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Design and analysis of a 3-DOF micro-positioning compliant mechanism with hybrid orthogonal compliant elements

Sheng Lin[1], Yuxin Yang[1]

[1] School of Mechanical Engineering, Dalian Jiaotong University, Dalian, Liaoning Province, 116028, China

*Corresponding author's e-mail: linsheng138@163.com

Abstract. The compliant mechanism plays an important role in the field of micro-positioning due to its excellent mechanical properties. In this work, we designed a hybrid compliant mechanism with three compliant elements, and the force is driven by the piezoelectric ceramic driver to drive the stage to rotate. The static simulation analysis of the compliant mechanism shows that the strain generated by the compliant element can satisfy the space rotation of the stage, and the compliant element will not be plastically deformed.

1. Introduction

The compliant mechanism has the advantages of good positioning accuracy, simple and light structure, no friction and no lubrication. It is widely used in the field of ultra-precision machining and micro-positioning.

Duan[1] designed a three-degree-of-freedom micro-motion positioning compliant mechanism with double parallel structure, which effectively eliminated the coupling deflection angle. Guo[2] designed a compact compliant mechanism with resolution of 0.1 nm in the 10um range. Zhang[5] synthesized a precision positioning compliant mechanism with flexible hinges as a guide rail. She designed the compliant mechanism to transmit and amplify the small displacement generated by the piezoelectric ceramic drive through a flexible hinge mechanism. Jia[6] adjusted the rod length of the parallel structure and replaced the rotary pair in the Delta mechanism with a single degree of freedom flexible mechanism.

Here, we designed a 3-DOF micro-positioning compliant mechanism with hybrid orthogonal compliant elements. The compliant mechanism is arranged in parallel with three compliant elements. The stage is driven by six piezoelectric ceramic drivers. The stage can rotate around the X-axis, the Y-axis, and the Z-axis. The simulation analysis of statics verified the reliability of this structure.

2. Structure

We designed a compliant mechanism with three compliant elements in parallel and driven by six piezoelectric ceramic drivers. The compliant mechanism includes a frame, three compliant elements, six drive bays, six piezoceramic drivers, a stage and a base structure.

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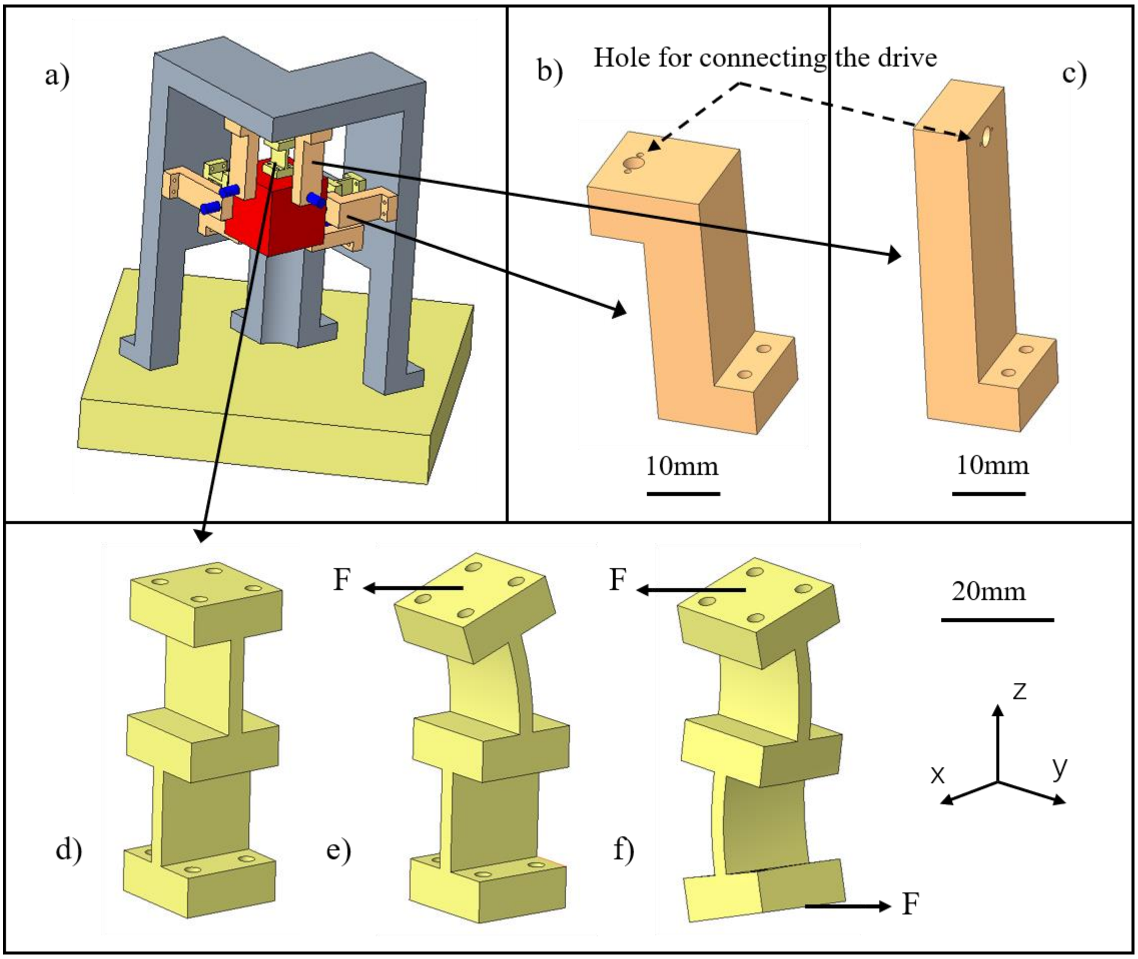

Figure 1. A hybrid orthogonal three-degree-of-freedom positioning compliant mechanism. a) Three-degree-of-freedom positioning compliant mechanism. b) Z-shaped drive frame. It is used to fix the piezoceramic actuator and provide the reaction force required for the drive to work and is bolted to the frame. c) L-shaped drive frame. It has the same function as the Z-shaped driving frame, and is arranged symmetrically with the Z-shaped frame. d) Compliant elements. Used to support the rotating stage and fix the stage to the frame. e) When the compliant element is subjected to a force in the X direction, the upper half is bent and the lower half is not deformed, and the lower connected part can be rotated in the XZ plane. f) The compliant element is subjected to forces from the X and Y directions, the upper and lower portions simultaneously produce bending in different directions, thereby providing a wider angle of rotation for the lower connected parts.

Figure 1 (a) shows a hybrid orthogonal three-degree-of-freedom positioning compliant mechanism. The stage is connected to the frame by three compliant elements arranged along the x-axis, the y-axis and the z-axis, respectively. Figure 1 (b) is a Z-shaped support frame, and Figure (c) is an L-shaped support frame. The three Z-shaped driving frames and the three L-shaped driving frames are symmetrically arranged on the inner side of the frame. Figure 1 (d) is a compliant element. The compliant element composed of straight beam structure has a larger range of rotation than the conventional single straight beam compliant element. The orthogonal compliant elements not only solve the problem of the instability of the pressure bar, but also reduce the mutual interference in all directions. Figures 1(e) and (f) show the deformation of the compliant element at the beam. The stage could be rotated to a predetermined angle by bending the three compliant elements.

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Figure 2 shows rotations about three coordinate axes. Among them, 1, 2, and 3 are compliant elements arranged along the X, Y, and Z axes. The blue arrow is the direction in which the stage rotates. And the red arrow indicates where the force is applied on.

Figure 2(a) shows the rotation of the stage around the X-axis while the force applied by the ceramic actuator in the YZ plane. Figure 2(b) indicates the rotation of the stage about the Y-axis. Figure 2(c) shows the rotation of the stage about the Z-axis if the forces are applied by the ceramic actuator in the XY plane.

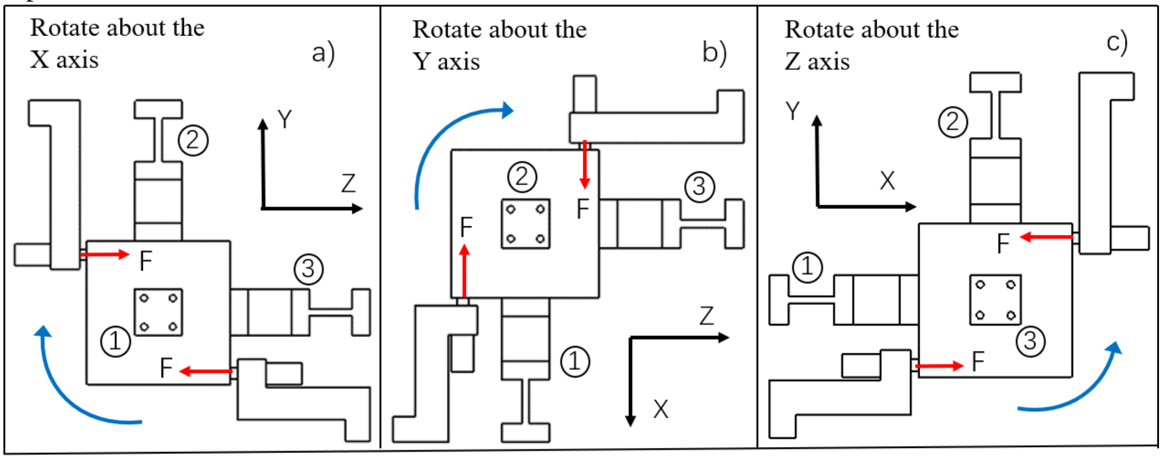

Figure 2. Schematic diagram of the stage rotating about the X-axis, Y-axis, and Z-axis. a) When the actuator applies a moment, the compliant elements 2, 3 are bent and deformed, the flexible element 1 is distorted as the stage rotates about the X axis, at which time the stage rotates clockwise. When the driving force disappears, the compliant element will return to its original shape, which in turn will bring the stage back to its original position. b) When the stage rotates about the Y axis, the compliant elements 1, 3 are bent and deformed, the compliant element 2 is twisted and the stage is rotated clockwise. c) When the stage rotates around the Z axis, the compliant elements 1, 2 are bent and deformed, the compliant element 3 is twisted, and the stage rotates anticlockwise.

3. Simulation analysis

Static analysis was conducted on the compliant mechanism. The material of the compliant element is aluminum alloy, and the material of the Z-shaped, L-shaped support frame, the frame and the base are structural steel. Figure 3 is a graph showing the strain and stress of the compliant element when the stage is driven to rotate about the X-axis. Forces of 200 N are generated by two drivers. The position and direction of the two forces are as shown in figure 2(a). Figure 3(a) is a strain diagram when the stage rotates about the X axis. The red arrow is the direction of rotation about the X axis. The results in the figure show that the beam of the compliant element has a strain of 0.17189~0.21487μm. The compliant element arranged along the X-axis direction undergoes only torsional deformation with a strain of less than 0.042973μm. Figure 3(b) is a stress diagram at this time. The maximum stress on the compliant element is 17.174 MPa, which does not exceed the elastic limit of the material. The results show that the stage can effectively achieve rotation around the X axis. The compliant mechanism is a symmetry structure, then the analysis process of rotation around Y and Z directions are similar with X axis.

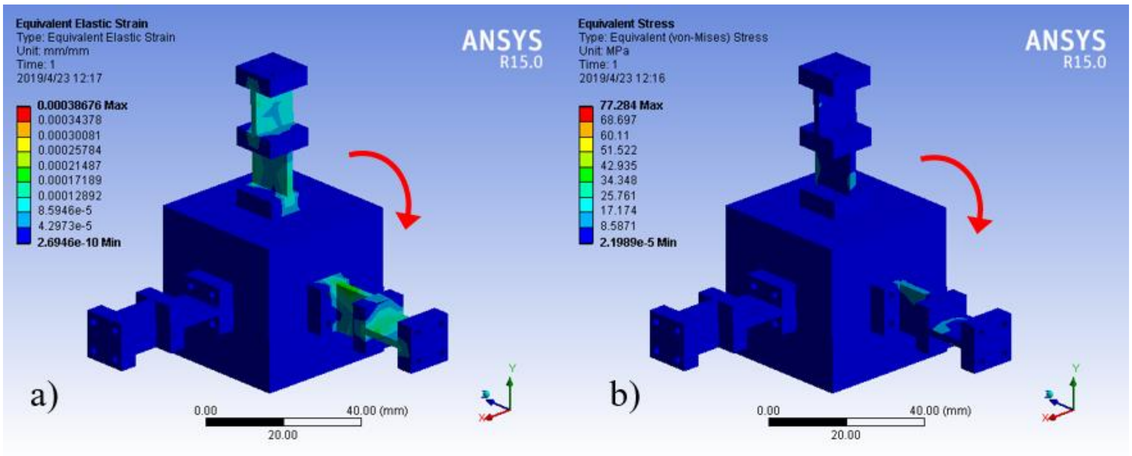

Figure 3. Strain and stress diagram of the stage rotating around the X axis

4. Conclusion

We designed a 3-DOF micro-positioning compliant mechanism with hybrid orthogonal compliant elements. The driving forces are proposed by piezoelectric ceramic drivers. Then the stage could rotate around the X, Y, and Z axes. The working principle of the compliant mechanism is presented. The results of static analysis show that the strain of the compliant element meet the requirement, and the stress does not exceed the elastic limit.

Acknowledgments

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