Design and Simulation of a Compliant Mechanism Based on Crossed Curved Beam

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Abstract. A compliant mechanism based on the crossed curved beam is proposed. The working principle of the mechanism is induced. The finite element method is utilized to analyse the statics and dynamics of the compliant mechanism. Results show that the compliant element of the crossed curved beam has higher bearing capacity. The six-order natural frequencies and vibration types of the compliant mechanism are obtained. The vibration types are in accordance with the degrees of freedom.

1. Introduction

Compliant mechanism is widely used in the fields of precision processing, biomedicine, and aerospace etc. Compliant mechanism has the advantages of no friction, no reverse clearance, no lubrication, easy control and high motion accuracy [1].

Scholars design a variety of compliant mechanism to meet different requirements. Chen[2] designed a distributed fully compliant mechanism with two degrees of freedom using symmetrical structure. And the working stroke is 300µm × 300µm. Yu[3] constructed a parallel compliant mechanism with compliant beams. Xu[4] enlarged the working space of positioning platform by combining the compliant beams with series type. Tian[5] synthesized a compliant mechanism with a two-layers structure. The upper layer is the guidance, and the lower layer is utilized to improve the stiffness of Z-axis. The above compliant mechanisms have the disadvantages of complex structure or less degree of freedom.

Here, we design a compliant mechanism based on the crossed curved beam compliant element. And its working principle is proposed. The statics and dynamics analysis of the compliant mechanism is conducted with finite element software.

2. Structure design of the compliant mechanism

The compliant mechanism consists of the base, the compliant element of the crossed curved beam and the stage. The base has a bottom and three sides, as shown in figure 1 a). The actuators are assembled to the base through the holes in the three sides and the bottom. The base and the stage are connected by four sets of the crossed curved beam compliant elements, and the shape of the compliant elements are shown in figure 1 b). The entire structure of the compliant mechanism is shown in figure 1 c).
3. The working principle of the compliant mechanism

As shown in Figure 2, the four actuators on the bottom input the same displacement, and then the stage is driven by the driving force to produce translation along the Z-axis; two actuators on the left side and two actuators in the symmetrical position on the right side input the same displacement, and the stage is driven to produce a rotation about the Z-axis; The translations and rotations in other directions can be obtained by the same way as Z-axis.

4. Finite Element Analysis of the Compliant mechanism

4.1 Static Analysis

ANSYS software is employed to conduct the simulation analysis of the compliant element. The material of the compliant element is selected as aluminum alloy, and the density is set as 2770kg/m3, the elastic modulus is 71GPa, the poisson's ratio is 0.33. The material of the base and the stage are steel. And the density is 7850kg/m³; elastic modulus is set as 200GPa; the poisson's ratio is set as 0.3. Force with 10N is applied on the single curved beam, crossed curved beam, and the compliant mechanism respectively. As shown in figure 3, the maximum displacement deformation of the single curved beam is 0.32µm, the lower part of the crossed curved beam is 0.29µm, and the upper part of the crossed curved beam is 6.1µm. The result means that the deformation of the upper part is larger than the lower part. Then the result is opposite if the force direction is opposite.
4.2 Modal Analysis

In order to obtain the dynamic character of the compliant mechanism, modal analysis is conducted correspondingly. The compliant mechanism can be considered as a vibration system composed of mass and elastic. The system can be expressed as,

\[ M \ddot{x} + Kx = 0 \]  

where, \( M \) is the mass matrix, \( K \) is the stiffness matrix, \( x \) is the displacement vector, \( \ddot{x} \) is the acceleration vector.

The free vibration of the structure can be decomposed into a series of the harmonic vibration superposition. Then substituting \( x = q e^{i \omega t} \) into equation (1), the equation can be obtained as

\[ (K - \omega_i^2 M)q = 0 \]  

where, \( q \) is the amplitude array of node displacement, \( \omega \) is natural frequency.

According the above equations, we employ the finite element software ANSYS to solve the problem. Then the first six orders natural frequencies are obtained as table 1. The first six order vibration mode are in accordance with the freedom of the compliant mechanism.

| Order | 1   | 2   | 3   | 4   | 5   | 6   |
|-------|-----|-----|-----|-----|-----|-----|
| natural frequency(Hz) | 4397.7 | 4430.1 | 5102.3 | 6312.9 | 6550.8 | 8184.6 |
5. Conclusions
We synthesize a compliant mechanism based on the crossed curved beam compliant elements. The specific structure and working principle are proposed. Finite element analysis is conducted using ANSYS software. The statics results demonstrate that the compliant mechanism is not only compact in structure but also has high bearing capacity. The dynamics results show that the first order natural frequency is 4397.7Hz, which meet the requirement. The compliant mechanism can be used as the precise positioning platform in many fields.

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