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DESIGN AND ANALYSIS OF A MONOLITHIC MICROGRIPPER

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ABSTRACT

Precision industries require high precision and controlled motion of microgripper. For this purpose compliant mechanism based monolithic microgrippers are used. In this study, a monolithic microgripper is designed adopting topological optimization met hod. MATLab code has been developed to derive the optimized shape of the monolithic microgripper. Post optimization process was carried o ut to overcome the manufacturing difficulties. Thickness of the microgripper was then designed using finite element method (FEM) to avoid out of plane sagging caused by the self-weight of the microgripper. The structural analysis using FEM was performed to obtain the Geometrical Advantage (GA) of the design. The proposed design of the microgripper proves that the out of plane motion is completely controlled as the thickness of the gripper is optimized and provides a better GA compared to the earlier designs found in the literature. This kind of design may be helpful to the designers who expect the gripping devices to be used in the situation where a minimum out of plane motion is required.

1. INTRODUCTION

MicroElectroMechanicalSystems

Some of the main markets of microelectronic components, e.g. consumer electronics, communication equipment, automotive and industrial control have shown an increasing demand for true integration. True integration means integrating a complete system (e g, large super computers to small laptops) or innumerable components in a single integrated circuit. A justified passion on micromanipulation is getting increased day by day. The demand for micro machined components such as microshafts, micro nuts and bolts, micro needles, micro spiral inductors, micro motors etc. has been rapidly increasing in aerospace, automotive, medical, optical, military and microelectronics packaging applications and many more. Miniaturization of components lead to material saving, energy saving, increased functionality and quick response. Indeed micro manipulation, handling of those micro objects is gone too tough with dimensions of 1um to 1mm.Handling and assembly of the micro components is highly challenging due to their small size. To manipulate the micro-components, micro grippers are used. Micro assembly and

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micromanipulation are widely applied in many fields. The micro gripper is an important component of the system to hold, pick, manipulate and assemble micro mechanical components. The general requirement of a micro gripper is that it should be able to pick up and release a component at a specified position. The positional uncertainty during assembly should be well defined and components should notbe damaged during assembly. With the increase of interests in micro robotic systems during the past two decades, MEMS-based microgrippers with various types of actuators and sensors have been proposed for the large applications which enable the achievement of compact size, low cost etc. Microgrippers mostly work on the assembly of micromechanical parts such as micro gears, optical lenses, and micro componentsfor integrated circuits and in Micro Biology lab tasks such as like picking tissues and in diagnostics. Microgrippers areused in the surgeries pertaining to larynx and nostrils.

Types of Microgrippers

With widespread application of MEMS microgrippers they are actuated with different types of actuation systemselectro thermal, electrostatic, electromagnetic, microfluidicsetc.For example electro thermalMicrogrippergives large displacementcompared to electrostatic actuation [10].Other actuating methods includepneumaticactuator in which compressed air is used as driving force,Electromagnetic actuators and shape memory alloy (SMA)actuation.

Electrostatic Microgripper

Electrostatic Microgripper has been widely applied in MEMS.The comb drives are the main components of this type of actuator. The actuator contains a large number of fingers(comb like structures),which are parallel-plate capacitors. When the voltage is applied between the movable and fixed plates, the actuator force is generated to move the comb. Early researchers, Kim presented siliconelectromechanical Microgripper in 1991[1].Later, in 1992, the electrostatically driven Microgripper was demonstrated to grasp 2.7μm diameter polystyrene spheres, dried red-blood cells and various protozoa in [2].

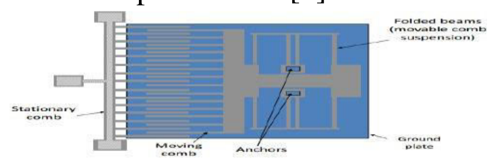

Figure 1.Schematic of comb drive actuator [17]

The electrostatic actuator can beseparated into two types, i.e., transverse comb-drive-type and lateral comb-drive-type.

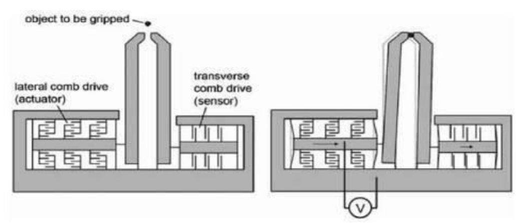

Fig 2. Schematic diagram of Electrostatic Microgripper

Micro-Pneumatic Actuator

Micro-pneumatic actuator is a type of actuator which employs compressed air as the driving force. This actuator has merits of high energy density, large displacement, large force and usage of various fluids as driving medium which is important for microsurgery manipulation [3]. The basic structure of the actuator contains a piston connected to the housing by two spring elements. When a pressure is applied, the spring elements enable the piston to move and provide the seal against the environment just similar to a bellowpiston [3].

2. LITERATURE REVIEW

Shinji et al (1998) in their work presented a procedure for a new formulation of multi-objective optimisation which was introduced for the design of complaint mechanism design. Mutual mean compliance was introduced in order to formulate the flexibility of structures, and its sensitivity was obtained for the structural optimisation. An optimisation algorithm was developed by the homogenisation method and the Sequential Linear Programming (SLP). It has been shown that the optimal topology configuration obtained by the multi-objective formulation is unique, regardless of the number of finite elements. It has also been shown that the optimal topology configuration is affected by a change in the total volume constraint of materials. The additional finite element analysis proved that the final compliant mechanism design satisfies the problem specifications.

Michael et al (2005) investigated topology optimisation with density dependent body forces and especially self-weight loading. Unexpectedly, the solution of such problems cannot be based on a direct extension of the solution procedure used for minimum compliance topology optimisation with fixed external loads. Next to first the exacting difficulties arising in the considered topology problems are pointed out: non-monotonous behaviour of the conformity possible unrestrained character of the optimum and parasitic effect for low densities when using the power model (SIMP). To overcome the last problem requires modifying the power law model for low densities. The other problems require revisiting the solution procedure and the selection of appropriate structural approximations. Numerical applications compared the efficiency of different approximation schemes of the Method of Moving Asymptotes (MMA) family.

Lau Du et al (2001) in this work they used the concepts of minimum compliance of maximum common compliance, substitute formulation, based on functional specification was proposed to solve for topology of compliant mechanism. Surrounded by numerous advantages, one of the functional specifications was posed as objective function while displacement constraint and material constraint are compulsory. The topological design of compliant mechanism was then solved as a problem of material distribution using spring and SIMP model without filtering technique. The result of this problem was obtained by using the method of moving asymptotes (MMA). The effect of problem formulation on final topology of compliant mechanism was then illustrated using two examples and the results are compared against their rigid body counterparts.

Canfield et al (2000) introduced a method for the design of displacement amplifying compliant mechanisms for piezoelectric actuators was developed using a topology optimisation approach. The overall geometric advantage of the mechanism and the overall mechanical efficiency of the mechanism are considered as objective functions. The maximisation of these purpose functions is accomplished using two different solution methods, one was Sequential Linear Programming and the another one was Optimality Criteria method. The focal point of this paper was on the fundamental topology optimisation problem formulations and the way out methods. Design examples were presented which demonstrates the method, with comparisons of the computation time and mechanism performance for the two formulations and solution methods. A procedure has also been developed to routinely convert the topology optimisation outcome to a solid CAD model. An example design has been fabricated to serve as proof of concept.

Mostafa et al (2003) in this work combined optimisation of a compliant mechanism and a piezoelectric stack actuator for maximum energy conversion efficiency is considered. The paper presents a system level analysis in which the actuator and the compliant mechanism are mathematically described as linear two-port systems. The combination of stack and compliant mechanism is used to drive a structure, modeled as a mass-spring system. The analysis assumes all components to be free from dissipation, and the piezoelectric stack is driven by an ideal voltage source. Energy conversion efficiency was defined as the ratio of the output mechanical energy to the input electric energy. Theoretical bounds on the system efficiency were obtained. It is shown that the stack actuator can be optimised separately and matched to the specified structure and an optimally designed compliant mechanism. The optimisation problem for the compliant mechanism is formulated to maximise a weighted objective function of energy efficiency and stroke amplification. The optimisation results were presented for ground structures modeled using frame elements.

3.MODELING AND SIMULATION

AIM:

To design of laterally drivenaluminium electro thermal microgripper for micro objects manipulation.

MODELING:

1. Creation of 3D model

3D model of micro gripper using COMSOL Multi physics 4.4 software. The Gripper has two arms these are hot and cold arms. Microgripperdesignin this studywas inspired by the well-established hot-and-cold-arm actuator design The hot-and-cold-arm actuator is composed of two arms of different widths that are joined at their free ends as shown from the figure 1.The initial dimensions of microgripper are as given in the table.

Parameter	Value
Length of the hot arm (Lh)	18300µm
Length of the cold arm (Lc)	18300µm
Flexure Length(Lf)	3000µm
Width of the arms (Wc,Wh,Wf)	900µm
Gap between the arms(Gb)	300µm
Initial Opening(g)	300µm
Thickness	500µm

Table1.1 : Dimensions of the microgripper

The total dimension of the structure are within20400 micrometers*3300 micrometers of scaled one.The two arms of the gripper are of different lengths but same cross-sectional area.

The gripper assemblyissplitinto 3 parts.

These are as follows:

• Arm of the gripper(hot and cold)

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• Anchors and contact pads
• Flexures
• Gripping pads

Modeling the micro gripper

In our simulation we first created a 3D model of the structure using COMSOL Multiphysics software environment.Specific materials were selected to assign.When a voltage is applied, a current is passed through the metallization layer and this will act as the heating element of the actuators. The temperature will increase, and the metal layer (with a higher coefficient of thermal expansion) will have a larger deformation than the polyimide. Therefore, the bilayer structure will bend toward the polymer side.First of all open COMSOL Multiphysics by double clicking on it. After opening a window menu we have to prepare our model so that select new in model wizard and choose 3D model. When selecting the physics choose the JOULE KELVIN AND THERMAL EXPANSION and add them as physics and in the column of study choose stationary studies and add them. For creating the model select the new work plane and add the geometry such as rectangles and give the values oftheir x and y positions as by the initial point and then extrude the microgripper.We also change the fillet radius.

The Micro gripper was modelled in COMSOL Multiphysics as shown in the figure

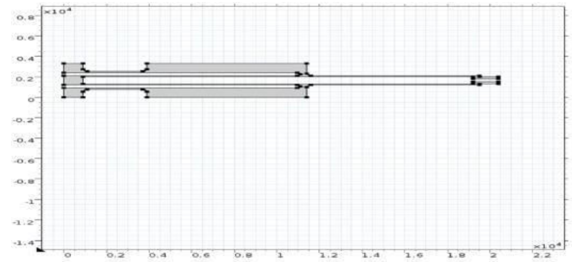

Figure.4: Modelled Microgripper in COMSOL

SIMULATION:

To simulate the assembly of the structure we used the Solid Mechanics interface. The anchors features of the structure were set with a fixed constraint. The free end of the structure was set to have a prescribed displacement. With the help of an auxiliary sweep and setting the study for large deformations (include geometric nonlinearity option) we were able to simulate the assembly.Simulation of the device has been carried outusing the COMSOL Multiphysics tool. During Simulation, material properties of Aluminum has been given to the developed micro gripper, model was meshed and Applied with necessary boundary conditions.JOULE HEATING AND THERMAL EXPANSION PHYSICShas been usedto describe the behaviorof the micro gripper as a function of the applied voltage. (**Joule Heating and Thermal Expansion**multiphysics interface combines thermal, electric, and structural Multiphysicseffects. The predefined interaction adds the electromagnetic losses from the electric field as a heat source. In addition, the temperature from the Heat Transfer in Solids interface acts as a thermal load for the Solid Mechanics interface, causing thermal expansion).All boundary

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settings are describedstep by stepin following sections.

Adding material

Now material added to the geometry.Aluminium materialwas chosen from material library of COMSOL Multiphysics.

Name	Value	Units
Heat capacity at constant pressure	900[J/(kg*K)]	J/(kg*K)
Thermal conductivity	238[W/(m*K)]	W/(m*K)
Relative permittivity	1	1
Coefficient of thermal expansion	23e-6[1/K]	1/K
Density	2700[kg/m^3]	kg/m^3
Young's modulus	70e9[Pa]	Pa
Poisson's ratio	0.33	1

Table 1.2 : Mechanical Properties of the Aluminium

Applying boundary settings:

We used COMSOL to simulate the assembly process and then use the solution,to compute another study to solve the Joule Heating problem and thermal expansion. The solution was used as a dependent for the heat transfer simulation. The boundary conditions applicable to the second study are: the environment temperature, the heat fluxdissipation and the potential applied to the metal boundary faces (one set as ground and the other one to an electric potential).

4. EXPERIMENTAL SETUP

Experimental setup has three main parts which are Microgripper, Microscope, Multimeter. Digital Multimeter which shows the voltage and current in volts and amperes respectively.Anchors of the gripper were fixedto a acrylic glass plate. Jumper wireswere connected from Variable DC power supplyto endsof the Microgripperand the centre one was grounded. Positivevoltage supplywas given toone side and negative voltage supply to the other side. Voltage was suppliedvarying from 0.1V to 1.5V. Deflection of the arms of the microgripper was captured using a microscope having microcature2.5softwareinterface with computer.The image were captured when the gripper actuated.And calculated the temperature by using heat sensors.It is too difficult to see the deflection by eyes so perfectly handle the electron microscope and capture the deflection for different voltages.Wait to see the good results.

Figure 5.Initial experimental setup

Figure 6.Monitoringthe experimentalresults

5. DISCUSSION AND RESULTS SIMULATED RESULTS

Our main goal wasto determine are liable approximation of the behavior of our fabricated device, and to verify. The displacement assemblysimulation is shown in Fig.7. The simulation results of both assembled structure and the joule heating results are shown in Fig. 9.Aluminium materialwas prescribed as material to themodel. Prescribed boundary conditionswere applied to the modelin the physics. Stationarystudy for the model. By

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varying voltage from 0.1V to 1.2V, we simulated the model and observed the results for vonMises Stress (MPa), Total displacement (um), Temperature (K) and Electric potential (V). For the applied voltage of 1.2 V, displacement was observed to be 231 microns as shown in figure below.

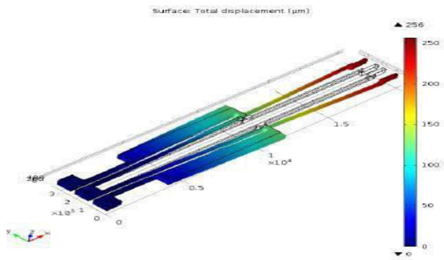

Figure 7: Displacement result for 1.2 voltage under simulation

For the applied voltage of 1.2 V, Stress was observed to be 231 MPa as shown below

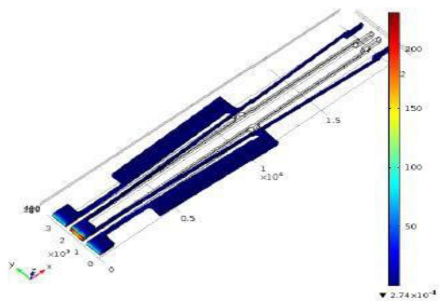

Figure 8: Stress result for 1.2 voltage under simulation

For the applied voltage of 1.2 V,Temperature was observed to be 352K as shown in below figure.

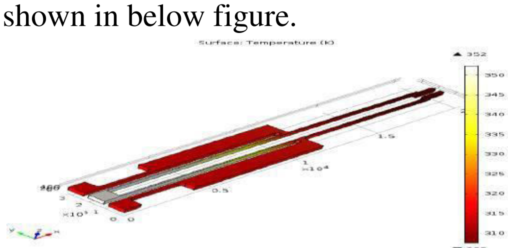

Figure 9.Temperature result for 1.2 voltage under simulation

CONCLUSION:

The result concludes that the electro thermal actuator is highly sensitive to geometrical variations. It has been realized that longer hot arms produce more deflections but a tradeoff lies in the sense that, on increasing the length of the hot arm, resistance also increases, so there is a chance of failure due to stiction to the substrate. On decreasing the gap between the beams of the actuator, tip displacement increases. Thus it is desired to use longer hot arms, narrower gaps between the beams, optimum flexure and cold beams and wider cold beams to produce more deflections. Wider hot beams will decrease the displacements. The geometrical variations in the actuator increases the displacement at the tip significantly but the maximum temperature in the actuator is less sensitive to the geometrical variations. And also we extrude the thickness upto 600 µm there is no change in the displacement but the Vonmisesstress and temperature are increase.(for 1.5v the both 500 µm and 600 µm will get the same displacement 400 µm as shown in the above table no 2). Like that go on increasing the thickness up to 700 µm the displacement will decrease by 399 µm.So on increasing the thickness the displacement will decreasing but the vonMisesstress and temperature are increasing as before.

Thus, these designs are easy to fabricate and provides large displacements even at smaller applied voltages. Also different materials can be usedlike polymers, as they are nonconductive, these can be usedfor the microgrippers in biomedical applications. Metals can also be used as they are more conductive than Aluminium, these can result in more displacements. The arrays of these types of actuators can be used for various applications like in switching applications, stepper motor.

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