Development of Meso-Scale Microgripper with Large Displacement Amplification Ratio

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Copyright Statement

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This work is dedicated to my father and late mother who always struggle and pray for my success.

Abstract

The microgripper has ability to handle and manipulate micron or sub-micron objects precisely. They have many applications in micro assembly, biology, tissue engineering etc. In this work microgripper new design approach is proposed. The design is fabricated by using wire cut EDM technique. Displacement and amplification factor are considered as most important parameters of microgripper. Optimization technique is performed in solid works to achieve high amplification ratio and large displacement for best microgripper.

FEM analysis is performed on solid works geometry to measure all the performance characteristics of design at simulation level to ensure required and efficient working after fabrication. Piezoelectric sensor is used for driving mode because of its fast response, high sensitivity, and low power consumption. Results shows an amplification factor of 37.53um which is greater than maximum amplification factor mentioned in literature.

Key Words: *EDM, Microgripper, FEM, SPCA, DIC, Design Optimization, PZTg* .

Table of Contents

List of Figures

List of Tables

Acronyms

PZT	Piezoelectric
CNC	Computer Numeric Control
EDM	Electrical Discharge Machine
FEM	Finite Element Method
SMA	Shape Memory Alloy
DAF	Displacement amplification factor
AC	Alternating Current
DC	Direct Current
DIC	Digital Image Correlation
EDM	Electrical Discharge Machining

Chapter 1: Introduction

The research work includes designing of MESO scale microgrippers used for multipurpose applications such as biomanipulation, grasping and transportation of MESO scale particles, and micro assemblies. In first step introduction to MESO scale s discussed than applications and market area of microgrippers is discussed. At last literature review of microgrippers is mentioned.

1.1 Introduction to Microgrippers

The microgripper is an electro-mechanical device with the ability to handle and manipulate micron objects precisely. Pinking and placing tasks are widely used in industries. Handling of these tasks become more complex when user wants to control objects in range from tens to hundreds of micrometres. If such tasks can be handled by microgripper design which provide high reliability and accuracy, it will bring a resolution micro assembly.

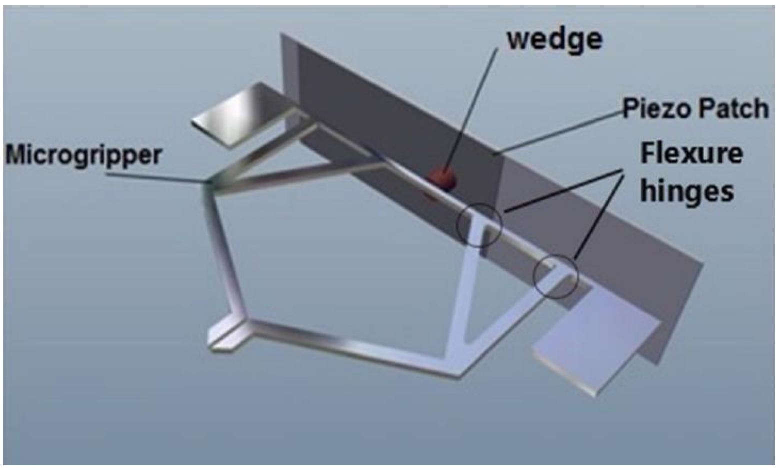


Figure 1-1: Design of microgripper [22]

Micro grippers are the devices which picks up and release the micro particles or cells at their specific position. Microgripper is an important tool in field of meso-scale/micro manipulation. For implementation of micromanipulation and micro assembly tasks, microgrippers have direct interaction with manipulated object. The grippers have a vast domain in assembly, biomedical and in medical optics [1-3]. Advancement in microgrippers will brings drastic change in micro assembly by increasing its precision, fragility, and compactness. The design of microgripper consists of one or more actuators for actuation principal, a translation mechanism for transition of motion generated by actuators and 2 jaws for gripping, The whole design converts the electrical or other form of energy like heat into displacement of jaws and force at tips of jaws. Multiple operations such as picking and grasping of objects, transportation of objects, and their sorting all are done by restoring to friction force. In microgripper design actuator selection is most important task for designer. As movement of jaws is totally dependent on actuators type so selection of actuator is crucial part in designing of actuator. Motion and resolution of microgrippers are dependent on actuators performance [4]. There are six types of microgrippers

- Electrostatic Microgrippers
- Mechanical Microgripper
- Electromagnetic Microgrippers
- Shape memory alloy Microgrippers
- Piezoelectric Microgrippers
- Thermal Microgrippers

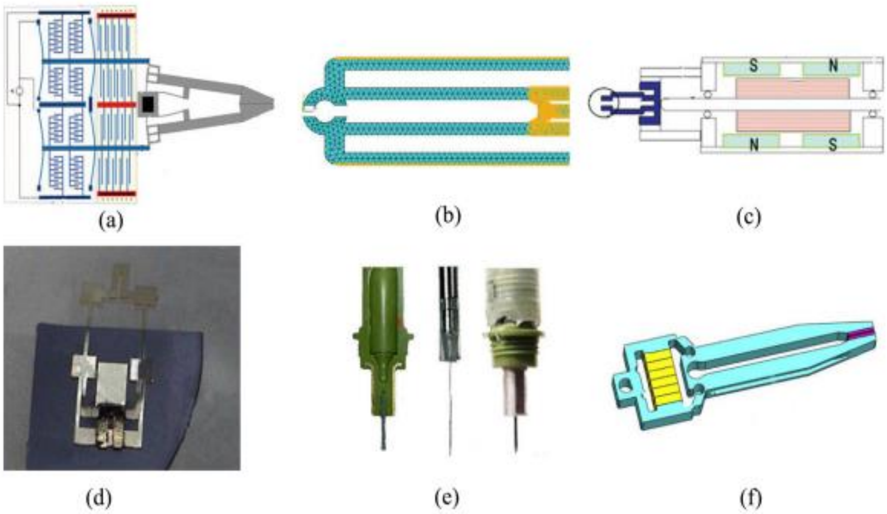


Figure 1-2: (a) Electrostatic microgripper [6]; (b) electrothermal gripper [7]; (c) electromagnetic microgripper [8]; (d) SMA microgripper [9]; (e)vacuum microgripper [9]. f) piezoelectric microgripper [5].

There are many limitations in designing the microgrippers which are defined on basis of applications for which microgripper is deigned. Microgrippers should have maximum displacement at the tips of gripper so that it can grasp various size objects. Microgripper should apply calculated force so that it may not harm the output objects and its own jaws too. A force sensing sensor should be included in design which is crucial in micro assembly. Contamination of environment and components should not be done. Design and control of microgripper should be kept simple for easy integration of microgripper in other systems. Microgripper having high temperature and high voltages at output jaws may limits its applications. Microgrippers design should be easy to fabricate, low in cost, easy to maintain for commercial use. The design of microgripper should lie in meso-scale limitations.

1.2 Applications Of Microgrippers

On launch of first microgripper, technology had a rapid advancement into many fields of engineering, biology, medicine and in micro assembly. Applications of microgrippers are

- Soft tissues grasping
- Micro objects manipulation
- Micro assembly
- Handling of optical fibres.

For medicine and in biomedical technology microgrippers has vital scope. In microsurgery and in drug delivery, there is a need of microgripper which do not allow clamping devices attachment along with digestive tract. g

1.3 Types of Microgrippers

Microgrippers works on principal of actuation done by multiple types of actuators such as thermal, electrical, piezoelectric, magnetic and shape memory alloys. Voltage applied across the plates attached to closure arm and drive arm causes the movement of grippers by initiating gripping action. In microgripper design actuator selection is most important task for designer. As movement of jaws is totally dependent on actuators type so selection of actuator is crucial part in designing of actuator. Motion and resolution of microgrippers are dependent on actuators performance [4].

1.3.1 Electrostatic Microgripper

Electrostatic actuation is most used actuation technique in microgrippers because of its scaling effect favours electrostatic force at meso-scale. Fabrication of these actuators is easy by sing simple silicon or metals. Electrostatic actuators work on two forces either lateral or horizontal which is examined by two plates. Electrostatic actuators include different design for actuation of microgrippers which includes parallel plate, comb drive, curved electrodes and womble motors as well. Comb drive actuator is used most to actuate microgripper. Comb drive structure have parallel fingers on which magnitude of force id dependant. The force has linear relation with output displacement which makes control of output displacement easy. Comb drive actuators may have unstable state. This unstable state occurs dur to the electrostatic forces of comb in z direction. The difference in fingers should remain equal. If the distance between combs is not equally distributed than comb may moves towards one end. Advantage of comb drive actuator is that it can produce large displacement at low input power. Disadvantage of comb drive actuator is that it requires high voltage for actuation. Figure 2.3 shows the latest design of comb drive actuator which solves many previous problems like high driving voltage. In this design one jaws of comb drive moves to move the actuator and the other one act as capacitive sensors to measure the force at output [10].

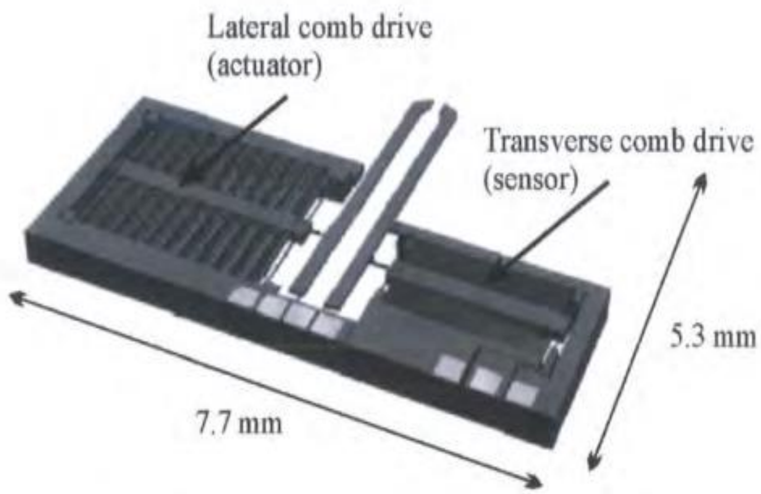


Figure 1-3: Schematic of electrostatic microgripper with capacitive sensor [10].

1.3.2 Thermal Microgrippers

Thermal actuators use conductive material which is used as heating material and expands dur to its properties. Thermal actuators consume high power input in comparison with electrostatic and piezoelectric actuators. Bimorph actuators are used for in plane and out of plane actuators. Bimorph actuators uses difference of thermal expansion coefficient for producing displacement.

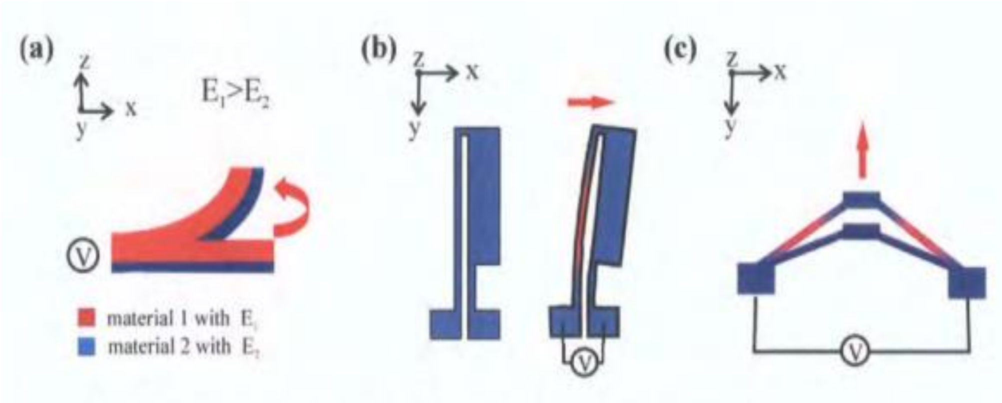


Figure 1-4: Types of thermal actuators (a) C-type (b) U-shaped (c) V-shaped (E: Young’s Modulus) [8]

U type actuators have same material, and it uses asymmetrical heating for expansion. U shape actuator consists of one hot and one cold arm. The resistance in hot arm is more than that of cold arm with rise of temperature high in hot arm. Due to high temperature raise in hot arm allows it movement or bending towards cold arm. U type actuator causes in plane movement. The third type of actuator also have asymmetrical heating. In this type two beam are connected at two fix ends with an angel by making v shape. When the current passes by fixed ends, beams expand dur to joule heating effect. Thermal actuators are not recommended for microgrippers dur to their high temperature results on output jaws.

1.3.3 Shape Memory Alloy Microgrippers

Output in shape memory alloys is produced by phase state shape transformation in its material when its passes through phase transition temperature. When material passes through phase change temperature it suffers from soft and deformable phase. To overcome the shape memory effect, training of material is required. This can be done during fabrication process by accumulating stresses. When this process is done in fabrication the material will come back to its original state on application of external or internal heating. Shape memory alloys has large displacement at low voltages. Disadvantages of these actuators are limited temperature range, large hysteresis, and slow response time. Table 1.1 shows the comparison of multiple actuators used for microgripper actuation.

Table 1-1: Comparison of different type of actuators

Actuators	**Device Description**	**Output**	**Force Sessor**
Electrostatic [10]	Comb drive, monolithic structure with fabrication in polysilicon	Displacement of 50um at applied voltage of 50V	Yes (Capacitive)
Piezoelectric [11]	An activation bar is used for connecting jaws to actuator	Displacement of 9um at applied voltage of 9V	No
Thermal [13]	U and V shaped actuator using polymer SU-8 for fabrication	Output results at input of 3V with min temperature <60◦	No
SMA [12]	Free standing Ni-Ti film	Displacement of 300um at applied power of 100mW	Yes (optical)
Electromagnetic [14]	Thin film cantilever with electromagnetic flux	Displacement of 210um at voltage of 1V	No

1.3.4 Electromagnetic Microgrippers

Electromagnetic microgrippers can produce large displacement at low power input and at low input force. They produce large displacement as compared to piezoelectric and electrostatic actuators. They can perform in fluid environments as well. When constant forces are maintained at input magnetic forces are generated, which results in heat dissipation. Electromagnetic actuators produce two types of forces. On is electric force in between two solid and other one is magnetic force through coils. Electromagnetic actuators are not recommended due to its complex fabrication and dur to external magnetic attachment and large device area.

1.3.5 Piezoelectric Microgrippers

Piezoelectric actuators convert electrical energy into displacement. Speed, output force, resolution, accuracy, accurate positioning, and low power consumption are the main points which makes piezoelectric actuators accurate for microgrippers. It requires high voltage for generating output while producing low displacement at output. Fabrication of piezoelectric actuators are difficult as compared to electrostatic actuators. As hybrid fabrication is used for piezoelectric actuators therefore only monolithic type of microgrippers is found in literature. Beside complex fabrication, accurate positioning of jaws and low power consumption make these piezoelectric under consideration for advancements.

1.4 Literature Review

Microgripper designing requires many efforts as multiple factors should need to be kept in mind to achieve maximum output. The gripper should have ability to grasp different object with great accuracy without causing any harm to grasped object. Gripping force needs to be in control for avoiding any damage to object with dimensions less than 1 mm. Multiple actuators are used to actuate microgrippers. Each actuator has some drawbacks and some advantages as well. PZT is selected for actuation of microgripper because of its speed, low power consumption, and accurate positioning. Liang et al. design a PZT microgripper [21]. This gripper grasps the objects by moving one jaw only while the other jaw remains fixed. The use controller for grasping the objects. The controller's main function is to control the gripping force to overcome the grasping force failures.

PZT actuators gives fast response on applied voltage input providing excellent positioning capacity. They provide large stiffness along with large output force. PZT provides high resolution in nanometers. That's why PZ are better options for actuation in microgrippers in MESO scale [30, 31]. If PZT are used separately in microgripper designs their output displacement is limited. Therefore, these actuators are used with amplification mechanisms to generate large output displacement. PZT with amplification mechanism act as best actuator for actuation in microgripper due to is avoidance of backlash, less friction, vacuum compatibility, and repeatable motions [32]. Nah et al. [33] design a microgripper with PZT actuator with one stage amplification mechanism giving 3-um deflection ratio. A lengthy stack PZT is used to increase the jaw output displacement. The low magnification factor and large area limits this design. Shi et al. [34]

In previous working on designs of microgrippers focus was on increasing the tip displacement. Hossein Mehrabi works on design which is easy to fabricate as well. This design includes PZT actuation mechanism with bending abilities which provides large displacement at tips by providing novelty in design [22]. This design includes some cantilever beams, corners and beam arms which makes a spring structure which was followed by flexure hinge mechanism having initial dimensions. Optimization process is used to obtain the best optimal design using design of experiments techniques. DOE is used to achieve maximum output displacement at tips. DOE is done in Minitab software to achieve maximum value of each input parameter. Pareto chart and Analysis of variance calculates the most important part of design geometry which is affecting the output most. Two layers bending PZT is used as actuator. When voltage is applied on bending PZT, it starts bending and generated displacement at output with some force. The force and displacement are translated by wedge that lies in middle of PZT and micro gripper. Following figure shows the details design of PZT single stage microgripper. Structural analysis is performed in ANSYS software and by mathematical models to calculate maximum stress in gripper design. There is good relation in calculated and experimental results which shows minimum stress deformation. The maximum stroke obtained by microgripper is 300-um. As there is linear relation in input and output displacement and linear PZT properties high precision is obtained. PZT promises high precision due to linear properties. Chemical deposition is used for fabrication

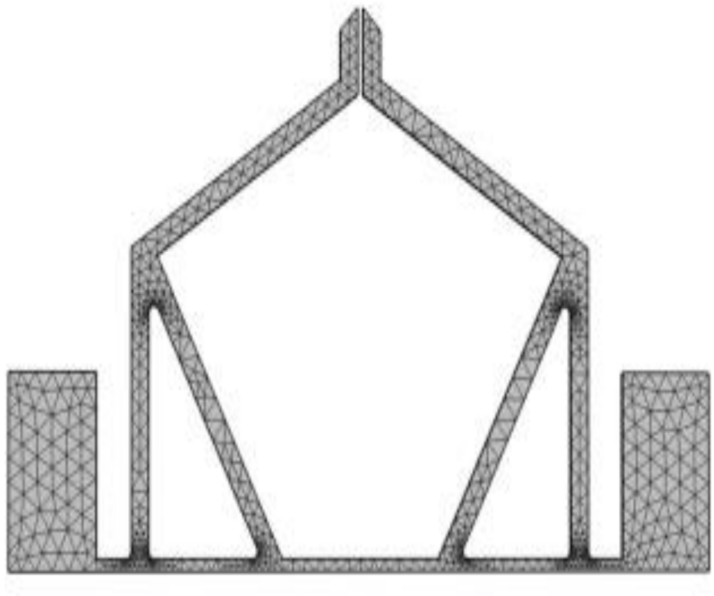


Figure 1-5: Schematic diagram of single stage PZT microgripper [22].

Cunman Liang designs asymmetrical PZT microgripper with one jaw fixed [23]. This paper includes 3-stage structural design to achieve large displacement amplification ratio. One jaw fixed microgripper has advantages of no dense mode over both jaws movable microgrippers. FEA is used to calculate the characteristics analysis of design. Wire cut EDM technique is used for fabrication of microgripper. FEM and experimental results show an amplification factor of 13.94 with frequency mode of 531. To obtain high precision and accuracy the design of microgripper needs to be done efficiently and carefully. Achievement of large displacement and large amplification ratio requires high knowledge of effecting parameters. The flow chart shows different steps for designing microgripper. In first step working environment and specifications of object must be defined. Environment conditions include dry, liquid, biological, vacuum and so on. Specifications of output objects determines the maximum grasping force, maximum grasping range and shape of tip of microgrippers. By keeping these factors in mind actuators are selected based on required output results. FEM and other Analysis software's are used for calculating stress deformation graphs. A flow chart is used to explain the design steps involves in designing a microgripper [24].

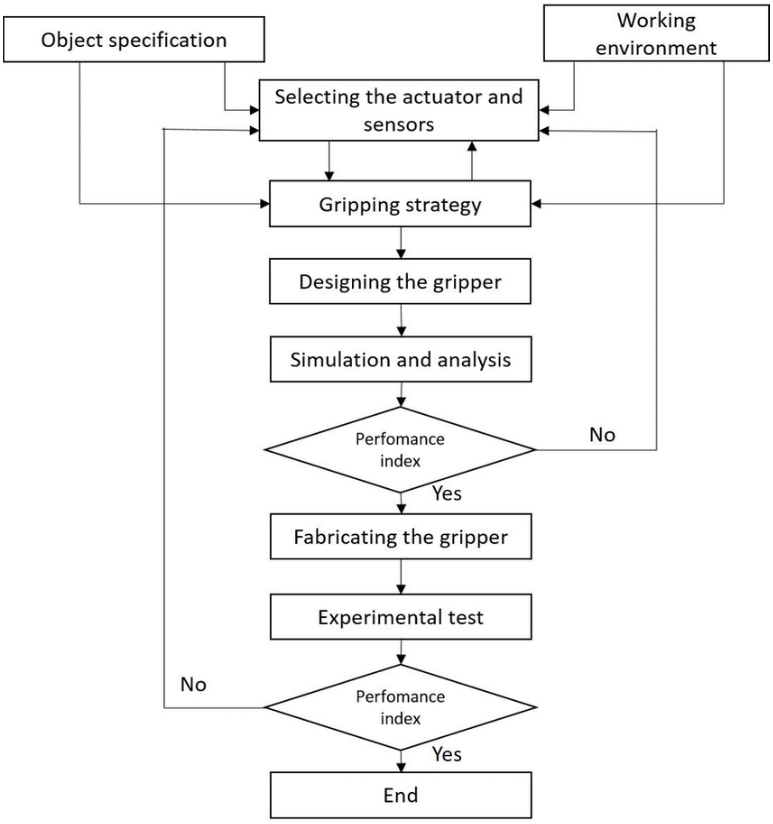


Figure 1-6: Algorithm for microgripper design [24]

. The simulation results showing force, maximum displacement at tips, stress deformations, parallel motion, out of plane motion are analyzed. If the results match with defined parameters than move towards fabrication process. Otherwise, previous steps should be repeated until desire results are obtained. Wire cut EDM and multiple other process are used for fabrication of microgrippers [15].

Mechanical amplifiers are used to translate the displacement generated by actuators to microgripper tip. The main purpose of amplifiers is to amplifies the input force/displacement generated by actuators into the required force/displacement at output inside driven mechanisms. Three types of amplifiers are used by Jaroslav Hricko to amplify the force/displacement with specific specifications. Characteristics of each amplifier is different from one another with respect to their specifications. This paper presents single material amplifiers without any rotatory element. In MESO scale most used mechanical amplifier is bridge type. The main drawback of this structure is it limited amplification ratio [28]. The bridge amplifiers are further divided into two types of the basis of their arm structure. One type used rigid arm connected with hinges while the other type uses flexible arms connected with hinges called as rhombus type bridges. Another type called compound bridge type has large stiffness and is more useful for protection of actuators as compared to other bridge type amplifiers. The oldest amplification mechanism is lever type mechanism used in all most all previous designs. Due to its easy understanding and fabrication, it is mostly used in robotics. Its main drawback is stress concentration in flexible joints. Rhombus type amplifiers show large input displacement at smallest external dimensions. The input-output relationship is not linear for all other amplifiers expect for lever mechanism. This point should be kept in mind while going for high accuracy achievement. It is suggested that while designing microgripper following points should be kept in mind.

- Simulate carefully
- Optimization of design
- Developing physical model
- Measurements of characteristics

All the details are studied for static point of view. There is no role of dynamic study analysis in previous studies. The amplification ratio is most crucial parameter in amplifiers design. The stress generated in flexure parts is dependent of actual displacement of structures. If you are working on force amplifiers than effects of external loads are also included in calculations. Using mechanical mechanisms in microgripper designs large amplification ratio is achieved at low input. Highest amplification ratio achieved using two bridge amplifier is 32-um.

Chaoyang Shi uses three stage amplification mechanism to achieve large amplification ratio with great linearity [29]. This design uses PZT for actuation principal. This gripper has large gripping force for micromanipulation and assembly. The first two bridges are attached in parallel manner to achieve high stiffness. First stage includes two parallel bridge amplification mechanisms to achieve large output displacement. In third stage leverage mechanism is used to ensure large displacement for whole gripper structure. Following figure shows the details design of three stage microgripper with highest amplification ratio of 32-um.

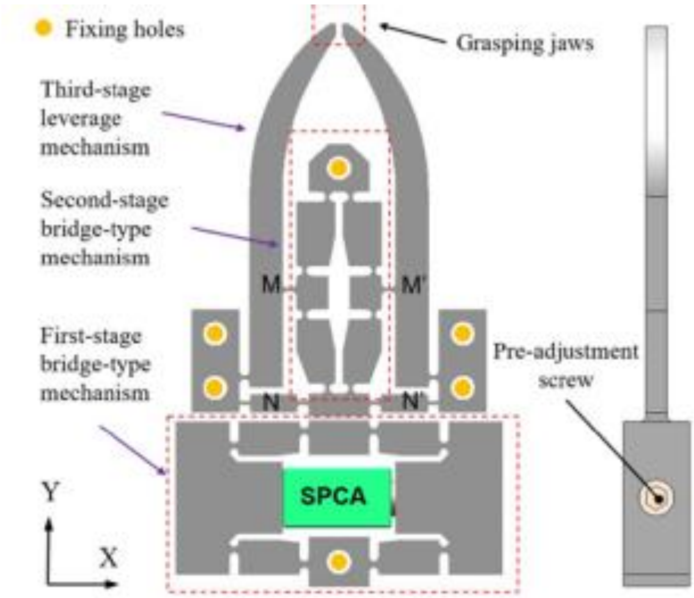


Figure 1-7: Design of PZT microgripper [29]

The first parallel bridge act as base of structure to stand up with large forces as compared to other two mechanisms. This base bridge plays important role in maintain the stability of whole structure. That's why size of first bridge should be design large. Due to the given dimensions of stack piezo the dimensions of first bridge are kept 5.5mm which is slightly greater than thickness of enhanced assembly. The dimensions of other two mechanisms are kept being 1.8mm. Aluminium alloy is used for fabrication material due to its light weight and great Eleatic properties. A theoretical model is also developed to calculate the magnification factor of gripper design. The experimental results show great agreement with FEM results by achieving an amplification factor of 32-um [29]. The first two bridge mechanisms possess high rigidity of design and ensures large magnification ratio with maximum frequency range. Table 1.2 shows the review of PZT based microgripper.

Table 1-2: Literature review of PZT based microgrippers

Sr	Author	Configuration	Size	Material	Actuation type	Grasping force (mN)	Amplification Stage	Max Displacement (um)
1	**Mehrabi et al (2019)**	Symmetrical Microgripper	40 x 22	Aluminum Alloy (7075)	Bending PZT	800	1	300
2	**Chen et al. (2019)**	Symmetrical Microgripper	39.68 x 23.6 x 5	Aluminum Alloy (7075-T6) (SN)	Stack PZT Ceramic Actuator (SPCA)	2000	2	235.36
3	**Liang et al. (2017)**	Asymmetric Microgripper	50.49 x 19.74 x 6	Aluminum 7075-T651	PZT Actuator	50	3	149.4
4	**Wang et al. (2019)**	Asymmetric Microgripper	59.56 x 28.2	Aluminum 7075-T651	Stack PZT Ceramic Actuator (SPCA)	NG	2	85
5	**Chen et al. (2019)**	Asymmetric Microgripper	68.8 x 34.55 x 5	Aluminum Alloy (7075-	Stack PZT Ceramic Actuator (SPCA)	270	4	632
6	**Nah & Zhong (2007)**	Symmetrical Microgripper	36 x 30 x 3	Spring Steel / Aluminum	Piezoelectric Actuator	NG	1	170
7	**Shi et al. (2021)**	Symmetrical Microgripper	46 x 27 x 5.5	aluminum alloy 5052-H18	Stack PZT Ceramic Actuator (SPCA)	1993	3	218

Chapter 2: Design of Micrograppers and Actuators

Designing micrograppers for accurate precision is not an easy job. To get accurate grip of microstructures at jaws and perfect realizing of objects along with fragile structures requires efficient design. To achieve maximum precision and accuracy without error is significant and difficult process. To achieve this high knowledge of design factors effecting the gripper is required. Use of operational indexes in designing process the new design comes with optimum high performance of microgripper. In this chapter important parameter effecting the microgripper performances are discussed.

2.1 Material Specification

Motion of jaws is totally dependent on actuation of actuators; therefore, material plays an important role in microgripper movement. Material selection should be done by considering all the desired factors in mind. One of the most important properties which should be kept in mind while selecting material is resilience. Resilience is the ability of material to absorb energy when material undergoes through elastic deformation. This energy is than released on unloading. The resilience modulus is defined as energy absorbed by material per unit volume without having any permanent deformation. In uniaxial tension, resilience can be defined as

$$Ur = \frac{S_y^2}{2E} \qquad [2.1]$$

S_y represents the yield strength and U_r is the modulus of resilience. E denotes the young modulus of material.

In literature it can be observed that many designs use silicon, aluminum, brass and nickel and titanium as well. Silicon is used in microgrippers actuated with thermal actuators. Steel is low-cost material and can be fabricated easily. Aluminum has high yield of strength along with high modulus of elasticity which gives fine finish after fabrication. Another important factor is compatibility between jaws and gripped object contact area.

In this work we use Stainless steel. Stainless steel is durable material. It is very easy to handle stainless steel as it can be easily cut and welded. Stainless steel can be shaped easily with good strength. This material lasts for longer time as compared to other materials. SS can be recycled easily. SS has high tensile strength. Its maintenance cost is very low. It is environment friendly. SS is temperature resistant. We use three types of stainless-steel SS-301, SS-316, SS-201. All these materials are compared with each other. Best results were achieved from SS-201 with Amplification ratio: 38.36. SS-316 and SS-301 demonstrated same Amplification ratio of 37.53. Following graph shows comparison of materials.

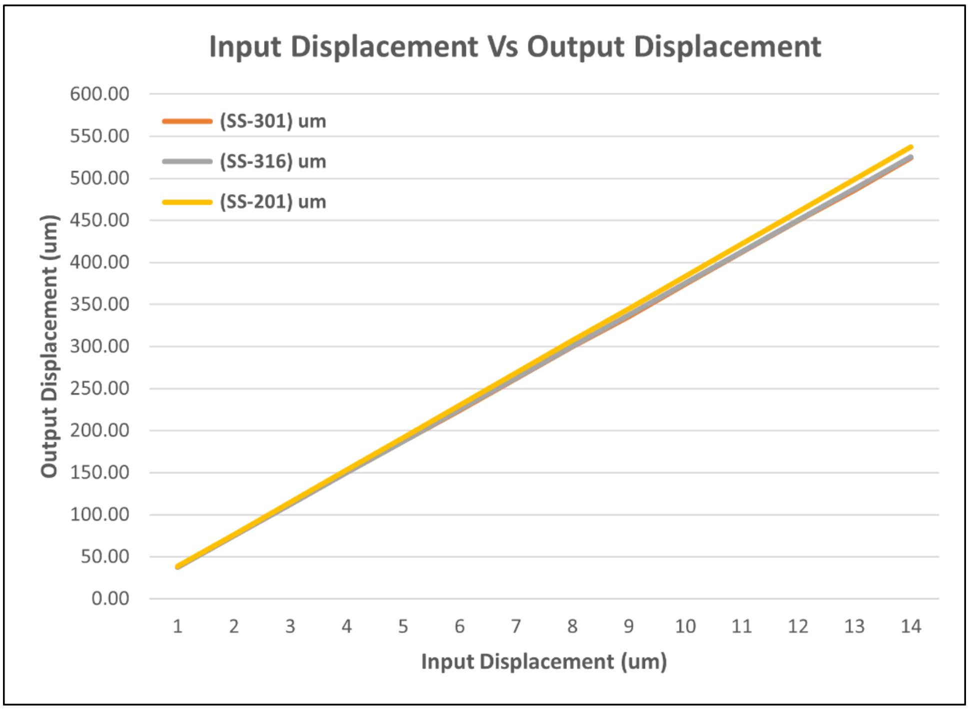


Figure 2-1: Graphical representation of input displacement Vs output displacement.

Calculation of Factor of Safety (FOS) under maximum loading of 14 µm is performed. Figure 2.2 shows that factor of safety plot of

- SS316 has highest FOS = 1.44
- SS-301 has FOS = 1.04
- SS-201 has FOS =1.35

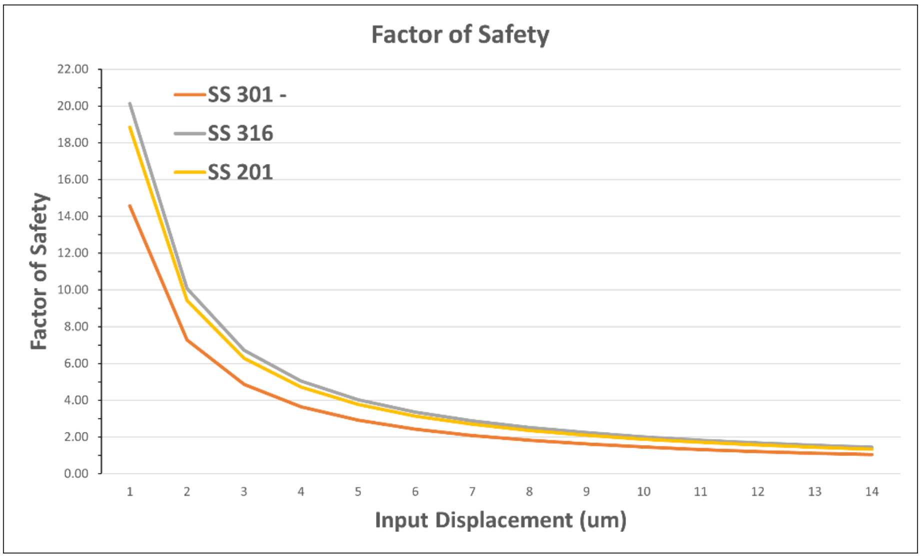


Figure 2-2: Graphical representation of input displacement Vs factor of safety

SS-316 is chosen in material selection due to these properties and due to its anti-rust properties.

2.2 Displacement Amplification

The displacement amplification factor can be abbreviated as DAF. DAF is the ratio between output displacement of jaws and input displacement actuated by actuators to microgripper structure.

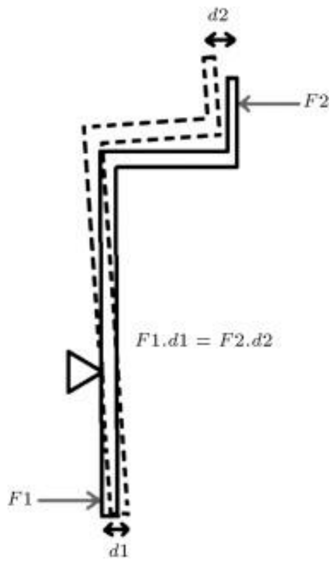


Figure 2-3: Schematic diagram of gripper [15]

By observing figure amplification ratio can be defined as

$$\text{DAF} = \frac{d2}{d1} \qquad [2.2]$$

Where d1 is defined as displacement of actuator and d2 is defined as displacement of gripper jaws. If this factor increases than it causes an increase in gripper range. In that case gripper can manipulate high dimension micro-objects. Actuators having low displacement at output like piezoelectric actuators can achieve more output displacement by achieving high displacement amplification ratio. By lever mechanism, if we increase the output displacement it will decrease the gripping force. In our case we try to achieve displacement amplification of 38 um.

To ensure maximum amplification, multiple stages in series are optimal where output of first stage would become input for the next stage and the resultant output will be amplified further. Keeping this principle in mind single stages with maximum DAF were designed for integration together. For output stage different designs were tested for achieving improved amplification ratio.

2.3 Number of Degree of Freedom

Jaws of actuators can be moved separately by their own actuator. In literature there are two- and three-degree freedom microgrippers available. These grippers can grasp objects of large size range as compared to 1 DOF grippers. The reason behind that is each jaw has its own actuation mechanism and its own actuator too. Designing of multiple degree of freedom in parallel jaw motion is easier as compared to single degree of freedom. In multiple degree of freedom high accuracy, accurate grasping and easy releasing process is achievable. On the other hand, adding multiple actuators increases the device size, fabrication cost and energy consumption.

2.4 Parallel Jaw Motion

During the rotational motion of microgripper jaws, x-component of reaction force grips the object between jaws. While y-component behaves parallel to longitudinal axis. It will move the object out from grippers range. The following figure shows rotational and parallel motion.

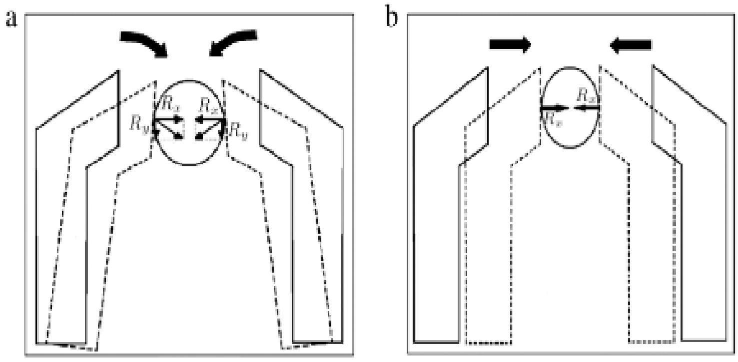


Figure 2-4: Schematic of (a)Rotational motion. (b) parallel motion.

To overcome the effect of y-component reaction force parallel motion jaws grippers are used. These parallel jaws grippers cancel the effect of y-component reaction force. The parallel motion of jaws will ensure accurate grasping along with equal stress distribution. Parallel jaws are the most reliable method of grasping. To achieve pure parallel motion of jaws is difficult as there is always some rotational motion in it. Parallelogram mechanism is a solution to this problem.

Deflection of Jaws:

- Angle of deflection of Jaws is Calculated. It Ranges between (0.03° to 0.5 °)
- This Angle is calculated from described method
- Length B is found from Directional deformation of x using Max-Min.

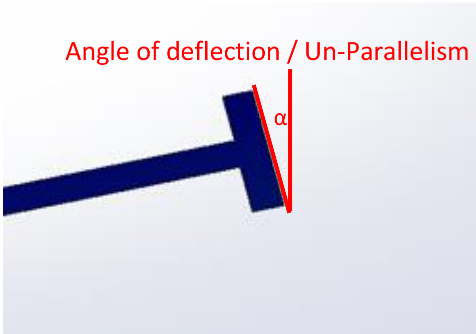


Figure 2-5: Deflection of jaws

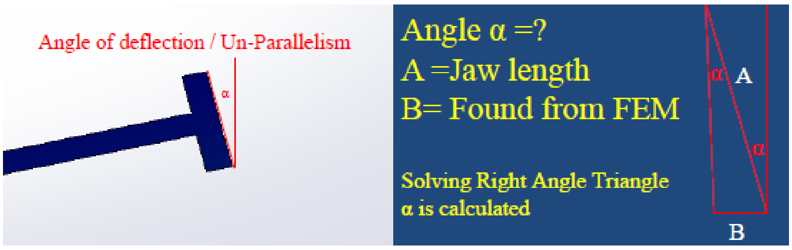


Figure 2-6: Calculation of deflection angle

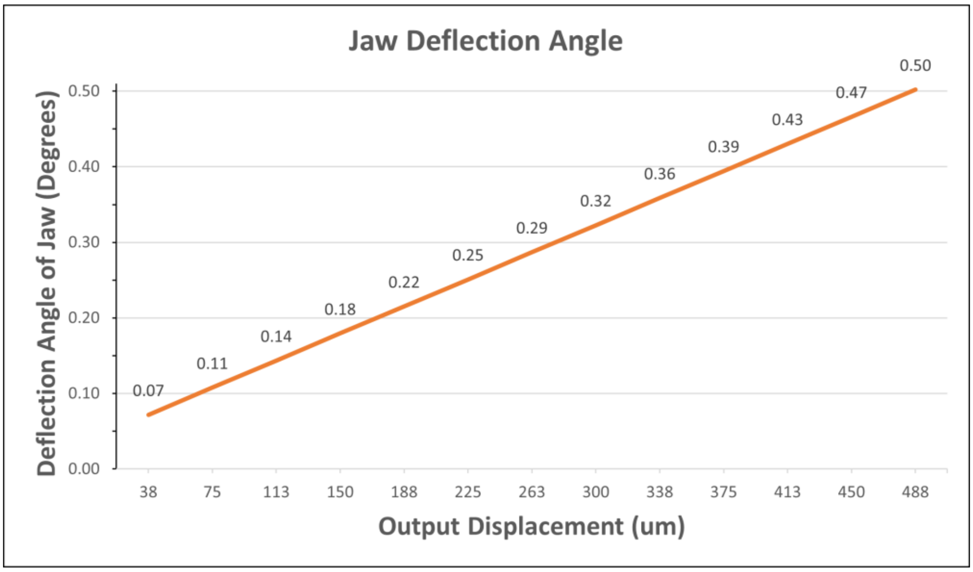


Figure 2-7: Graphical representation of output displacement Vs deflection angle of jaws

2.5 Normally Open and Normally Close Gripper

In normally open grippers the distance between jaws is maximum. The distance starts decreasing by applying force on actuator which will keep decreasing until object is grasped fully

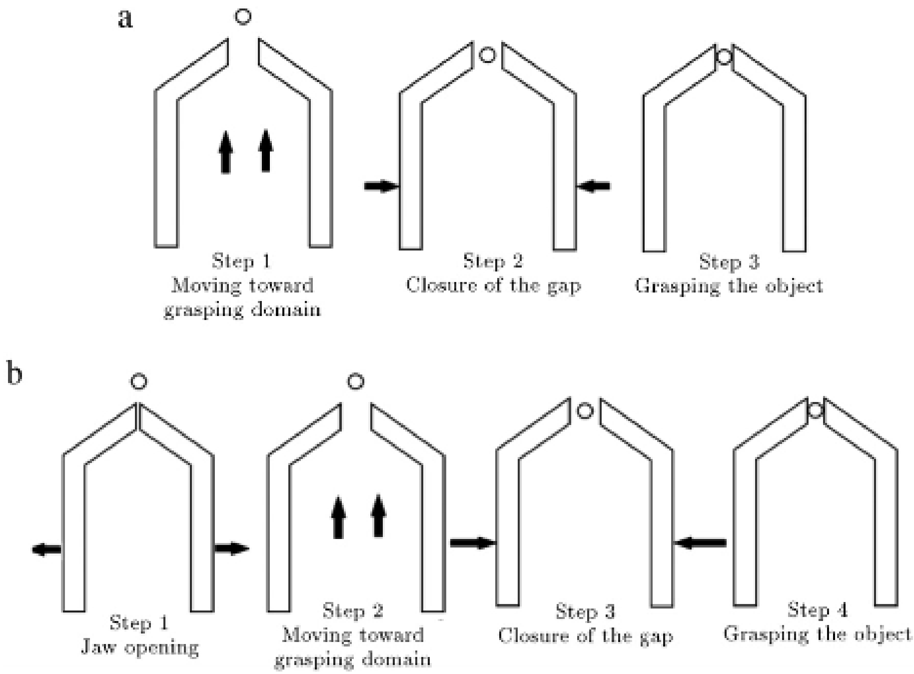


Figure 2-8: (a) Normally Open Grippers (b) Normally close grippers [15].

During transmission, actuation force must be kept. Precise control of gripper force is a key factor in this method. Its disadvantage is consumption of energy. In normally close grippers the distance between the grippers is increased by actuation to grasp the object. The jaws will open according to the size of object. Electric strain energy will provide force for increasing the distance between jaws. For manipulation of large objects large electric force needs to be consumed for increasing the distance between jaws. It may cause a chance to damage the object. So, normally open grippers are used in our design. Figur2.3 shows normally open and normally close grippers.

2.6 Gripping Range and Stroke

The range of microgrippers is defined by calculating the maximum and minimum dimensions of object gripped by jaws. Stroke of microgripper is defined as maximum stroke of each jaw. For manipulation of various objects large gripping range along with large stroke is required. The largest gripping range defined in literature is 900 µm [16]. By increasing the range of microgripper jaws resolution decreases. High accuracy microgrippers has less gripping range. Stroke range can be increased or decreased by changing levers and hinges dimensions and positions.

2.7 Shape of Tips

The shape of tip jaws is an important factor in designing. In literature most of the microgrippers uses flat shape tips. These tips help in manipulation of irregular and uniform shaped objects. If we decrease the contact area between object and tip than in releasing it will help in reducing Van Der forces. It is preferred to use rough surface on the tip of gripper. Van Dar forces can be reduced by introducing saw and pyramids on microgripper tips [17]. Tips of microgripper jaws can be designed according to requirement or according to shape of object. This makes manipulation tasks easier. Combination of flat along with cylindrical shape is introduce on tips which can grasp simple as well as specific objects. Changeable tips of actuators are also available which makes manipulation easier [18,19].

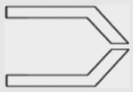
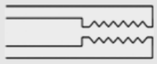
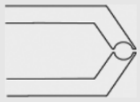
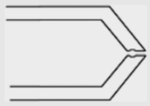
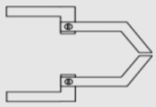
Gripper tips	Sample diagram	Description
Flat surface tips		Grasping of uniform & irregular shapes
Rough surface tips		Reduction of slipping and Van Der Waals force
Special shape for special application		Cell manipulation
		Teflon wire manipulation
Changeable tips		Grasping of different size, shapes and material

Figure 2-9: Different tips of microgripper jaws [15]

2.8 Microgripper Design

In our design we use flat surface grippers. These grippers are used for grasping uniform and irregular shaped objects. The surface of microgripper is rough to reduce Van Der forces. In our design we use normally close grippers. As for manipulation of large objects in normally open grippers large electric force needs to be consumed for increasing the distance between jaws. It may cause a chance to damage the object. Normally Closed Gripper jaws are

- Energy Efficient
- Large Uncontrolled Griping Force
- Jaw Type: Flat Surface

Maximum Displacement of Gripper is 525 um output under an input of 14um. So, normally close grippers are used in our design. Figure 2.6 shows the detail schematic of grippers.

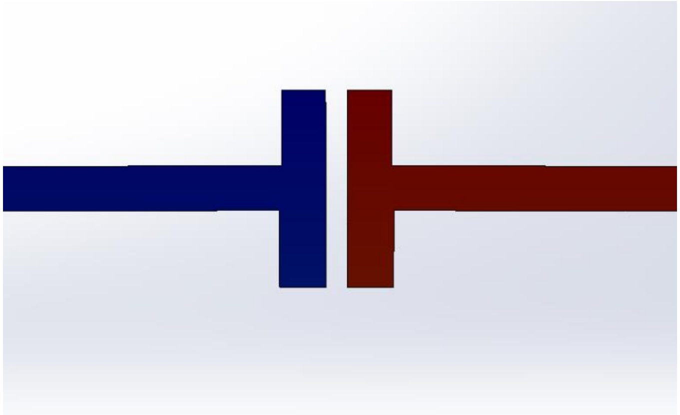


Figure 2-10: Close view of microgripper design

Figure 2-11: Schematic of normally close microgripper design

For the multistage gripper designed in this study, a wide range of actuation was achieved. With an input displacement of 14µm, an output of 525µm was achieved.

2.9 Actuator Selection

Actuators are the essential component in microgripper designing. Actuators produces force which move the arms of microgrippers Among all the available actuators in literature, piezoelectric is most suitable one for our design. Speed, output force, resolution, accuracy, accurate positioning, and low power consumption are the main points which makes piezoelectric actuators accurate for microgrippers. There are some drawbacks of this actuator too like high input voltage requirement, high cost, inherent hysteresis, creep, and low amplification range. Piezo Drive actuator

SA050510 is selected because it is an SPCA type piezo electric actuator which provides a significant actuation displacement of 0-14µm with a. output force of upto 900N. the second factor was its compact size. With a mass of just 2 g, and (5 × 5 × 10) mm^3 volume, it is ideal for fitting with the structure without the need for special modifications.

Figure 2-12: Schematic diagram of piezoelectric actuator

Figure 2-13: Selected Piezoelectric Actuator

2.10 Mechanism of Microgripper

We design 2 stage microgripper to achieve high amplification. An amplification factor of 38 um is achieved with this 2 stage MESO scale microgripper.

2.10.1 Stage 1 Mechanism

Different designs were tested for achieving improved amplification ratio for a single stage first. Solid works is used for designing the stage I amplification mechanism. Each design uses novel structure for amplification.

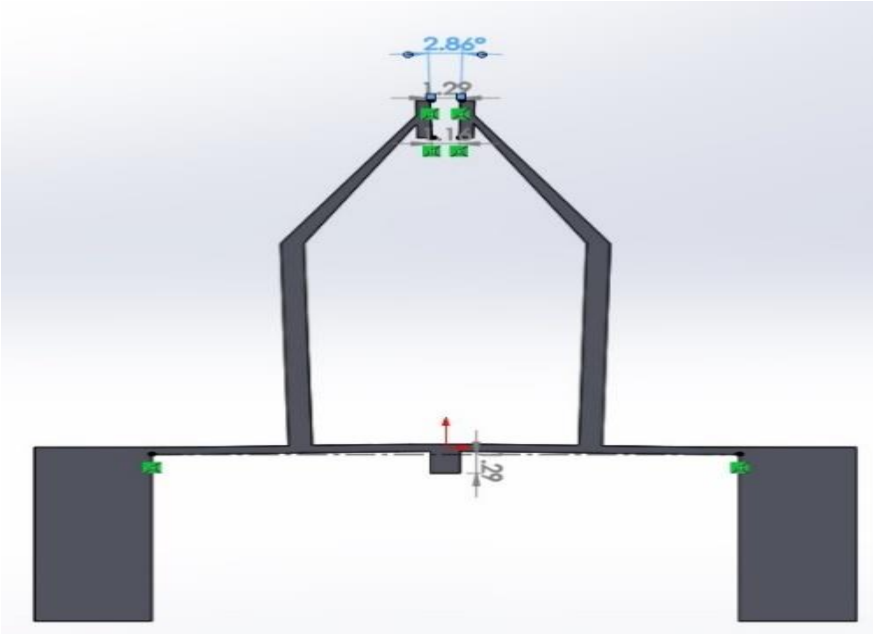


Figure 2-14: SolidWorks design 1 for stage I amplification

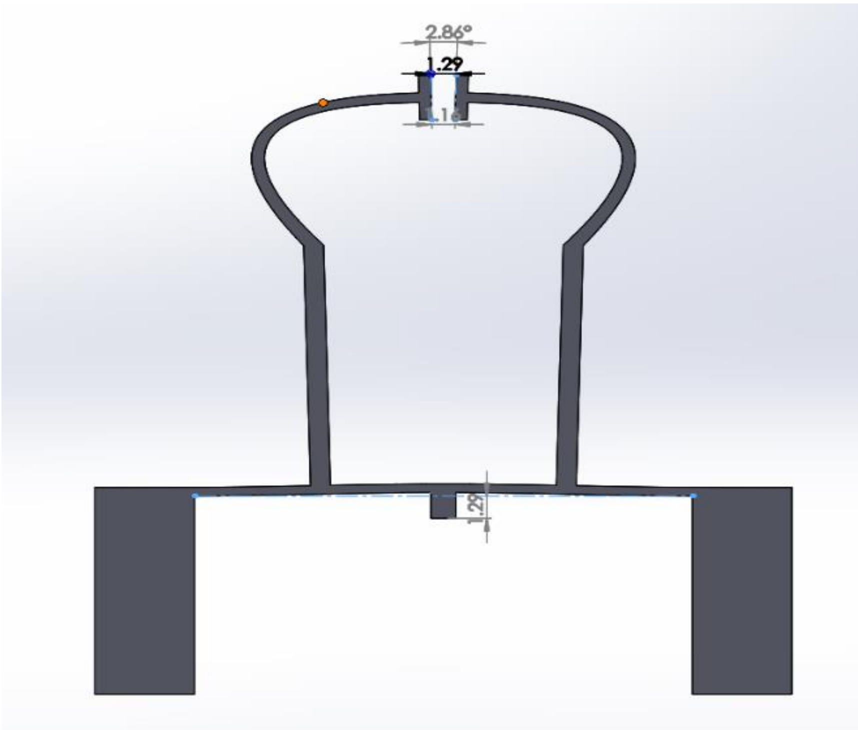


Figure 2-15: SolidWorks design 2 for stage I amplification

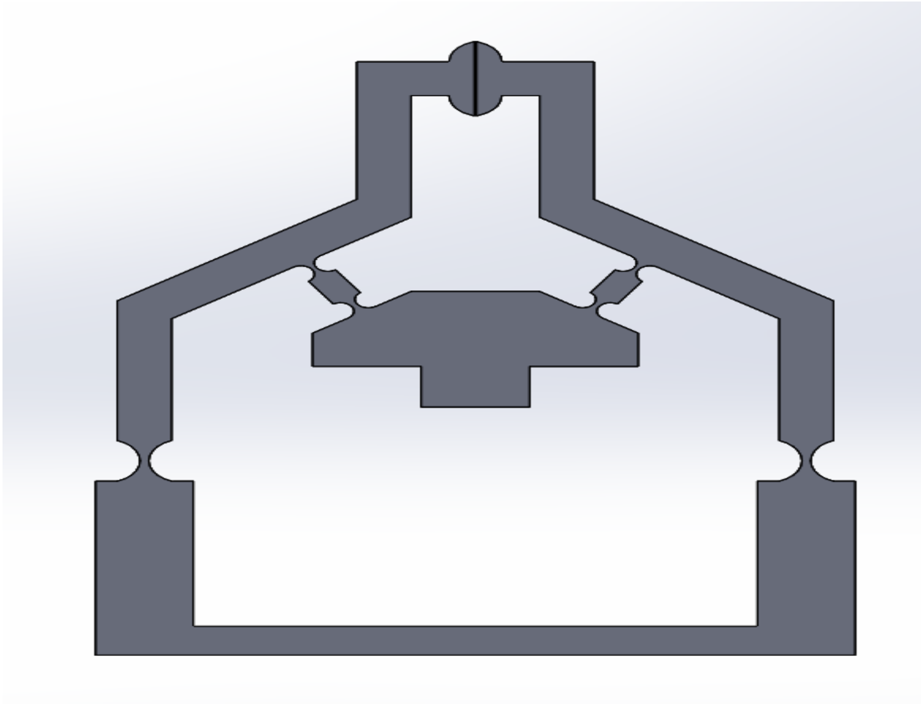


Figure 2-16: SolidWorks design 3 for stage I amplification

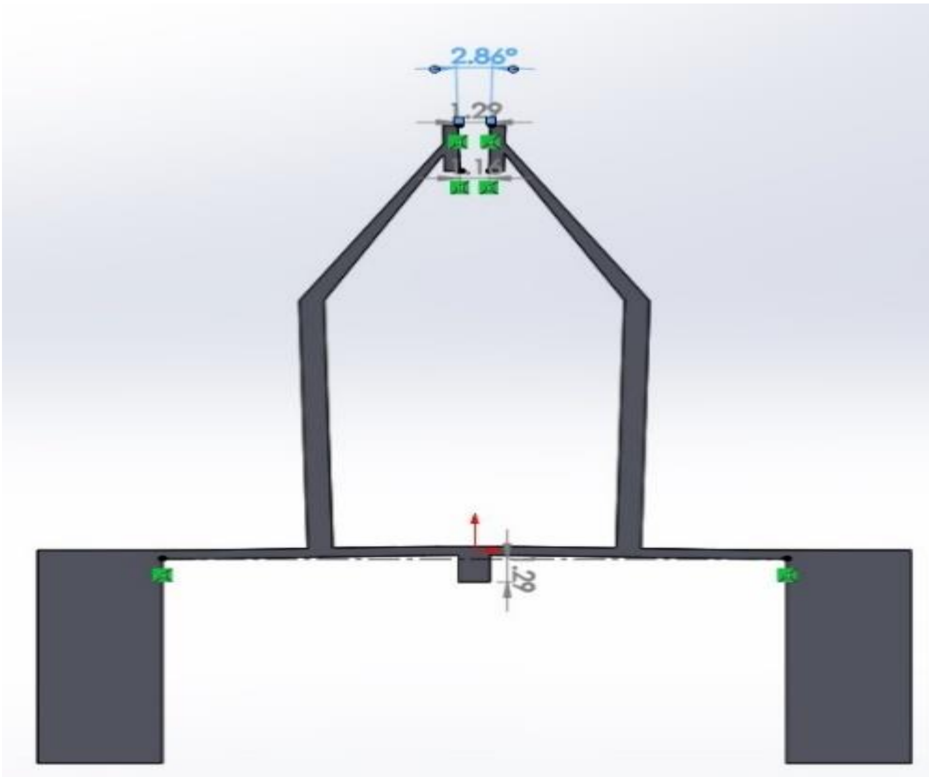


Figure 2-17: SolidWorks design 4 for stage I amplification

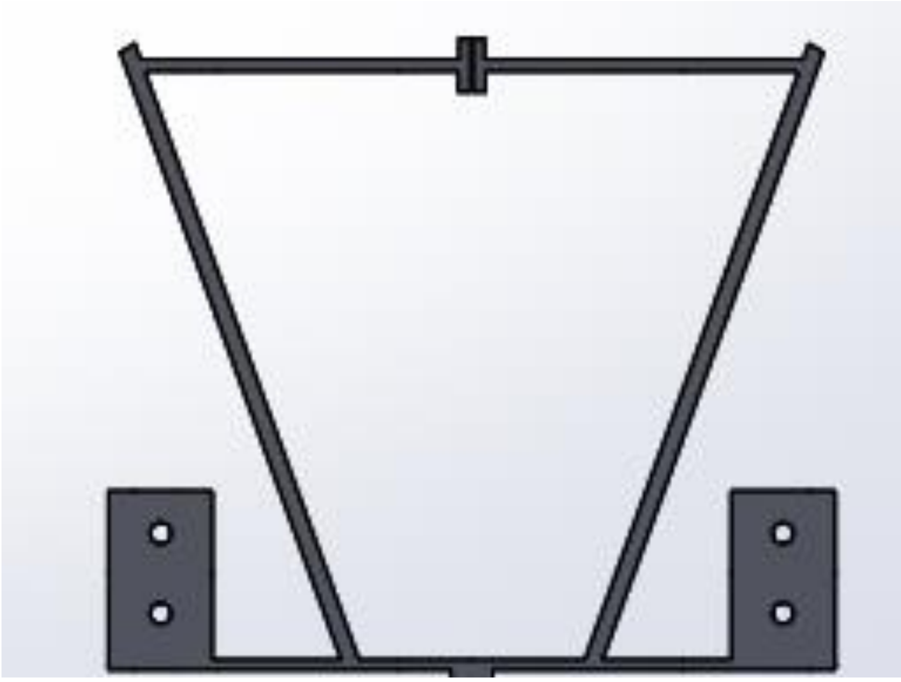


Figure 2-18: Final SolidWorks design for stage I amplification

2.10.2 Stage 2 Mechanism

Just like mechanism I multiple designs were tested for achieving improved amplification ratio for a second stage first. Solid works is used for designing the stage II amplification mechanism. Each design uses novel structure for amplification.

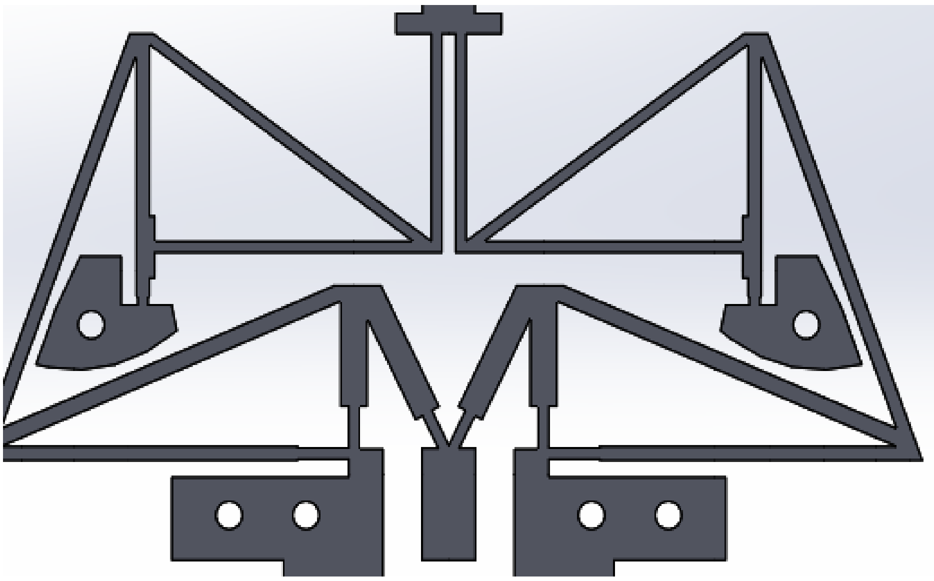


Figure 2-19: Stroke type design for stage II amplification

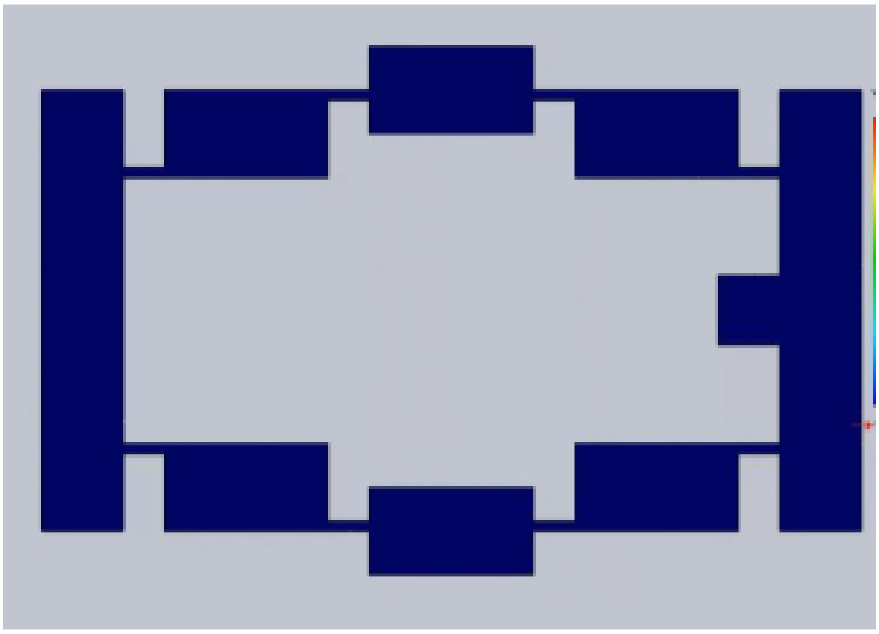


Figure 2-20: Bridge design for stage II amplification

2.10.3 Microgripper Design with PZT Actuators

The complete design of two stage amplification is shown in figure 2.17. Solid works is used for assembling of two mechanisms. Each mechanism is made in separate file than these files are join in solid works using assembly module.

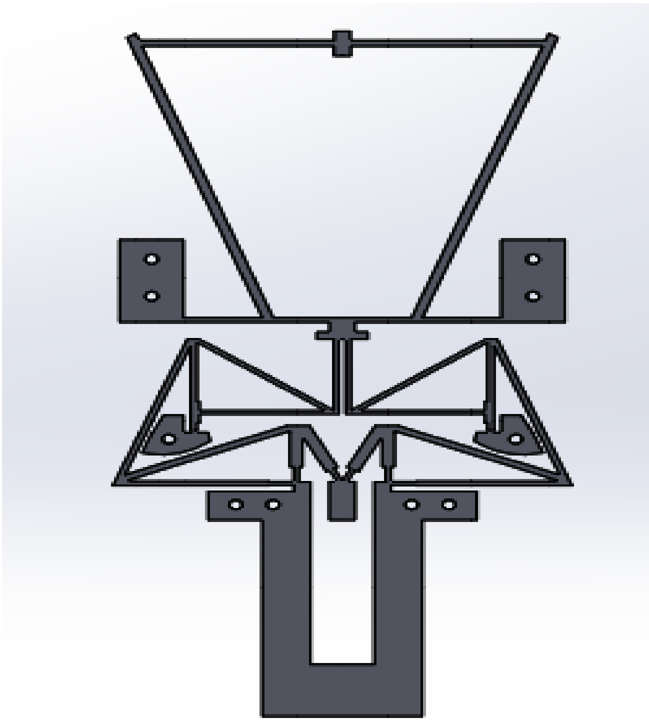


Figure 2-21: Schematic of complete design of two stage amplifier

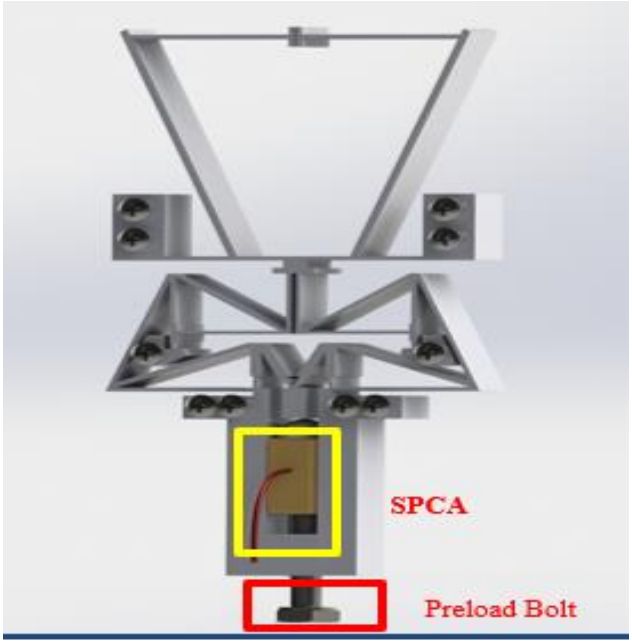


Figure 2-22: Schematic of complete design with PZT actuator.

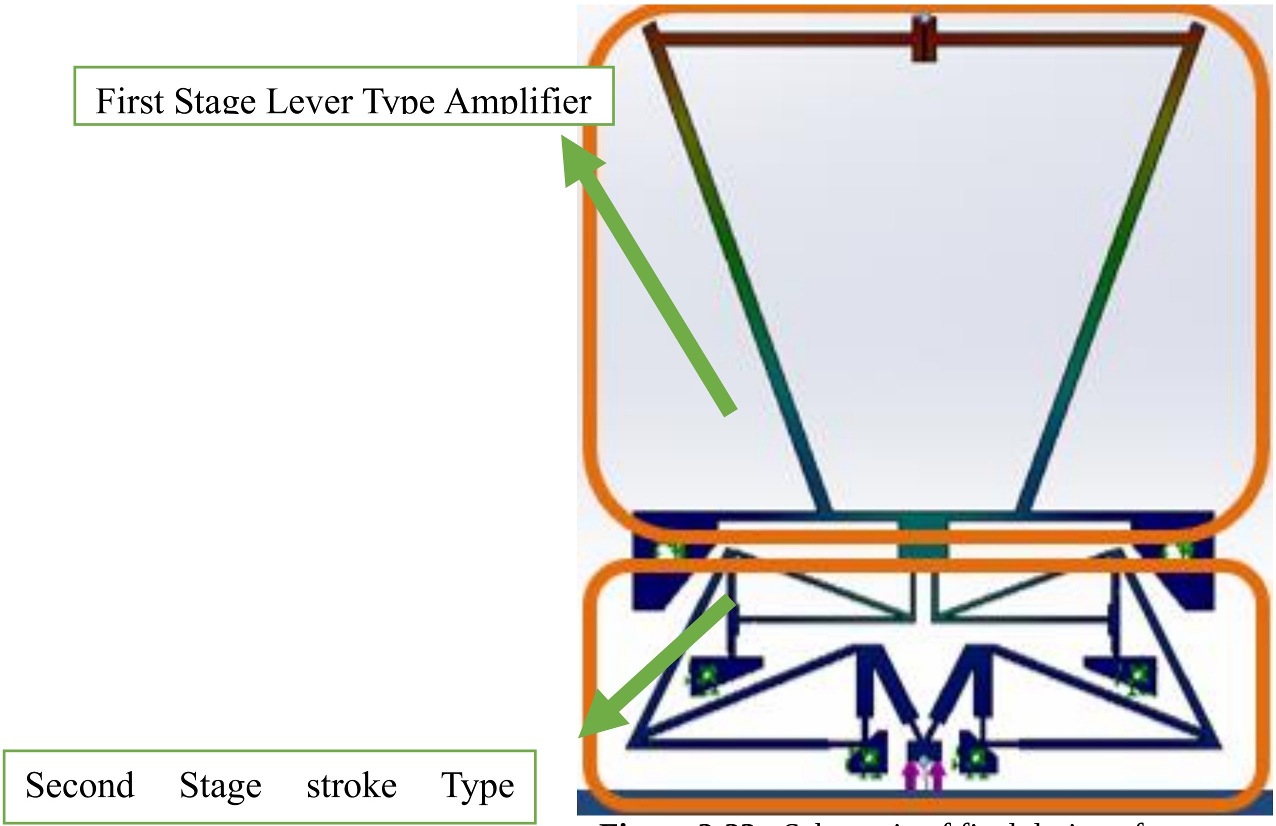


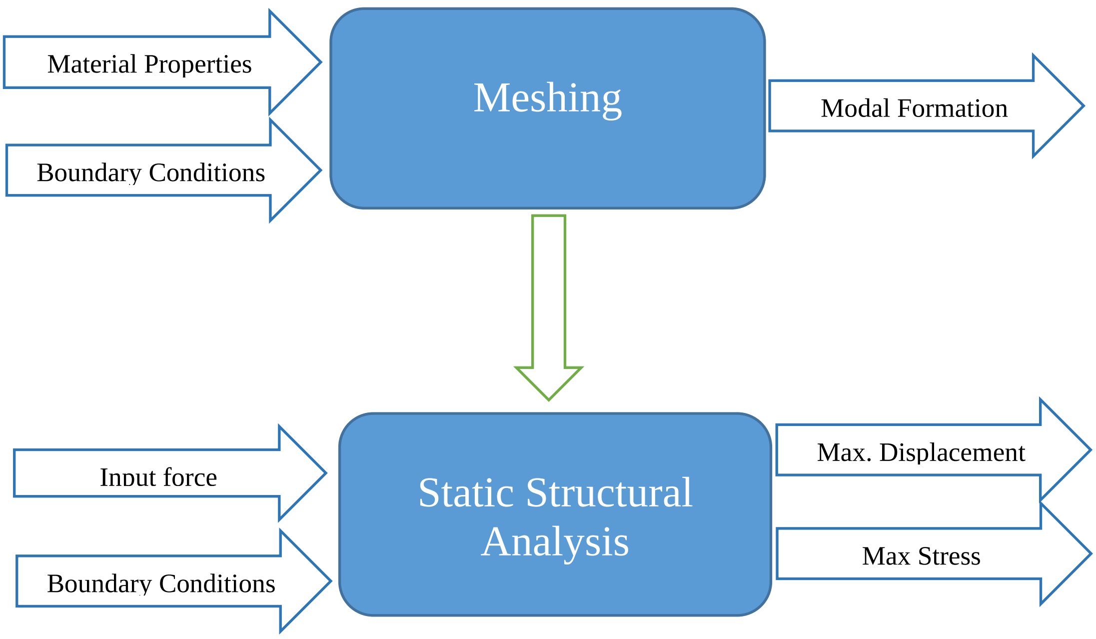
Figure 2-23: Schematic of final design of two stage amplifier

Chapter 3: Solid Works and Finite Element Method Based Modelling

Solid works and Finite element method involves the computational method to investigate the technical issues in modelling and mathematical part. Solid works modelling involves static structural analysis only while FEM analysis method includes structural analysis, fluid flow analysis, heat transfer analysis, and Electro thermal and thermos-mechanical analysis which computes results based on magnetic attraction potential. We solve static structural analysis to calculate stress analysis in microgripper structure.

3.1 FEM Based Static Structural Analysis

Finite element-based analysis is done for 2 stage microgripper amplification. FEM analysis is the numerical solution to solve the mathematical equations and verification of the mathematical model results. The whole geometry is divided into small portions. Mathematical equations are solved for each portion executing thousands of simulations runs. Boundary conditions are applied to the structure which results in accurate solutions at output.



The parameters on right side of the flow chart shows the output parameters and the parameter on left side shows input parameters in sequential diagram of FEM analysis.

To perform the analysis ANSYS 12.1 software is used. The geometries used in ANSYS were imported from Solid works software.

3.1.1 Statis Structure Analysis of Stage 1 Mechanism

Design study was used on each single stage amplified mechanism to find best results. Out of 72 scenario the best optimized design for Max Displacement in X-direction was chosen using SolidWorks Design Study Module.

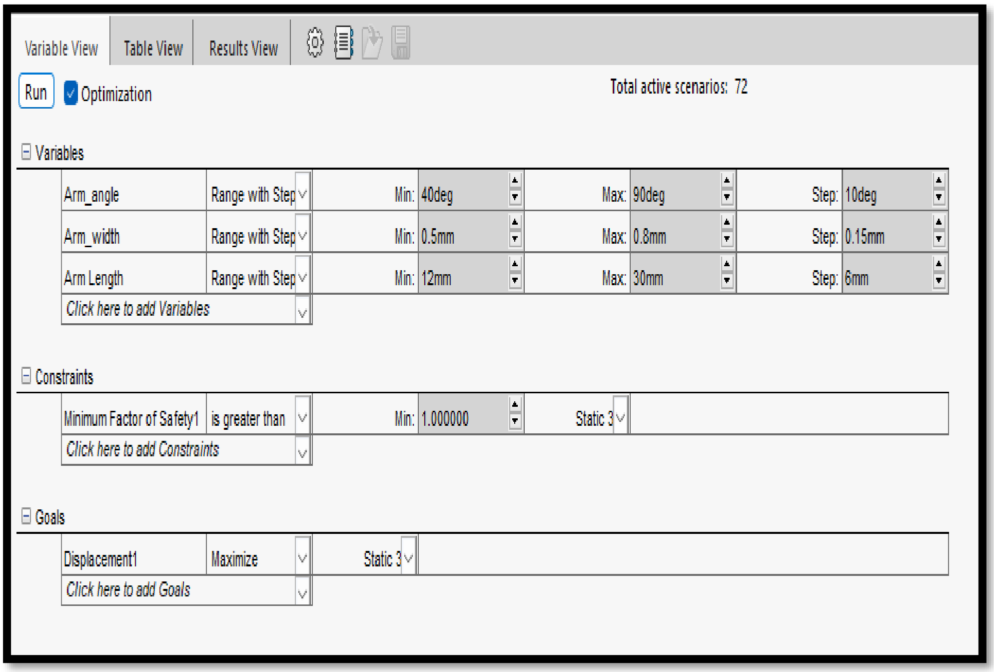


Figure 3-1: Design study screen for PZT actuator

Optimal Solution from Design Study for First Stage Amplification is achieved using solid works optimization module. Following points shows the output parameters of design study of stage I amplification.

- Input displacement: 20 µm
- Output displacement: 212 µm
- Amplification Ratio: 10.6

At input of 20 µm single stage amplifier gives an output of 212 µm with an amplification ratio of 10.6. This is the best design that could be achieved after optimization for stage I. All the values of input parameters are set according to optimization results.

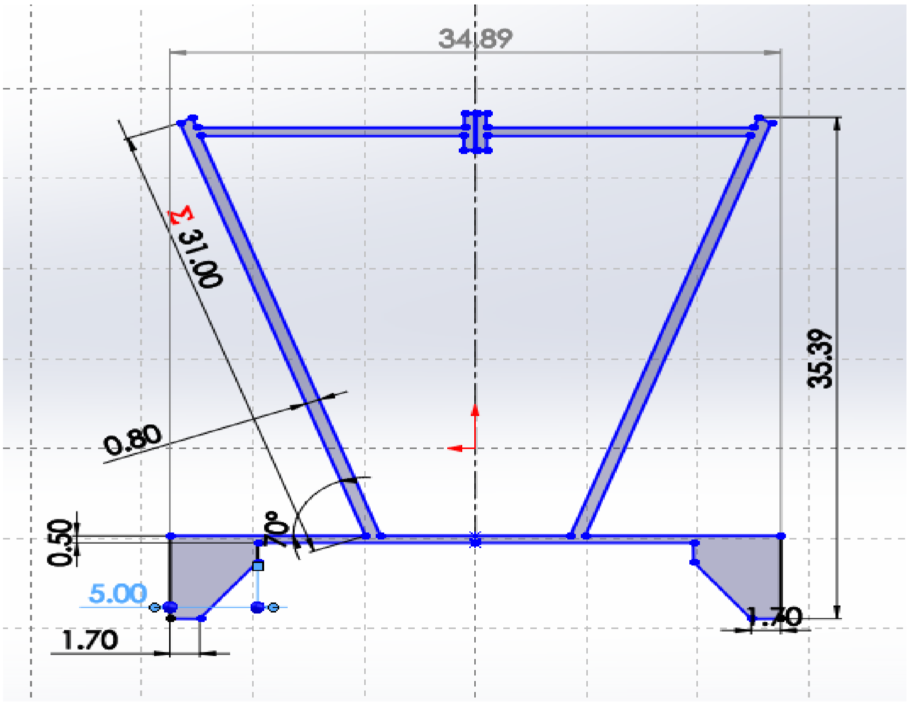


Figure 3-2: Analysis of design study for first stage amplification

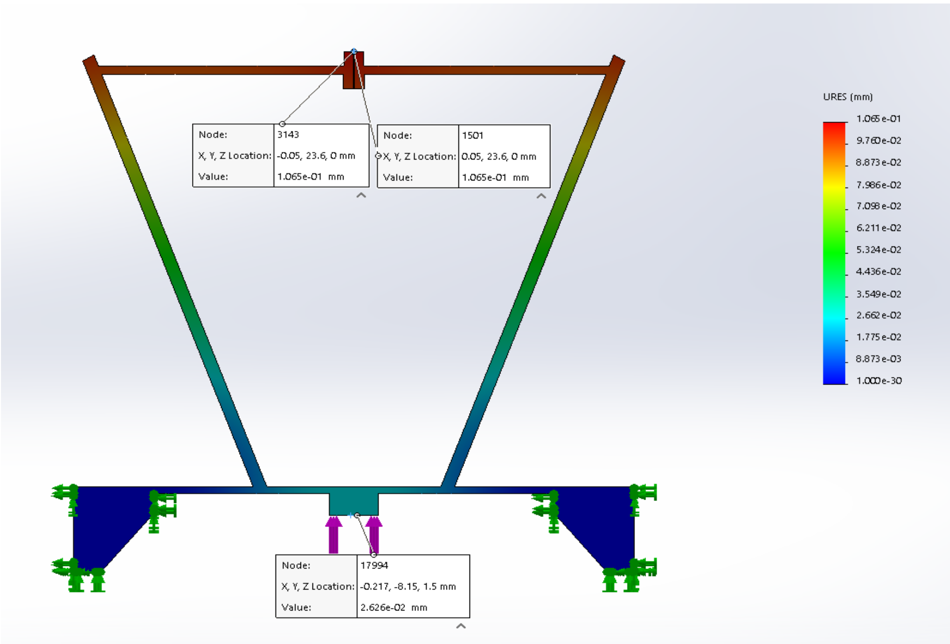


Figure 3-3: Solid works analysis of design study of stage I.

3.1.2 Static Structure Analysis of Stage 2 Mechanism

Multiple designs were tried for second stage amplification of displacement. Stroke type amplification was found most effective but is never used before in mezzo scale microgrippers. Second stage Amplification is also optimized using design study of SolidWorks. Following points shows the output parameters of design study of stage II amplification.

- Input: displacement: 0.297 µm
- Output displacement: 2.393 µm
- Amplification Ratio: 8.05

At input of 0.297 µm single stage amplifier gives an output of 2.393 µm with an amplification ratio of 8.05. This is the best design that could be achieved after optimization for stage II.

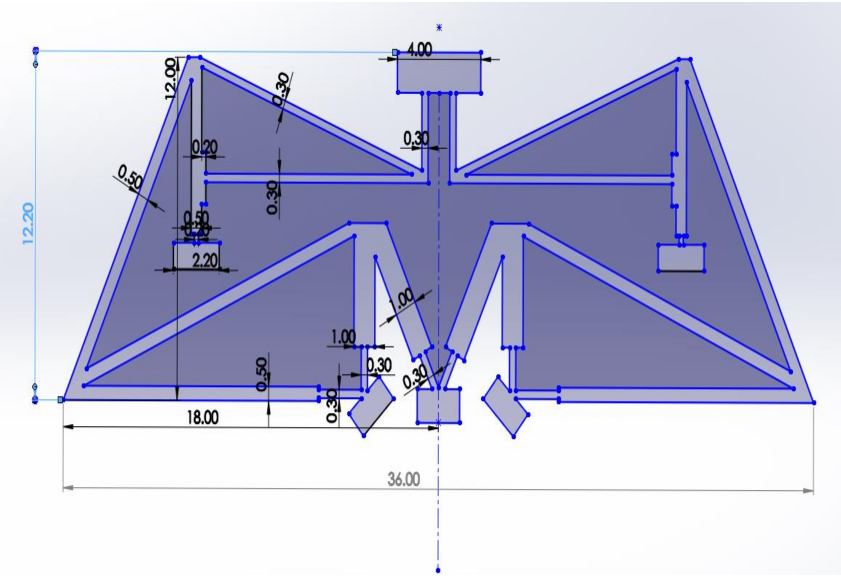


Figure 3-4: Schematic diagram of second stage amplification

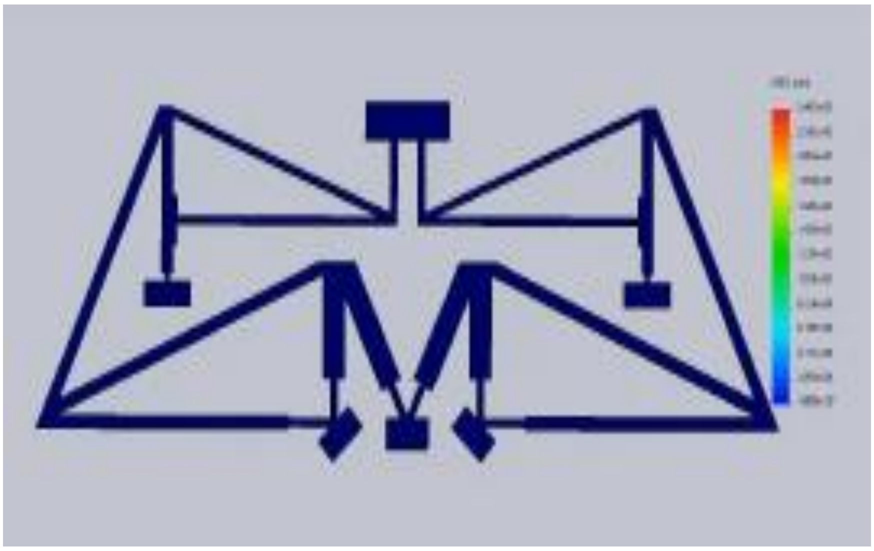


Figure 3-5: ANSYS analysis for stage II amplification.

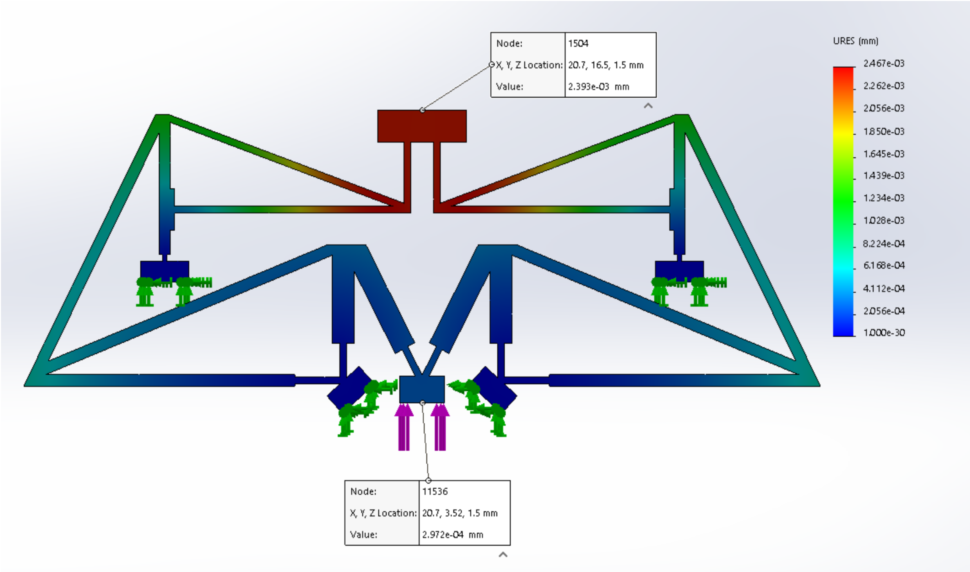


Figure 3-6: Analysis of different design studies for second stage amplification

3.1.3 Static Structure Analysis of Complete Structure

Final design gives amplification ratio of 37.53.

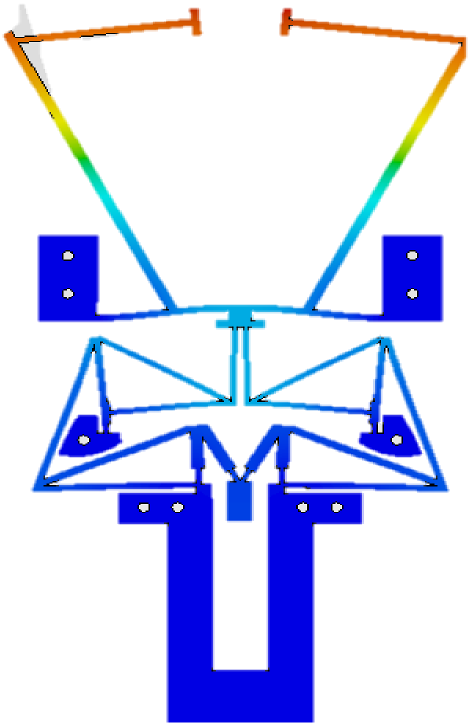


Figure 3-7: Analysis of complete design studies for two stage amplification

Final Design of Amplifier is shown in figure 3.7 with following output results.

- Material = SS-316
- Amplification Ratio: 37.53

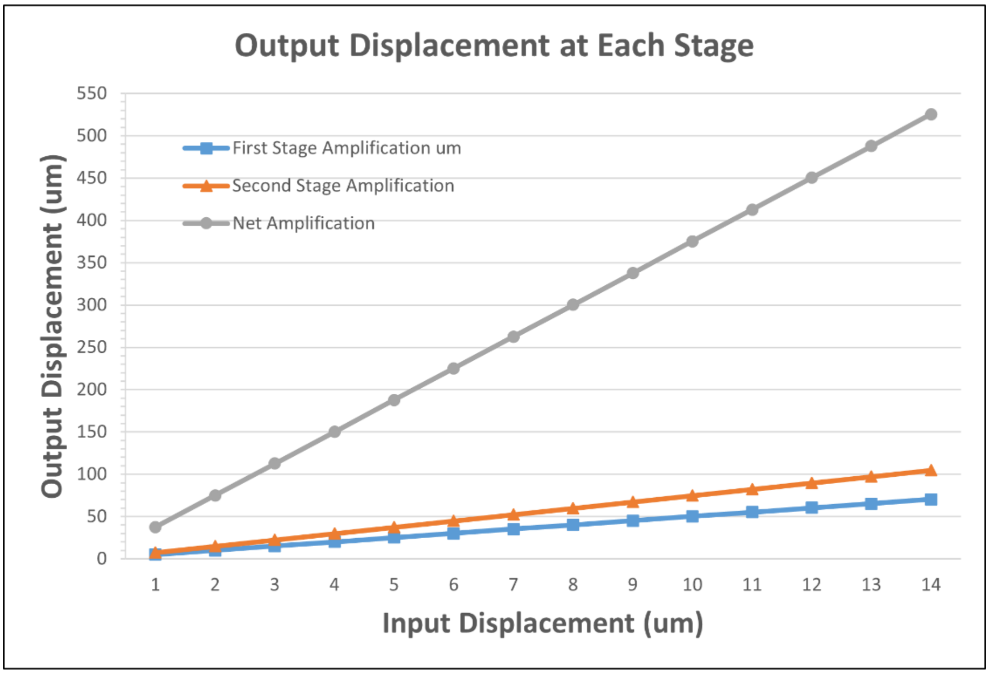


Figure 3-8: Representation of output displacement at each stage.

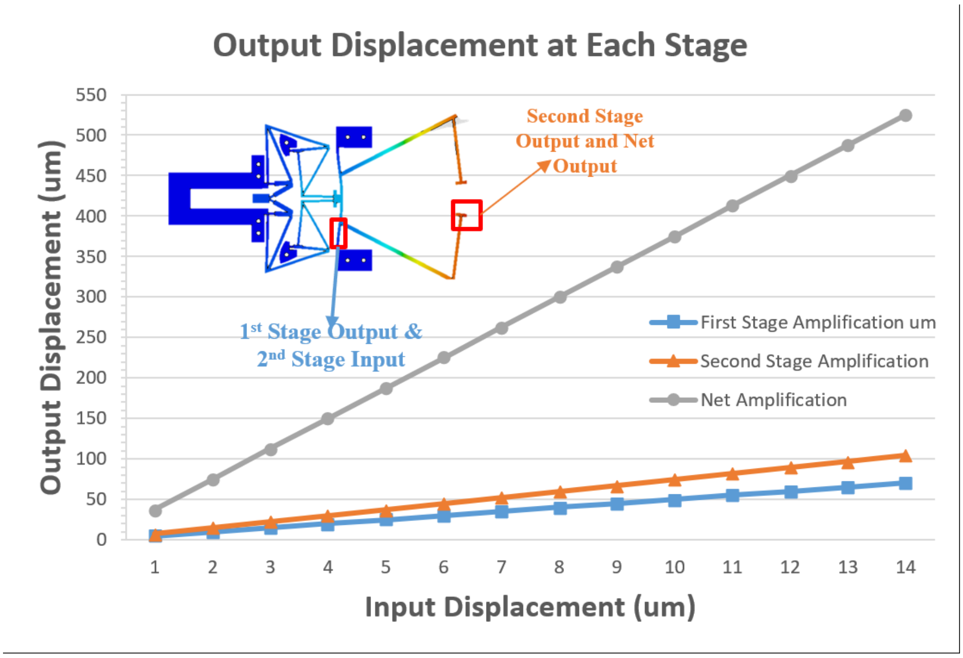


Figure 3-9: Detail representation of output displacement at each stage.

Reaction Force on Input is measured in FEM Ranging between 17.8 N to 249 N

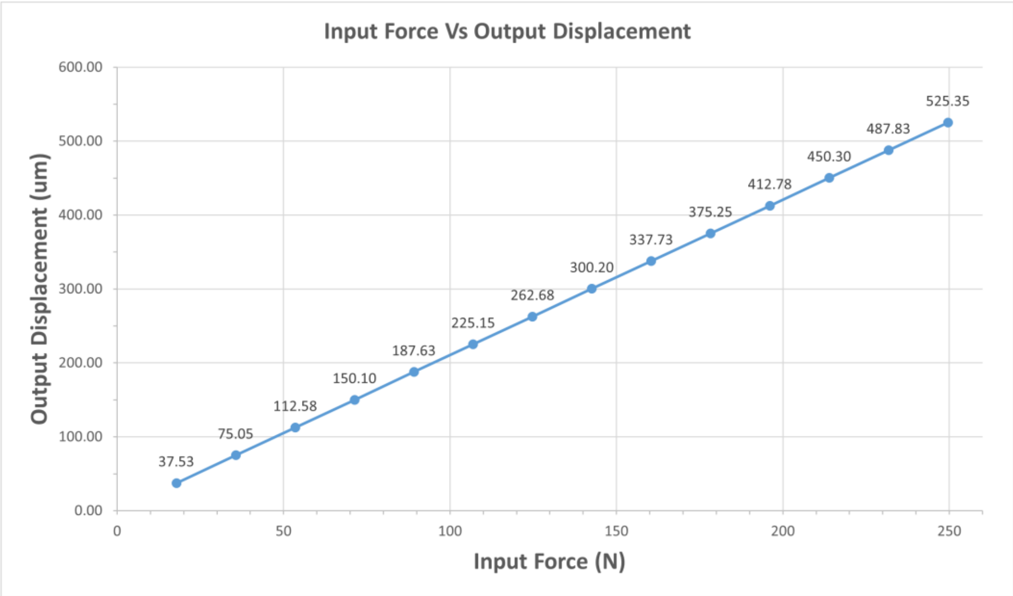


Figure 3-10: Graphical representation of input force Vs output displacement

3.1.4 PZT Simulation in ANSYS

Finite element-based analysis is done for 2 stage microgripper amplification. Finite element method involves the computational method to investigate the technical issues in modelling and mathematical part. FEM analysis is the numerical solution to solve the mathematical equations and verification of the mathematical model results. The whole geometry is divided into small portions. Mathematical equations are solved for each portion executing thousands of simulations runs. Boundary conditions are applied to the structure which results in accurate solutions at output.

Piezo Electric Simulation of structure was done in ANSYS using APDL commands and Piezo Module. Voltages were applied Ranging from 25V to 300V and displacement of 0.26 um to 3.13 um was achieved. Exact specification of Procured Piezo are not known so the exact response could not be replicated. Amplification Factor of the Structure was confirmed to be same.

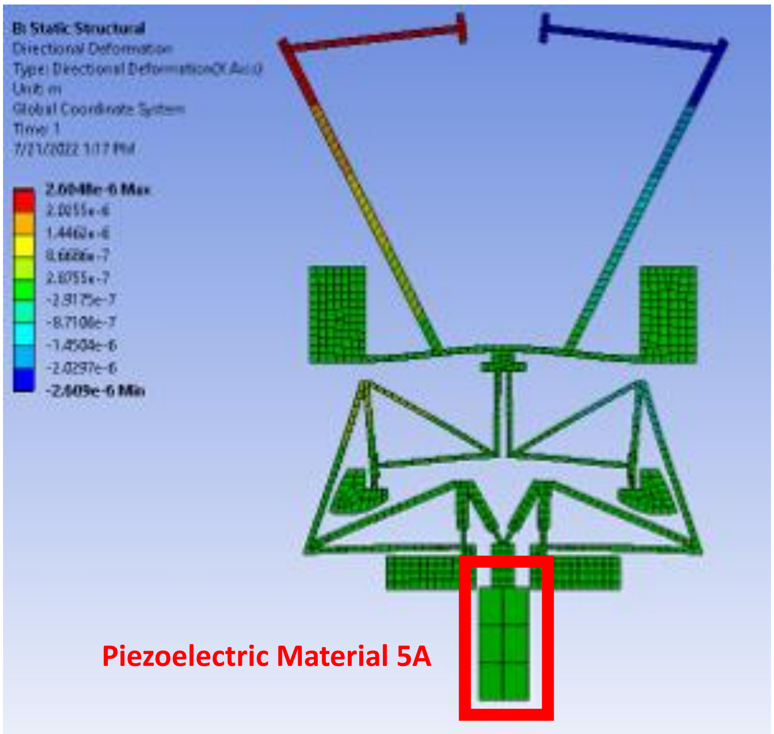


Figure 3-11: Analytical representation of input voltage vs output displacement

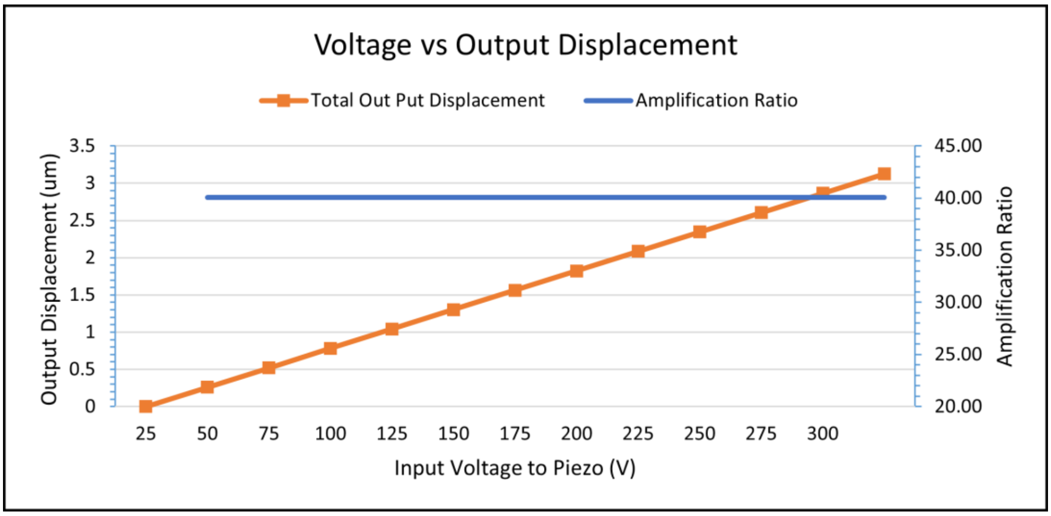


Figure 3-12: Graphical representation of input voltage vs output displacement.

3.1.5 Stress Concentration in ANSYS

Stress Concentration areas are found on flexural hinges (Marked Red in Picture). Maximum Stress (200 MPa) is found when gripper is maximum open (535um). Yield Strength of the structure is (292 MPa). Minimum Factor of safety is 1.44. Highest Stress concentration areas were identified through stress analysis in

Solid works to verify the structural integrity at boundary conditions. Stress concentration areas were found to be in the flexural hinges. Maximum Stress (200 MPa) is found when gripper is maximum open (535 µm). Yield Strength of the structure is 292 MPa), which means the structure is not in risk of plastic deformation. As per the analysis data, Minimum Factor of safety is 1.44.

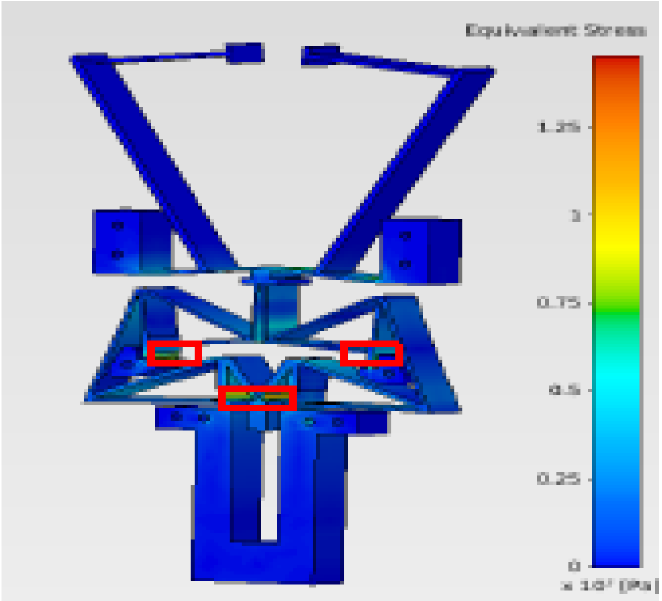


Figure 3-13: Analytical representation of output displacement Vs maximum stress

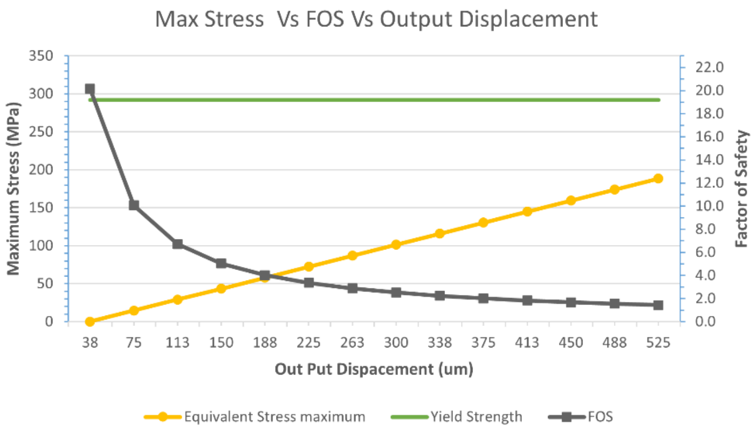


Figure 3-14: Graphical representation of output displacement Vs maximum stress

Chapter 4: Fabrication and Material Selection

In this chapter, fabrication of microgripper with wire cut EDM technique is explained briefly. Material used for fabrication is studied. Experimental results are calculated and compared with analysis results to observe the error in between both outputs.

4.1 Fabrication Process

We use Wire cut EDM for fabrication of piezoelectric microgripper. This fabrication technique is used for cutting narrow angels and more complex patterns. Material selection is an important part in fabrication. As wire cut EDM works for metals therefore we choose aluminum for fabrication

4.1.1 Wire Cut EDM

Wire cut EDM is the great achievement affecting the machining and tooling industry so far. This procedure helps in attaining high accuracy, better quality, and more productivity. In wire cut EDM electric spark is introduced in between work piece and wire electrode. This spark shows the flow to electric current. The spark generation comes with high rise in temperature up to 9000 Celsius which almost melts everything. Controlling this wire electrode needs high precision so that it only effects work piece material. Th diameter of wire electrode is 0.1 mm or 0,3 mm and it is made of copper or bras material. The main purpose of wire cut EDM technique is to provide high accuracy, better stability, and high productivity. Wire cut EDM is a non-conventual process for matching more complex parts which are difficult to manufacture by other conventional manufacturing processes. WEDM can manufacture conducting materials only such as metals like aluminum, brass etc.

4.1.1.1 Working of Wire Cut EDM

Wire cut EDM uses a metal wire electrode which passes through work piece. Monitoring of this wire is done precisely through numerically controlled (CNC) system. Like all other machines, wire cut ED also removes material. It removes material by electric spark erosion process. That’s why conductive material is used for wire cut EDM process. Electrical DC pulses are generated in between work piece and wire of EDM. Figure 4.1 shows the detail diagram of working of Wire cut EDM machine.

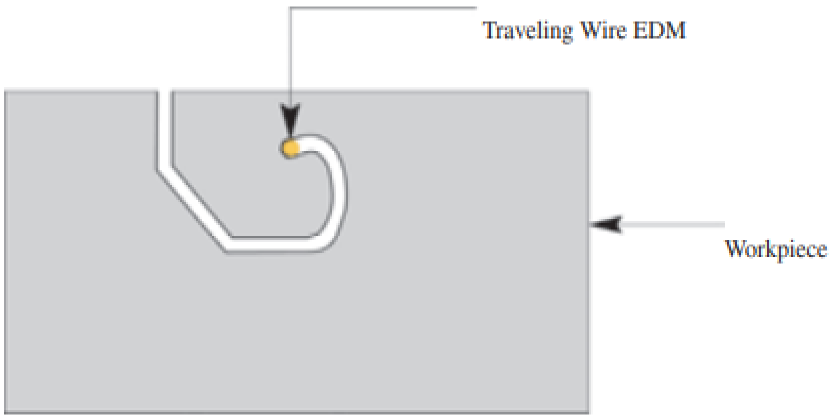


Figure 4-1: Working of wire cut EDM.

A dielectric (ionized water) is placed between work piece and wire. Mineral water is an insulator. This process uses tap water as it contains minerals that causes water to be conductive for process. The conductivity of water is controlled by passing it through resin tank which removes excessive conductive elements. When water passes through tank it is called as deionized water. As the machine starts cutting the water conductivity rises. A pump automatically push water towards risen tank when conductivity level of water rises too high. . Figure 4.2 shows the detail image of working of wire cut EDM process.

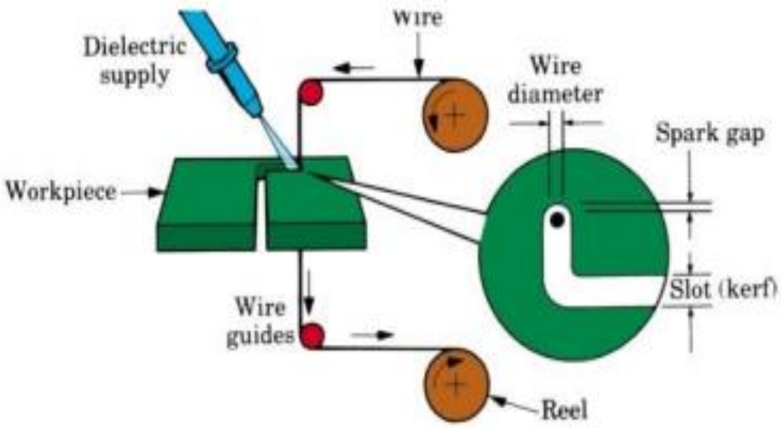


Figure 4-2: Schematic of detailed working of wire cut EDM [20].

Fluid ionizes on sufficient voltage application. After that a controlled spark erodes a smaller portion of work piece forcing it to melt and vaporize at same time. The electrical pulses are than repeated thousands of times per second. Cooling of vaporized metal is done by pressurized cooling fluid that forces the resolidified eroded particles from gap. A filter is used to remove suspended solid particles of dielectric fluid. Resin than removes solid particles and filter removes suspended particles [20]. Dielectric fluid is moved to chiller to have the liquid at room temperature for maintaining the accuracy of machine and part as well. An AC or DC system maintains gap between workpiece and wire. This mechanism helps wire electrode from shorting out against the workpiece. As the wire does not touch the workpiece, therefore this process is stress free. Wire electrode is made of brass, brass and zinc or tungsten material

4.2 Fabrication of Design

Following figure shows the manufacturing process details of wire cut EDM.

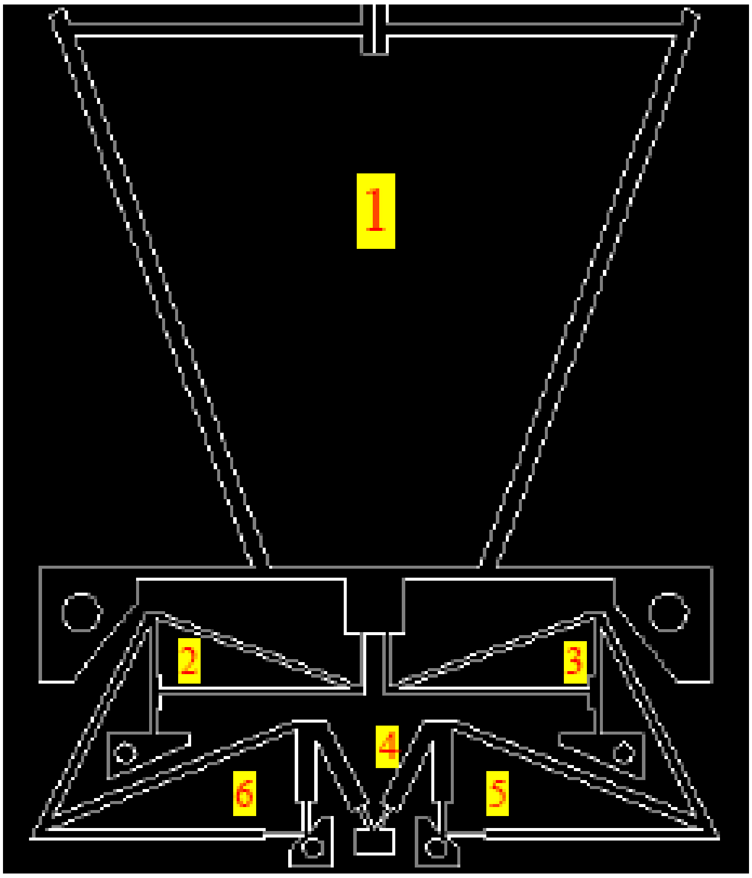


Figure 4-3: Manufacturing process for two stage amplification

Figure 4-4: Image of wire cut EDM machine screen.

Figure 4-5: Wire cut EDM manufacturing process

4.3 Material Selection

As our fabrication process removes material by electric spark erosion, that's why conductive material is used for wire cut EDM process. AS metals are conducting material therefore, we use metals as our material. Most sued metals are aluminum, gold, platinum, and nickel. These metals can be easily deposited by evaporation, deposition, and erosion. In fabrication process metals can be used for interconnectors, structural material and for electrodes as well. Metals used in actuators provides large displacement due to high coefficient of thermal expansion and they require less power for large stroke. Fabrication of metals are simple, and their fabrication cost is low too. Their deposition on electrical board is easy. Material properties of stainless-steel and aluminum are compared for selection of our material. Initially Aluminum was selected for the above stated reasons. Three different alloys of Aluminum were used due to uncertainty of manufacturing constraints on such a scale. Following three locally available alloys were chosen for fabrication.

SS-316 is chosen in material selection due to these properties and due to its anti-rust properties.

4.3.1 Aluminum & its Manufacturing limitation:

The cutting of very small thicknesses is difficult. Multiple attempts were made to manufacture it in Aluminum. Aluminum and its manufacturing limitation:
Three different Aluminum Alloy were used for cutting operation

- 1100
- 5083
- 2024

But due to limitation of machining operation in Pakistan and poor quality of material they keep on breaking. (Attempts to cut with Aluminum are still ongoing)

Figure 4-6: Structures of manufactured designs

Eventually considering the constraints of available fabrication technologies and facilities, steel was selected for testing and similarly three different alloys of steel were selected for fabrication,

Figure 4-7: Structures of raptured manufactured designs.

4.3.2 Manufacturing With Stainless Steel

Three different Steel Alloy were used for cutting operation

- 201
- 301
- 316

All three are cut with EDM and 316 is chosen as described above.

Figure 4-8: Manufactured two stage amplifier

Figure 4-9: Manufactured designs of stainless-steel.

Table 4-1 Factor of Safety for different grades of steel

Material	**SS-201**	**SS-301**	**SS-316**
Factor of safety	1.35	1.04	1.44

After successful fabrication, factor of safety was plotted against input displacement and SS-316 was selected for testing due to highest FOS.

Table 4-2: Comparison of Stainless-steel Vs Aluminum.

Input Displacement	**SS - 201**		**SS - 301**		**SS - 316**	
	Total Output (µm)	**FOS**	**Total Output (µm)**	**FOS**	**Total Output (µm)**	**FOS**
1	38.36	18.85	37.60	14.57	37.53	20.14
2	76.71	9.42	75.00	7.28	75.05	10.07
3	115.07	6.28	112.60	4.86	112.58	6.71
4	153.43	4.71	150.20	3.64	150.10	5.04

5	191.79	3.77	187.60	2.91	187.63	4.03
6	230.14	3.14	224.00	2.43	225.15	3.36
7	268.50	2.69	262.00	2.08	262.68	2.88
8	306.86	2.36	300.00	1.82	300.20	2.52
9	345.21	2.09	336.00	1.62	337.73	2.24
10	383.57	1.88	374.00	1.46	375.25	2.01
11	421.93	1.71	412.00	1.32	412.78	1.83
12	460.29	1.57	450.00	1.21	450.30	1.68
13	498.64	1.45	486.00	1.12	487.83	1.55
14	537.00	1.35	524.00	1.04	525.35	1.44

4.4 Fabricated Design

A pre-loading bolt id added to the structure. The purpose of this bolt is to adjust any free play between fitting of SPCA and structure. M-1.5 × 13 bolts are used for fixing. Base plate is prepared from Aluminum and is threaded for M1.5 bolts.

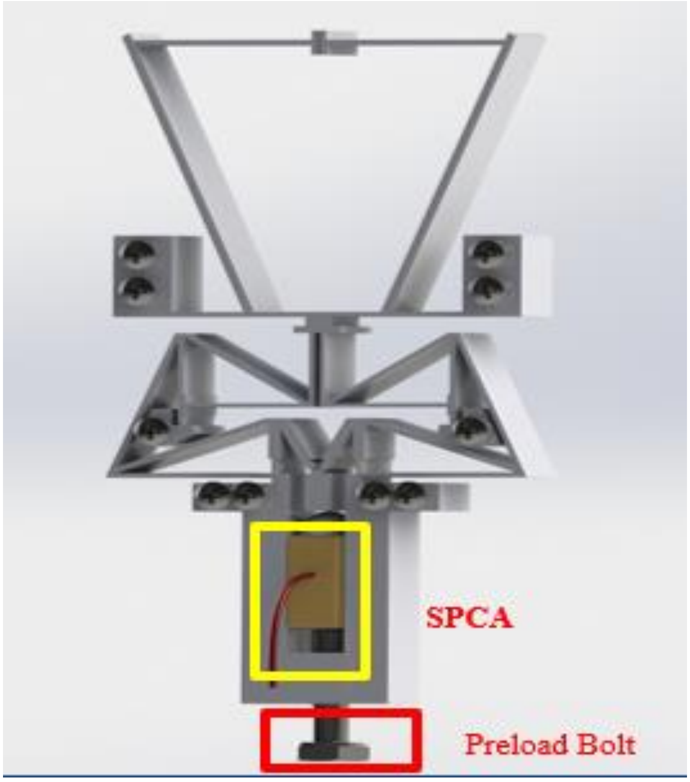


Figure 4-10: Two stage amplifier with PZT actuator.

Chapter 5: Experimental Results and Discussions

All the results calculated from solid works modeling and from ANSYS simulations are compared with experimental results. A complete setup was made to take readings of amplifier. A high-quality camera is required to capture the results of two stage amplifier.

5.1 Assembly of Complete Design

Assembly of the structure with base plate is complete. For installation of Piezo one bolt for pre-loading is installed on bottom to fill gap. For installation of Piezo one bolt for pre-loading is to be installed on bottom to fill gap. The hole for this bolt is to be done in y axis. This bolt will be fitted, and then Experimental results will be added here.

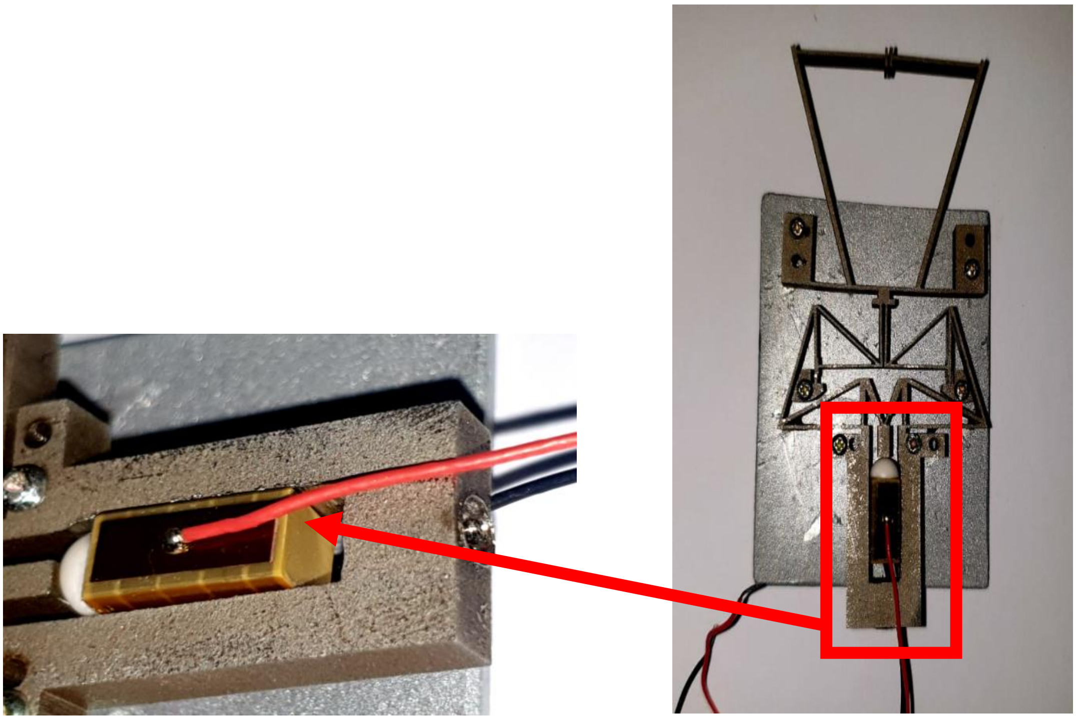


Figure 5-1: Installation of PZT actuator

5.1.1 Verification of Results

For testing, setup was made as follows

- SS 316 was mounted on base plate
- Force meter was used to give input force to the structure

- Force meter specifications: 500 N Range, Resolution: 0.1 N
- Camera Specifications: 12 MP, f/1.5-2.4, 26mm (wide)
- Digital Image Correlation (DIC) method was used to measure the results of amplification.

Figure 5-2: Testing Arrangement using Force Meter.

Figure 5-3: Close view of testing Arrangement using Force Meter,

5.2 Digital Image Correlation

DIC is a way to check and measure changes in two images and could also be used to measure and relate different parameters in a same picture. It uses pixels of pictures to measure and correlate with other pictures. For measurement using DIC we need to provide a scale or measurement information inside picture so that each pixel length could be calculated by software.

Error in DIC could be caused by invalid color scheme/light conditions, camera noise, human errors etc. GOM Correlate was used in this work for DIC. GOM Correlate is a software provided by Zeiss. It is provided with free access for 2D image correlation. For DIC we need to apply stochastic pattern to study area. Stochastic pattern was applied to study areas as shown below. For measurements of results Digital

Image Correlation (DIC) method was used to measure the results of amplification GOM CORELATE by ZEISS was used for image processing and distance calculations.

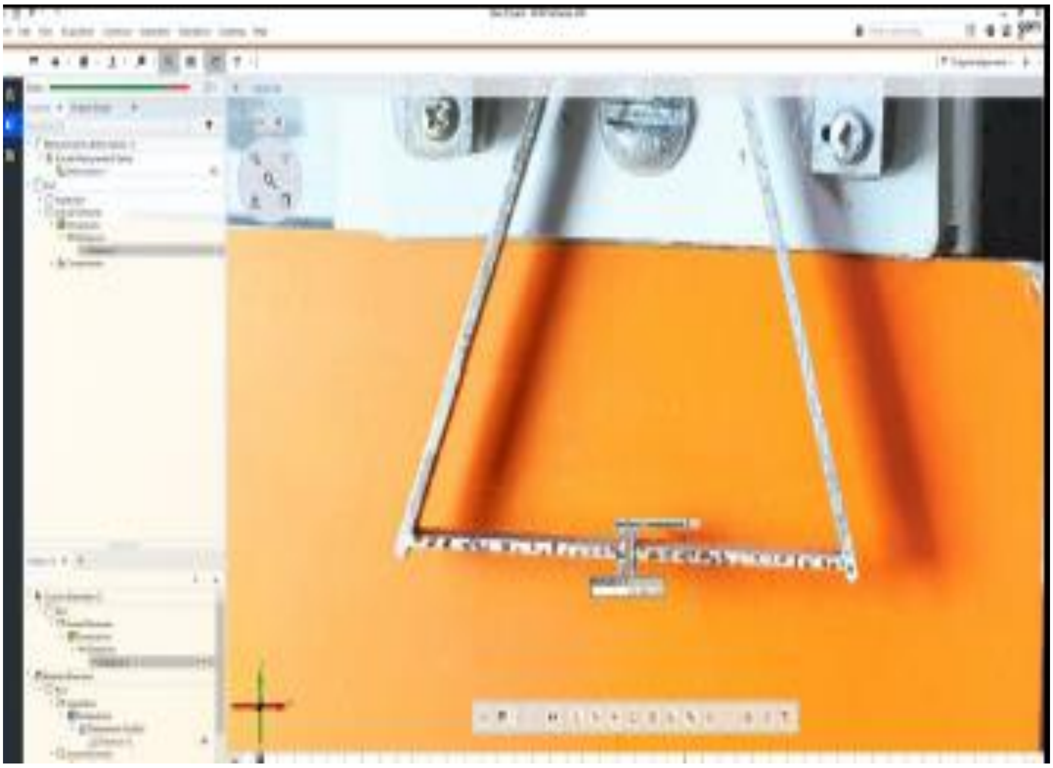


Figure 5-4: Distance measurement using DIC.

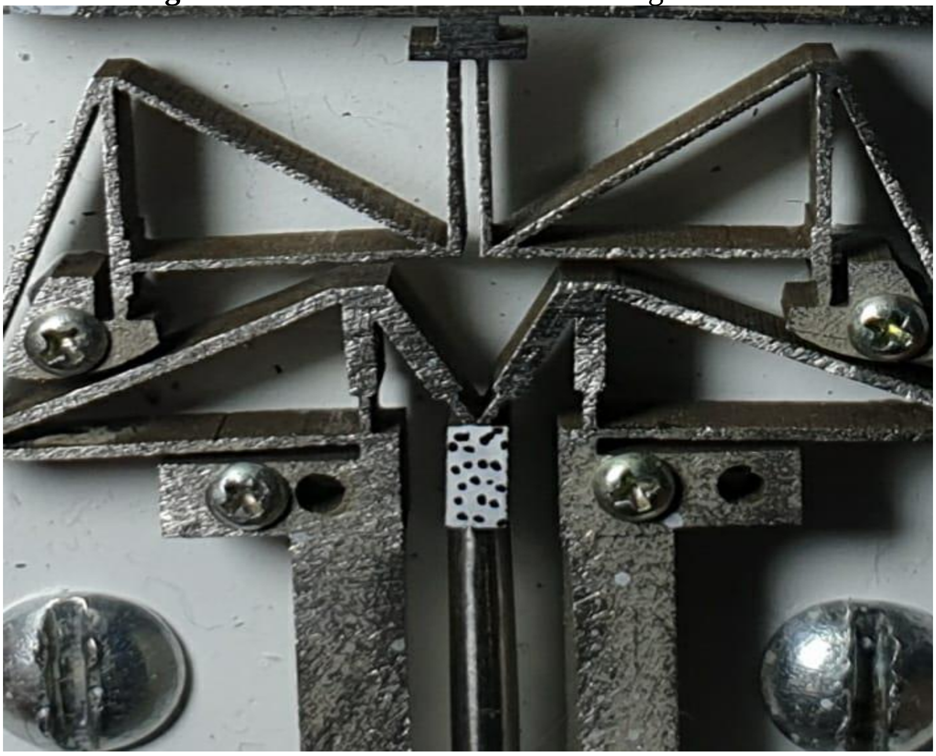


Figure 5-5: Detail Image of second stage amplifier in DIC (Stochastic Pattern).

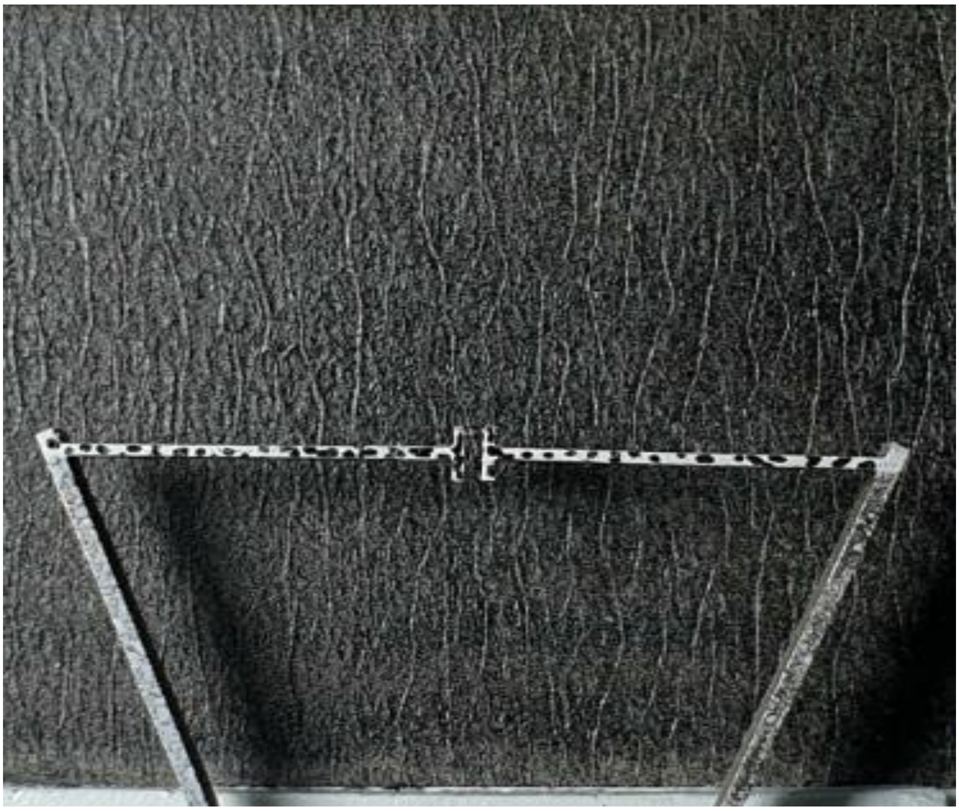


Figure 5-6: Detail Image of microgripper amplifier in DIC (Stochastic Pattern)

5.2.1 Experiment No 1

Multiple experiments were conducted to verify results. Results of two experiments are shared. Input force was applied and varied between 20 N and 230 N to get output displacement.

Table 5-1: Data of experiment 1 of DIC.

Sr	Input Force (N)	Output Displacement (um)
1	20	29
2	40	62
3	57	112.3
4	80	175
5	109	237
6	140	306
7	180	374

8	190	417.2
9	200	426
10	230	477.8

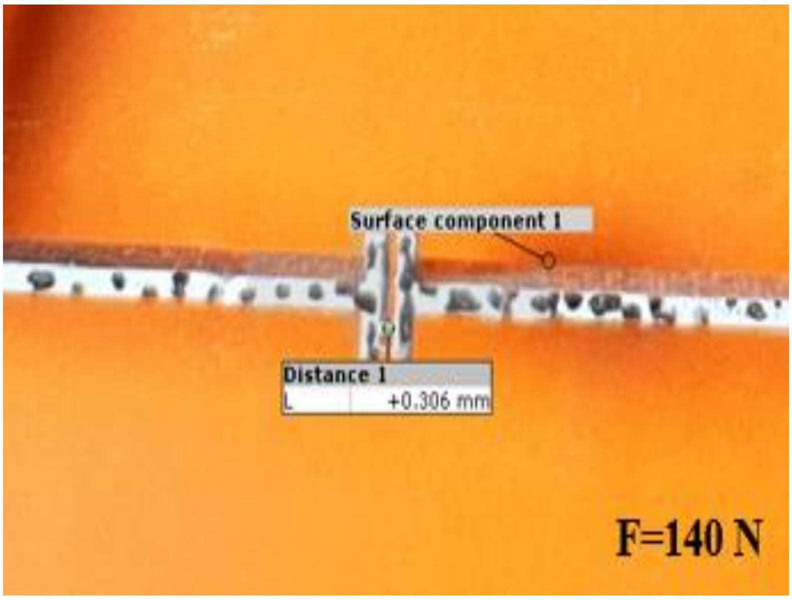


Figure 5-7: Detail image of output displacement calculation using DIC

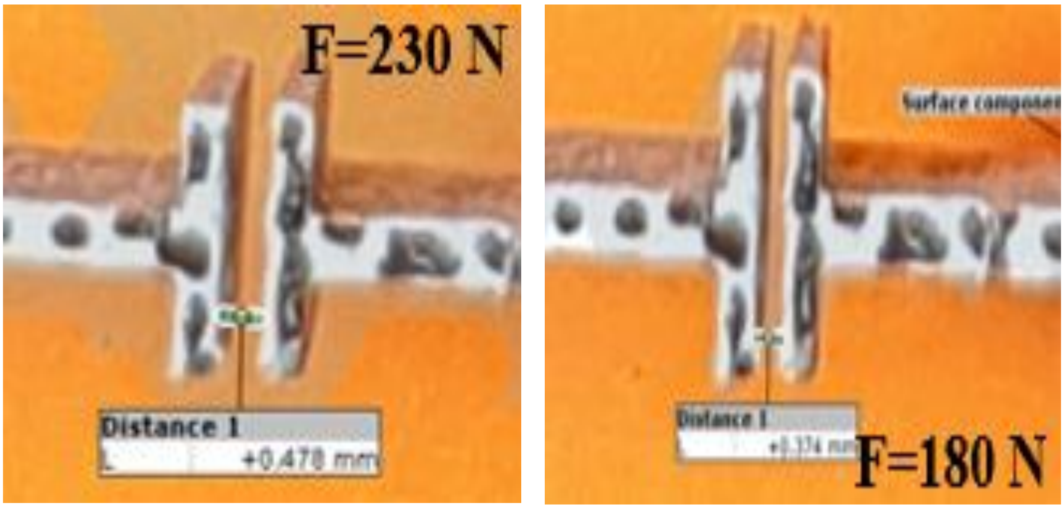


Figure 5-8: Image of output displacement calculation using DIC.

Following figure shows the graph of input force vs output displacement for experiment 1 results.

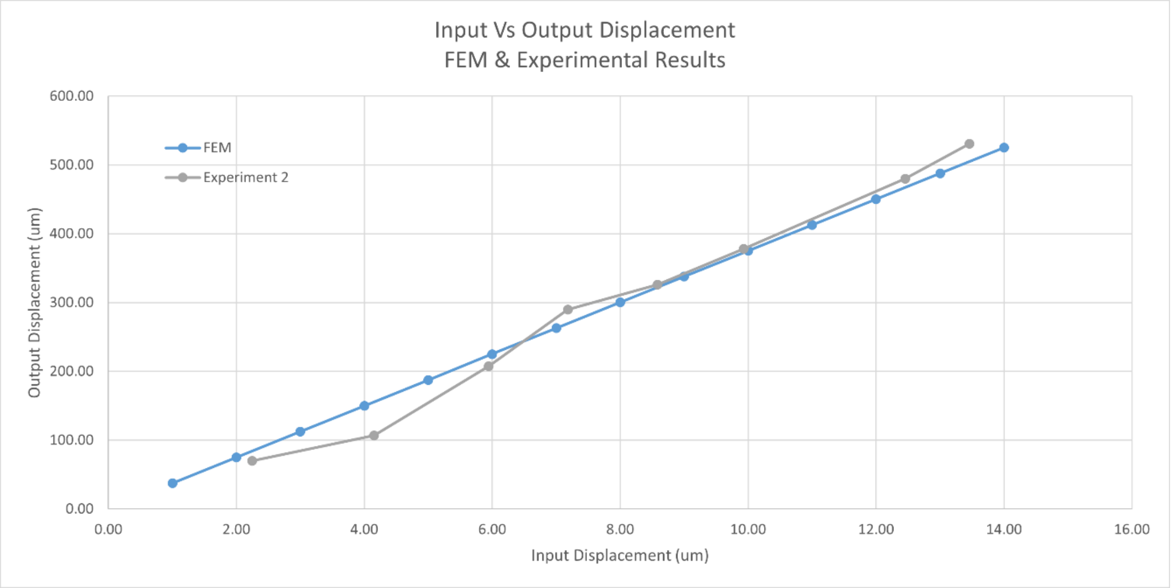


Figure 5-9: Graph of input force vs output displacement for experiment 1.

5.2.2 Experiment No 2

Results of another experiment are shared here. Input force was applied and varied between 40 N and 240 N to get output displacement.

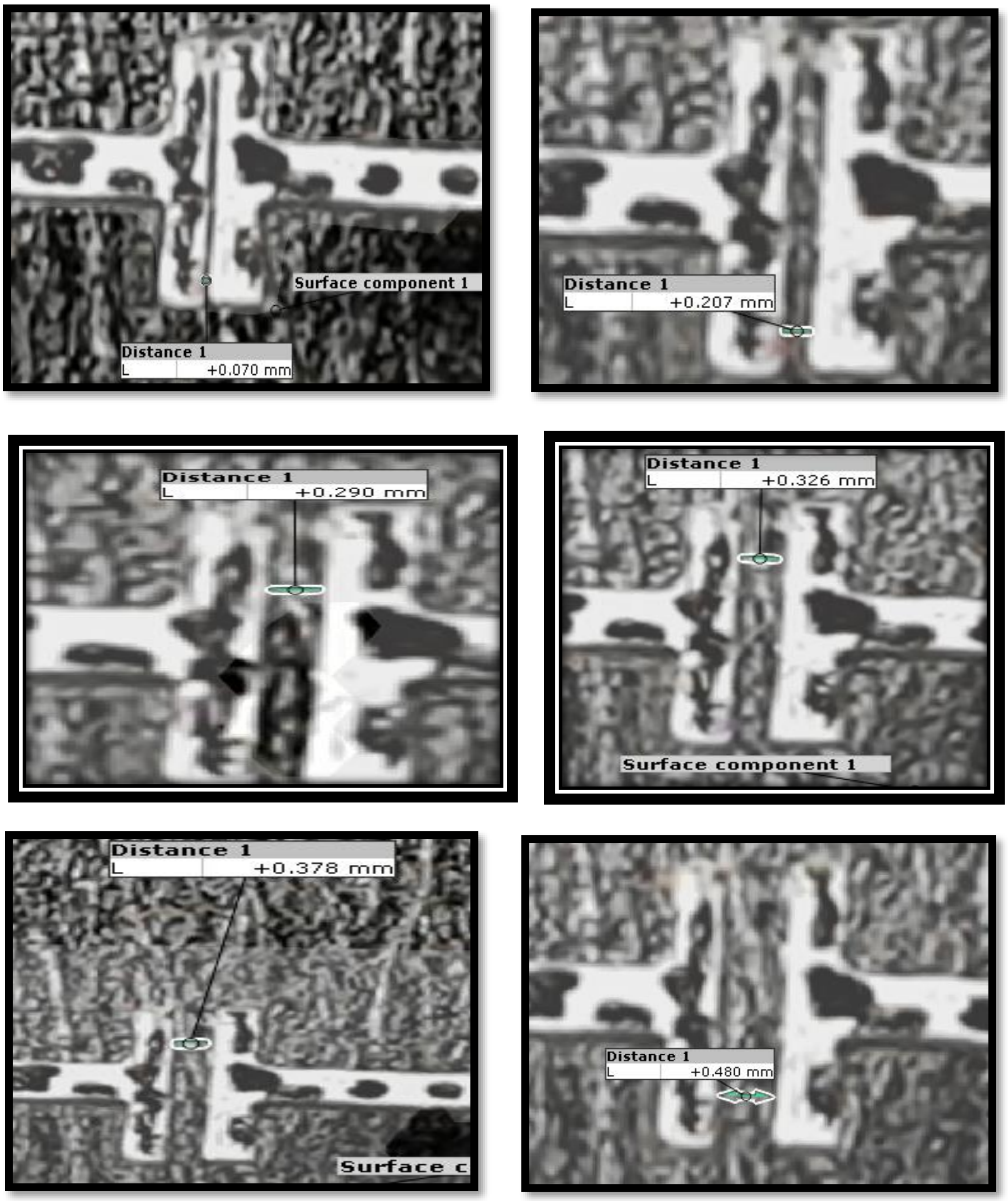


Figure 5-10: Output Displacement calculation images using DIC.

Table 5-2: Data of experiment 1 of DIC.

S	F (N)	D (um)
1	40	70.2
2	106	207.3
3	128	290
4	153	326.3

5	177	378
6	222	480
7	240	531

Following figure shows the graph of input force vs output displacement for experiment 2 results.

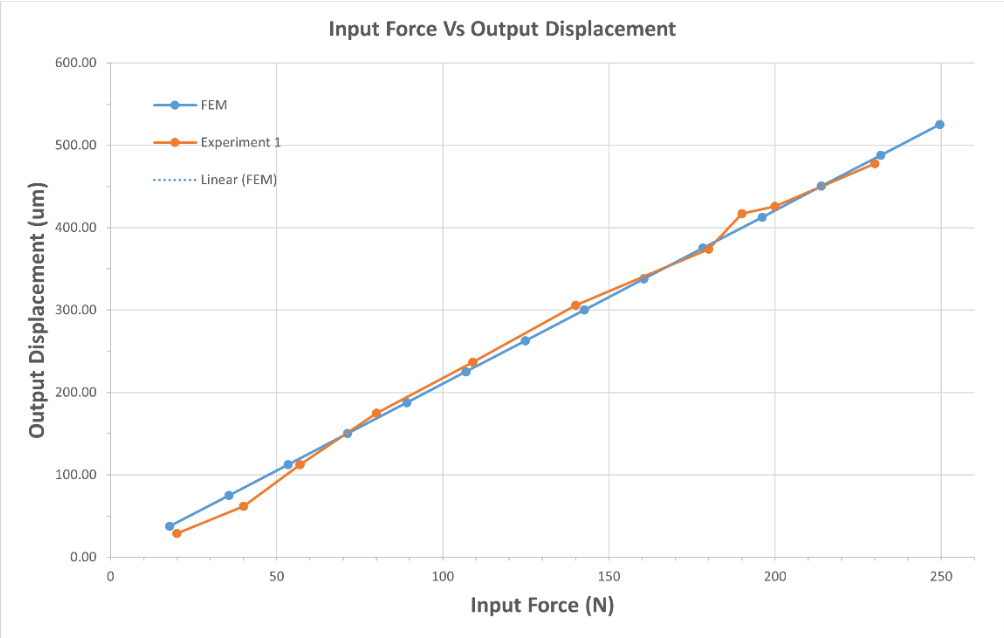


Figure 5-11: Graph of input force vs output displacement for experiment 2.

5.3 FEM Vs Practical Results

FEM and experimental results second each other with a small difference. This difference could be due to difference in machined part and actual design or error of DIC method.

- FEM amplification is a linear line
- Experimental results match with FEM results
- Average error percentage: 9%.

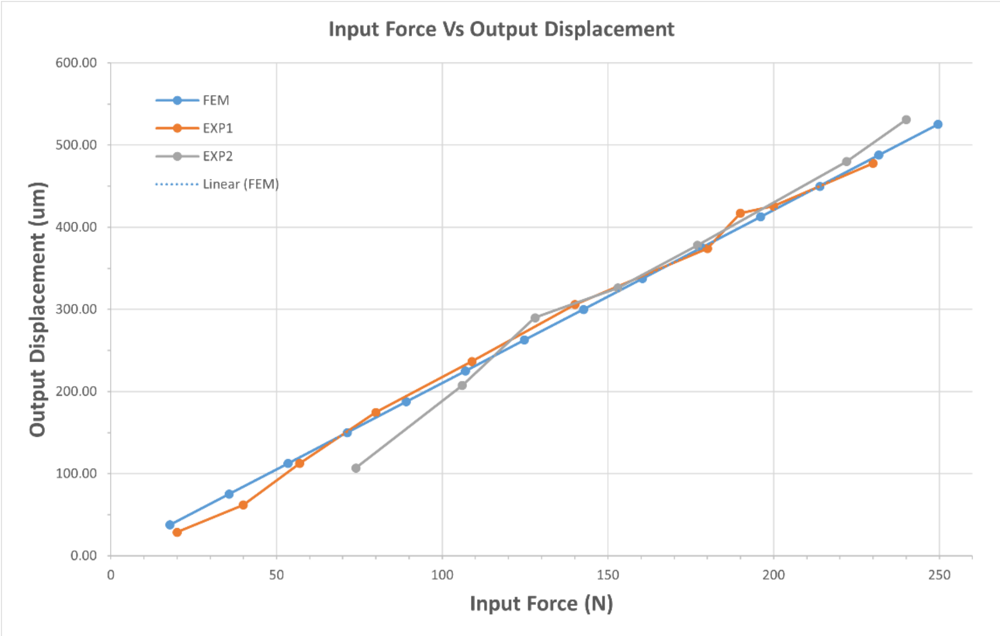


Figure 5-12: Comparison of output displacement (FEM vs experimental results)

Below table provides a comparison of this work with available literature in different parameters.

Table 5-3: Comparison of this work with available literature

Sr	Author	Year	Configuration	Size of Gripper Length(mm) x Width(mm) x Thickness(mm)	Material	Manufacturing Technicque	Actuation type	Amplification Stages	Magnification (Factor)	Design Max Displacement (um)
1	Mehrabi et al	2019	Symmetrical Microgripper	40 x 22	Aluminium Alloy (7075)	EDM	Bending PZT	1	2	300
2	Chen et al.	2019	Symmetrical Microgripper	39.68 x 23.6 x 5	Aluminium Alloy (7075-T6) (SN)	EDM	Stack PZT Ceramic Actuator (SPCA)	2	23.2	235.36
3	Liang et al.	2017	Asymmetrical Microgripper	50.49 x 19.74 x 6 (Approx)	Aluminium 7075-T651	EDM	PZT Actuator	3	13.94	149.4
4	Wang et al.	2019	Asymmetrical Microgripper	59.56 x 28.2	Aluminium 7075-T651	EDM	Stack PZT Ceramic Actuator (SPCA)	2	11.12	85
5	Chen et al.	2019	Asymmetrical Microgripper	68.8 x 34.55 x 5	Aluminium Alloy (7075-T6) (SN)	EDM	Stack PZT Ceramic Actuator (SPCA)	4	31.6	632
6	Nah & Zhong	2007	Symmetrical Microgripper	36 x 30 x 3	Spring Steel / Aluminium	EDM	Piezoelectric Actuator	1	3	170
7	Shi et al.	2021	Symmetrical Microgripper	46 x 27 x 5.5	aluminum alloy 5052-H18	EDM	Stack PZT Ceramic Actuator (SPCA)	3	31.88	218
8	This Work		Symmetrical Microgripper	36 x 51 x 5	SS 316	EDM	Stack PZT Ceramic Actuator (SPCA)	2	37.53	525

Chapter 6: Conclusion

In this thesis report, Development of a meso-scale microgripper with large displacement amplification ratio is presented. In microgrippers we have different design parameters that have impact on performance and use of microgripper. These parameters include Displacement amplification, material of gripper, its range and stroke, jaw shape and parallel motion and whether it is normally open or normally closed. Furthermore, actuation source is also an important parameter.

As title demonstrates, in this work focus is on a large amplification ration. Larger amplification ratio provides high displacement on output for small inputs and is desirable in micro assemblies. A multistage displacement amplification mechanism is used. First stage of amplification was a stroke type amplifier, and second stage was a simple lever type amplifier. Both stages are optimized for maximum deformation using software techniques before assembling them as a single amplifier. A net amplification of 37.53 is achieved from FEM results.

Structure is made of stainless-steel grade 316 which is highly resistant to atmospheric conditions and does not corrode. Parallel jaw motion was a desirable as it provides better gripping. Maximum 0.5° deflection of jaw was observed which is close to parallel. Gripper range is 525 um. Factor of safety is 1.44 at range. Normally closed jaws are adopted it is energy efficient. Motion of both jaws is kept symmetrical. Box volume of micro gripper is 36mm x 51mm x 5mm.

EDM wire cut machining method is used for manufacturing and M1.5 bolts are used for assembly. Preload bolt is provided to remove any free play in structure before actual actuation through Stack Piezo Ceramic Actuator (SPCA). In comparison of literature this is the maximum amplification achieved of 37.53 using two stage amplification.

References

[1] R. Cecchi, M. Verotti, R. Capata, A. Dochshanov, G.B. Broggiato, R. Crescenzi, M. Balucani, S. Natali, G. Razzano, F. Lucchese, et al., Development of micro-grippers for tissue and cell manipulation with direct morphological comparison, Micromachines 6 (11) (2015) 1710–1728

[2] M. Garcés-Schröder, M. Leester-Schädel, M. Schulz, M. Böl, A. Dietzel, Micro-gripper: a new concept for a monolithic single-cell manipulation device, Sens. Actuators A Phys. 236 (2015) 130–139.

[3] R.R. Panepucci, J.A. Martinez, Novel SU-8 optical waveguide microgripper for simultaneous micromanipulation and optical detection, J. Vacuum Sci. Technol. B Microelectron. Nanometer Struct. Process. Meas. Phenom. 26 (6) (2008) 2624–2627. [6] A.P. Vijayasai, G. Sivak

[4] Z. Long, J. Zhang, Y. Liu, C. Han, Y. Li, Z. Li, Dynamics modeling and residual vibration control of a piezoelectric gripper during wire bonding, IEEE Trans. Compon. Packag. Manuf. Technol. 7 (12) (2017) 2045–2056.

[5] W. Ai, Q. Xu, Overview of flexure-based compliant microgrippers, Adv. Robot. Res. 1 (1) (2014) 1.

[6] S.A. Bazaz, F. Khan, R.I. Shakoor, Design, simulation, and testing of electrostatic SOI MUMPs based microgripper integrated with capacitive contact sensor, Sens. Actuators A Phys. 167 (1) (2011) 44–53.

[7] D.-H. Kim, M.G. Lee, B. Kim, Y. Sun, A superelastic alloy microgripper with embedded electromagnetic actuators and piezoelectric force sensors: a numerical and experimental study, Smart Mater. Struct. 14 (6) (2005) 1265.

[8] S. Iamoni, A. Somà, Design of an electro-thermally actuated cell microgripper, Microsyst. Technol. 20 (4–5) (2014) 869–877.

[9] Roch, P. Bidaud, D. Collard, L. Buchaillot, Fabrication and characterization of an SU-8 gripper actuated by a shape memory thin alloy film, J. Micromech. Microeng. 13 (2) (2003) 330

[10] F. Beyeler, A. Neild, S. Oberti, D. J. Bell, Y. Sun, J. Dual, and B. J. Nelson, "Monolithically fabricated microgripper with integrated force sensor

for manipulating microobjects and biological cells aligned in an ultrasonic field," Journal of Microelectromechanical Systems, voi. 16, pp. 7-15,2007.

[11] S. K. Jericho, M. H. Jericho, T. Hubbard, and M. Kujath, "Micro-electro-mechanical systems microtweezers for the manipulation of bacteria and small particles," Review of Scientific Instruments, vol. 75, pp. 1280-1282, 2004.

[12] M. Kohl, B. Krevet, and E. Just, "SMA microgripper system," Sensors and Actuators APhysical, vol. 97-8, pp. 646-652, 2002.

[13] N. Chronis and L. Lee, "Electrothermally Activated SU-8 Microgripper for Single cell manipulation in Solution," Journal of Microelectromechanical systems, vol. 14, pp. 857-863, 2005.

[14] D. H. Kim, M.G. Lee, B. Kim, andY. Sun, "A superelastic alloy microgripper with embedded electromagnetic actuators and piezoelectric force sensors: a numerical and experimental study," Smart Materials & Structures, vol. 14, pp. 1265-1272,2005.

[15] Nikoobin, M. Hassani Niaki, Deriving and analyzing the effective parameters in microgrippers performance, Scientia Iranica, Volume 19, Issue 6,2012,

[16] Jayaram, K. and Joshi, S. ‘‘Development of a flexure-based, force-sensing microgripper for micro-object manipulation’’, J. Micromech. Microeng., 20(1), pp. 15001–15010 (2010).

[17] ukuda, T. and Arai, F. ‘‘Micromanipulation and robot technology’’, Int. Conf. Model. Simul. Microsys., pp. 11–16 (1998)

[18] hronis, N. and Lee, L.P. ‘‘Polymer MEMS-based microgripper for single cell manipulation’’, 17th IEEE Int. Conf. Micro Electro Mech. Syst., pp. 17–20 (2004).

[19] Agnus, J., Hériban, D., Gauthier, M. and Pétrini, V. ‘‘Silicon end-effectors for microgripping tasks’’, J. Precis. Eng., 33(4), pp. 542–548 (2009)

[20] Panchal Yogesh Ratilal, Review of research work in wire cut electro-discharge machining on metal matrix composite materials, (2016).

[21] Liang C, Wang F, Shi B, Huo Z, Zhou K, Tian Y et al (2018) Design and control of a novel asymmetrical piezoelectric actuated microgripper for micromanipulation. Sens Actuators A Phys 269:227–237

[22] Hossein Mehrabi1 • Mohsen Hamedi1 • Iman Aminzahed2, HNICAL PAPER A novel design and fabrication of a micro-gripper for manipulation of micro-scale parts actuated by a bending piezoelectric Microsystem Technologies (2020) 26:1563–1571.

[23] Cunman Liang, Fujun Wang, Beichao Shi, Zhichen Huo, Kaihuan Zhou, Yanling Tian, Dawei Zhang, Design and control of a novel asymmetrical piezoelectric actuated microgripper for micromanipulation, Sensors, and Actuators: A Physical https://doi.org/10.1016/j.sna.2017.11.027.

[24] Chen, B.K., Zhang, Y. and Sun, Y. ‘‘Active release of microobjects using a MEMS microgripper to overcome adhesion forces’’, J. Microelectromech. Syst., 18(3), pp. 652–659 (2009).

[25] Raghavendra, M.R.A., Kumar, A.S. and Jagdish, B.N. ‘‘Design and analysis of flexure-hinge parameter in microgripper’’, Int. J. Adv. Manuf. Technol., 49(9–12), pp. 1185–1193 (2010).

[26] Kim, D.H., Lee, M.G., Kim, B. and Sun, Y. ‘‘A superelastic alloy microgripper with embedded electromagnetic actuators and piezoelectric force sensors’’, J. Smart Mater. Struct., 14(6), pp. 1265–1272 (2005).

[27] Kim, B.S., Park, J.S., Moon, C., Jeong, G.M. and Ahn, H.S. ‘‘A precision robot system with modular actuators and MEMS micro gripper for micro system assembly’’, J. Mech. Sci. Technol., 22(1), pp. 70–76 (2009)

[28] Dong, W., Chen, F., Gao, F., Yang, M., Sun, L., Du, Z., Tang, J., Zhang, D.: Development and analysis of a bridge-lever-type displacement amplifier based on hybrid flexure hinges. Precis. Eng. 54, 171–181 (2018). ISSN 0141-6359

[29] Chaoyang Shi, Xinyu Dong, and Zhan Yang, A Microgripper with a Large Magnification Ratio and High Structural Stiffness Based on a Flexure-Enabled Mechanism June 01,2021 at 19:58:21 UTC from IEEE Xplore.

[30] F. Wang, C. Liang, Y. Tian, X. Zhao, and D. Zhang, "Design of a Piezoelectric-Actuated Microgripper with a Three-Stage Flexure-Based

Amplification," IEEE/ASME Transactions on Mechatronics, vol. 20, no. 5, pp. 2205-2213, Oct 2015.

[31] F. Wang, C. Liang, Y. Tian, X. Zhao, and D. Zhang, "Design and Control of a Compliant Microgripper with a Large Amplification Ratio for HighSpeed Micro Manipulation," IEEE/ASME Transactions on Mechatronics, vol. 21, no. 3, pp. 1262-1271, Jun 2016.

[32] F. Wang, B. Shi, Y. Tian, Z. Huo, and D. Zhang, "Design of a Novel Dual-Axis Micromanipulator with an Asymmetric Compliant Structure," J IEEE/ASME Transactions on Mechatronics, vol. 24, no. 2, pp. 656-665, Apr 2019.

[33] S. Nah and Z. Zhong, "A microgripper using piezoelectric actuation for micro-object manipulation," Sensors and Actuators A-physical, vol. 133, no. 1, pp. 218-224, Jan 2007.

[34] K. Qi, Y. Xiang, C. Fang, Y. Zhang, and C. Yu, "Analysis of the displacement amplification ratio of bridge-type mechanism," Mechanism Machine Theory, vol. 87, pp. 45-56, Mar 2015.

[35] Y. Guo, J. Kong, H. Liu, H. Xiong, and Q. Li, "A three-axis force fingertip sensor based on fiber Bragg grating," Sensors Actuators A Physical, vol. 249, pp. 141-148, Oct 2016.

[36] H. W. Ma, S. M. Yao, L. Q. Wang, and Z. Zhong, "Analysis of the displacement amplification ratio of bridge-type flexure hinge," Sensors Actuators A Physical, vol. 132, no. 2, pp. 730-736, Nov. 2006.

[37] P. Liu and P. Yan, "A new model analysis approach for bridge-type amplifiers supporting nano-stage design," Mechanism and Machine Theory, vol. 99, pp. 176-188, May 2016. [

[38] C. Lv, S. Wang, and C. Shi, "A High-Precision and Miniature Fiber Bragg Grating-Based Force Sensor for Tissue Palpation During Minimally Invasive Surgery," Annals of biomedical engineering, vol. 48, no. 2, pp. 669-681, 2020. [28] C. Shi, M. Li, C. L

Completion Certificate

It is certified that the contents of thesis document titled "***Development of Meso-Scale Microgripper with Large Displacement Amplification Ratio***" submitted by NS Absar Ahmad, Registration No. 00000275558 have been found satisfactory in all respects as per the requirements of Main Office, NUST (Exam branch).

Supervisor:

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Dr. Amir Hamza

Date: 4 August

2022