Analyzing Deflection and Torsion of MEMS Bridge

[1]Leila Mohammadian, [2]Asghar Mohammadian

[1]Sama technical and vocational training college, Islamic Azad University, Tabriz Branch, Tabriz, Iran
[2] Islamic Azad University , Ilkhchi Branch, Ilkhchi, Iran
Lm_b81@yahoo.com, Asgharmohamadian@gmail.com

Abstract

In this paper we discuss and compare regarding various methods in analyzing deflection of MEMS Bridge that the deflection occurs due to a point force and distributed force. We solved deflection of a bridge under the electrostatics forces by considering the linear and nonlinear methods and by comparing the results, we calculated that in which range of dimension the linearity has good accuracy. For this purpose first in Macsyma we wrote a code to solve the nonlinear differential equation numerically and draw the results and solved linear O.D.E. using definite methods, comparing the results then rescaling the all dimensions and forces, we could get the acceptable range of linearity. Then we solved the same problem by Ansys in two cases, linear element and nonlinear element, and then compared the results of Ansys with Macsyma. The results showed that nonlinearity increases exponentially by decreasing the dimensions. Finally, we compare the effect of point force and distributed force on linear and nonlinear analysis. The results showed that increasing the force increases the nonlinearity.

Keywords— Deflection, Micromechanical switches, MEMS Bridge, RF MEMS switches, Newtonian laws,Torsion.

1. INTRODUCTION

Development in MEMS technology has made possible the design and fabrication of control devices suitable for switching microwave signals. Micromechanical switches were first demonstrated in 1979 [1] as electrostatically actuated cantilever switches used to switch low frequency electrical signals. Since then, these switches have demonstrated useful performance at microwave frequencies using cantilever [2], [3], rotary [4], and membrane topologies [5], [6]. These switches have shown that moving metal contacts possess low parasitics at microwave frequencies (due to their small size) and are amenable to achieving low on-resistance (resistive switching) or high on-capacitance (capacitive switching).

Micromechanical membrane switches have several advantages compared to FET or p-n diode switches. Eliminating the use of semiconductor p-n and metal-semiconductor junctions in radio frequency (RF) devices serves three very useful functions. First, the contact and spreading resistance associated with ohmic contacts are eliminated, significantly reducing the resistive losses in the device. Instead, high conductivity films are used to fabricate metal structures that carry RF currents with ultra-low losses. Second, the removal of nonlinearities associated with semiconductor junctions significantly improve the distortion characteristics and power handling of the RF MEMS devices. RF MEMS switches exhibit no measurable harmonics or intermodulation distortion. Meanwhile, the power handling of these devices is limited mostly by current density limitations. Third, electrostatic operation of the mechanical motion of RF MEMS devices requires negligible quiescent current consumption. Typical switching energy is approximately 10 nJ. The main limitation of these switches is their switching speed. Microsecond switching precludes their use in high-speed applications such as transmit/receive switching. However, these speeds are more than sufficient for a variety of applications including beam steering in phased antenna arrays. This paper describes significant improvements to the design of metal membrane switches which operate with significantly reduced losses, increased operating frequencies, and improved switching speeds over previously reported work.

Mechanic laws which governing on MEMS Mostly have not investigated, so all O.D.E's or. P.D.E's are Newtonian laws .but the other point in MEMS is Where we can use linear analysis [1,4,6,7,9,11,13] and where we must use nonlinear analysis [2,3,5,8,10,12].

In some cases researchers consider the behavior of system nonlinear and solve the nonlinear differential equation [2,5,10,12]. In some cases they consider the system nonlinear but try to linearism the differential equation [3,7,8,13]. Otherwise we consider linear equation and solve it [1,4,6,9,11].

In this work we try to show that from which range of dimension nonlinearity becomes important for bending of a MEMS switch membrane, and how much is it's value. So in different cases we solve:

$$\frac{\frac{d^2 y}{d\ x^2}}{((1+(\frac{dy}{dx})^2)^{\frac{3}{2}}} = \frac{M(x)}{E \times I} \qquad (1)$$

As a nonlinear equation and

$$\frac{d^2 y}{dx^2} = \frac{M(x)}{E \times I} \qquad (2)$$

As linear O.D.E, which is commend in Macromechanics

2. Membrane properties

Below shows two figures of MEMS membrane which is fabricated by Texas Ins. Co. The side-view architecture of one such MEMS switch is shown in Fig. 1(a). The switches are manufactured on a GaAs substrate, over which a "bow-tie" metal membrane is deposited by evaporation. The material used in the membrane is an aluminum alloy. This membrane is the only moving part of the device. Its shape, size and mechanical properties determine the behavior of the MEMS switch. Two of its edges are attached to thin posts that maintain it suspended over an insulated electrode. Microfabrication details and employed materials have been reported by Goldsmith et al.4,6 Switching is achieved by applying a pulling-in voltage between the membrane and the bottom electrode. Figure 1(b) shows the top view of a switch together with its dimensions. The membrane thickness is 300 nm with a variability of 10 nm from membrane to membrane. The gray circular dots over the membrane are small holes, 2 μm in diameter, which are necessary for plasma etching of the polymer–sacrificial layer. These holes also play a role in the dynamic behavior of the switch, by providing viscous damping, if actuated in an inert gas or air.

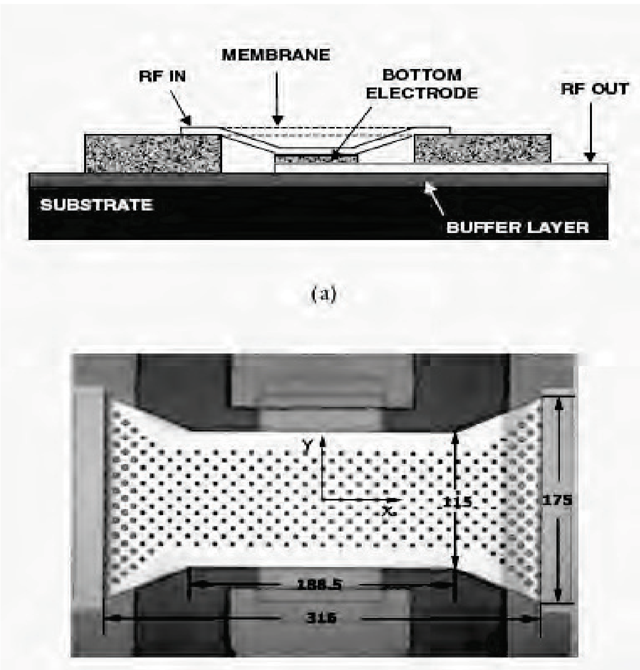

Fig. 1—(a) Cross-section of MEMS RF, switch. (b) Optical micrograph of the "bow-tie" membrane mounted on posts. The membrane is made of the same aluminum alloy used in the microfabrication of the Digital Micromirror Array Device developed by Texas Instruments Co., and contains a pattern of holes for membrane release during plasma etching. All dimensions are in micrometers.

3. Solution of O.D.E for point force

For solving the nonlinear O.D.E (1), in first step we tried to cache a solution by Lie groups, perturbation but we couldn't reach any result, so we tried to solve numerically the O.D.E. Using the ready numerical packages of software isn't possible, because they don't work for MEMS dimensions. So we wrote a program in Macsyma to solve the O.D.E (2) by Runge-kutta method and exact solution for (1).this program, which can be considered as a function of software, accepts the below table's data for run. The moment is defined as

$$M = \frac{a}{2} \times \left(\frac{l}{4} - x\right)^m$$

runge(n,l,y0,dy0,a,m,e,ii):=

Fig2-The shape of function

Table 1
the argument of function

n	number of differences	Y0	B.C
l	length	dy0	B.C
a	Coefficient of moment	m	Power of moment
e	Module of elasticity	ii	Momentum of inertia

and draws the graph of both deflections and the difference of them for point force ($M = F \times X$).

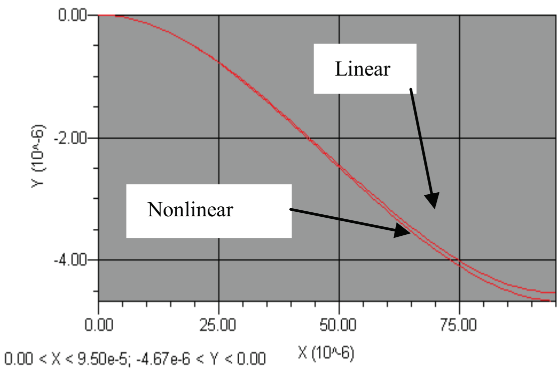

Fig 3-nonlinear/linear deflection under point force

Where:

L=190 μm f=2 μN E=70GPa

$$I = (\frac{9}{40})\mu m^4$$

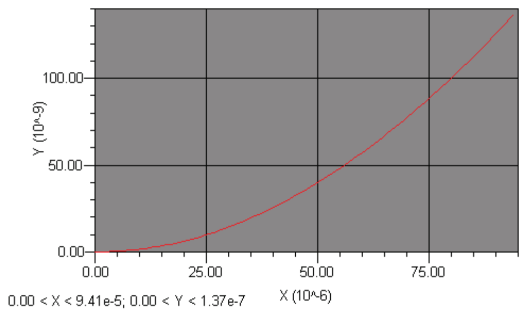

Fig 4-diffrence between nonlinear and linear deflections

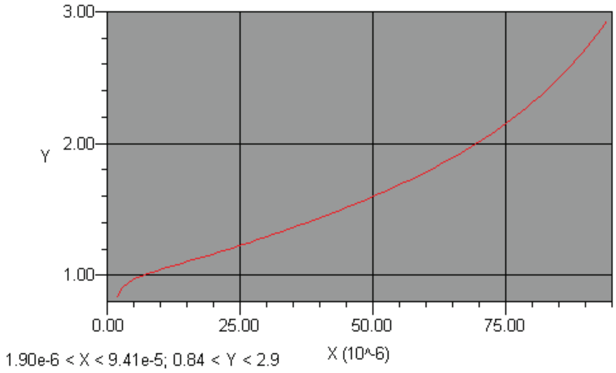

Fig 5-relative error of linear analysis

4. Ansys Analysis

In second stage, we simulated the Membrane .The used element is Shell 93. This element is nonlinear.

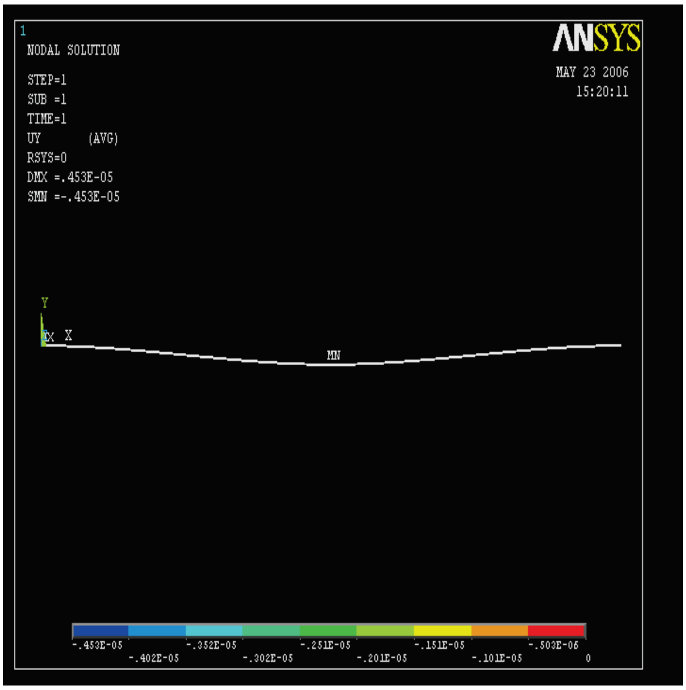

Fig 6- Ansys analysis

Table 2
compareing the results

	Linear	Nonlinear	Ansys
Max deflection	4.54e-6	4.67e-6	4.53e-6
Max deference	1.37e-8	0	1.38e-7
Max Error	10%	0	10%

5. Solution of O.D.E for distributed force

Distributed forces are associated as an important kind of forces which act along the membrane. By function runge we solved the below.

L=190 μm f=0.02222 N/m E=70 GPa $I = (\frac{9}{40})\mu m^4$

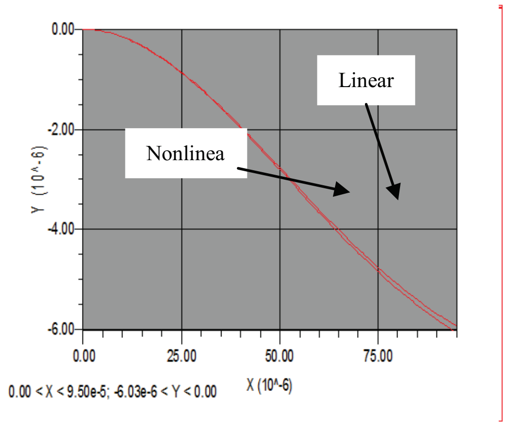

Fig 7-nonlinear/linear deflection Under distributed force

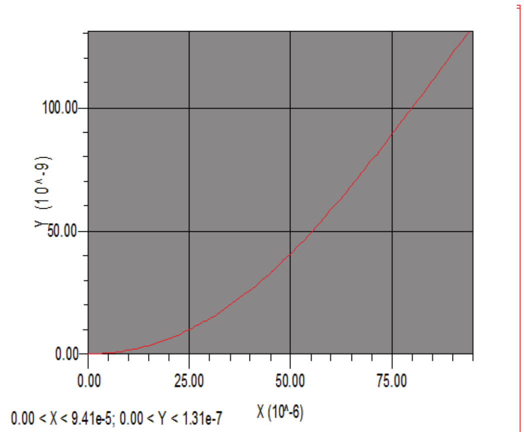

Fig 8-diffrence between nonlinear and linear deflections

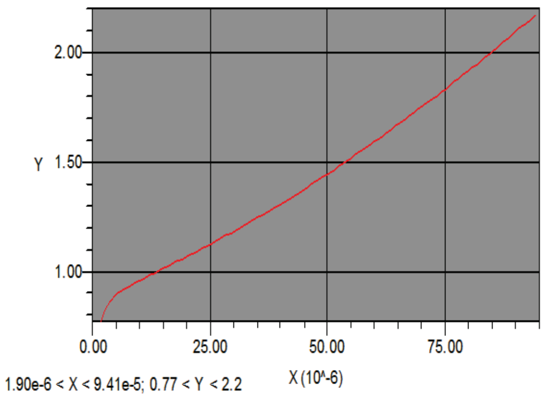

Fig 9-relative error of linear analysis

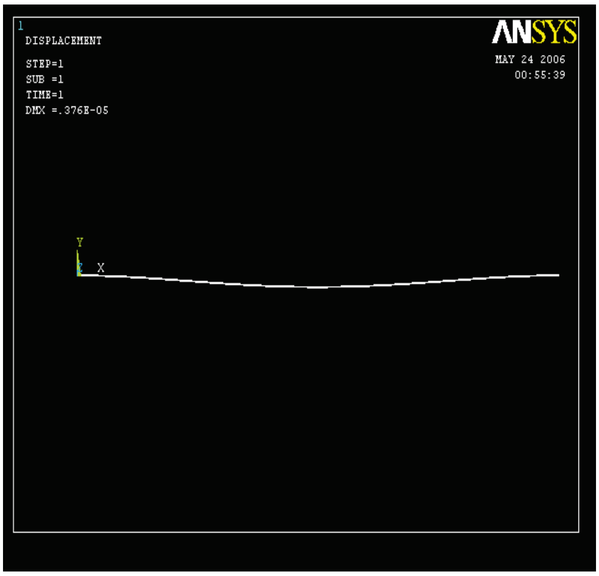

Fig 10- Ansys analysis

Table 3
compareing the results

	Linear	Nonlinear	Ansys
Max deflection	6.03e-6	5.94e-6	3.5e-6
Max deference	1.37e-7	0	err
Max Error	6%	0	Err

6. Taylor Method

Taylor expansion create the below polynomial from order 13, which we couldn't increase the order.

$$
\begin{aligned}
&2.3128733453333898459b42\ x^{13} \\
&- 3.8591695507500743224b38\ x^{12} \\
&+ 1.4826987878593083018b35\ x^{11} \\
&- 5.9209873437337337833b31\ x^{10} \\
&+ 1.2062728077547297305b28\ x^{9} \\
&- 1.2811994879357203319b24\ x^{8} \\
&+ 1.0851604746409565 18b21\ x^{7} \\
&- 3.3925439218015524663b17\ x^{6} \\
&+ 3.8499428774057143924b13\ x^{5} \\
&- 1.5239357223064286136b9\ x^{4} \\
&+ 1.0582010582010582011b7\ x^{3} \\
&- 1.5079365079365079365b3\ x^{2}
\end{aligned}
$$

Fig 11-Taylor expiation of O.D.E solution

Then we compared the nonlinear analysis with Taylor solution for point force.

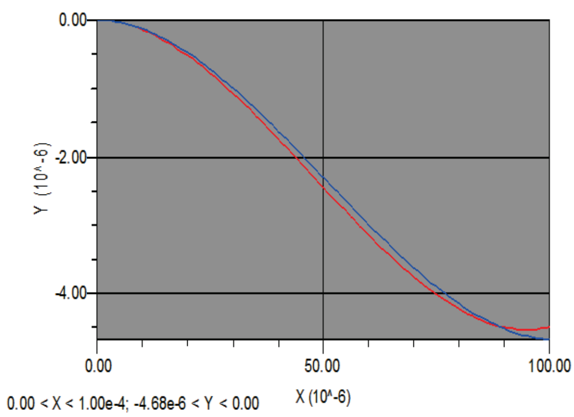

Fig 12-nonlinear/Taylor deflection Under point force

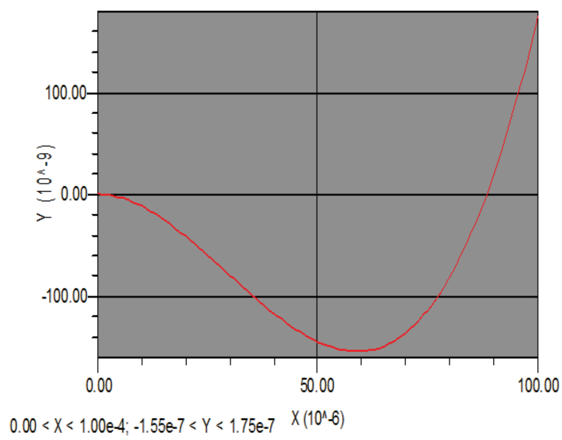

Fig 13-diffrence between nonlinear and linear deflections

7. Effect of force on nonlinearity

For predict of force effect, we wrote a function in Macsyma that calculates the maximum deflection of Membrane under any kind of force on it, in form of

$$M=\frac{a}{2}\times\left(\frac{l}{4}-x\right)$$ in a range of $a0<a<an$

runge(n,l,y0,dy0,a0,an,v,m,e,ii):=

Fig14-The shape of function

Table 4
the argument of function

n	number of differences	y0	B.C
l	length	dy0	B.C
a0	The first Coefficient of moment	an	The last Coefficient of moment
e	Module of elasticity	Ii	Momentum of inertia
m	Power of Moment	V	Step of moment

runge(100,190*10^-6,0,0,1*10^-6,4*10^-6,10^-7,1,70*10^9,9/4*10^-25)

Fig15-The Data of function

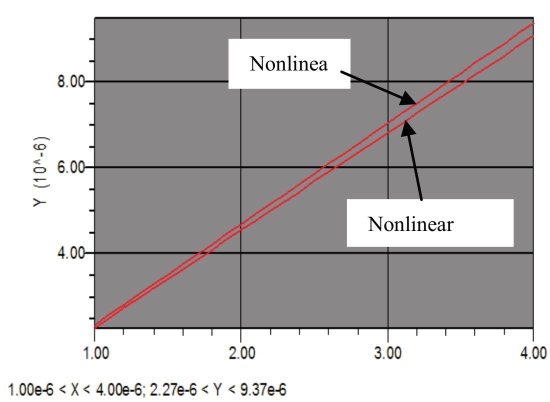

Fig16- Maximum deflection of membrane Under different forces

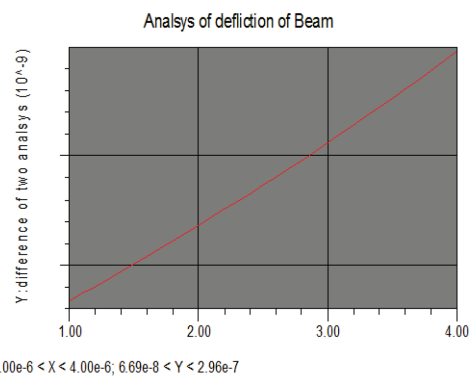

Fig17-Error of Maximum deflection of memberane Under different forces

8. Conclusion

The results of comparison showed that nonlinearity increases exponentially by decreasing the dimensions, and when we compare the effect of point force with distributed force on linear and nonlinear analysis, it is clear that increasing the force, increases the nonlinearity. So, by considering the all references, works and current work, it seems that because the nonlinearity has a very wide effect on the Micro levels, all analyses must be considered nonlinear. The nonlinearity effects exponentially in Micro level, it is not predictable in which dimensions we can use the linear analysis, so for tale safe side it is good to use the nonlinear analysis in all cases.

9. References

[1] Jinghong Chen, Sung-Mo Kang, *Fellow,* Jun Zou, *Member,* Chang Liu, José E. Schutt-Ainé, Reduced-Order Modeling of Weakly Nonlinear MEMS Devices with Taylor-Series Expansion and Arnoldi Approach, Journal of Microelectromechanical systems, Vol 13, No 3 June 2004

[2] N.Bushyager, B.McGarvey and M.M.Tentzeris, Adaptive Numerical Modeling of RF Structures Requiring the Coupling of Maxwell's, Mechanical and Solid-State Equations, Submitted to the 17th Annual Review of Progressing Applied Computational Electromagnetic Session

[3] D. Q. Caoa; ¤, Dongsheng Liua, and Charles H.-T.Wang, Nonlinear dynamic modeling for MEMS components via the Cosserat rod element approach,

[4] C-Y Hui†, J-L A Yeh‡ and N C Tien‡, Calculation of electrostatic forces and torques in MEMS using path-independent integrals, J. Micromech. Microeng. 10 (2000) 477–482. Printed in the UK

[5] JonathanWWittwer, Troy Gomm and Larry L Howell, Surface micromachined force gauges: uncertainty and reliability, J. Micromech. Microeng. 12 (2002) 13–20

[6] Feixia Pan, Joel Kubby and Jingkuang Chen, Numerical simulation of fluid-structure interaction in a MEMS diaphragm drop ejector, J. Micromech. Microeng. 12 (2002) 70–76

[7] Dong Yan, Amir Khajepour and Raafat Mansour, Modeling of two-hot-arm horizontal

[8] Rajashree Baskaran and Kimberly L Turner, Mechanical domain coupled mode parametric resonance and amplification in a torsional mode micro electromechanical oscillator, J. Micromech. Microeng. 13 (2003) 701–707

[9] Minhang Bao, Heng Yang, Yuancheng Sun and Paddy J French, Modified Reynolds' equation and analytical analysis of squeeze-film air damping of perforated structures, J. Micromech. Microeng. 13 (2003) 795–800

[10] Ilya V Avdeev, Michael R Lovell and Dipo Onipede Jr, Modeling in-plane misalignments in lateral combdrive transducers, J. Micromech. Microeng. 13 (2003) 809–815

[11] Yu-Chuan Su, Jatan Shah and Liwei Lin, Implementation and analysis of polymeric microstructure replication by microinjection molding, J. Micromech. Microeng. 14 (2004) 415–422

[12] Jao-Hwa Kuang and Chao-Jung Chen, Dynamic characteristics of shaped micro-actuators solved using the differential quadrature method, J. Micromech. Microeng. 14 (2004) 647–655

[13] Dong Yan, Amir Khajepour and Raafat Mansour, Design and modeling of MEMS bidirectional vertical thermal actuator, J. Micromech. Microeng. 14 (2004) 841–850