Multiple Interconnected Parallelogram Actuators And Parallelogram Rigid Frames

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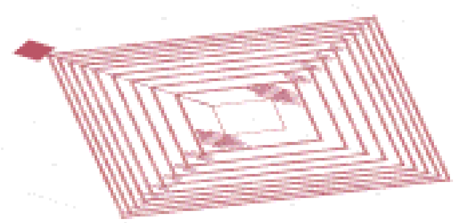
Abstract
In this paper, we present the design and simulation results of multiple interconnected parallelogram actuators and parallelogram rigid frames that can be used for large amplitude static displacement. The design stands as an un-optimized example of the basic idea of accumulating displacement and force through the multiplication of similar, interconnected smaller unites. For a MUMPS structure of ten parallelogram actuators and frames with side lengths ranging from 200μ to 1099μ, a max of 39.9μ lateral displacement and 21μN force (at 53V) was achieved through simulation.



1. Introduction

With the new multilayer surface micromarching processes emerging, the next generation microactuation schemes are becoming more attractive and therefore are subjects of many ongoing researches. Microsteam engines [1], surface-tension-driven micropumps [2], and milli-rotary internal combustion engines [3] are all examples of this new trend among the MEMS community. However, good old electrostatic microactuation is still considered by many to be the most popular and easy to design form of actuation, with many practical applications and more room to growth.

Among the electrostatic actuators, one may find two basic designs. The first design utilizes parallel plate capacitors with one moving plate that is allowed to displace in the direction of the major field lines. The second basic design utilizes the fringe field of capacitors to drive the moving plate parallel to the fixed and perpendicular to the major field lines. Suitable for medium-low static displacements [4] or small amplitude resonant displacements [5], larger structures consisted of several smaller units of these actuators do not yield larger amplitudes relevant to their size increase and will ultimately reach a saturation limit, thereafter only the force gets proportionally larger with the addition of each smaller unite. There are also other forms of non-electrostatic actuators that suffer from the same limitation, such as the heatuator [6] where an amplitude increase cannot be achieved through multiplication of the basic unite.

In this paper, we present the design and simulation results of a multiple interconnected parallelogram actuators [7] and parallelogram rigid frames (MIPARF), that can be used for large amplitude static displacement in places where precise positioning is also highly desirable, an example of which would be in optical devices for lateral control of micromirrors (or shutters). The design stands as an un-optimized example of the basic idea of accumulating displacement, on top of force duplication, through multiplication of similar, interconnected smaller unites.

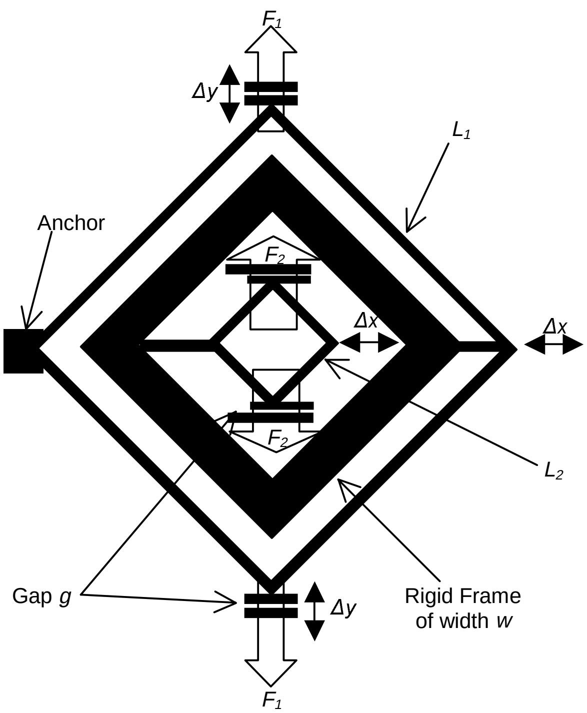


Figure1: Principle behind the motion and transformation of the multiple inter-connected parallelogram actuators/ parallelogram frames.

2. Design

Figure 1 illustrates the principle behind the motion and force transformation achieved by the parallelogram structure. A normal force, F_1, is developed across a gap, *g*, between the electrode plates on the top and bottom of the suspended parallelogram structure, resulting in a deflection Δy at each of the two parallelogram electrode plates. The deflection at the plates is approximately given by:

$$\Delta y = \frac{F_1 L_1^3}{12EI} \qquad (1)$$

where L_1 is the length of one parallelogram side, *E* is the Young's modulus of the structural material and *I* is the moment of inertia of the parallelogram beams. The deflection Δy is proportional to the square of applied voltage. The deflection Δy is in turn transformed into a deflection Δx at the other vertex (the vertex of action) of the parallelogram. Therefore, the deflection Δx is controlled with the applied voltage. The relation between Δy and Δx is given by:

$$\Delta x = 2\Delta y \qquad (2)$$

when one vertex of the parallelogram is fixed to the substrate. Through the inner rigid parallelogram frame of width *w*, the force and displacement vectors of the vertex of action are transferred to the second parallelogram actuator, pulling it to the left of the Fig. 1. A normal force F_2 is developed across the gap *g* between the electrode plates on the top and bottom of the surrounded parallelogram structure, in such a way that $F_2 L_2^3 = F_1 L_1^3$, resulting in a deflection Δy at each of its electrode plates. Thus, this parallelogram actuator, itself moved to the left by Δx, moves the new vertex of action to the left by another Δx resulting in a total displacement of $2\Delta x$ with respect to a fixed location. Repeating the same type of parallelogram actuator/frame structures until constrained by the inside geometry, it is possible to accumulate a large number of Δx displacements. The area surrounded by the inner most parallelogram actuator is the load area where the final vertex of action gets connected to the load (ex: a mirror, shutter).

Because of the small beam deflections in each parallelogram, use of the simple beam theory is adequate enough for the design and other calculation purposes [8].

Eliminating Δy from equations 1 and 2 and replacing F_1 with the electrostatic force using parallel plate theory, the overlap area required for generating the force can be determined. Figures 2 and 3 show the layout of the actual design in MUMPS process. For a 3μ gap, Δx=2μ, w=7μ, v=53V, and a 200μ x 200μ real estate for the load area (mirror), a total nodal displacement of 39.9μ and a max of 21μN was achieved through simulation.

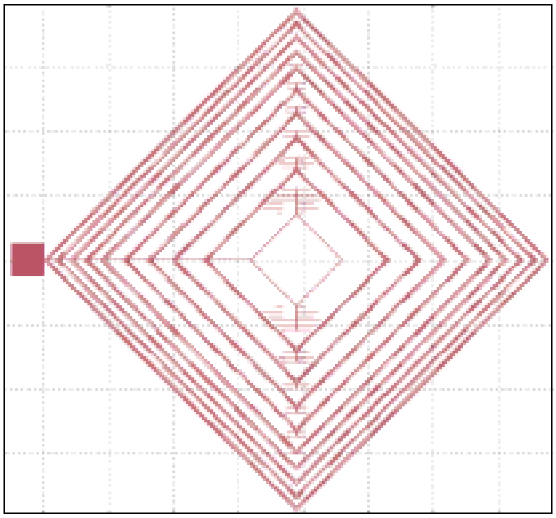


Figure 2: The actual layout of the design shows that more gap-closers are required for the inner parallelogram actuators.

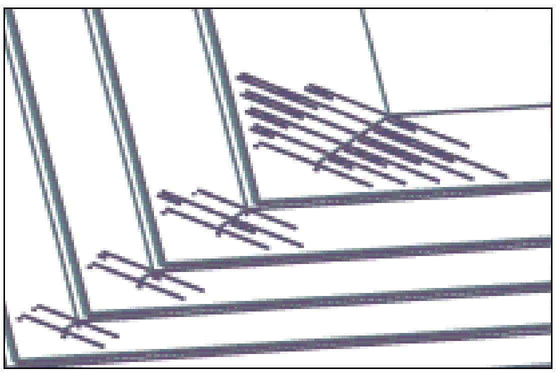


Figure 3: For the inner actuators, the path of the beam connecting the gap-closers to the parallelogram structure should be clear of the anchored electrodes while the overlap area should remain constant throughout the actuation.

3. Fabrication

The simulation of our design is based on MUMPS fabrication. Our task was to observe the MUMPS design rules as much as possible. The moveable structure is made of poly 1. The electrodes are also Poly1 anchored to Poly0 to provide electrical connection.

4. Discussion

Although the simulation pointed to a successful operation, there are many concerns about this design. During release in the MUMPS process the large beams might stick to the substrate due to surface tension. Also during high voltage operation, the same failure may occur due to electrostatic attraction between the beam and substrate. Although bushing will prevent such failures, it was not included in our layout because of the simulator limitations. Also, the theoretical determination of static displacement is dependent on the accuracy of both Young's modulus (165GPa) and the suspension beam widths and depths. Our model assumes perfect geometric dimensions whereas the actual structure will have dimensions that vary slightly with the fabrication process.

4. References

1. Sandia National Laboratories, *Intelligent Micromachine Initiative,* http://www.sandia.gov/mems/micromachine/movies8.html
2. K.-S. Yun, I.-J. Cho, J.-U. Bu, G.-H. Kim, Y.-S. Jeon, C.-J. Kim, E. Yoon, "A micropump driven by continuous electrowetting actuation for low voltage and low power operations," Technical Digest, MEMS 2001, 14th IEEE International Conference on Micro Electro Mechanical Systems, Interlaken, Switzerland, 2001, 21-25 January, pp.487-490.

3. University of California, Berkeley, Dept. of Mechanical Engineering, http://www.berkeley.edu/news/media/releases/2001/04/02_engin.html
4. R. A. Brennen, M. G. Lim, A. P. Pisano, and A. T. Chou, "Large Displacement Linear Actuator," Technical Digest, IEEE Solid-State Sensor and Actuator Workshop, Hilton Head Island, South Carolina, USA, June 4-7, 1990, pp.135-139.
5. W. C. Tang, T.-C. H. Nguyen, R. T. Howe, "Laterally driven polysilicon resonant microstructures," Technical Digest, IEEE Micro ElectroMechanical Systems Workshop, Salt Lake City, Utah, USA, February 20-22, 1989, pp.53-59.
6. J. H. Comtois, V.M. Bright, "Surface micromachined polysilicon thermal actuator arrays and applications," Technical Digest, Solid-State Sensor and Actuator Workshop, Hilton Head Island, SC, USA, June 3-6, 1996, Tranducer Res. Found, 1996. pp.174-177.
7. N. Takeshima, K. J. Gabriel, M. Ozaki, J. Takahashi, H. Horiguchi, H. Fujita, "Electrostatic parallelogram actuators," TRANSDUCERS '91, 1991 International Conference on Solid-State Sensors and Actuators, Digest of Technical Papers, San Francisco, CA, USA, June 24-27, 1991, pp.63-66.
8. G. K. Fedder, Design of Polysilicon Micromechanical Flexures, EECS 290-0 Final Report, Spring 1991 University of California at Berkeley