Strathprints Institutional Repository

Li, L. and Uttamchandani, D.G. (2002) *Analysis of microsprings for calculating the force produced by microactuators.* [Proceedings Paper]

Analysis of microsprings for calculating the force produced by microactuators

Lijie Li, Deepak G Uttamchandani*
Microsystems Group
Department of Electronic and Electrical Engineering
University of Strathclyde
204 George Street
Glasgow G1 1XW, UK

Abstract:

We present models of two types of microsprings namely box-spring and zig-zag spring that can be used to measure the force generated by microactuators. The spring constant for both springs is calculated by FEM using ANSYS software. In these models, the effects of short beams that act as connectors in the spring structures are considered and analyzed by changing their width. Also, from the results, we find that the box spring appears more balanced than the zig-zag spring when the force is applied in the single central direction. A series of SDAs with box spring have been fabricated and forces of those SDAs have been calculated.

Keywords: microspring, microactuator, box spring, zig-zag spring

Introduction:

Microactuators offer many applications in MEMS (Microelectromechanical System) technology. MEMS devices that require to be moved must have microactuators to drive them in order to achieve some special functions [1]. Different devices have different actuation requirement and the forces that they need to operate are also different. The calculation of a microactuator's force is therefore very important. Certain microactuators use microsprings to pull them back to the original position by the restoration force of the spring, because these actuators are single direction actuators. An example of this is the scratch drive actuator [2]. Microsprings can be used to measure the force of microactuators by measuring the displacement of the spring, providing the spring constant is known. Therefore, it is important to develop the model for such a spring. In terms of modeling of these springs the spring constant can be controlled by adjusting the dimensions and geometry of the springs. In this paper, two types of springs have been investigated, namely the zig-zag spring and the box spring. Several 'Z' shape micromechanical beams connected to each other form the planar zig-zag. Box springs have several planar rectangular frames joined by small bars. These

* Prof. Deepak Uttamchandani, email: du@eee.strath.ac.uk, tel: +44 141 5482211, fax: +44 141 5531955

Design, Test, Integration, and Packaging of MEMS/MOEMS 2002, Bernard Courtois, Jean Michel Karam, Karen W. Markus, Bernd Michel, Tamal Mukherjee, James A. Walker, Editors, Proceedings of SPIE Vol. 4755 (2002) © 2002 SPIE · 0277-786X/02/$15.00

two types of springs are analyzed assuming the spring has been fabricated by a polysilicon surface micromachining process. All the material properties of the polysilicon used in this analysis apply to the MUMPs process [3].

The in-plane behavior of the zig-zag spring and box spring are analyzed by the finite-element method using the PC ANSYS software. A number of springs having different dimensions have been analyzed using this method.

Scratch drive actuators (SDAs) with two box-springs have been fabricated by the MUMPs process. The SDA plate dimensions are 65um width and 75um length, the spring width is 2um. The force character of these SDAs is measured.

1. 'Box' spring in-plane distortion

We first begin to analyse the box spring using simple formulae from mechanical beam theory to obtain an approximate value. The geometry of the spring is schematically illustrated in Fig. 2. This spring contains three boxes connected together by two short bars. All the bars have been designed as the same width. We call each box a cell.

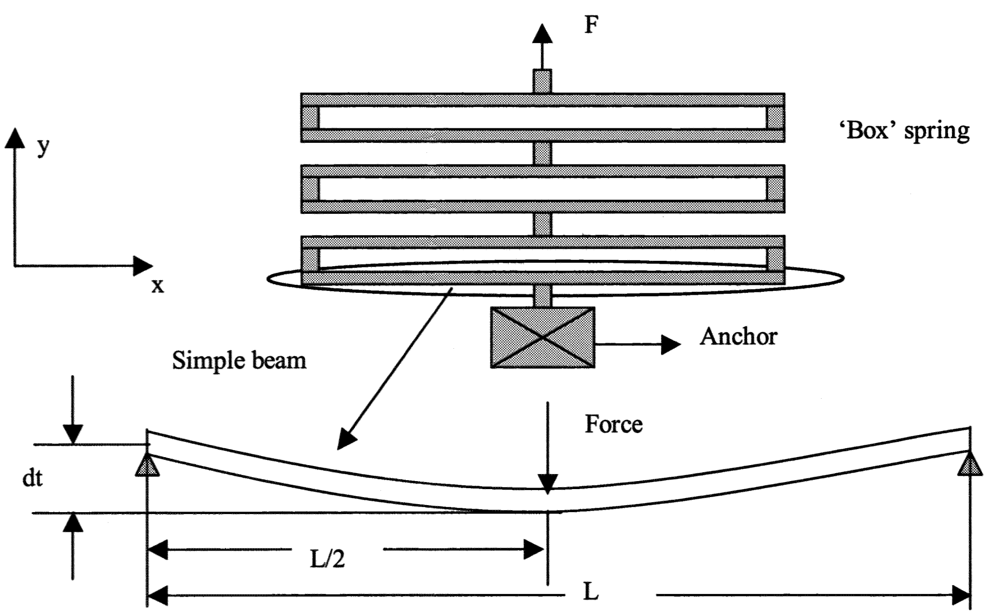

Fig. 1. The geometry of the 'box' spring. 'L' is the length of single beam, 'dt' is the maximum displacement of beam. 'F' is the force applied to the middle of the beam.

All the three cells are of the same structure and we only need to analyse one of these cells. From the Figure, one cell contains four mechanical beams, two short beams and two long beams. The force is applied in the y direction and we assume that the two short beams cannot stretch in the y direction. Selecting one of two long beams, centre loaded clamped beam theory can be used to calculate the displacement in this case. The centre displacement of the clamped-clamped beam under centre loading is[4]:

$$dt = \frac{FL^3}{192EI} \qquad (1)$$

Where, 'dt' is the displacement at centre position in the y-axis, 'F' is the force applied to the centre of the beam, 'L' is the length of the beam, 'E' is the Young's Modulus, and 'I' is the moment of inertia.

So the spring constant of N 'boxes' connected together is easily obtained as (assuming the short bars of box have no effect on the spring constant) as follows:

$$k = \frac{96EI}{nL^3} \qquad (2)$$

We assume the following: E=169GPa, L=50 μm, n=3, polysilicon thickness is 2 μm, width of polysilicon is 2 μm. Substituting 'E', 'I', 'L' and n to the formula (2), the box spring constant is calculated to be 51.28 μm/μN.

Next we build a beam model of the spring using ANSYS finite-element package (version 5.7.1). The model of the spring structure is described here. We consider a spring made from polysilicon. All the polysilicon bars have the same width and depth. The dimension of the spring is as follows: the length of the polysilicon box is 50 um, the width of the polysilicon box is 2 um and the thickness of the polysilicon layer is 2 um. The thickness is the same

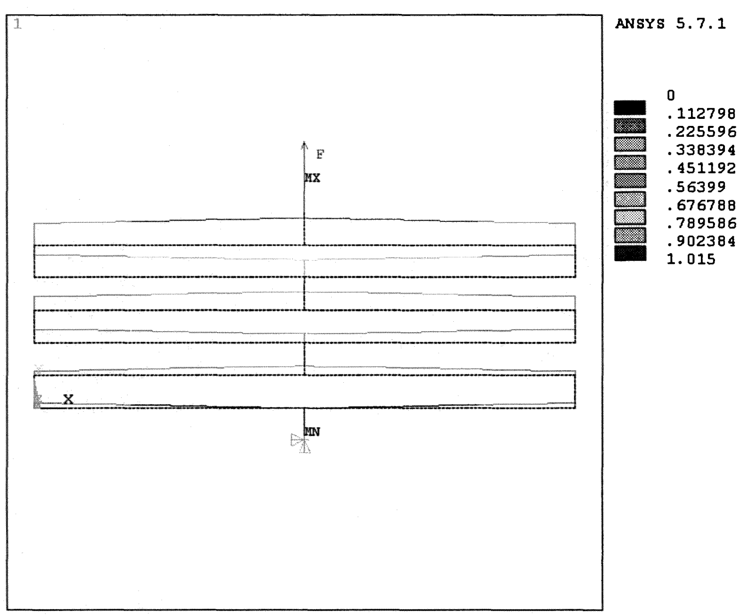

Fig. 2. Result from ANSYS software, the numbers in the right of the figure represent the nodes displacement in y direction. The unit is micron.

value as normally obtained from the MUMPs process. In this model, the Young's Modulus of polysilicon is 169 GPa, again as obtained from the MUMPs process. One end of the spring is fixed and a force is applied to the other end of spring at its centre. The ANSYS static analysis can directly calculate the displacement of the centre corresponding to an applied force, then the formula $k = \frac{F}{x}$ is used to calculate the spring constant k. The spring constant k of this spring is shown in table 1 where a series of forces are separately applied to the box spring. One of the results of the spring distortion under a force is shown in Fig. 1. From Table 1, we can see that the theoretical approximations and ANSYS results are close in value.

TABLE 1. Results of 'box' spring constant k using ANSYS static analysis

Applied force (μN)	Maximum Displacement (μm)	Spring constant k (μN/μm)
50	1.015	49.2611
100	2.03	49.2611
150	3.046	49.2499
200	4.061	49.2490
250	5.076	49.2514

In order to analysis the effect of the short bars, we change the width of the short bar and analyse the box springs again using ANSYS. A series of values of short bars that were analysed is shown in Table 2. One of ANSYS results is shown in Fig. 3.

TABLE 2. Results of different wide of bars

Short bar width (μm)	Maximum Displacement (μm) (force is 50 μN)	Spring constant k (μN/μm)
2	1.015	49.26
3	0.971662	51.46
4	0.954371	52.39
5	0.951012	52.58
10	0.950474	52.61
20	0.950477	52.61

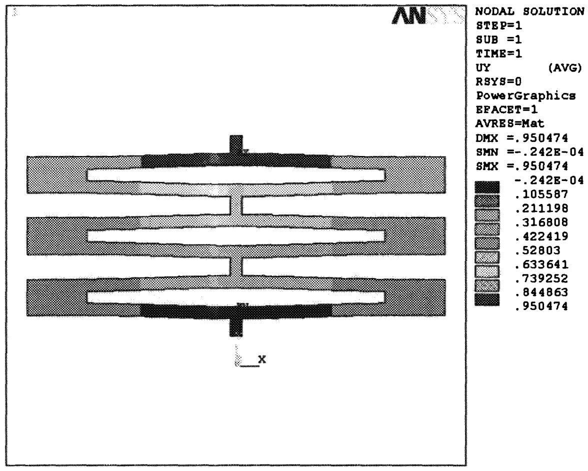

Fig. 3. One of results from ANSYS, where the short bar width is 10 μm.

2. 'zig-zag' spring in-plane distortion

Another spring that has been analysed is called 'zig-zag' spring. This type of spring contains a numbers of bars connected in a 'zig-zag' path. A beam model has been constructed for analysing in ANSYS software. In this model, one end of this spring is fixed and at the other end a series of forces are applied and a series of displacement results are obtained as shown in Table 3. The spring constant k is calculated as before. The force direction is along the y-axis as shown in Fig. 4. It is noticed that together with the extension in the y-direction, there is a small distortion of the structure in the x-direction. The unbalance of the spring appears in Figure 5. The reason is the short bar between two long bars also bends when the force is applied.

TABLE 3. Results of 'zig-zag' spring constant k using ANSYS static analysis

Applied force (μN)	Maximum Displacement (μm)	Spring constant k (μN/μm)
50	11.489	4.3520
100	22.978	4.3520
150	34.467	4.3520
200	45.956	4.3520
250	57.445	4.3520

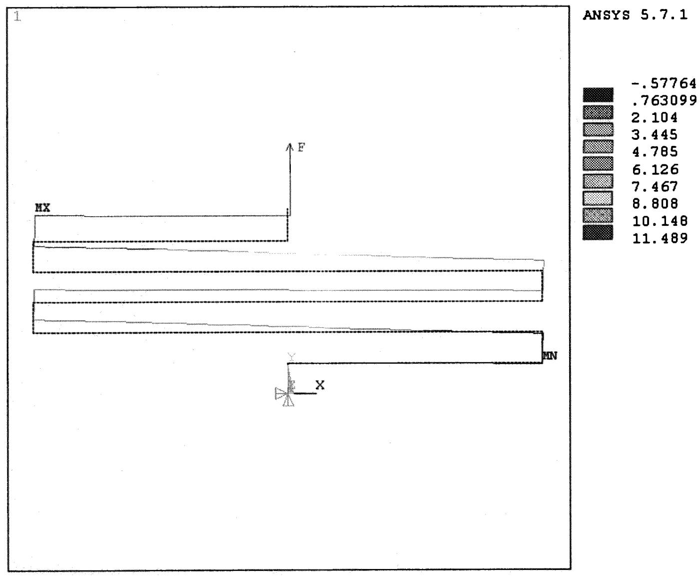

Fig. 4. ANSYS analysis of 'zig-zag' spring, the force F_y=50uN. The result shows the y-axis displacement. The numbers (um) on the left of the figure represented the displacement value.

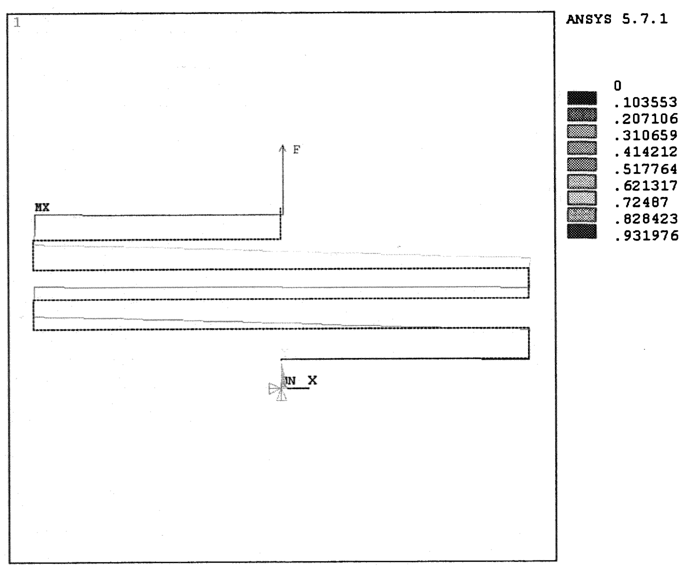

Fig. 5. ANSYS analysis of 'zig-zag' spring, the force F_y=50uN. The result shows the x-axis displacement. The numbers (um) on the left of the figure represented the displacement value.

The zig-zag spring has been analyzed in the same way as the box spring. Table 4 shows the spring constant calculated from the ANSYS static analysis. Fig 6 shows one example of an ANSYS result. The short bar width is 20 μm.

TABLE 4. Results of different width of bars for zig-zag spring

Short bar width (um)	Maximum Displacement (μm) (force is 50 uN)	Spring constant k (μN/μm)
5 um	10.504	4.76
10 um	10.482	4.77
20 um	10.482	4.77

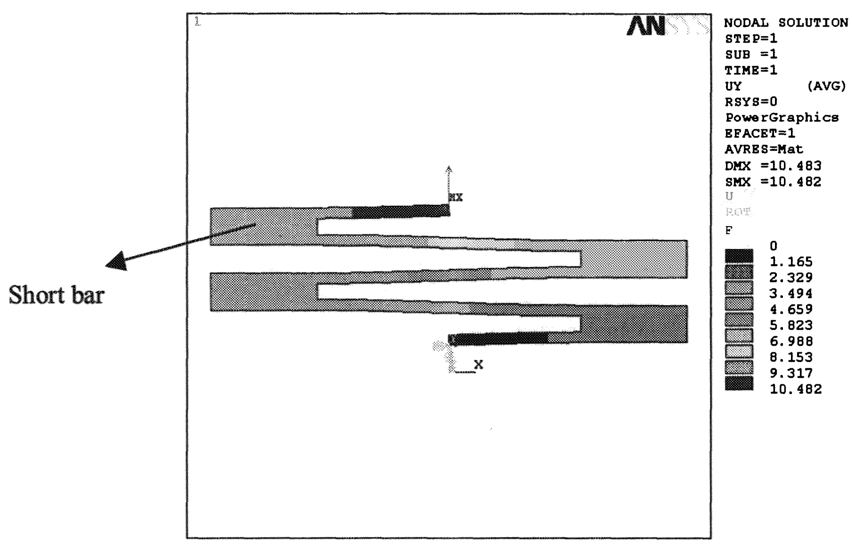

Fig. 6. One of results from ANSYS, where the short bar width is 20 μm.

3. Scratch drive actuator force analysis

Four different designs of SDAs have been fabricated. They have from 1 to 4 plates with two 'box' springs. They have been designed for analysing the force characteristics of scratch drive actuators. Fig. 7 is the picture of the device with 1 plate. In this picture, the small comb is the scale for measuring the displacement of the SDA. When voltage is applied to SDA, it moves forward and stretches the spring. The stretch can be measured from the scale. Once the SDA's force equals the spring's restoration force, the system achieves a balance and the SDA will stop. Thus, using this displacement and the spring constant k we can calculate the force that the SDA generates.

In this design, the spring constant of the box-spring is 49.3μN/μm (by ANSYS) and 51.3 μN/μm (by theoretical). So the value of 50μN/μm will be used to calculate the spring restoration force. Different voltages from 100-200V have been applied to the SDA. The frequency is constant and has a value of 100Hz. Fig. 8 shows the results of the SDAs' forces for different voltage conditions. At the same time, 2-plate, 3-plate, and 4-plate SDAs also have been investigated by the same method. The results show that increasing the SDA plates generates more force, but the force does not increase linearly with the number of plates.

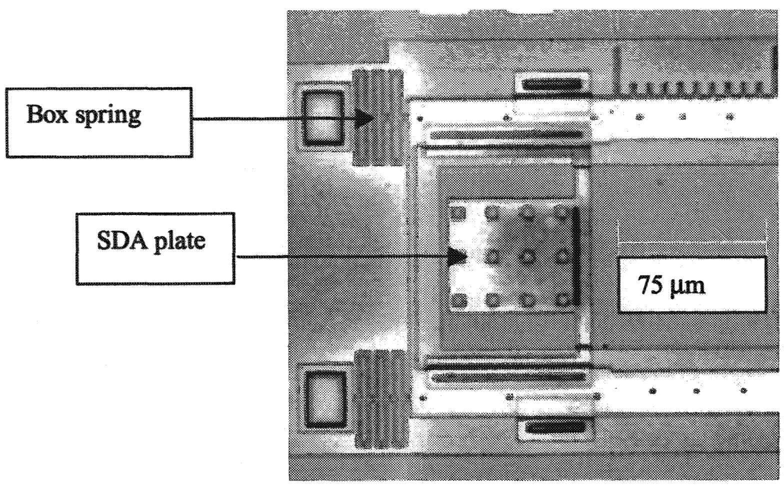

Fig. 7. Photograph of scratch drive actuator with 'box' spring.

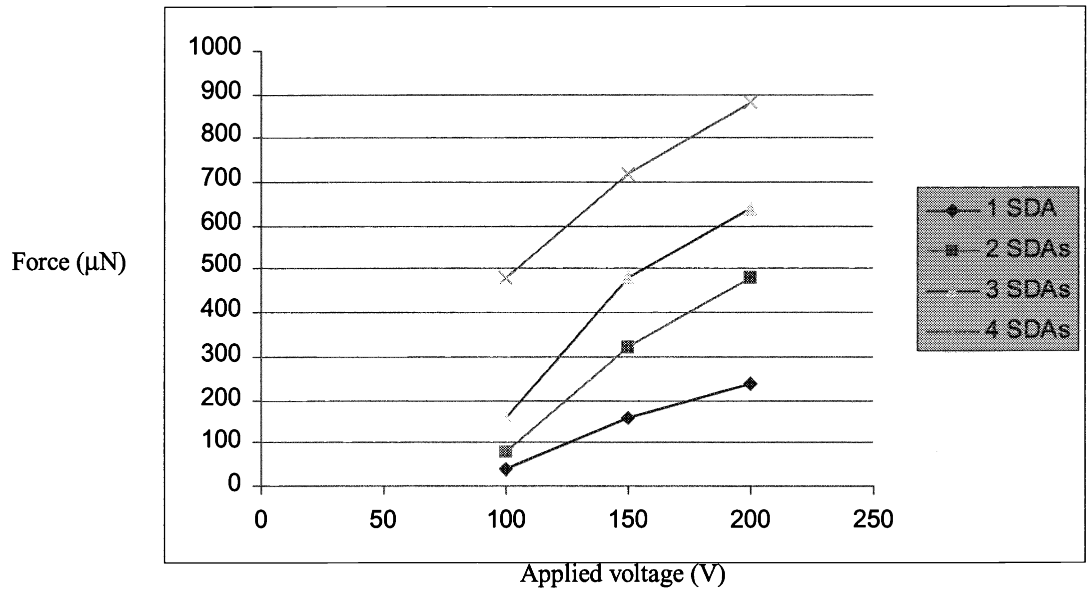

Fig. 8. Forces of single SDA, 2-stage SDA, 3-stage SDA and 4-stage SDA while applied different voltage.

4. Conclusion

Two types of microsprings have been analysed by FEM using ANSYS. For the 'box' spring, the results from ANSYS and from mechanical theory are very close. We also call this type of spring 'balanced' spring, because when applying force only in y direction, the displacement occurs only in y direction. On the contrary, the so called 'zig-zag' spring is not balanced when applying single central force to it. Some scratch drive actuators with box springs have been fabricated using the MUMPs process. These SDAs have been experimentally analysed to indicate their force properties. Forces of 250 µN for one plate SDA, 900 µN for 4 plate SDAs have been estimated.

References:

[1]. Hiroyuki Fujita, "Microactuators and Micromachines," Proceedings of The IEEE, Vol. 86, No. 8, August 1998, pp.1721-1998.

[2]. Terunobu Akiyama and Katsufusa Shono, "Controlled Stepwise Motion in Polysilicon Microstructures," Journal of Microelectromechanical Systems, Vol. 2, No. 3, September 1993, pp.106-110.

[3]. David A. Koester, Ramaswamy Mahadevan, Buzz Hardy and Karen W. Markus, "MUMPs™ Design Handbook," Cronos Integrated Microsystems.

[4]. J. M. Gere and S. P. Timoshenko, Mechanics of Materials, 3rd ed. Boston, MA: PWS-Kent, 1990.