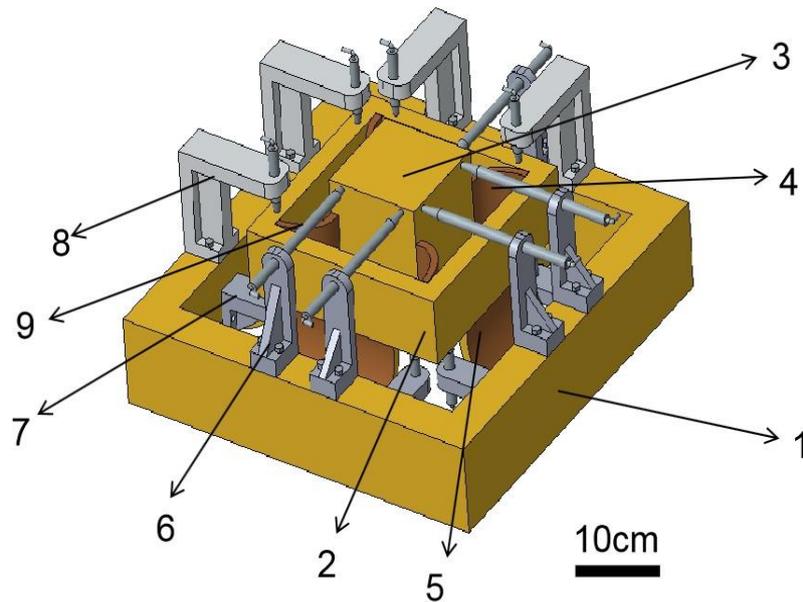


Figure 1. The structure of the six-degree-of-freedom worktable. 1)Outer base. 2)Inner base. 3)Worktable. 4)Vertical curved beam compliance elements. 5)Horizontal curved beam compliance elements. 6) driving frame. 7)Horizontal L-type driving frame. 8)C-type driving frame. 9)piezoelectric ceramic actuators.

3. Working principle

As shown in Figure 2, The driving forces and torques are provided by the piezoelectric actuators. The driving forces can be obtained by driving the actuators in the same direction. The driving torques can be generated if the two force in the opposite position and the magnitudes of the force are the same. The loading modes of all the force and torque are presented.

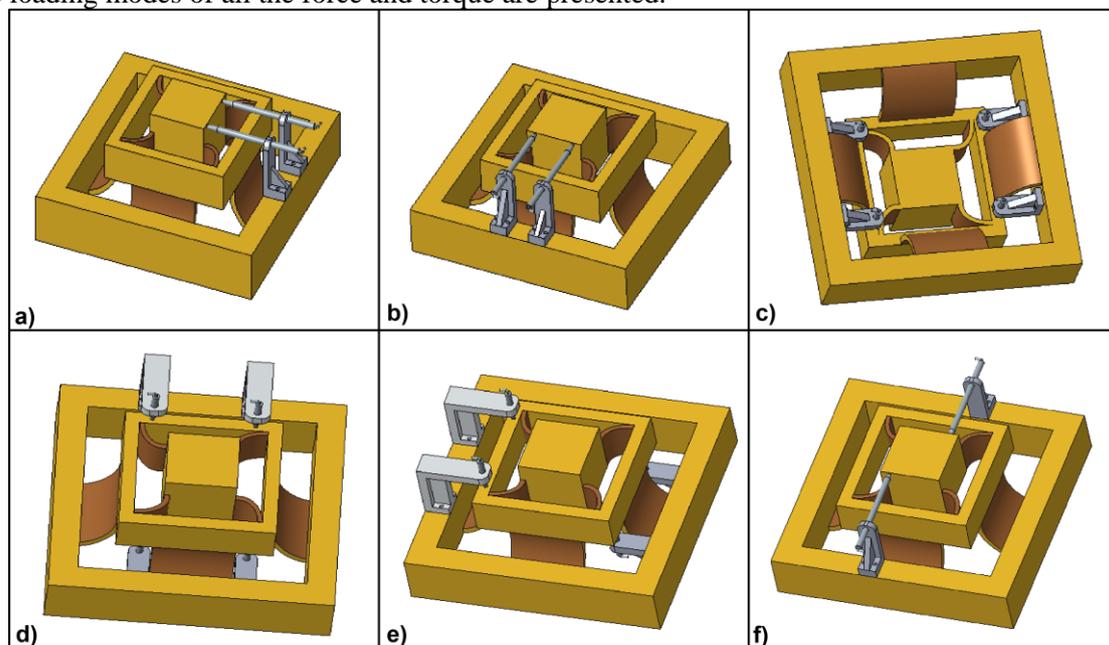


Figure 2. Schematic diagram of the work of achieving six degrees of freedom. a) X-direction movement. b) Y-direction movement. c) Z-direction movement. d) Moving around the X axis. e) Moving around the Y axis. f) Moving around the Z axis

4. Finite element statics analysis

The finite element static analysis of the structure was carried out using ANSYS Workbench. The material was chosen as an aluminum alloy with an elastic modulus of $E = 73\text{GPa}$ and Poisson's ratio of $\nu = 0.3$. All the freedom of the outer base is constrained.

Set the driving force in X-direction as 100N, then the deformation and stress were obtained in Figure 3. Results shows that the maximum deformation is $5.4804\text{e-}003\text{mm}$ and the stress range is between $2.4248\text{e-}004\text{MPa}$ and 2.8094MPa .

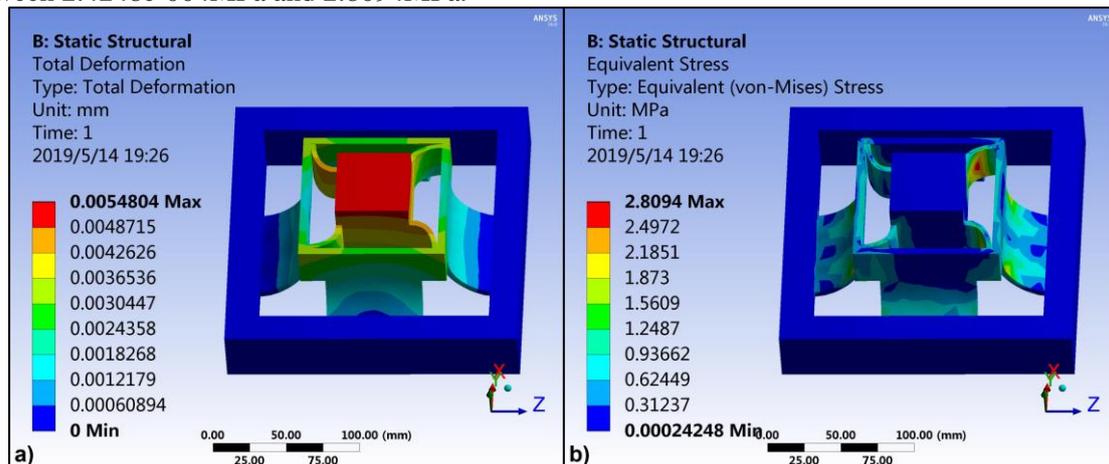


Figure 3. Deformation and stress Analysis of X Axis Motion of Worktable. a) Deformation analysis. b) Stress Analysis.

Analysis process in Y-direction is the same as X-direction. Figure 4 shows the total deformation and stress cloud of the compliant mechanism. Results shows that the maximum deformation is $5.4804\text{e-}003\text{mm}$ and the stress range is between $2.4248\text{e-}004\text{MPa}$ and 2.8094MPa .

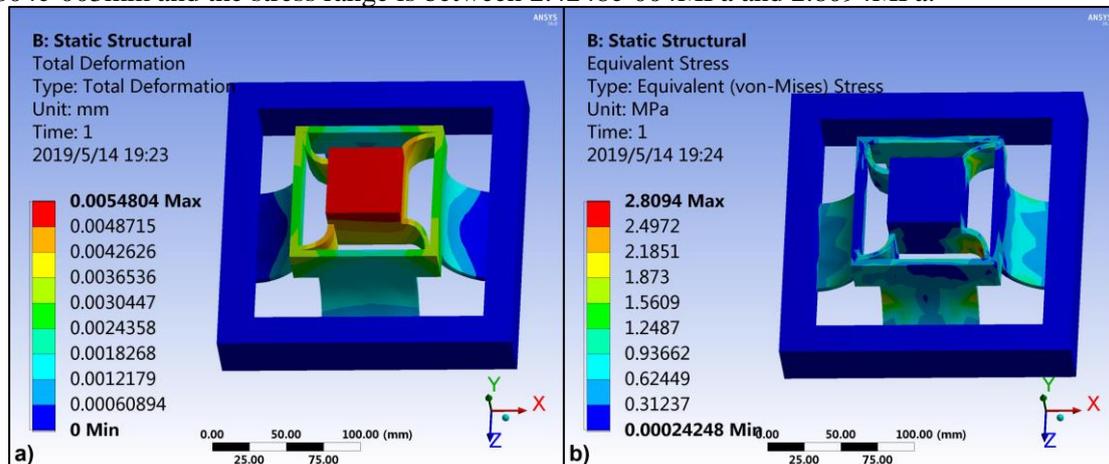


Figure 4. Deformation and stress Analysis of Y Axis Motion of worktable. a) Deformation analysis. b) Stress Analysis.

The load in the Z-direction was applied on the center of the worktable. We set the driving force as 100N. Figure 5 indicates the deformation and stress. Results shows that the maximum deformation is $6.5101\text{e-}003\text{mm}$ and the stress range is between $4.762\text{e-}003\text{MPa}$ and 5.0246MPa .

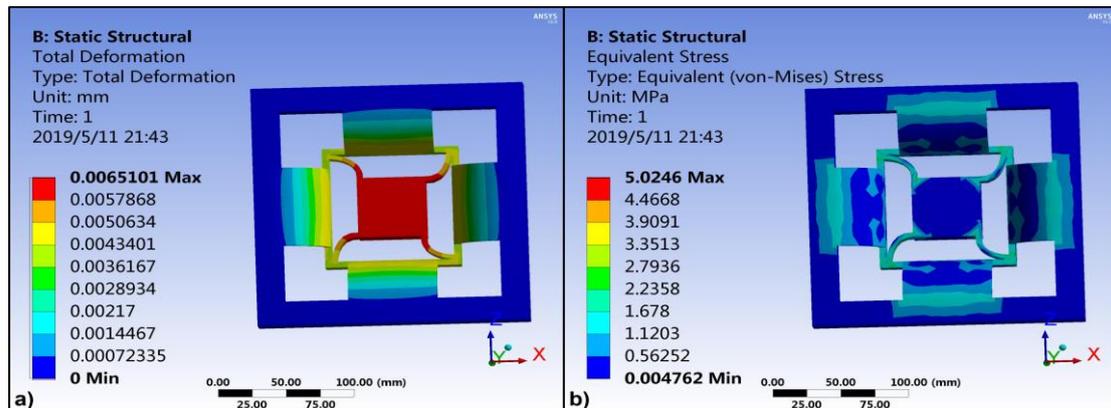


Figure 5. Deformation and stress Analysis of Z Axis Motion of worktable. a) Deformation analysis. b) Stress Analysis.

Two loads are applied on the upper side and lower side of the worktable to generate torque around X-direction. We got the deformation and stress in Figure 6. Results shows that the maximum deformation is $6.9792e-003$ mm and the stress range is between $6.4085e-004$ MPa and 5.3803MPa.

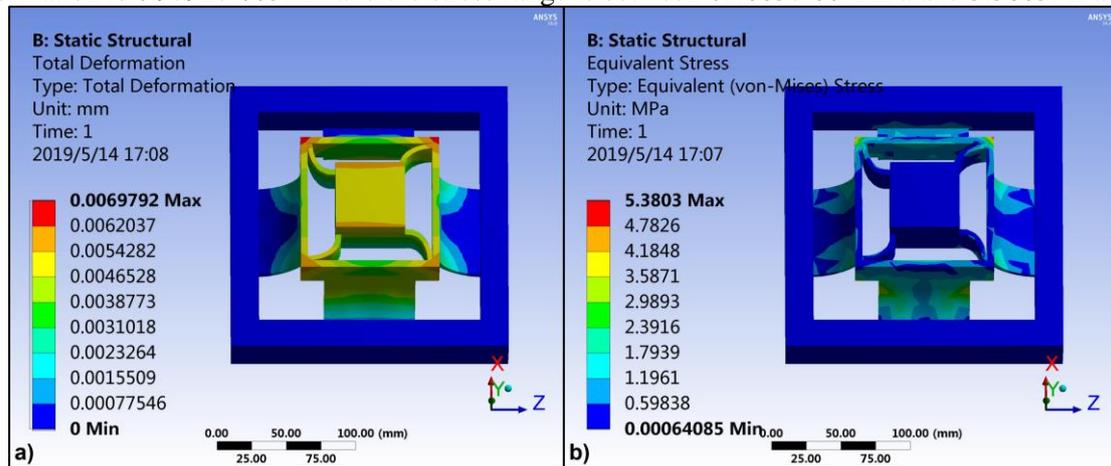


Figure 6. Deformation and stress analysis of the worktable rotation around the X axis. a) Deformation analysis. b) Stress Analysis

The condition of the torque around Y direction is the same as that in X direction. Results shows that the maximum deformation is $6.9792e-003$ mm and the stress range is between $6.4085e-004$ MPa and 5.3803MPa. Figure 7 shows the total deformation and stress of the compliant mechanism.

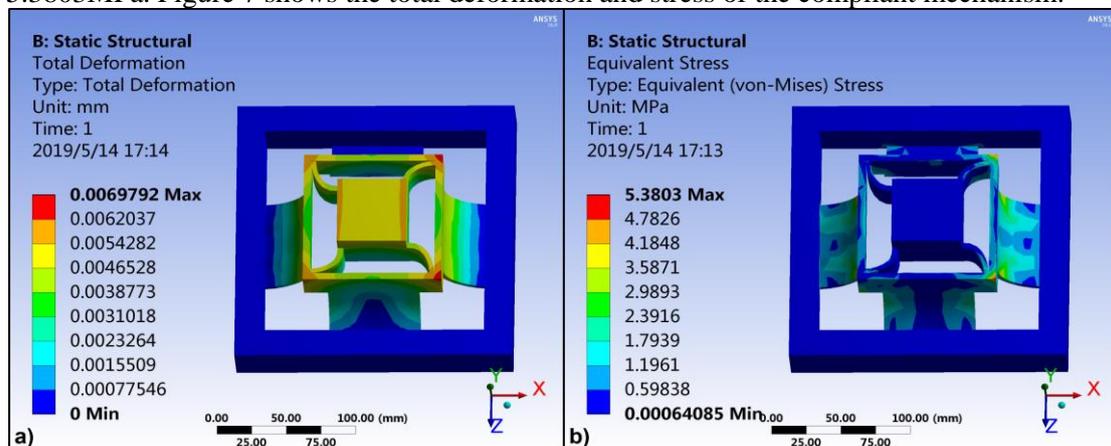


Figure 7. Deformation and stress analysis of the worktable rotation around the Y axis. a) Deformation analysis. b) Stress Analysis.

The two loads are applied on the two sides of the worktable. A torque around Z-direction is generated. Figure 8 shows the total deformation and stress of the compliant mechanism. Results show that the maximum deformation is 1.5493×10^{-4} mm and the stress range is between 2.5323×10^{-5} MPa and 0.14232 MPa.

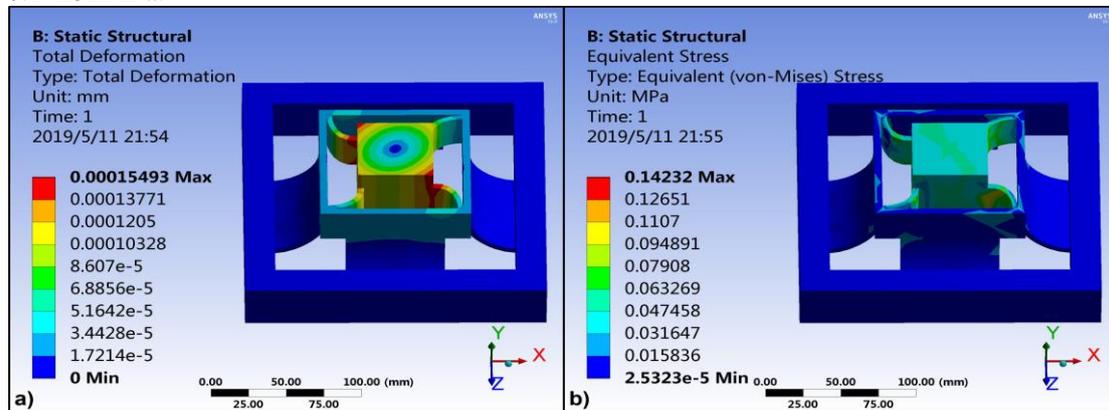


Figure 8. Deformation and stress analysis of the worktable rotation around the Z axis. a) Deformation analysis. b) Stress Analysis.

5. Conclusion

A compliant mechanism based on the hybrid curved beam is proposed. The specific structure and the working principle of the compliant mechanism is presented. The static analysis is conducted to obtain the stress and deformation ranges of the compliant mechanism. Results indicate that the deformation and stress of the mechanism are within a reasonable range, which verify the feasibility of the design. This kind of mechanism can be utilized in many different fields.

Acknowledgments

This project is supported by National Natural Science Foundation of China (Grant No.51775078)

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