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Design and development of high precision and high amplification ratio micro gripper

Neha Patel[1], Jerry Caleb[2], V Ramalingam[3] and GL Samuel*[4]
[1 &4] Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai - 600036
[2] Department of Mechanical Engineering, Karunya University, Coimbatore - 641 114
[3] Department of Mechanical Engineering, PA College of Engineering and Technology, Pollachi, Coimbatore- 642 002
Email: [1]nehavpatel1992@gmail.com; [2]calebjerry90@gmail.com; [3]ovramalingam@yahoo.com; *4samuelgl@iitm.ac.in
(Corresponding Author)

Abstract

As there are technological advancements from macro to micro and nano scales, there arises a need for micro manipulation and assembly. In this paper a design for a flexure based monolithic compliant micro gripper is proposed for micro assembly. The grippers design is simple and its size is relatively small inclusive of the actuator and provides high amplification ratio. The actuator can be placed along with the compliant thus reducing the complexity of the gripper. The stress analysis of the gripper is analyzed using Finite Element Analysis and displacement of gripper is found and is verified experimentally. The gripper's prototype was fabricated using micro wire electro discharge machining. A piezoelectric actuator is used for actuation and to provide high accuracy, precise motion with zero backlashes. The details of the design, fabrication and the experimental results will be presented in this paper.

Keywords: Microgripper, Piezoactuator, Manipulation, compliant mechanism

1. INTRODUCTION

The technologies have become smarter and smaller and there is a need for cost effective manufacturing of the product with precision and accuracy. Due to recent advancements in MEMS and NEMS technology the necessity of micro gripper have risen for micro and nano level assembly of the products. With so many developments in microfabrication methods, research is also taking leap in developing different microhandling methods.

Handling of microparts with high precision and a gripping force that does not damage the object is a challenging task. These cannot be assembled directly by humans or other equipment's as the products to be assembled are so fragile and delicate which require considerable attention to the forces; little higher force can damage the product. Microhandling can be achieved by contact methods, mostly mechanical or other non contact methods like using acoustic and ultrasonic waves, magnetic field, electrical field. Microhandling can be carried in any environment like in air, vaccum and liquid. The advantage of using contact method is different actuation methods and robotic principles can be applied.

Mostly, MEMS are fabricated as a monolithic structures due to which there are limitations on functionalities of microsystems. There should be newer ways to make assembled microproducts. Due to limitations in robotic capabilities in micro assembly, it is not considered for MEMS. The microassembly processes rely on human dexterity and hence researches are going on to make the complete automated microassembly system. But in last few years, micromanipulation methods of good performance have been developed.

Microhandling devices has many applications like in optical fibers, biomedical applications, electronic package of micro components. Microhandling device consists of three major components namely the microgripper, the actuation system and the manipulator. The microgripper has to grip and hold very small and fragile objects of micrometer size with accurate grasping forces so that it don't damage the object. There are different actuation methods like electrothermal actuation, electrostatic actuation, electromagnetic actuation, piezoactuation, Smart memory alloys etc [14]. Of all this methods, piezoactaution method has many advantages like stable displacement, large generated force, high response speed and ease of use. Hence in this work, piezoactuation method is used.

S.K.Nah and Z.W. Zhong (2007) designed, analysed, fabricated and tested a monolithic compliant-flexure based microgripper [17]. The analysis of the designed geometry was done in ANSYS to study Von Mises stresses and deformation. The gripper was fabricated using wire-EDM and then tested for its performance. It was seen that the gripper had displacement amplification ratio of 3 and maximum stroke of 170μm. Xiantao et.al. (2014) presented a novel design of microgripper based on compliant mechanism driven by piezoactuator [20]. The working principle of the gripper model was based on the inner six-bar linkage mechanism and the two sided parallelogram mechanisms. The jaw displacement of 150.8 μm was obtained. Yilin Liu et.al. (2016) used the basics of Scott Russell straight line mechanism to achieve parallel motion of the gripping jaws in microgripper design [22]. The microgripper was used in microassembly application like pick and place of optical fibre. Mohd Nashrul et.al. (2009) designed a gripper which had single stage motion amplification to obtain identical motion of two jaws [13]. The experimental tests were carried out to grip a wire of diameter 76.2μm. The maximum stroke of 100 μm is attained. A.Nikoobin and M. Hassani Niaki (2012) reviewed and compared different microgrippers for their performances and they suggested parameters for designing microgrippers like displacement amplification ratio, gripping range and stroke, parallel motion of jaws, normally open or normally closed gripper[1]. The new design of microgripper having three stages of amplification was developed by Fujung Wang et.al. (2016). The results show that the developed microgripper has a large amplification factor[6]. In his work Volland B E et.al. (2002) fabricated SOI wafers using few

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number of fabrication steps like surface and bulk micromachining technology [18]. This has advantages like thick parts can be produced with stable force in Z-direction. There are micromanipulation systems that have microgripper actuated by a hybrid actuator like thermo-piezoelectric actuator. The working of this microgripper is based on the working principle of both the thermal actuation and piezoelectric actuation. Micky Rakotondrabe et.al. (2011) used this principle and brought a new micromanipulation system for microassembly [12]. Yong Zhang et.al.(2009) presented a robotic system with the vision based control that visually recognized the microgripper and microspheres and also the contact between them [24]. This system successfully micromanipulated the glass spheres grasped with MEMS microgripper. The automatic robotic system has a high speed of micromanipulation found out in the literature.

In this work, the attempt has been made to design and develop an open jaw type of microgripper from a monolithic compliant mechanism. This microgripper will open its jaws on actuation and close them when voltage to actuation system is removed. Many designs are developed using combinations of flexure hinges and flexure beams in the process to obtain a novel design which will satisfy the requirements of gripping. The microgripper model is analysed using finite element analysis to obtain deformation and von Mises stresses. The wire-EDM process is used to fabricated the prototype of microgripper which was tested to check its functioning.

2. DESIGN OF THE MICROGRIPPER:

A 1-DOF micro gripper was designed to hold fine, delicate parts without damage for applications such as micro assembly. Grippers are usually used for holding up macro objects, but in case of micro grippers, the design and working and actuation is entirely different. The gripper needs to be precise and accurate and hence it is designed of a monolithic compliant with flexure hinge providing zero backlash and no wear resulting in a compliant free from lubrication and friction. The gripper opens when actuator provides displacement and closes when the actuation is stopped. The actuation can be controlled by varying the voltage thus allowing us to hold a part. Thus it yields a motion that can be repeatable motion N number of times. In order to support the cantilever mechanism to provide the displacement a filleted leaf hinge and a elliptical hinge were used in this micro gripper. The design is capable of providing higher output displacement for a small input displacement. It provides single stage amplification. It is found that the hinge thickness plays a major role in magnification ratio, as hinge thickness is increased the magnification ratio of the input to output displacement decreases and vice versa. Hinge radius does not affect the rotational motion but reduces the stress.

Fig.1 illustrates the design of the micro gripper. The elliptical hinge thickness was provided to be 1mm with a radius of 3mm and corner filleted leaf hinge was provided a thickness of 0.8mm. The minimum space of 0.30mm is provided between the gripper arms when no actuation is provided. The leaf hinge provides a point load onto the supporting arms to provide displacement in the gripper.

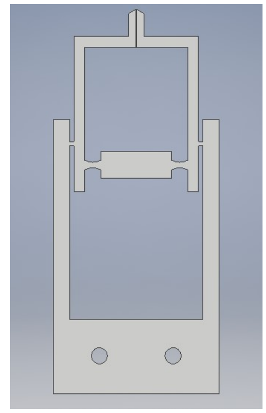

Fig.1 2D Sketch of the micro gripper

The material that is used for micro gripper is selected to be Aluminum 7075 as it is commonly selected for micro manipulation devices and are easy to manufacture and fabricate. Wire EDM process is used to fabricate the gripper as EDM process has higher accuracy and precision and can cut even intricate shapes resulting in a fine product with tolerance. The thickness of the final fabricated product is 4 mm, increasing the thickness of the gripper decreases the stress produced but at same time decreases the amplification ratio. The dimension of the gripper is 71mm*31mm.

3. MODELLING ANALYSIS:

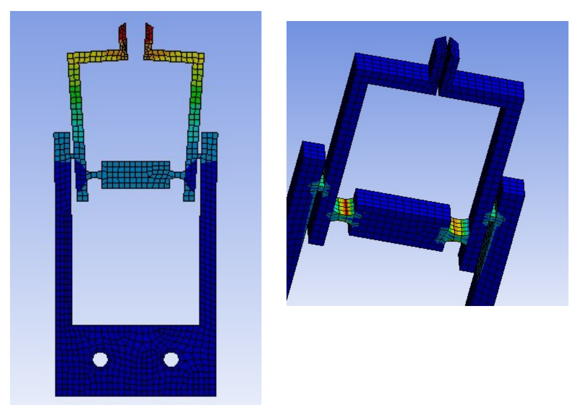

Fig.2 FEA Analysis of total deformation and Von Mises stresses produced

Ansys was used for Finite Element Analysis to analyze the grippers amplification ratio and stress levels to avoid failures. The young's modulus of the gripper was given as 71.7GPa and yield strength of 503Mpa. Multizone meshing method was used with hexagonal mesh type as it provides fine spacing throughout the body producing better results. A force of 50N was provided and simulated and the displacement and stress was found out. The stress produced in the system is much lower compared to the yield stress. From Fig.2 is also observed that the stress induced on the flexure hinge is high and it was found that increasing the hinge thickness reduced the stress induced at those points. The first picture represents displacement and second represents stress. A maximum displacement of 340µm was obtained for an input displacement of 32µm for a 50N force during simulations.

4) Experimental Setup and Results:

The piezo electric actuator used is from Physik, P-820; It has an maximum push force of 50N and a displacement of 15µm for voltage ranging from 0-105V. The length of the piezo acruator is 26mm. The setup consists of a piezo actuator, power supply, amplifier, fixtures and Zeiss Stereo Microscope (with Axio Vision software) are shown in Fig.3. Initially the 24V power supply is connected to amplifier and the piezo is connected to amplifier. On changing the voltage in power supply the amplifier amplifies the voltage by a factor of 10 and the displacement by the piezo actuator varies accordingly. The actuators input displacement is amplified by the gripper which is recorded and measured using the computer through stereo microscope.

Fig.3 Experimental Setup that includes Power Supply, Amplifier, Piezo Actuator, Micro gripper and stereo microscope

Since the setup is an open loop system the setup must be pre calibrated. The displacement provided by the actuator cannot be measured as such, hence a setup is created to measure displacement of the piezo actuator for a given voltage. The piezo is fixed firmly and a capacitance sensor is placed closely to the piezo actuator. When the voltage changes the amplifier amplifies the voltage to the piezo actuator which results in change in capacitance through which the displacement of the actuator can be found. The range of the gripper varies from 300µm to 420µm which can be varied based on the voltage. In the final setup the capacitance sensor is removed and the piezo actuator is placed in the fixed frame and brought under stereo microscope. Using the displacement values it is compared along with the measured data to find the amplification ratio.

The stereo microscope is used to capture the images and measure the distance between the gripper arms as the distance is quite large. The setup is completed by fixing the micro gripper along with the piezo actuator as demonstrated in the Fig.4. The voltage is varied between 0-105V and 3 sets of readings were taken including 2 sets from 0-105V and one from 105-0V and was found to be linear. The Fig.5 illustrates the displacement of the gripper for 0 and 105V respectively. The results were compared with the simulation results and were found to be little higher than the experimental results to non-ideal conditions. Fig.6 illustrates the graph plotted between the input and output displacement. The repeated experiments also showed that there was a same linear pattern that the datas followed for both 0-105V and vice versa. The gripper is only limited by the actuator and its range can be increased by changing the piezo actuator.

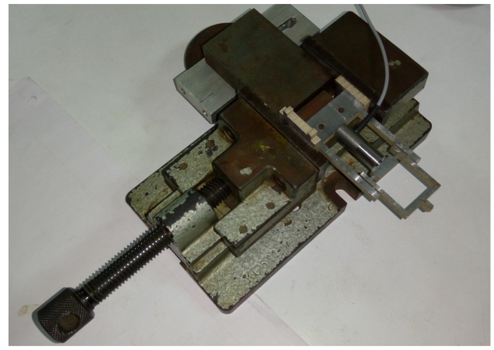

Fig.4 The Experimental Setup of the micro gripper along with actuator

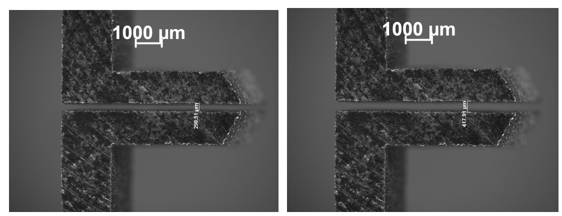

Fig.5 Grippers arm at 0V and 105V (0µm and 15.86 µm)

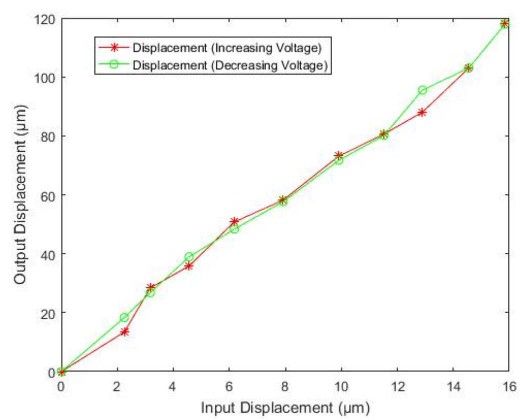

Fig.6 The Displacements from experimental data sets

5) CONCLUSION

The objective of this project work was to develop a novelmicrogripper for grasping of micro objects of sizes between 300-500 microns. The concept of comlpliant mechanism is used to develop the novel design of open jaw microgripper. The design was analyzed using Ansys 18.0 and displacement amplification factor of 10.625 is obtained. The prototype was fabricated using wire cut EDM and it was experimentally found out to have an amplification ratio of 7.59. It provided and maximum amplification of 120.41µm for an input displacement of 15.86µm.

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