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A Detection Mechanism of Clamping Force based on Spatial Micro-gripper

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Abstract

A new type of spatial micro-gripper is designed. In order to avoid the spatial micro-gripper from causing damage or falling off during the clamping of small objects, it is required to predict and control the clamping force, A clamping force detection mechanism based on spatial micro-gripper is proposed, the detection mechanism includes: 3 identical clamping branches used to perform micro-clamping operations, a piezoelectric ceramic stack for inputting micro-displacement, piezoelectric driver for driving piezoelectric ceramic stack, resistance strain gage for receiving deformation signal of the cantilever beam of the clamping branch, transmission circuit and data processor, controller for controlling the input voltage value of the piezoelectric driver, and install the disk holding the branch chain. When the spatial micro-gripper is clamping the object, the clamping branch chain cantilever beam deforms, and the resistance strain gage on it receives the relevant deformation signal, and transmits it to the data processor for processing through the transmission circuit, so as to realize the detection of clamping force. The controller can control the size of the clamping force, so as to avoid damage to the clamping object by the micro-gripper during micro-operation. The proposed design methods provide a new idea for the design of micro-grippers.

Keywords

Spatial Micro Gripper; Resistance Strain Gage; Force Sensing; Gripping Force.

1. Introduction

Micro-gripper is the end effectors of micro-operated [1,2], with micro-nano-level operation accuracy, and is widely used in the frontier field has broad application prospects, for example the assembly of micro-electromechanical systems (MEMS), biological cell engineering, precision instruments, fiber optic docking, and optical focusing, etc..In the field of micro-electromechanical systems, micro-gripper can be used to grasp and assemble micro-components [3]; in the field of bioengineering, micro-gripper can be used to grasp cells and perform micro-operations on cells [4]. In the field of optical engineering, the micro-gripper can be used for micro-operation and adjustment of optical components. However, the currently designed micro-gripper can not meet the requirements of engineering application well. During the micro-gripping process, the micro-gripper not only need to complete the clamping operation of small-sized objects, but also avoids damage or falling off of the small objects during the micro-clamping process, so real-time detection of the clamping force is required, in order to predict and control the clamping force.

At present, the research on micro-gripper of domestic scholars is mainly focused on the structural design and theoretical modeling of the clamping function. Dahai Yu proposed a multi-purpose micro-gripper suitable for ICF target clamping [5]; Yong ping Hao proposed a micro-gripper structure for MEMS assembly [6]; Daihua Wang proposed a micro- gripper which is driven by piezoelectric and

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proposed its open-loop displacement characteristics [7]. However, the micro- gripper that they designed can only realize the micro-clamping function, without considering how to integrate the micro- gripper force sensor into the structure, and cannot detect the clamping force of the micro-gripper in the working state.

Since the clamping force of the micro-gripper is relatively small, it is necessary to use micro-force detection technology for measurement. At present, the micro-force detection technology is mainly non-contact and contact detection. The non-contact type mainly uses machine vision technology to detect the deformation of the holder to measure the micro-clamping force, but in the detection process, a high-precision micro-detection system must be used. The structure is complex and the cost is high. The contact detection mainly includes several types such as strain type, piezoelectric type, inductive type and capacitive type. Kim used a piezoelectric film as a micro-force sensor and directly pasted it on the micro-gripper to measure the force of the micro-gripper [8]; Sun used capacitive two-dimensional force sensing technology for micro-manipulation of the egg cells of the animals [9]; Xiaojun Tian proposed a three-dimensional force micro-gripper which is nano micro-manipulators based on atomic microscope probes [10]. However, the current clamping force sensing method is expensive and difficult to implement. Therefore, it is necessary to find a way to integrate force sensing into the structure, which can realize both the micro-clamping function and the micro-force sensing function. Moreover, the strain sensor has the advantages of high sensitivity, fast dynamic response, compact structure, low price, convenient use, etc. [11,12], so the strain gage is selected to be integrated in the micro-gripper to detect the clamping force.

In addition, the structure of the micro-gripper is mainly a flat compliant mechanism. When it clamps the objects, it has two-point contact, which cannot adapt to the clamping operation of irregular and small objects. Therefore, it is necessary to design a micro-gripper with the function of spatial clamping operation and the micro-gripper can achieve multi-point contact clamping.

The resistance strain gage is integrated into the structure of the spatial micro-gripper, to form a spatial micro-gripper with force sensing to realize the structure-sensing integrated design. In order to accurately predict and control the clamping force.

2. Structure Design of the Spatial Micro-Gripper

The current clamping form of the micro-gripper is 2-point contact planar clamping, which cannot guarantee the clamping stability of the operation object in the irregular shape of the clamping. It is necessary to design a new type of spatial micro-gripper. The design idea is to increase the contact points from 2 points to 3 points when clamping small objects. Design 3 plane compliant mechanism branches to realize the clamping function of contact points ①, ② and ③, and place these 3 plane mechanism branches evenly in 360°, which can make the micro-clamping object receive uniform force and maintain the stability of the clamping operation, see Figure 1.

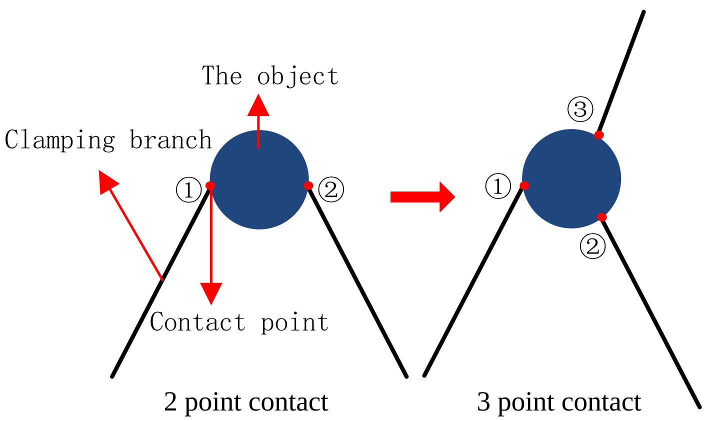

Figure 1. The clamping mode

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In order to design a spatial micro-gripper with a compact structure and a large amount of expansion, the principle of lever amplification is used to design a planar clamping branch chain that can achieve 1 point contact, see Figure 2, *I* is the displacement input location of the clamping branch, which is driven by piezoelectric ceramics, the output location *O* is the clamping branch of the clamping branch, *A* is the fixed location of the clamping branch, *B* represents the flexible hinge, and *C* represents a cantilever beam. *I*, *A*, *B*, *C*, and *O* constitute the amplifying mechanism. The input displacement Δx of the point *I* is used as the input displacement of the amplifying mechanism, and the output displacement Δy of the branch chain mechanism is obtained after amplification.

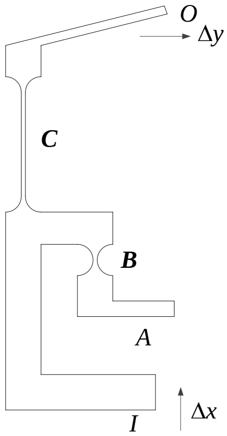

Figure 2. The sub-chain

In order to evenly place the 3 clamping branches in 360° to achieve 3 point contact spatial clamping, the installation disk is designed, and there are 3 rectangular slots and 3 same fixing holes on the installation disk. The fixing holes are used for fixing. Three miniature slide rails are installed in the three rectangular slots. The fixed location *I* of the 3 clamping branches are respectively installed on the three miniature slide rails. The 3 clamping branches can be adjusted and slid on the sliding rail, so as to realize the adjustment of the opening and closing amount of the spatial micro-gripper, see Figuer 3.

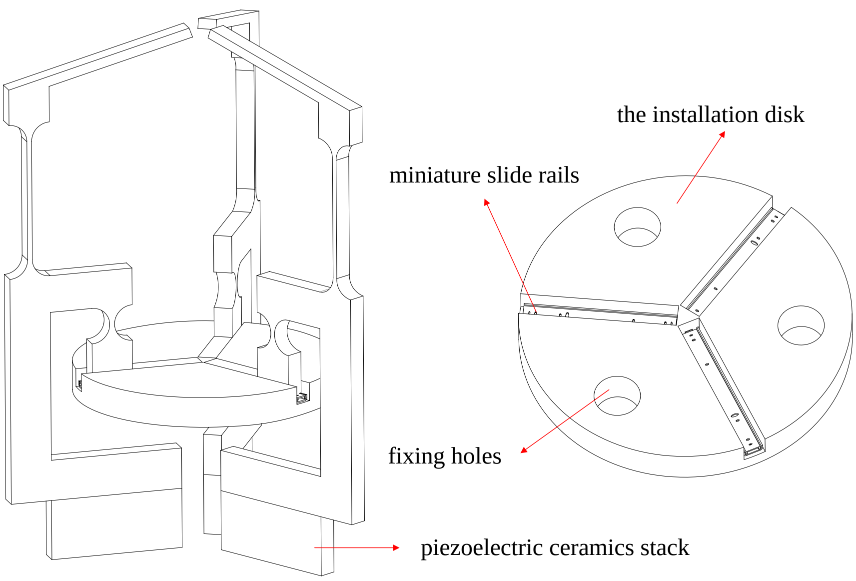

Figure 3. The spatial micro-gripper

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3. Design the Detection Mechanism of Clamping Force

Since the spatial micro-gripper needs to determine the gripping force when operating small-sized objects, it is necessary to integrate a force sensing unit in the structure shown in FIG. 2. Based on the structure shown in Figure 2, the strain distribution under the clamping force is analyzed to select the maximum strain as the position of the force sensing unit, and the strain of the unit is used to reflect the clamping force, and determine the position of the sensitive unit and the sticking position of the strain gage, see Figure 4.

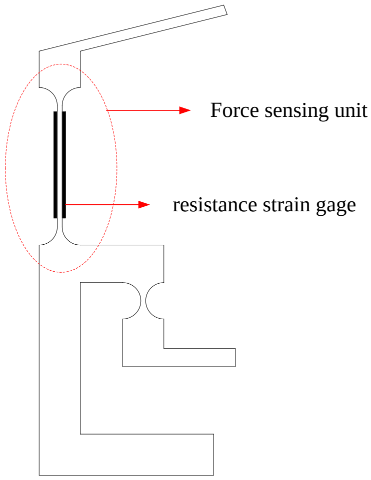
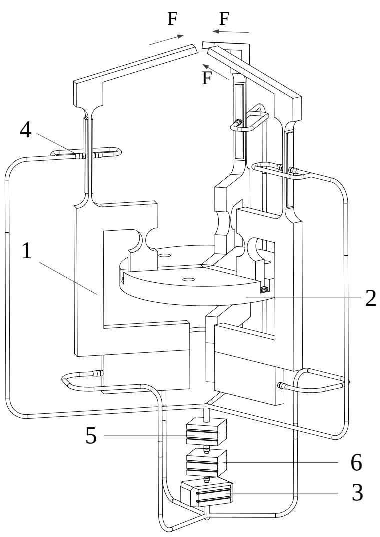


Figure 4. Force sensing unit

The clamping force detection mechanism of the spatial micro-gripper is obtained by assembly. The detection mechanism includes: 3 identical clamping branches used to perform micro-clamping operations, a piezoelectric ceramic stack for inputting micro-displacement, piezoelectric driver for driving piezoelectric ceramic stack, resistance strain gage for receiving deformation signal of the cantilever beam of the clamping branch, transmission circuit and data processor, controller for controlling the input voltage value of the piezoelectric driver, and install the disk holding the branch chain. see Figure 5.



1.clamping branch; 2. installation disk; 3. piezoelectric driver; 4. transmission circuit; 5. data processor; 6.controller

Figure 5. The detection mechanism of clamping force based on spatial micro-gripper

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The detection calculation process is as follows: the piezoelectric driver drives the piezoelectric ceramic stack to output micro-displacement Δx, thereby pushing the flexible hinge *B* in the clamping branch to produce elastic angular displacement, causing the cantilever beam *C* to deflect and deform. The corresponding output voltage *U* can be obtained through the strain gages pasted on the cantilever beam, the transmission circuit and the built-in bridge of the data processor, at this time, the clamping port *O* produces a micro-displacement Δy. At this time, the clamping force of the clamping branch is *F*, which can be expressed as $F=KU$, where *K* is the calibration coefficient, which can be obtained through calibration experiments. see Figure 5.

The control process is as follows: if the clamping force *F* of the clamping branch is less than the threshold value F_0 of the built-in computing system, where F_0 can be set according to the specific clamping object, the controller increases the input voltage of the piezoelectric driver and continues to drive piezoelectric ceramic stack to output micro-displacement, which causes the cantilever beam *C* to continue to deflect and deform, thereby increasing the clamping force *F* of the clamping branch until $F=F_0$. At this time, the clamping stability of the operating object can be maintained, and the clamping stability of the operating object can be maintained. Protect the clamping object from damage due to excessive clamping force *F*; if the clamping force *F* of the clamping branch chain is greater than the threshold value F_0 of the built-in computing system, the controller will reduce the input voltage of the piezoelectric driver, the piezoelectric ceramic stack is driven to reduce the output micro-displacement, so that the cantilever beam *C* reduces the deflection, thereby reducing the clamping force *F* of the clamping branch, until $F=F_0$.

4. Conclusion

A new type of spatial micro-gripper is designed, and a resistance strain gage is integrated into the structure of the spatial micro-gripper. In order to realize real-time measurement of the clamping force of the spatial micro-gripper, and real-time control can be carried out through the controller. The proposed design idea of integrated clamping force sensor provides a new idea for the designing of micro-gripper design.

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