Design and simulation of MEMS based accelerometer for crash detection and air bags deployment in automobiles

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International Journal of Mechanical Engineering and Technology (IJMET)
Volume 8, Issue 4, April 2017, pp. 424–434 Article ID: IJMET_08_04_045
Available online at http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=8&IType=4
ISSN Print: 0976-6340 and ISSN Online: 0976-6359

DESIGN AND SIMULATION OF MEMS BASED ACCELEROMETER FOR CRASH DETECTION AND AIR BAGS DEPLOYMENT IN AUTOMOBILES

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ABSTRACT

This paper mainly subsume design and development of MEMS based accelerometer for crash detection and air bag deployment in automobiles. So far modern cars uses traditional accelerometers which gives high linearity and high cross sensitivity these can be replaced with cutting edge MEMS technology through which the entire accelerometer can be made within micro meters i.e.;(1-1000µm) which increases the operational speed in crash detection and air bags deployment. It is assumed that car moves at initial velocity of 0 Kmph and final velocity of 60 Kmph and maximum value final velocity of 180 Kmph it develops a g force range of 6g-18g. When sudden displacement occurs due to impact the comb gets shock loads or forces and that movement is observed by differential capacitance concept with dielectric as air. The simulations were carried out in COMSOL, the actual theoretical calculation and the simulations were compared in order to get accurate results. The capacitance output obtained were carried to the Electronic control unit which sends the impulse signal to air bag system and deployment of air bags takes place.

Key words: MEMS, Accelerometers, Differential Capacitance, Crash Detection, COMSOL.

Cite this Article: P.Vinay, Ch. Venkata Satya Sri Vamsi, M.Hemanth, A.Saiteja, Mohammad Abid Ali and P. Ashok Kumar, Design and Simulation of Mems Based Accelerometer For Crash Detection and Air Bags Deployment In Automobiles, *International Journal of Mechanical Engineering and Technology*, 8(4), 2017, pp. 424-434.
http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=8&IType=4

1. INTRODUCTION

A device which detects or senses the accelerations in three-dimensional space is called accelerometer. These are used in various electrical, electronic and electromechanical devices to detect acceleration, vibrations, tilts etc. These devices came into existence in late 1920s the first accelerometer was and manufactured by McCollum and peters it is a resistance bridge type accelerometer and weighed half a kilogram but the system is also highly complex. The increasing importance of accelerometer from 1920-1996 is described by Prologue and Epilogue, 2006 Patrick L. Walter, Texas Christian University, Ft. Worth, Texas[1] and later the device turned its phases into many forms like piezoelectric accelerometers Zhang zhong- cai designed a accelerometer which can detect the acceleration of a high velocity moving object in a impact environment[2].Laser accelerometers described by Wolfgang Holzapfel had a Nd:Yag laser crystals and incorporates the use of push pull mode for common proof mass which gives high linearity[3], Magnetic induction accelerometers presented by Hao Zhao is having a angular acceleration measurement feature for fault diagnostics in rotary machines[4]. Accelerometers designed by optical actuation technique is presented by A. S. Gerges, has sensing element as weighted diaphragm and incorporates the use of Fabry–Perot interferometer[5].surface acoustic wave accelerometers Wen Wang uses the ST-X quartz cantilever beam and senses the impound acceleration on beam and the deflection waves measure the acceleration occurred[6].

MEMS is a emerging topic in multidisciplinary field of engineering it can be simply explained as manufacturing of micro level system which will impart outstanding results in many fields of science. MEMS is an amalgamation of micro sensors, microelectronics, microstructures. Inertial navigation grade accelerometers proposed Y. Dong figures out the concepts regarding closed loop MEMS accelerometers and the concept of sigma-delta accelerometers which are used in navigational grade [7].P.Zwahlen explained the importance of ultra-high precession accelerometer to overcome drifts and errors in accelerometers [8]. Michael Perlmutter carried out the insights about the latest trends in MEMS field and also deeply analyzed the systems of accelerometers and gyroscopes [9]. Lei Zhao had observed the FEA simulations of the new biaxial silicon resonant accelerometer and attained the sensitivity values for x-axis as 180.03 Hz/g for y-axis as180.75 Hz/g with lowest cross sensitivity value for x-axis as 0.046 Hz/g for y- axis as 0.027 Hz/g [10]. Microelectronic and mechanical systems can be defined as miniaturized mechanical and electro-mechanical elements that are made using the techniques of micro fabrication, so that the entire accelerometer will have huge cut down in size and shape. This micrometer scale of accelerometer will also leads for quality results in very less place in any machinery or system. Overall in these types of accelerometers the capacitive spring mass base system is efficient due to high responses in operation and does not always produce false acceleration readings. In this technical paper many iterations are done to miniaturized the volume of entire accelerometer setups proof mass to 1.54 mm^2 for high sensitivity, low cross sensitivity, linearity and these sensors has low consumption of energy better results can be obtained with high precision and integration through this technology

2. PRINCIPLE

The below system explains Newton's second law of motion fig 1, it comprises a system of a damper, spring, mass and reference support.

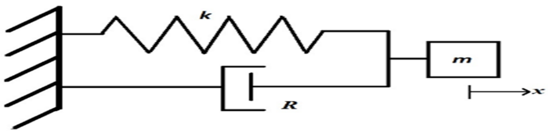

Figure 1 Represents newton’s second law of motion

When there is a displacement in the system due to mass of the system and force being applied on it. It is factual that displacement in the spring and the impulse moment is observed by the damper in the system. In this system the spring is made of structure like a double folded spring and damper was said to be the anchor.

3. PROPOUND STRUCTURE

The figure 2 shown below gives the proposed structure of accelerometer it consists of a single proof mass and the extensions which are known as fingers or projections. The fingers which are adjacent and attached to the proof mass are driving fingersand the fingers or projections which are opposite and parallel to driving fingers are sensible fingers. The entire setup is mounted with the help of spring system and anchors they were placed on the either side of proof mass, the anchors have the direct contact to the ground and also to the springs. Many iterations had been made in order to get high sensitivity and low cross sensitivity. The proof mass consists of area 3900µm x 1000µm the spring material was made up of poly-silicon having density $\rho = 2.33x10^3$ kg/m^3 and spring stiffness k =0.75. The entire accelerometer is made of aluminium because it has highelectrical conductivity and also have high thermal conductivity. It also exerts physical parameters like less weight and high strength to weight ratio. The dimensions for the entire setup is tabulated below.

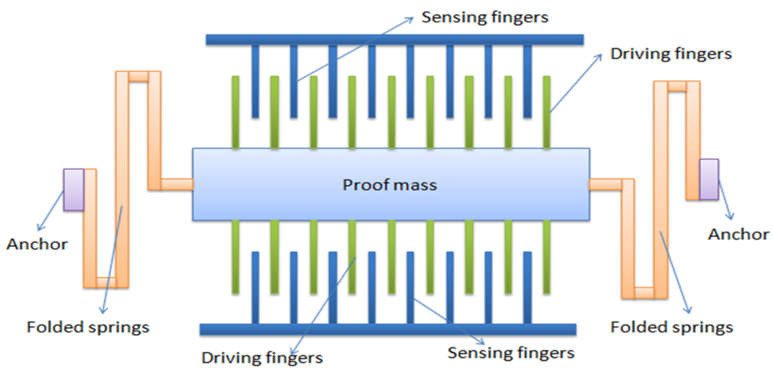

Figure 2 Represents the proposed structure of accelerometer

Table 1 Design parameters for the proposed accelerometer

Design parameters	Physical parameters	Dimensions/response
Proof mass	width	3900μm
	height	1000μm
	material	Aluminum
Sensible fingers	Width	100 μm
	Height	1000 μm
Driving fingers	Width	100 μm
	Height	1000 μm
Anchors	Width	200 μm
	Height	400 μm
Folded springs	Material	Polycrystalline silicon

Total number of driving fingers	18
Total number of sensing fingers	16
Device thickness	100μm
Overall design area	6500μmX4500μm

4. PERFORMANCE ANALYSIS

The theoretical calculations of the comb drive can be calculated from the below shown formulas. In order to find the frequency of the poly-silicon folded spring i.e., the resonant frequency (f_o) of the spring mass system can be said as $f_0 = \frac{1}{2\pi}\sqrt{\frac{K_{total}}{M_s}}$

Where k_{total} = sum of all spring constant values

M_s = sensing mass of the accelerometer (proof mass)

f_o= resonant frequency of spring mass system

The sensing mass *Ms* of the accelerometer, includes the seismic mass and all the movable fingers Attached to it, can be expressed as follow $M_s = \rho t\,(W_m L_m + N_f W_f L_f)$

The spring constant (K_b) can be calculated by

$$K_b = \frac{12EI_b}{L_b^3}$$

Where I_b= Inertial moment of the spring

E = Young's modulus of the spring material

L_b = Length of the folded spring

Inertial moment of the spring is said to be $I_b = \frac{1}{12}W_b t^3$

Since our design consist of spring which is of six folds the spring constant can be calculated six folds and the summation of them gives the total spring constant. Since the design has six folds and has different numerical values K_{total} can be written as

$$K_{total}= K_{b1} + K_{b2} + K_{b3} + K_{b4} + K_{b5} +K_{b6}$$

Suppose if there are two parallel conducting plates separated by a minute distance (Dielectric) due to the principle of electro motive force there exists a mutual transfer of energy between them, this concept was coined as differential capacitance principle. The dielectric is still air which has a constant value called as dielectric constant (Ɛ). Where $Ɛ=Ɛ_0 r_0$. when the accelerometer is static condition i.e.; no displacement in the system so no capacitance is observed in the system. If there is a displacement in the system the electro motive force transfers the capacitance (F), Differential capacitance of this accelerometer is given as (C_0).

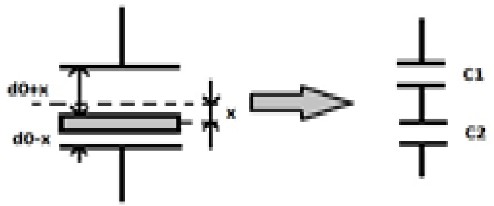

Figure 3 represents the Differential capacitance concept

$$C_0=\frac{Ɛ.Ns.L_f.t}{d_0}$$

Where C_0= Capacitance of the accelerometer

Ɛ = Dielectric constant of air

N_s= Number of sensible fingers

L_f = Length of the fingers

t = Thickness of the system

d_0 = Difference between the two successive fingers

The above stated statement is valid for only in the static conditions .In order to get the capacitance we must have to calculate the difference of two capacitive ends (C1, C2). So, the actual capacitance value can be only calculated through

$$\Delta C = C_1 - C_2 = \frac{2\mathcal{E}.Ns.L_f.t}{d_0}.\left(\frac{X}{d_0}\right) = 2C_0\left(\frac{X}{d_0}\right)$$

x= Displacement of the system

X can be calculated through the following equation as stated below.

$$x = \frac{F_{inertial}}{K_{total}} = \frac{-M_S.a}{K_{total}}$$

$$F_{inertial} = -M_S.a$$

TABLE II Displacement table

TABLE II Displacement is dependent of Acceleration

S.no	Acceleration	Total Displacement(µm)
1	1g	2.10E-07
2	2g	4.30E-07
3	3g	6.40E-07
4	4g	8.50E-07
5	5g	1.04E-06
6	6g	1.28E-06
7	7g	1.49E-06
8	8g	1.71E-06
9	9g	1.92E-06
10	10g	2.14E-06
11	11g	2.35E-06
12	12g	2.56E-06
13	13g	2.78E-06
14	14g	2.99E-06
15	15g	3.20E-06

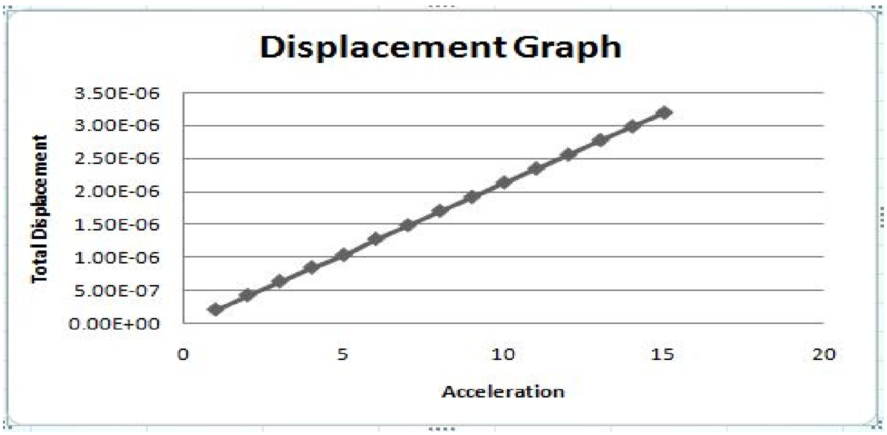

Figure 4 represent the Displacement graph

TABLE III Theoretical capacitance VS Practical capacitance

S.no	Acceleration	Theoretical capacitance(F)	Practical capacitance(F)
1	1g	3.47E-15	3.10E-15
2	2g	7.11E-15	6.80E-15
3	3g	1.06E-14	1.02E-14
4	4g	1.41E-14	1.36E-14
5	5g	1.72E-14	1.54E-14
6	6g	2.12E-14	2.40E-14
7	7g	2.46E-14	2.51E-14
8	8g	2.83E-14	2.67E-14
9	9g	3.17E-14	3.09E-14
10	10g	3.54E-14	3.69E-14
11	11g	3.89E-14	4.38E-14
12	12g	4.23E-14	4.62E-14
13	13g	4.6E-14	4.92E-14
14	14g	4.94E-14	5.36E-14
15	15g	5.29E-14	6.26E-14

The figures represented below shows various graphs which are drafted according to the results obtained in the theoretical and simulations results Fig 5 and Fig 6 represents the linearity and sensitivity for the accelerometer which are quite important in designing. It is important that for a good accelerometer the linearity and sensitivity must be high in order to obtain the accurate results. From the graphs it clearly shows the results that it is linear and the sensitivity also has the low correction factor

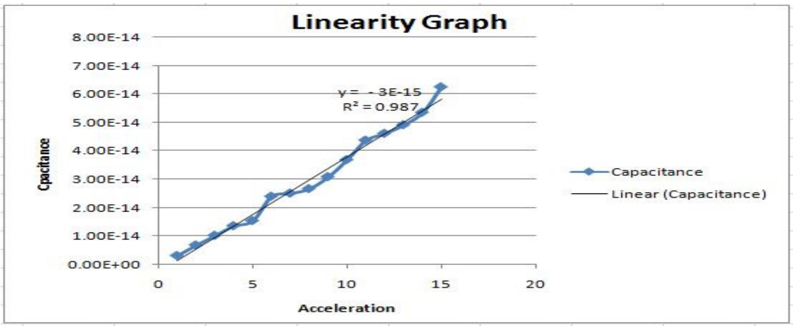

Figure 5 represents linearity graph

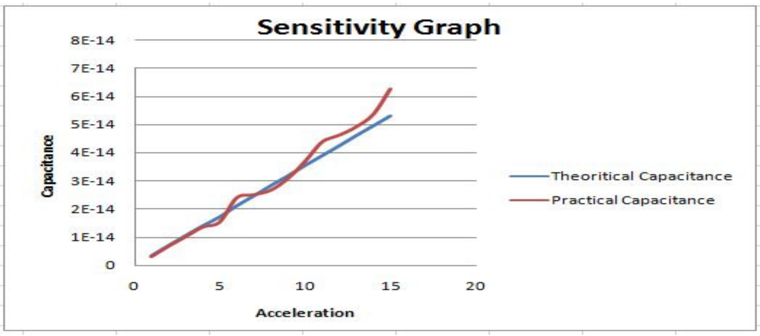

Figure 6 represents sensitivity graph

5. SIMULATIONS

The entire simulation were done by using COMSOL 5.2 Multi physics. In order to calculate the best possible Eigen frequency level we had applied 5N force in Y axis direction to proof mass such that displacement can be evaluated. The best possible Eigen frequency tells about the optimal frequency required in order to get maximum displacement. The below shown figures tell about the displacement at various levels of Eigen frequency.

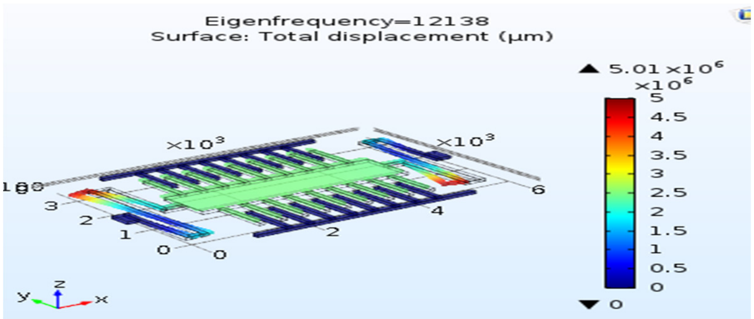

Figure 7.1 represents the displacement of 5.01 x 10^5 μm for the accelerometer at Eigen frequency of 12138

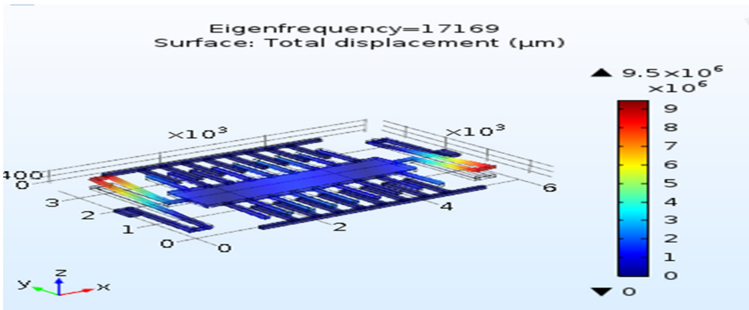

Figure 7.2 represents the displacement of 9.5 x 10^5 μm for the accelerometer at Eigen frequency of 17169

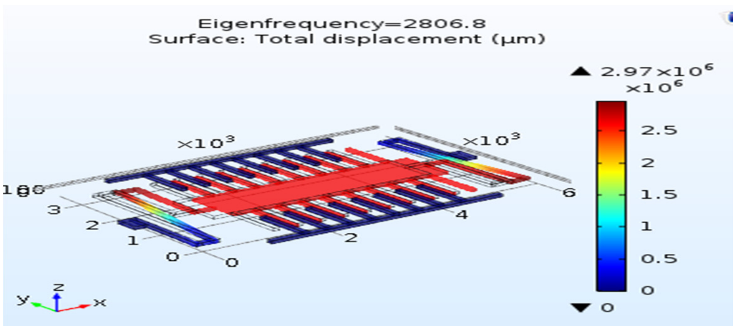

Figure 7.3 represents the displacement of 2.97 x 10^5 μm for the accelerometer at Eigen frequency of 2806.8

From the fig 7.2 it clearly shows the maximum displacement of the accelerometer 9.5 x 10^5μm at Eigen frequency of 17169.It is important in order to get the highest displacement possible in order to get the quickest response time.

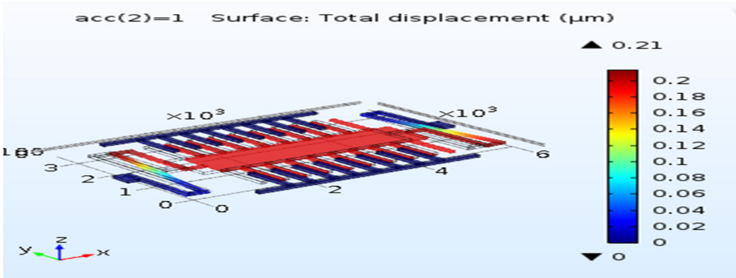

Figure 7.4 Represents Minimum displacement for accelerometer at an acceleration of 1g force

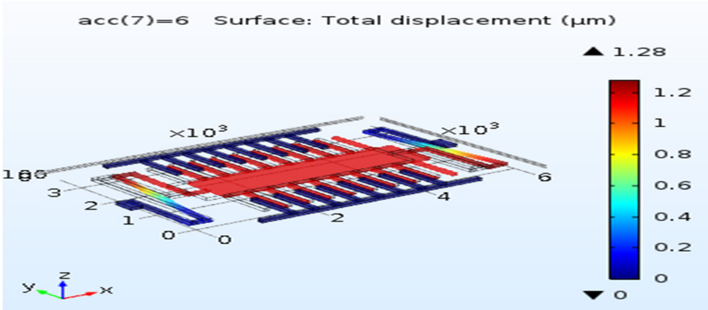

Figure 7.5 Represents Moderate displacement for accelerometer at an acceleration of 6g force

The simulations are carried out for the actual displacement i.e.; Dynamic structural analysis for the accelerometer. A 5N of force on Y axis direction is applied to the system on proof mass and acceleration on the X axis direction were given at different acceleration levels such as 1g, 6g, 18g.

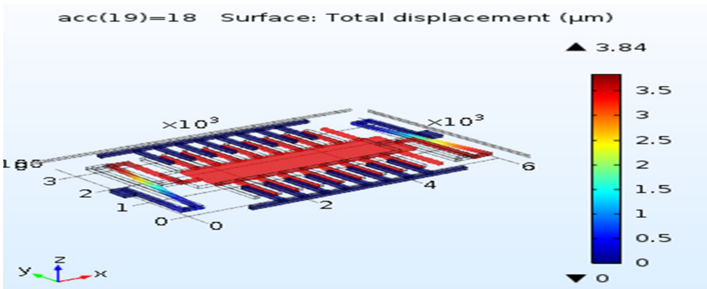

Figure 7.6 Represents Maximum displacement for accelerometer at an acceleration of 18g force

In order to calculate the practical capacitance we must have to give a minimal amount of electric potential to the system. So, in this simulation we had given a 1V of electric potential to the system by using COMSOL electro mechanics

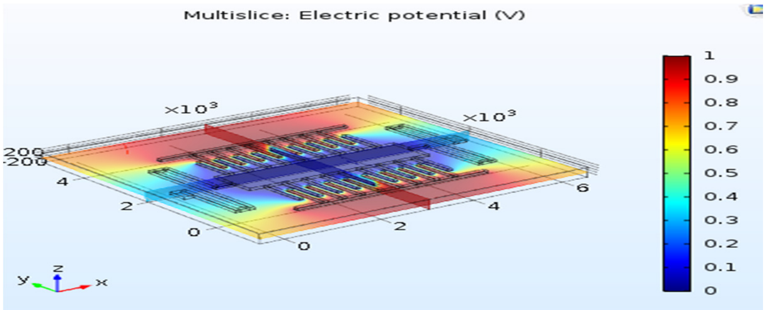

Figure7.7 Represents Maximum electric potential of 1V for the accelerometer

After obtaining the necessary inputs the simulation for Capacitance were processed. In this simulations we had given the inputs like acceleration and electric potential. So according to the previous simulations when the acceleration takes place there will be certain displacement in the system from that displacement

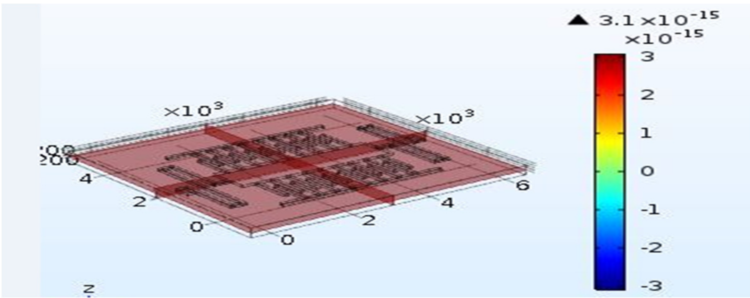

Figure 7.8 Represents capacitance for accelerometer at an acceleration of 1g force

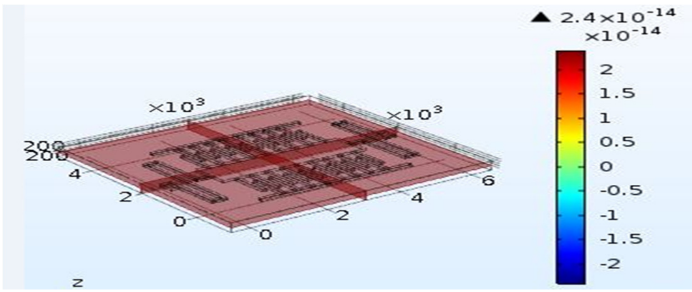

Figure 7.9 Represents capacitance for accelerometer at an acceleration of 6g force

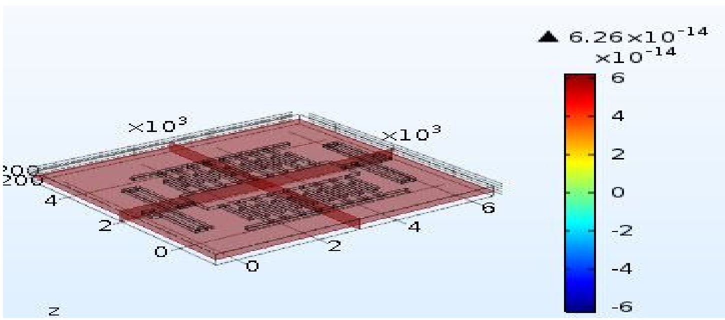

Figure 7.10 Represents capacitance for accelerometer at an acceleration of 18 g force

The driving fingers which are connected to the proof mass displaces resulting change in their coordinates. If the driving fingers were too close to the sensible fingers due to electro static forces the capacitance will be changed. The capacitance on driving fingers (C_1) and sensible fingers (C_2) changes. From this change of capacitance we can say the direction of force experienced on the accelerometer i.e. the point at which the capacitance change is Maximum.

6. CONCLUSION

This quality optimized accelerometer produces high sensitivity and high linearity as a shown in the results. This accelerometer can be used as a crash detection unit, the obtained signal i.e. capacitance output is directly sent to the electronic control unit (ECU) which is present in the vehicle. According to the code that is preprogrammed in the ECU whenever the capacitance value is between in the range of 6g -18g acceleration the ECU sends the impulse signal to the Air bag system i.e. to the crash sensor and the system deploy the air bags through a small explosive device called Squib. NaN_3 Sodium azide which is present in the system through the explosion of squid and burns with tremendous speed generating N_2 and the nitrogen inflates the air bags within 45-55 milliseconds and saves the life of the personal.

ACKNOWLEDGEMENT

The authors would like to thank NPMASS for providing necessary computer tool for simulation.

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