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A Review on Comb Drive Actuator

Mohita, Seema

Abstract: ***The Large displacement comb actuators at low actuation voltage should employ large number of comb fingers, reduced distance between the combs and by increasing the width of the fingers. Polysilicon has been the dominant mechanical materials for MEMS fabrication (PDF) MEMS Electrostatic comb actuators with a novel trapezium comb shape produces less actuation voltage then regular rectangular shape.***

Index Terms: Actuator, shaped Comb Drive, Capacitance.

I. INTRODUCTION

Micro-Electro-Mechanical Systems, or MEMS, is a technology that includes, both mechanical and electronic components on a single chip, and are made using the techniques of micro fabrication. The main elements of MEMS are sensors, actuators, and microelectronics[1]. Actuators are used for the transformation of non-mechanical input energy into mechanical output energy. There are many types of micro actuation techniques, most commonly used are piezoelectric, magnetic, thermal, electrochemical, and electrostatic actuation[2]. Electrostatic actuation is the most commonly used actuation technique. Electrostatic actuators do not require additional elements like coils or cores, or special materials like alloys or piezoelectric ceramics. The electrostatic actuation mechanism is less affected by scaling and is favorable for VLSI actuators [3]. One of the common electrostatic actuators is comb-drive actuators. Comb-drive actuators consist of two interdigitated comb-finger structures, where one comb is fixed and the other is connected to a compliant suspension. Applying a voltage difference between the comb structures will result in deflection of the movable comb structure due to electrostatic forces[4].Comb-drive actuators are used for obtaining large displacement at low driving voltage. It was first developed by Tang et al in 1989[5]. Applications of such actuators include resonators[6], optical shutters[7], micromechanical gears[8], microgrippers[9], and microtweezers[10]. Voltage controlled comb-drive actuators exert a lateral electrostatic force which controls the displacement of movable combfingers making them attractive for micropositioning applications, such as, xy-microstages[11,12,13]. The advantages of using electrostatic comb-drive actuator approach include low power dissipation, simpler electronic control, and easy sensing mechanism(Capacitance-based)[10]. A suspension, which has lower mechanical spring constant in the direction of desired displacement and higher spring constant in the orthogonal directions, is required. Electrostatic forces increase with an increasing number of comb fingers and decreasing gap spacing between the comb fingers[4]. Other than these parameters, the length of suspension is varied as well in order to obtain large displacement for low driving voltage.

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***** Correspondence Author

Mohita, M.Tech Scholar, Department of Electronics and Communication Engineering, Om Institute of Technology & Management, Hisar (Haryana)-125005, India. E-mail: mohitachaudhary91@gmail.com

Seema, Assistant Professor, Department of Electronics and Communication Engineering, Om Institute of Technology & Management, Hisar (Haryana)-125005, India. E-mail: seemagrover230@gmail.com

II. LITERATURE

This paper [2] presents an actuation mechanism based on the interdigitated comb drive MEMS resonator. The important role of that device is to establish MEMS resonators for the second order systems. Comb drive model is one of the basic model which uses the principle of electrostatic and force can be generated for the capacitive sensors. This work is done by overlapping movable and fixed comb fingers which produces an energy. The specific range of the polyimide material properties of young’s modulus of 3.1GPa and density of 1300 Kg/m3 . Results are shown in the structural domain performance of a lateral motion which corresponds to the applying voltage between the interdigitated comb fingers. It has laterally driven about 40µm with driving voltage. Also the resonance frequency 24Hz and 15Hz with high quality factors are depending on the spring length 260µm and 360µm and structure thickness of 2µm and 5µm. Here Finite element method (FEM) is used to simulate the various physics scenario and it is designed as two dimensional structure multiphysics domain. The prototype of comb drive MEMS resonator has been suitable for energy harvesting system applications.

The purpose of this paper [3] is to determine an optimum design for a DC-actuated, jagged-edge shaped comb drive incorporable in micro electromechanical systems (MEMS) as gripper actuator for micro-robotics domain precise manipulation. The commercial Comsol Multiphysics software based on finite element method (FEM) was used to carry out all the simulations in the 2D domain. Several geometries were analyzed here, starting with the design having a minimum and maximum gap distances between fingers of 3 and 7 µm, wich complies with the Multi-User MEMS Process (MUMPs). Comb displacement with respect to actuation voltage and electrostatic force acting upon the movable comb teeth as a function of finger displacement were plotted and compared to all the designs. A comb-drive actuator consists of two interdigitated comb structures, where one comb is fixed and the other comb is connected to a spring structure.

A design of electrostatic comb-drive actuator is presented in this paper with different spring configurations i.e. fixed-fixed beam, crab-leg flexure beam and folded-flexure beam. The design parameters considered here are beam length, number of comb fingers and gap between the comb fingers. The effect of their variation on displacement and driving voltage of movable comb has been studied.

Such actuators find extensive use in micro-positioning applications such as micro-tweezers. An increased displacement of comb drive actuator is subsequently accomplished for the same driving voltage, for folded-flexure beam configuration with increased beam length, higher number of comb-fingers and reduced gap between the comb-fingers. The beam length has been varied from 280μm to 320μm, number of moving comb fingers from 8 to 32 and gap between fingers has been reduced from 7μm to 1.6μm. The structures are further modified to decrease the requirement of driving voltage for even larger displacement, which include use of three-folded flexure and usage of jagged-shaped comb fingers and thus reducing requirement of driving voltage to 17V, increasing displacement to 11.102μm and increasing capacitance to 7819.728pF. Polysilicon is the structural material used for the designs. The simulation software used in this study is COMSOL Multiphysics, which offers Finite Element Analysis for calculation of displacement of movable fingers.

This paper [4] presents the design and evaluation of a high force density fishbone shaped electrostatic comb drive actuator. This comb drive actuator has a branched structure similar to a fishbone, which is intended to increase the capacitance of the electrodes and hence increase the electrostatic actuation force. Two-dimensional finite element analysis was used to simulate the motion of the fishbone shaped electrostatic comb drive actuator and compared against the performance of a straight sided electrostatic comb drive actuator. Performances of both designs are evaluated by comparison of displacement and electrostatic force. For both cases, the active area and the minimum gap distance between the two electrodes were constant. An active area of 800 × 300 μm, which contained 16 fingers of fishbone shaped actuators and 40 fingers of straight sided actuators, respectively, was used. Through simulation, improvement of drive force of the fishbone shaped electrostatic comb driver is approximately 485% higher than conventional electrostatic comb driver. These results indicate that the fishbone actuator design provides good potential for applications as high force density electrostatic microactuator in MEMS systems.

This paper [5] is the first demonstration of large-stroke parametric resonance excited by an in-plane “shaped-finger” electrostatic comb drive. A custom-shaped comb finger profile is used to produce a quadratic capacitance-engagement response. The ability in selecting electrostatic stiffness coefficients by engineering the comb finger profile allows the excitation of the nonlinear parametric resonance for various applications such as the mode-matched gyroscopes and gravimetric sensors. The shaped-finger comb enables the study of the parametric resonance in systems with high energy storage. The shaped-finger comb parametric resonator is fabricated by a 15 μm-thick SOI-MEMS process.

In paper [7] authors successfully developed finite element models to analyze the electrostatic force produced in electrostatic comb actuator. The finite element modelling and analysis is to design comb structure, and its limitation are important for a realistic design. Design objective were to achieve higher actuation force. Since a computational model for design analysis at micro-scale based on FEM had never outdated. With reference to the simulation results, it was fair to say that FEM can be applied to design MEMS components prior to actual fabrication to improve design, and also save time and fabrication cost. Results showed that the comb structure with more fingers and high aspect ratio produce higher actuation force. The geometry of FEM model used for verification would be created exactly the same as the one in real world. The mathematical foundation needs to be revaluated. Stress induced in the components due to actuation force should be addressed.

In paper [8] authors concluded that by reducing the gap space between comb drive fingers it can increase its sensitivity i.e. by change in capacitance due to displacement. The minimum feature size of standard fabrication foundries is 2 microns. To reduce the gap beyond a minimum feature size, authors proposed that the comb drive fingers be initially disengaged to facilitate the fabrication of gaps without conventional limits. Post-fabrication assembly however required to electrostatically translate the stator to engage the comb fingers. Previously, researchers had investigated using engaged variable finger widths; however, compared to what this paper propose, the previous method results in a jump in the electrostatic force and non-passive sensing. Through modelling and simulation, it can examine that various stator translation configure and comb drive instability were reduced due to the smaller gap size. MEMS comb drives have been frequently used for electrostatic capacitance sensing. For comb fingers with reduced gap, the capacitance of the plates change by larger amounts as the structure is deflected. Having larger sensitivity to changes in capacitance will improve the device sensing. Moreover, undesirable stray capacitances known as parasitic capacitances often interfere with capacitance sensing. Although the stray capacitances may be minimized by shielding and good layout practices, the parasitic capacitances may limit the charging and discharging of the comb finger plates and affect the sensing. Thus, it is beneficial to have reduced gap space between comb fingers as this gives larger capacitance readouts with smaller displacements, much higher than the noise from stray capacitances, to greatly improve accuracy in sensing. MEMS comb drives uses capacitive sensing in measuring physical variables such as acceleration or pressure.

In paper [10] the authors fabricated a device which requires just over 45V for closing the gripper and which may find applications in microrobotic arms and also concluded that a lower pull-in voltage could be achieved through optimization of the restoring springs.

The parallel plate configuration can be a good approach for realizing switching actuators where intermediate position control is not of concern. Parallel plate electrostatic actuators occupy a smaller area than that needed by a comb-drive design for a given output force and are more suitable for the typical postprocessing and microassembling handling that is required in the realization of complex micromachines. In paper [11] the authors concluded that the area-changed type of capacitance detection scheme provides an attractive alternative approach to overcome the disadvantages

Arising from the air-gap change type of accelerometer. Area-changed accelerometers uses a ribbed fingers structure on the movable mass as a differential capacitor and suspended over stationary electrodes composed of differential comb fingers by means of suspension beams. With the arrangement of the sensing electrodes on top of another, the differential capacitance was shown to vary linearly with the overlapped area of the proof mass and the fixed electrodes underneath and independent of the gap between the proof mass and the electrodes. Also, as the sense electrodes move coplanar with respect to each other, the operational range of the device was not limited by the thickness of air gap. High sensitivity can be obtained either by increasing the mass of the proof mass or lowering the spring constant of the suspension beam. The mass of the proof mass can be increased by increasing its thickness and the size. Folded suspension designs can be used to achieve high sensitivity by offering a low spring constant in the sensing direction. It is also desired that the suspension is compliant in the direction of displacement and very stiff in the orthogonal directions. With this approach, the sensitive axis was parallel to the air gap of the sense fingers and therefore the pull-in voltage of the device was increased considerably. Lastly, squeeze film damping between the sense fingers was avoided as there was no movement towards one another.

In paper [13] the authors proposed that by careful measurement of the capacitance versus actuation voltage, the lateral and parasitic normal components of the comb drive motion can be very accurately separated by a simple analytical model. MEMS comb drives made in surface micromachining could suffer from a parasitic out of plane motion (levitation) in addition to the intended lateral motion. By accurately describing the capacitance changes of an actuated comb drive that suffers from levitation, it can extract accurately the lateral motion as a function of actuation voltage. This enables comb drive as a position sensor with very high accuracy, which does not suffer from levitation-induced non-linearity. The levitation force shows up as a detrimental effect if one is interested in measuring displacement of actuated comb drives by monitoring the capacitance changes.

III. MOTIVATION

The comb based on the parabolic shaped comb design [10] which tells us that the force – displacement evolution is not linear or constant and a stepwise continuous variation of force with displacement is considered here. I.P.F. Harouche and C. Shafai [11] introduced a novel concept of jagged-edge comb drives for the design of MEMS microtweezers. By modifying area between the comb electrodes due to engagement witch is a function of driving voltage we can establish the move-and-lock mechanism. We studied comb drive on the MEMS module in COMSOL Multiphysics®, using the plane-stress mode in 2D in order to simulate a displacement of the comb fingers. In our simulation, we use a limited number of comb fingers for simplicity purposes. Modeling with too many comb fingers results in a lot of computer memory usage and meshing. The geometry simulated involved a set of 10 fixed fingers and 9 movable fingers attached to folded flexure springs and 2 fixed fingers and 1 movable fingers attached to folded flexure springs Mesh optimization represent an important step for solving FEM problem. As a means of validation, the triangular mesh sizes were decreased in order to see if further refinements yielded to any appreciable changes in the results.

IV. PROBLEM FORMULATION

Actuator as microtweezers must produce enough displacement to grip the object of interest and reside a stable level of tension to hold. The issue of controllability is vital. The shaped fingers could be used to create linear voltage displacement behavior for an actuator, so that the control system for the actuator could be simplified. As the rectangular comb drive doesn't provide less actuation voltage. Many different geometries are designed to produce multiple stable positions in its motion but they have other problems like controllability, heating, high actuation voltage, slippage. An actuator could be designed which uses shaped comb fingers to create low actuation voltage with more controllability. The shaped comb drives are used to stiffen and weaken actuator springs and hence offer more controllability over the device functions.

V. ELECTROSTATIC COMB DESIGN

The designing of electrostatic comb structures and their comparisons, using different geometries are very useful at this scale and also been used as structural or functional materials with great success. Different structures are designed using COMSOL3.5a (Common Solution Version 3.5a). Mechanical microgripper and microtweezer as shown in figure 4.1 are useful in many current research areas. Such devices were developed as biological micromanipulators [4], robotic grippers [22], and general out-of-plane manipulators [29]. A successful microtweezer actuator must generate enough displacement to hold and apply suitable tension on to the object. The open-close movement doesn't assurance the object will not slip. Disproportionate closing force may damage the object. The actuator design is defined by the electrostatic driving force and the resultant mechanical displacement. It implies that, in order to properly simulate the device, two domains must be coupled the electrostatic domain and the mechanical domain. This is, therefore, characterized as a multiphysics problem. Simulation of such a problem using the Finite Element Method (FEM) is not trivial and difficulties arise in developing a mesh capable of approximating large deformations.

Additionally, a parametric simulation generates increasingly deformed meshes, which in turn become unstable and solutions do not converge.

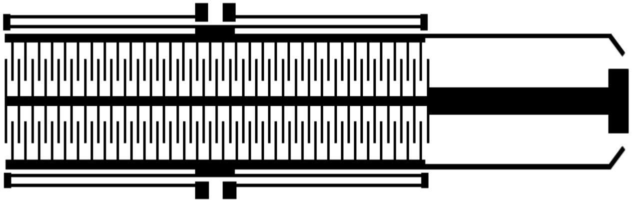

FIGURE 1: ELECTROSTATIC MICROGRIPPER [5].

Actuators are used for the transformation of non-mechanical input energy into mechanical output energy. Electrostatic actuators have a long history dating back to the 18th century when several types of electrostatic motors were built. Electrostatic actuation is one of the simplest actuation method based upon attractive or repulsive forces between positive and negative charges and the most widely used structures for this mechanism are comb drive structures. Comb drive structures are made of two combs, a movable one and a fixed one, where an electrical potential difference between them generates an attraction force, moving the movable comb [2]. The basic design of a comb drive relies on the theory of parallel-plate capacitors, which in turn is a function of the plate's area and shape.

For designing these types of structures you need to have MEMS simulation software which should be user friendly and reliable. Any MEMS simulation software uses either of two approaches. System level (or behavioral or reduced order or lumped parameter) modeling: This approach captures the main characteristics of a MEMS device. It provides a quick and easy method to predict the main behavior of a MEMS device. The requirement is that the device can be described by sets of ordinary differential equations and nonlinear functions at a block diagram level. This approach originated from control system engineering. The multidomain problem is avoided since, typically, the simulation tools are physically dimension less only, the user interprets the input and output of the various blocks in a physically meaningful way. Finite element modeling (FEM): This approach originated from mechanical engineering where it was used to predict mechanical responses to a load, such as forces and moments, applied to a part. The part to be simulated is broken down into small, discrete elements a process called meshing [2]. Each element has a number of nodes and its corners at which it interacts with neighboring elements. The analysis can be extended to non mechanical loads, for example, temperature. Additionally, finite element simulation techniques have been successfully applied to simulate electromagnetic fields, thermodynamic problems such as squeeze film damping, and fluidics. FEM results in more realistic simulation results than behavioral modeling, but it is much more computationally demanding and hence it is difficult to simulate entire systems. One of the most powerful finite element (FEM), partial differential equation (PDE) solution engine is COMSOL Multiphysics 3.5a

VI. CONCLUSION

Microelectromechanical Systems (MEMS) has led to a drastic development in the field of actuators. This paper presents a idea of shaped low voltage design of a electrostatic comb drive with different parameters. The analysis of MEMS electrostatic comb drive can be done with different structures. An increased displacement of lateral comb drive actuator will subsequently be accomplished with the low actuation voltage. COMSOL Multyphysics 3.5a can be used for designing the comb drive. It offers Finite element analysis to prove the concept of displacement of movable comb fingers, achieved by the amount of electrostatic force generated by the device.

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