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DESIGN AND ANALYSIS OF A VOICE COIL DRIVEN MICROGRIPPER FOR PRECISION HANDLING

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Abstract

A voice coil-driven microgripper is a small robotic tool that can be used for precise object handling and manipulation. The device is well-designed for micro-assembly, micro-surgery, and micro-manipulation operations. This paper presents a new microgripper actuated by voice coil motors that are designed and analyzed for precise positioning tasks. The driving force of the microgripper comes from a voice coil actuator. The levered parallelogram mechanism was used to linearize the output displacement of the jaw. Two different types of flexure hinges, such as leaf and circular flexure, are used for designing and analyzing the compliant microgripper in this paper. Finite Element Analysis (FEA) was used to evaluate the characteristics of the voice coil-driven microgripper. The FEA results show that the microgripper can achieve a maximum jaw displacement of 1.0027 mm. Modal analysis is also conducted to find the natural frequency of the microgripper. The modal analysis shows that the first natural frequency of 116.05 Hz can be achieved. The safety factor of the mechanism is 2.19, which ensures that the microgripper can perform repeated manipulation tasks while operating at maximum jaw displacement.

Keywords: Microgripper, Flexure hinges, Computational analysis, Voice coil actuator.

1. Introduction

A microgripper is a small mechanical device used to grasp and manipulate microscopic or nanoscale items. It is widely used in the fields of biomedical engineering, microelectronics, material science, biology, tissue engineering and precision equipment [1]. Microgrippers are more preferred than other touch and contactless micromanipulation and assembly techniques, such as optical, electrostatic, Bernoulli, ultrasonic, and mnetic, due to their inexpensive cost and excellent accuracy in grasping a variety of shaped items [2]. Therefore, it is essential to design innovative high-performance microgrippers to meet the demanding requirements of modern micromanipulation and assembly tasks [3]. There are different types of microgripper have been developed. Some of them are, electrostatic microgrippers, electro thermal microgrippers, magnetic microgripper, SMA actuated microgrippers, fluidic microgrippers and piezoelectric microgrippers [4]. Different types of actuators such as electrostatic, electrothermal, voice coil and piezoelectric actuator are used to manipulate microgripper [5]. Piezoelectric actuators can generate a lot of force, but their output motion is limited. Voice coil actuators have been found to have greater motion range and smaller force range. These Voice coil actuators (VCAs) work constantly and without touch, avoiding mechanical hysteresis, force or torque ripple, and backlash. This makes them very useful in precision motion applications [6,7]. Microgripper works based on the principle of microactuation through voice coil actuator. When voltage is applied across the plates connected to the drive arms, the gripping action at the gripper's tip is started. The electrostatic force produced by these misaligned plate pairings tends to align itself, bending drive arms and preventing the arm's extension for gripping. The output displacement of gripper produced by Hao, G., & Hand, R. B. et al. [15] was 0.3 mm. The linearity of jaw displacement in a horizontal direction necessitates an output linear guiding mechanism to be connected to moveable jaw in order to prevent sliding motion between the jaw and the object being gripped as much as possible and to distribute the gripping force evenly across the sample being manipulated. The simultaneous horizontal displacement of the jaw refers to a controlled movement of both gripping jaw of the microgripper device in a horizontal direction either toward or away from each other. And the linearity of jaw displacement and the simultaneous displacement of jaw along vertical direction is very small, that's why it has been avoided. Several research in literature have demonstrated and compare several microgripper designs as well as analyze the outcomes of recent experimentation and simulation studies. Zhang & Xu et al. [8] designed a novel constant-force voice coil driven microgripper. They found the mechanism could obtain the travel of 2.5 mm with an input force of 9.0 N. Yang and Xu et al. [9] presented a novel compliant microgripper with the ability for bidirectional linear actuation and force sensing. They found the mechanism could obtain 2 mm gripping

displacement. T.K Das et al. [10] presented an asymmetric microgripper actuated by piezoelectric elements for handling micro-objects. The results showed that the microgripper had an amplification ratio of close to 17.65 and a maximum displacement of 353 μm. Zubir et al. [11] presented a novel compliant-based microgripper powered by piezoelectric actuators. The results showed that the microgripper had an amplification ratio of close to 3.68 and a maximum displacement of 100 μm. Xu et al. [12] proposed a novel compliant gripper with integrated position and force sensors for automated micro assembly activities operated by A voice coil motor (VCM). The results showed that a force of 4.11 N was required to grasp an object with a gripping displacement of 2.20 mm. T.K Das et al. [13] developed a flexure-based microgripper actuated by piezoelectric elements for achieve high precision grasping tasks. The results showed that the displacement amplification ratio of 23.96 and an overall output displacement of 338.3 μm. Zhang & Xu et al. [14] developed a 2-DOF compliant gripper with constant-force flexure mechanism that is capable of rolling and gripping operations. They found the gripping range of the gripper was demonstrated to be between 2.7 and 3.1 mm.
The aim of this work is to design and analysis of a voice coil driven microgripper for precision handling.

2. Methodology

2.1 Methods

At first, preliminary research was conducted. Then, a concept was developed by creating sketch to visualize the product. Then we were choosing voice coil actuator for driving the microgripper. A model was developed by using CAD software based on the concept. Finally, finite element analysis with corresponding boundary conditions has been performed in the FEA software.

2.2 Proposed design of the microgripper

The goal of this research is to develop a flexure-based compliant microgripper that is driven by a voice coil actuator. The design is carried out using SOLIDWORKS software where a lever type compliant displacement amplifier is used. Actually, lever type displacement amplifier increases the deformation. That's why it is included in the compliant microgripper design. The modified design presented in Figure 1.

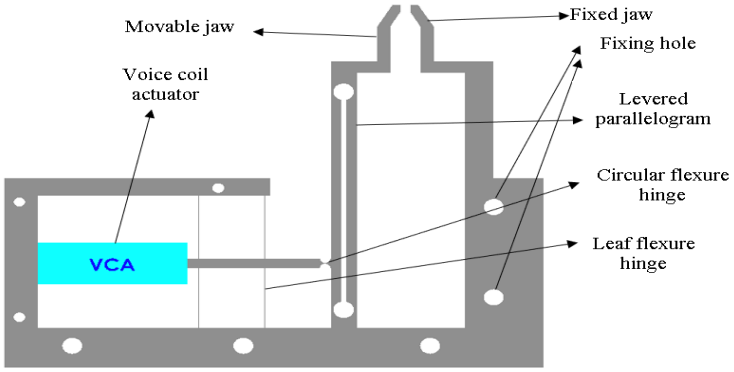


Fig. 1: CAD model of Proposed microgripper

2.3 Material selection

At the beginning of design, we have to choose design materials. Before we select material, we have to consider the cost, availability, gripper's performance and efficiency. Because the material's properties affect gripper motion, deformation, and performance. Many types of metal or alloy can be chosen for fabricating microgripper. Here we choose Aluminum 7075-T651. Because of its extraordinary mechanical properties, which include great ductility, high strength, toughness, and exceptional fatigue resistance.

Table 1: The properties of Aluminum 7075-T651 [17].

Properties	Value
Density	2810 kg/m^3
Young's modulus	71 GPa
Ultimate tensile strength	572 MPa
Yield strength	503 MPa
Poisson ratio	0.33

2.3 Actuator selection

The dimensions of a voice coil actuator typically include parameters such as coil diameter, coil height, and magnet gap. The size of the voice coil actuator directly influences its force output and displacement capabilities. Proper selection of voice coil actuator dimensions is crucial for achieving desired system dynamics and responsiveness. Table 2 shows the design parameters of selected (LCA50-050- 75-2) model voice coil actuator.

Table 2: Design parameters of (LCA50-050- 75-2) model voice coil actuator [16].

LCA Series	Stroke (mm)	Cont. Force (N)	Cont. Current (A)	Peak force (N)	Peak current (A)	Force constant (N/A)	Rec. voltage (Vdc)	Moving mass (g)	Total mass (g)	Ø (shaft) (mm)
LCA50-050- 75-2	50	34	1.13	80	3	30	48	465	4.340	10

3. Results and Discussion

3.1 Boundary conditions

Necessary boundary conditions were applied before simulating the microgripper which is shown in Figure 2. Fixed support was applied in 8 holes in the base of the microgripper. 80 N input force was applied along x-axis that imitate the action of a voice coil actuator.

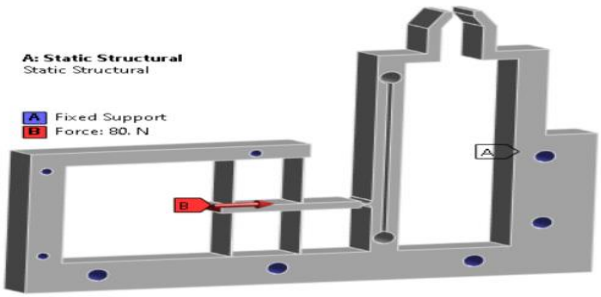


Fig. 2: Boundary conditions

3.2 Total deformation

Total deformation also known as total displacement of a flexure based compliant microgripper is the total deformation or displacement under a given force or displacement. This includes both plastic deformation and elastic deformation of the flexure hinges. It depends on the material properties and mechanical behavior of the object. Total deformation of 1.0027 mm was found when 80 N input force was applied. Total deformation via FEA is shown in Figure 3.

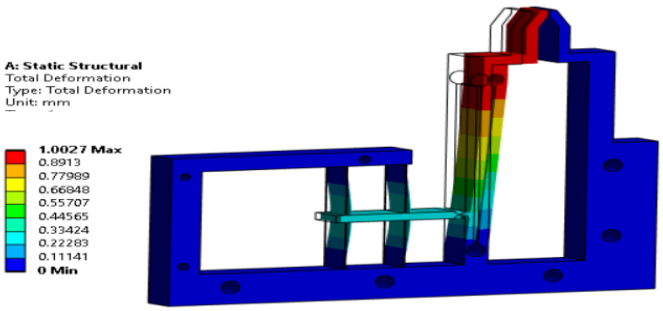


Fig. 3: Total deformation of the microgripper

3.2.1 Equivalent (von-Mises) stress

The Von Mises equivalent stress of a compliant microgripper based on flexure indicates the level of stress present in the flexure hinges and its distribution. During operation, cyclic tension occurs because the flexure parts in this type of microgripper are designed to undergo elastic bending and twisting. Figure 4 shows the maximum equivalent stress occurring at the circular flexure hinge. Maximum stress of 229.24 MPa was found under the input force of 80 N. The equivalent stress was very less than tensile yield strength of material. Equivalent von-Mises stress via FEA is shown in Figure 4.

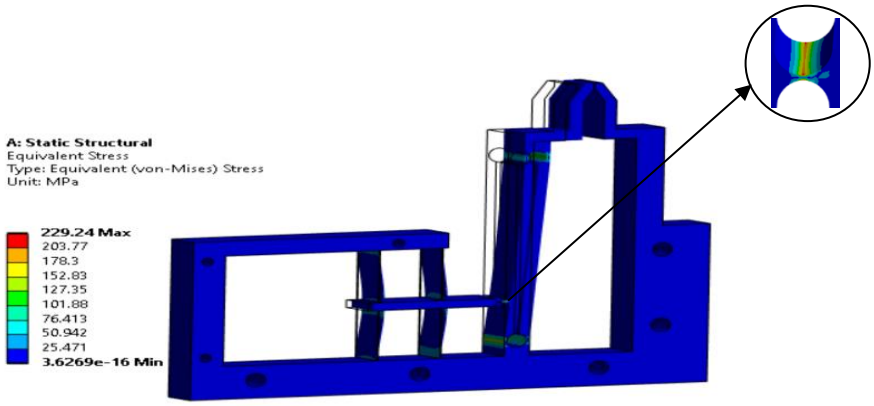


Fig. 4: Equivalent (von-Mises) stress of the microgripper

3.2.2 Modal analysis

Modal analysis is a technique used in structural engineering and dynamics to study the dynamic characteristics (modes) of a structure or system. It is commonly performed using software tools like ANSYS Workbench. It involves identifying the natural frequencies, mode shapes, and damping characteristics of a structure or system by performing experimental tests or numerical simulations. By utilizing this knowledge by using this data, the structures may be designed and modified to reduce vibrations, increase durability and dependability, and increase efficiencies. The structure will vibrate at its natural frequencies in the absence disturbances. These frequencies are dependent on loads and boundary conditions. It also depends on the mechanism's mass and stiffness. The microgripper's natural frequency in its operating state was discovered to be 116.05 Hz by means of modal analysis. First mode of the modal analysis was shown in Figure 5.

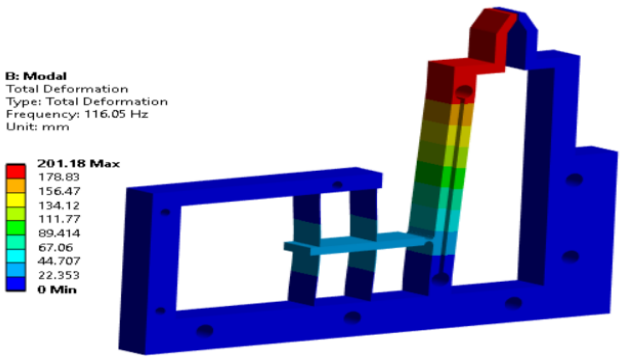


Fig. 5: Modal analysis of compliant microgripper

3.3 Input force, output displacement, equivalent stress and amplification ratio

The connection between input force and output displacement is established through the flexure's geometry and mechanical characteristics. Input force refers to the motion of the flexure's input or actuated end, while the output displacement is the movement of the flexure's output or controlled end. How much output displacement may be achieved for a given input force depends on the flexure's stiffness, which is determined by its geometry and material properties. Table 3 shows the variation of input force, output displacement, amplification ratio and equivalent von miss's stress.

Table 3: Input force, output displacement, equivalent stress and amplification ratio

Input force (N)	Output displacement (mm)	Input displacement (mm)	Equivalent stress (MPa)	Amplification ratio
20	0.2506	0.0798	57.309	3.14
30	0.3760	0.1197	85.964	3.14
40	0.5013	0.1596	114.62	3.14
50	0.6267	0.1995	143.27	3.14
60	0.7520	0.2394	171.93	3.14
70	0.8773	0.2793	200.58	3.14
80	1.0027	0.3193	229.24	3.14

The relationship Input force vs Output displacement and between input force and equivalent stress is shown in Figure 6 and Figure 7.

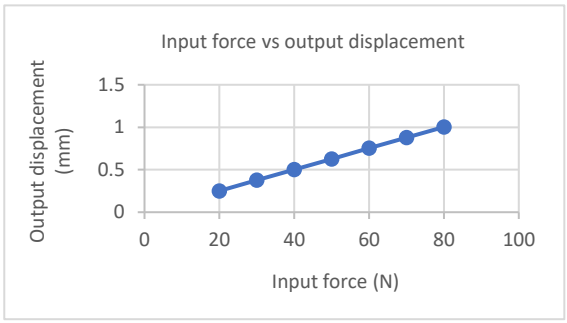


Fig. 6: Input force vs Output displacement

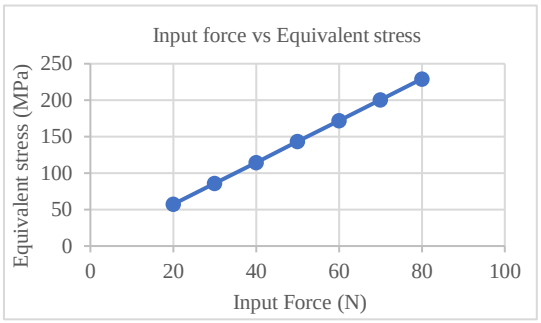


Fig. 7: Input force vs Equivalent stress

3.4 Input stiffness

Stiffness is a mechanical property that describes the resistance of a material or a structure to deformation when subjected to an applied force or load. It indicates how much a material or structure will deflect or deform under a given load. A material or structure with high stiffness will deform less under load, while a material or structure with low stiffness will deform more. Stiffness is typically measured in units of force per unit length, such as Newtons per meter (N/mm). The equivalent stiffness can be calculated as following equation:

Computational input stiffness

$$K=\frac{F}{x}=\frac{80}{0.3196}=250.312 \text{ N/mm}$$

3.5 Factor of safety

The factor of safety is a measure to determine the margin of safety of a structure. It indicates how much stronger a structure is than what is necessary for it to serve its intended purpose. According to stress analysis, maximum equivalent stress found was 229.24 MPa when 80N force was applied on the input end of the microgripper. Figure 8 shows that the most vulnerable position is the circular hinge connected to the levered parallelogram mechanism which is subjected to the maximum stress.

$$\text{Factor of safety} = \frac{\text{Yield stress}}{\text{maximum allowable stress}} = \frac{503}{229.24} = 2.19$$

Figure 8 shows the relationship between input force, output displacement and factor of safety.

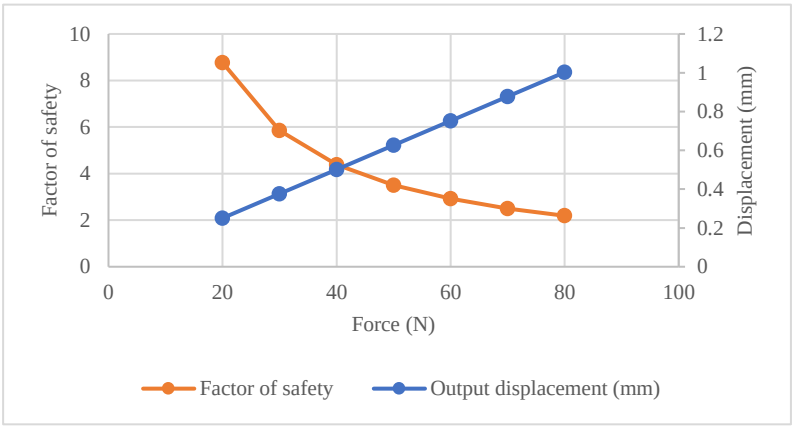


Fig. 8: the relationship between input force, output displacement and factor of safety

4. Conclusion

In this research, a new flexure based compliant microgripper has been designed and analyzed. This compliant microgripper consists of leverage mechanism. It increased the amplification of the mechanism. Levered parallel-ogram mechanism was used to achieve linear motion of microgripper jaw. Two different flexural hinges have

been used for designing and analyzing the compliant microgripper. Design was accomplished in a CAD software. After completion of design process, FEA simulation was conducted to evaluate the performance of the microgripper such as displacement of jaw, equivalent stress. The following key findings are observed from this work.

- A new flexure based compliant microgripper achieved maximum output displacement of 1.0027mm.
- The displacement amplification ratio is 3.14.
- When input force of 80 N was applied it undergo maximum equivalent (von-Mises) stress of 229.24 MPa.
- From the modal analysis, the working state of compliant microgripper is found and the finding natural frequency of compliant microgripper is 116.05 Hz.
- The lowest safety factor computed was 2.19. By utilizing the microgripper within a reduced displacement range, the safety factor could be increased.
- The input stiffness of the microgripper is 250.312 N/mm.
- The displacement amplification ratio is 3.14.
- In this model, the distance between two jaw is 4 mm, which may be used to grip relatively large delicate object with at minimum a diameter of 2.9973 mm.

Finally, it is hoped that the prototyped version of the compact compliant gripper can be fabricated in the near future.

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