Design and Modeling of Electrostatically Actuated Microgripper

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Abstract — **The application of microgrippers for handling and assembling micro parts in various fields attracts more attention by the growth in micro electro mechanical systems. In this paper an electrostatic microgripper using comb drive is designed and analyzed using IntelliSuite, MEMS simulation software based on finite element analysis. The use of modified fingers in the combdrive amplifies the output displacement of microgripper for given supply voltage. It also provides a linear force displacement behavior over a range of displacement. To show this amplification, finite element simulations are performed on the proposed design of microgripper models. It was found that displacement of about 7 µm has been obtained at a voltage of 14 volts with 28 fingers only with one of the proposed designs of microgripper against 25 volts for rectangular finger microgripper 9 with 28 fingers.**

Keywords- Amplified Displacement, Combdrive, Finite element Method, linear force profile, Microgripper, Modified finger Shape.

I. Introduction

In recent days miniaturization of components is gaining increasing acceptability due to its wider application in the field of biology, aerospace, nuclear science, electromechanical systems and microsurgery. Miniaturization of product creates a large number of problems due to scaling effects, [1] fabricating difficulties. Picking, handling and releasing of micron objects in the field of robotics, bio-manipulation and assembling of micro parts is a challenging concept, which requires proper design and analysis of the devices like microgrippers. Microgrippers are needed for the manipulation of microscopic sample in biology and other fields of research as for example microassembly. Micromanipulation of biological cell and tissues in dry (or) aqueous environments has got attraction [2] in the field of tissue engineering. Micromanipulation of devices is based on the principle of micro tweezers that will grasp the objects using the force created by the microgripper. Different kinds of microactuators have been used for construction of micromanipulation including shape-memory alloys; piezoelectric bimorph actuators, electro thermal actuators [3], electrostatic [4] and electromagnetic. Thermal actuators [5] could be preferred due to small voltages and large output force generated at the jaws. But they cannot be used for biological cells (or) fluid media. This actuation mechanism also involves thermal expansion of jaws, which is non-linear movement, and it is very hard to control. Their sensitivity is also poor [6]. Electromagnetically actuated grippers are larger in size so they are meso scale grippers rather than microgrippers. Fabrication of such grippers is also very difficult [7]. Piezoelectric microgrippers [8] has small output displacement which restricts its usage to limited applications. Their performance may alter due to change in temperature.

Electrostatic gripper is one of the simplest actuation based gripper. The main part [9] of this type of actuators is comb drives. Comb drives are made of two combs a movable one and a fixed one. When voltage is applied between fixed and movable combs it generates a force, moving the movable comb. Comb drives movement occurs parallel to the fingers. Inter-digitated comb drives utilized in in-plane motions. In electrostatic actuated microgripper the only problem is its high operating voltage. Many researchers have worked in this area, in order to reduce the actuation voltage. Volland et al [10] proposed a design which gives a displacement of 20 µm at the applied voltage of 80 volts with 1020 fingers. Another design [11] which operates at 80 volts producing a displacement of 25 µm has 2904 fingers. The other design [4] which operates at 50 Volts and producing a displacement of 17 µm has 6400 fingers.

Application of shaped comb fingers is addressed a little in literature. An analytical model is developed for shaped comb fingers [12]. A closed form approach is used to derive the shape of the comb-finger [13]. Optimal shape comb fingers are used in scanners [14] to give maximum force at large displacement. In this paper we propose an electrostatically driven microgripper which uses inter digitated comb drive with non-rectangular finger shapes. The objective of this paper is to design a simple microgripper of good displacement, with less number of fingers which operates on lower voltage as compared to existing electrostatically actuated microgripper. Here the three different finger shapes are chosen which are having linear force profile, as linear force profile is required for effective actuation and control of microgrippers. The linear force profile simplifies control system required for the microgripper [12]. The amplification of displacement was achieved with one of the finger shape, which has given a displacement of 7 µm at a voltage of 14 volts with 28 fingers and it also has a linear force profile.

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II.COMB FINGER MODELLING

Voltage controlled comb-drive actuators exert a lateral electrostatic force which is independent of position making them attractive for micro positioning applications. It can have two types of movement configurations whose typical layouts are given below in fig. 1(a) and 1(b).

a) Lateral movement configuration
b) Transverse movement configuration

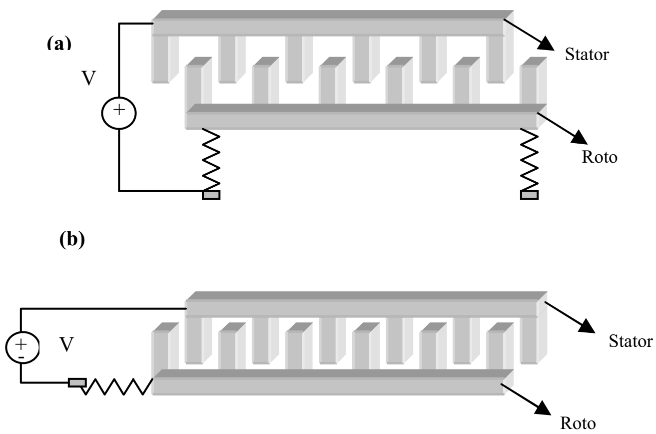

Figure 1. (a) Lateral Comb drive (b) Transverse Comb Drive

The transverse comb based gripper is not widely used, because of the nonlinear relationship between force produced through actuator and finger gap. Therefore, force produced is difficult to control; and also Pull-in between the fingers is also very difficult to control. Thus it is not suitable for use in a [4] microgripper. But in lateral comb drive, the force developed is linear and it is easy to control. This is the most widely used actuator for a microgripper.

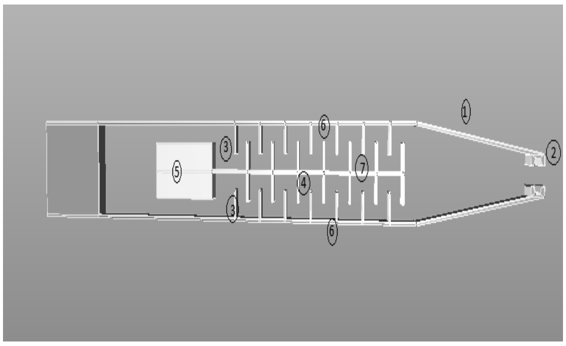

Figure 2. Model of a microgripper with rectangular finger

1 Extension arm
2 – Jaw
3 – Movable finger
4 – Stationary finger
5 – Actuator pad
6 – Outer beam
7 – Central beam

The fig. 2 shows a diagram of a proposed microgripper with rectangular finger. In this gripper comb drive actuator with interdigitated rectangular fingers is used. The central beam consists of the stationary fingers. The two outer beams consist of the movable fingers. Actuation voltages of 25V and 0V are applied to the central beam and outer beams respectively. Electrostatic force of attraction causes the movable fingers to move, and resulting in the movement of jaws towards each other thus grasping micro objects.

A comb-drive has moving and fixed fingers. If voltage is applied it generates electrostatic force. The magnitude of the force depends on the applied voltage and the geometry of the fingers. For rectangular fingers, the force generated is constant as the gap between fixed and moving fingers is constant. But in shaped fingers the gap between the fingers is varied as they engage. In this work three new designs are proposed. The force values are calculated and compared with the force values obtained from simulation. Further the proposed designs are used in a microgripper and its performance is verified with analytical model and simulation.

In fig. 3, *g(x)* and *f(x)* are the finger profiles for stationary and moving fingers respectively. We can determine the electrostatic force developed, by calculating the change in capacitance as the moving finger engages the fixed finger [12]. The force between the fingers F_x is represented by

$$F_x = \frac{\partial E}{\partial X_1} = \frac{1}{2} V^2 \frac{dC}{dx_1} \tag{1}$$

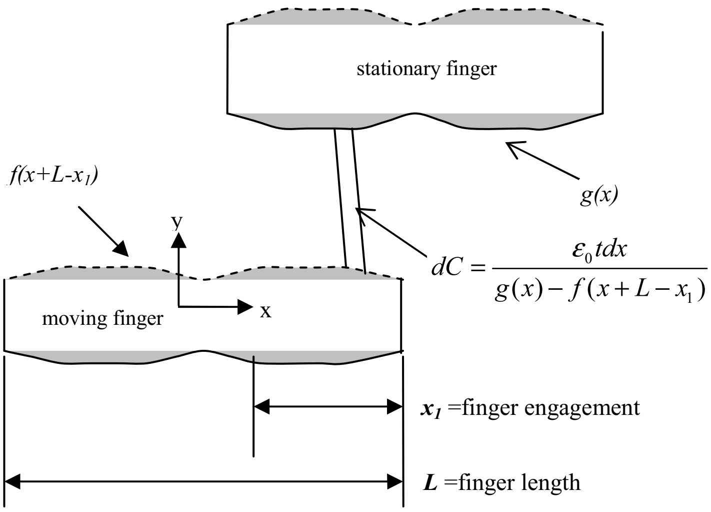

Figure 3. The engagement of arbitrarily shaped fingers

where E is the stored energy, C is the capacitance, x_1 is the engagement of the moving finger and V is the applied voltage.

The capacitance can be calculated as given in (2).,

$$C(x_1) = 2\varepsilon_0 t \int_0^x \frac{dx}{g(x) - f(x+L-x_1)} \tag{2}$$

when one of the finger is rectangular the capacitance is given as in (3).,

$$C = 2\varepsilon_0 t \int_0^{x_1} \frac{dx}{h(x)} \tag{3}$$

where *h(x)* is the gap between fingers, *h(x)=g(x)-f(x).*

when the moving finger is rectangular, *f(x)* becomes equal to a constant.
Therefore,

h(x) = g(x)-constant [12].

Substituting (3) in (1), (4) is arrived

$$F_x = \frac{V^2 \varepsilon_0 t}{h(x_1)} \tag{4}$$

where t is the out of plane thickness of the fingers and ε_o is the permittivity of free space. The factor 2 is used because the capacitance is the same on both sides of the symmetrical finger shape. Thus force formula (4) is used to calculate the resulting force of different finger shapes. The formula is valid if any one of the finger shape is rectangular. If both the fingers are non-rectangular then numerical solutions are required. [12].

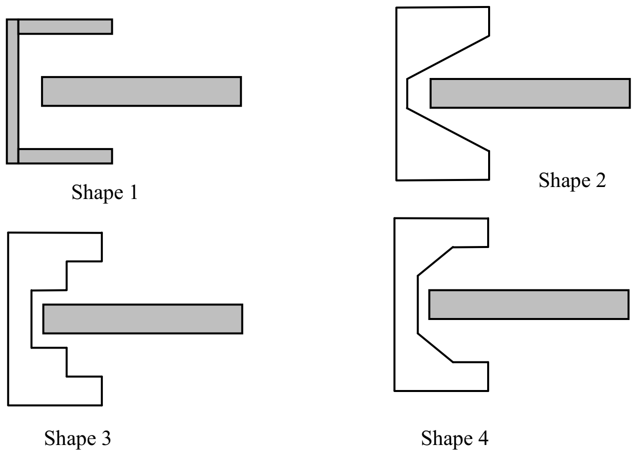

Figure 4. Geometry of proposed Finger shapes

The rectangular shape fingers are placed as a movable finger to reduce the inertia of the movable structure [13]. The force values for stationary and moving fingers are calculated and tabulated in Table I. Here the proposed three finger shapes with the rectangular finger design is also considered for analysis. Fig. 4 gives the geometry of proposed finger shapes.

The Shape 1 is the rectangular comb finger with a constant gap of 5µm. This design is used to verify the constant force. Shape 2,3, and 4 also provides a linear increase in force with respect to finger engagement. Each finger was modeled in IntelliSuite. Electrostatic analysis was done and the capacitance was calculated. The derivative of capacitance with respect to engagement was estimated using central difference equation [12]. Electrostatic force was calculated using (1). Out of plane thickness of finger was 4µm, and the length of fingers was 15µm. All the simulations were performed at 1 V. Mesh convergence study was also done and about 50,000 elements were used for all the simulations.

III. MODELING RESULTS

TABLE I. SHAPES AND THEIR FORCES

Shape	Engagement (µm)	Force (pN)		% Error
		FEM	Analytical	
Shape 1 (Rectangular)	5	11.5	10.628	7.5%
	11	12	10.628	11.43%
Shape 2	5	21.8	15.62	28.35%
	11	77.5	40.86	47.28%
Shape 3	5	19.8	10.628	46.32%
	11	47.5	35.41	25.45%
Shape 4	5	18	10.628	40.96%
	11	38.25	29.51	22.85%

Table I shows the simulation results and analytical results using (1). For analytical results the thickness used was 6µm to account [12] for fringing fields. The results for rectangular finger show that data trend predicted by simulation matches the analytical results. The results for the remaining finger shapes show that the difference between the analytical results with the simulation results is in the range of 50%

IV. MICROGRIPPER MODELING

The microgripper with the conventional rectangular finger has been simulated using the IntelliSuite software by following the same procedure as mentioned for single finger modeling. The dimensions are given in Table II. Then the rectangular finger

TABLE II. VALUES OF THE PARAMETERS COMMON TO ALL FOUR MICRO GRIPPERS

Parameters	Length of the finger	Width of the finger	Height of the finger	No. of fingers	Length of the extension arm	Gap between fingers	Overlap	Width of the beam	Gap between jaws
Values (µm)	15	1	1.2	28	101	10	5.6	1.2	10

has been replaced with the proposed finger shapes and the new microgripper models with the proposed finger shapes have been simulated. The simulation results showing displacements of microgrippers for shapes 1-4 has been shown in figures 5 to 8.

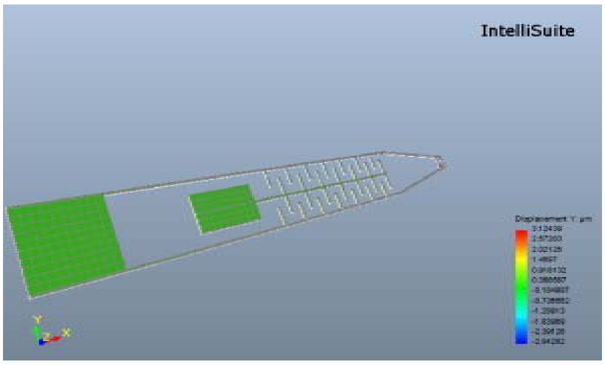

Figure 5. Simulation model of Microgripper with finger shape1

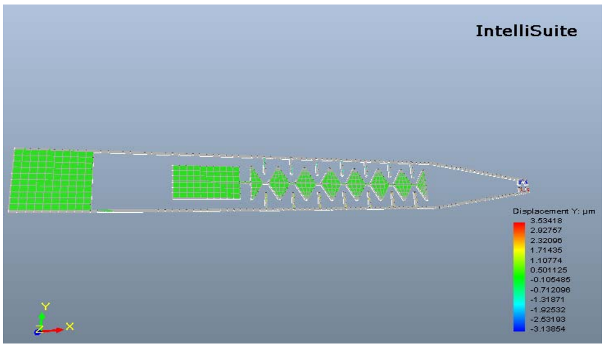

Figure 6. Simulation model of Microgripper with finger shape 2

It is found that displacement of about 6µm has been obtained at a voltage of 25 volts for the rectangular finger (shape1). On the other hand similar displacement values have been obtained at a reduced voltage of 20 volts for microgrippers with finger shapes 2 and 3 and at a further reduced voltage of 14 volts for the microgripper with finger shape 4. The minimum voltage of 14 volts using shape 4 is obtained due to the much reduced gap distance between fingers compared to the other two shapes. Thus for the same displacement the actuation voltage has been reduced by modifying the finger shapes and also it provides linear force profile. This concept of modified finger shape has been verified by modeling a simple gripper. Further it can be applied for a complex design of gripper, to amplify the output displacement.

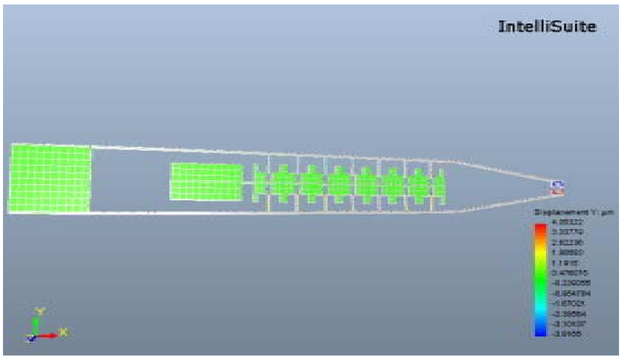

Figure 7. Simulation model of Microgripper with finger shape 3

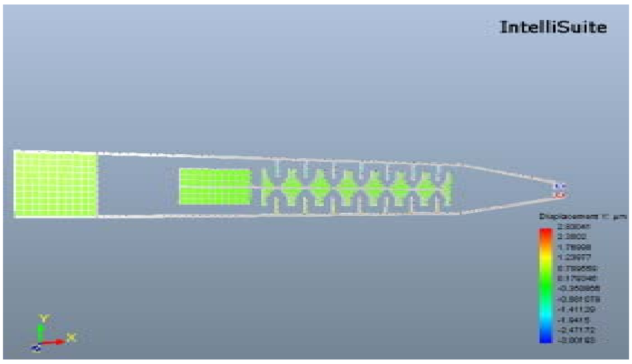

Figure 8. Simulation model of Microgripper with finger shape 4

TABLE III. COMPARISON OF DISPLACEMENT OF MICROGRIPPERS WITH FINGER SHAPES

Microgripper with Finger	Voltage (Volts)	Displacement (µm)
Shape 1	25	6.06
Shape 2	25	10.739
	20	6.66
Shape 3	25	9.91
	20	5.83
Shape 4	25	21.25
	20	12.29
	14	6.66

V. CONCLUSION

In this work, Single finger analysis for modified finger shapes are designed, simulated and analyzed. Then these finger shapes are used in the comb drive of simple structured Microgripper which has 28 fingers only. It is found that a displacement of 6.66µm has been obtained at an actuation voltage of 14volts for a particular shape with linear force engagement behavior. But 25 volts is required for rectangular comb drive to develop the same displacement with constant force. This design and concept is very useful in the field of microgripper.

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