Implementation of Time based 3-Axis Capacitive Accelerometer using COMSOL Multiphysics

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***Abstract*—Micro-electro-mechanical system or MEMS simply can be understood as a miniaturized mechanical and electro-mechanical elements i.e sensors, actuators, and microelectronics, that are made using methods of fabrication. Capacitive accelerometers are devices that measure the acceleration on a surface using capacitive sensing techniques. It can sense both static and dynamic acceleration. After this, it converts this acceleration into voltage or current. Whereas, in the capacitive pressure sensors, the pressure is sensed by mechanical elements such as plates, shells, and tubes that are designed and constructed to deflect when pressure is applied. These Capacitive pressure sensors have an edge over the piezoresistive ones since they consume less power. They are usually less temperature sensitive and have a lower fundamental noise floor. This model performs an analysis of a hypothetical sensor design using the electromechanical interface of COMSOL. The sensor is part of a silicon that has been bonded to a metal. The results throw light on the importance of considering packaging in the MEMS design process.**
Keywords-Micro-electro-mechanical system (MEMS); Capacitive Accelerometer; Capacitive Pressure Sensor.

1. INTRODUCTION

The accelerometer is an electromechanical device that can measure the change in velocity or force of acceleration caused by gravity or movement over time. It is used to measure acceleration in any of the three axes. Most of the accelerometers comes under the category of MEMS devices. There are various types of accelrometers such as capacitive , pizoelectric and piezoresistive based on the effect to sense the displacement of the proof mass. This displacement should be proportional to the acceleration. The output voltage of the capacitive sensor is dependent on the distance between the two capacitive plates. The acceleration of piezoelectric sensor is directly proportional to the force. Whenever certain type of a crystal is compressed, the charges of opposite polarity accumulate on opposite sides of the crystal. In addition to this, we also have a piezoresistive pressure sensor which is one of the very first products of the MEMS technology. These devices are widely used in household appliances. We are using the capacitive sensing accelerometer because it is known for its accuracy and stability. In addition to this, they are less prone to noise and its variation with temperature is also marginally less. The properties of MEMS accelerometer like smaller size, low power and high scale integration make them very usefull to fit in most of the applications nowadays.The MEMS sensing technologies like pizoelectric, pizoresistive and capacitive are used to convert acceleration to an electric signal. The capacitive type of design and sensing is selected because it offers the fetures like long term stability, high accuracy and its sensitivity to the real time performance. For this reason, our high-performance sensors are used in some of the challenging applications that are addressed by MEMS sensors.

The paper is organized as follows. Section 2 briefly introduces the capacitive accelerometer sensor with the parallel plate capcitance related to Hook's law. Section 3 describes the properties of the materials used in implimemtation. Section 4, talks about the implementation of model design in COMSOL Multiphysics. Applications for this design are noted in section 6. Simulation results of accelerometer are shown in Section 5. Finally conclusion is drawn in section 7.

2. Capacitive Accelerometer Sensor

Accelerometer implemented using capacitive sensing, gives a voltage output dependent on the distance between two planar surfaces i.e. capacitive plates. Both these plates are charged with the help of electric current. The electric capacity of system changes with respect to change in the gap between capacitor plates, which will be noted as the output voltage [16]. The biggest advantage of using capacitive sensor is that, it has a very large bandwidth due to internal feedback circuitry. Furthermore, these sensors are very stable and accurate and it dissipate very less power[1].

2.1. Parallel Plate Capacitance

The electric field between two parallel plates is given by

$$E = \frac{\sigma}{\epsilon}$$

Where, σ = Charge Density, ϵ = permittivity

$$\sigma = \frac{Q}{A}$$

The voltage difference between the two plates is expressed as work done on positive test charge q when it moves from positive to negative plate. This can be understood from figure (1).

$$v = \frac{workdone}{charge} = \frac{Fd}{q} = Ed$$

$$c = \frac{Q}{V} = \frac{Q}{Ed} = \frac{Q\epsilon}{d\sigma} = \frac{QA\epsilon}{Qd} = \frac{A\epsilon}{d}$$

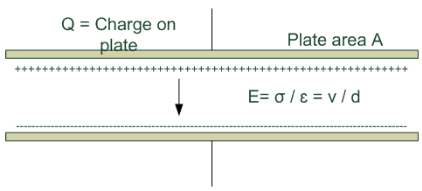

Figure 1. Capacitor Plates [1]

2.2. Hook's Law

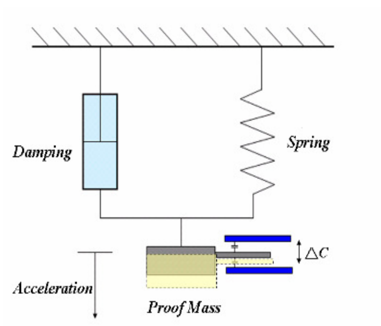

Figure 2. Proof Mass [3]

Hooke's law is a principle of physics that states that the force (F) needed to extend or compress a spring by some distance X scales linearly with respect to that distance. That is:

$$F = kX$$

where, k is a constant factor characteristic of the spring,and X is small compared to the total possible deformation of the spring. When we equate this law with the standard Newton's equation of force i.e

$$F = ma$$

we get,

$$F = kX = ma$$

Equating them we get,

$$kX = ma$$

As shown in figure (2) a proof mass is known as test mass which is used in a measuring system, as a point of reference for the measurement of an unknown quantity [2]. A Movable proof mass is a linear system mounted as a structure with conical spring connected to fixed anchor beams. This will act as a linear force actuators to absorb the damping in the stucture due to impulsive disturbance. It deforms the spring to which it is attached to an accelerometer [3].

2.3. 2-axis Capacitive Accelerometer

The figure (3) represents a 2-axis capacitive accelerometer. A MEMS transducers consists of a proof mass, which is a movable micro-structure. This proof-mass is connected to a reference frame, which is nothing but a suspended mechanical system. The capacitor plates formed by movable plates and the fixed plates [18]. The proof mass moves Whenever acceleration is applied to it. the capacitance is produced between the capacitor plates with this movement. When we apply acceleration, the distance between two capacitive plates X1 and X2 changes. With the change in distance capacitance produces between the movable and the fixed plates [1]. All the sensors in 2-axis capacitive accelerometer have multiple capacitors sets, which are shown in figure 3. The overall capacitance C1 is produced by upper capacitors, which are wired parallely and overall capacitance C2 is produced by lower capacitors [4].

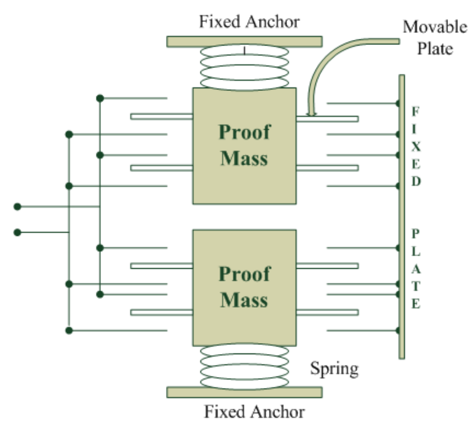

Figure 3. 2-axis Capacitive Accelerometer [1]

2.4. 3-axis Capacitive Accelerometer

Here we get a method for inputting the motion measurement data into a computationally based device. The first version of three-axis accelerometer determines components of an inertial force vector with respect to an orthogonal coordinate system [6]. The accelerometer comprises of a sensor die that is made up of a semiconductor substrate having a frame element, a proof mass element, and an elastic element mechanically coupling the frame and the proof mass [15]. The accelerometer also contains three or more stress-sensitive IC components integrated into the elastic element

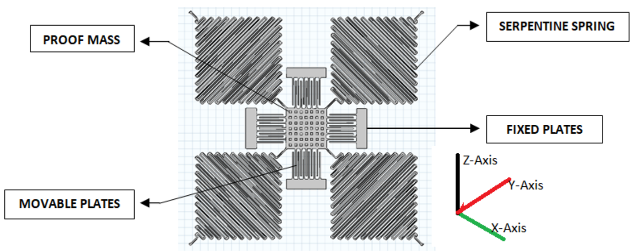

Figure 4. 3-axis Capacitive Accelerometer [9]

next to the frame element for electrical connectivity without any metal conductor traversal of the elastic element [17].

3. MATERIALS

The choice of good material for MEMS devices in not largely based on the carrier mobility of microelectronics, but more on the mechanical aspect. In MEMS devices, silicon and silicon compounds are widely used in the fabrication of micro pressure sensor. Silicon has excellent mechanical properties. It is a strong material but lighter than steel [13]. It has large critical stress and no elasticity limit at room temperature and is also a perfect crystal that ensures it will recover from large strain. It has a large piezoresistive coefficient for sensing applications. Silicon has a greater density in a liquid state than in solid state [6]. Silicon material is used to design the diaphragms of the pressure sensors and is also used to measure ultra-low pressure. Steel AISI material is also used in the MEMS devices [5].

4. COMSOL Multiphysics Design

4.1. Features of the COMSOL Multiphysics used in the model design

The system equipped with COMSOL Multiphysics version 5.2 is used for the design and implementation purpose. The mechanical model is designed in COMSOL. By using the materials mentioned above, the study is added with the feature of powerful meshing and the model is tested for the applied force using plot annotations. The step-wise implementation is explained in next section. For mechanical simulations the nonlinear materials can be expressed as C code [2].

4.2. WORKING OF THE MODEL

In microaccelerommeter, a comb finger type acclerometer is an important device used in MEMS. Our proposed MEMS capacitive accelerometer design contains a proof mass suspended by four serpentine spring structures. The serpentine spring structure was chosen to provide the greatest flexibility and allow for maximum displacement of the proof mass and sensing regions. The entire model is 2mm x 2mm x 100m with a critical dimension of 10m. The proof mass itself is 395m x 395m featuring forty-nine 20m x 20m damping holes. The sensing mechanism produces a capacitance that will serve as the raw output data for the system. The proof mass is main component of a capacitive accelerometer , which is supported by suspended mechanical system like beams. This component can be modeled in COMSOL as springs. These beams are connected to the ground and provide support to the model. On four edges, the proof mass is equally suspended and supported on beams. Through this suspension beams ,the acceleration is transferred to the proof mass, ultimately movable plates along and against the force direction but the fixed plates remains stationary. Because of this movement, the capacitance between movable plats and fixed plates changes. With the applied external force, the changed capacitance is measured and calibrated.

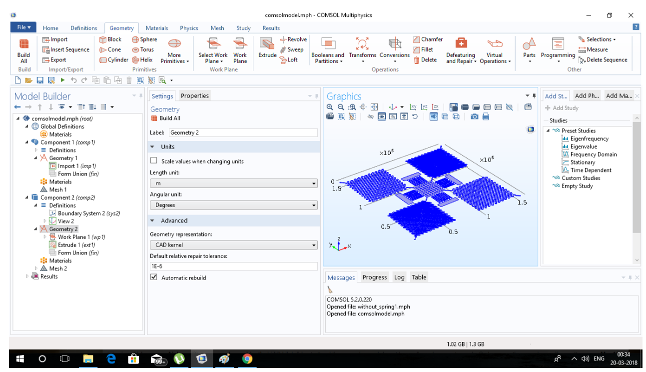

Figure 5. The COMSOL Snapshot of design of proof mass with springs.

4.3. IMPLEMENTATION OF MODEL

The capacitive accelerometer is designed and tested in COMSOL multiphysics.

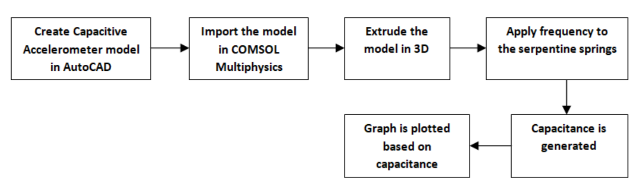

Figure 6. stepwise flow of Implementation

Implementation steps of the Model in the COMSOL multiphysics are given below:-

Step:1 In the First step we have to design 2D or 3D geometry. It can be done by two way importing support file in COMSOL or by constructing geometrical shapes as shown in figure 7

Step:2 In second step the material is selected for the model, see figure (8).

Step:3 After applying material, the physics for the model is selected. See figure (9)

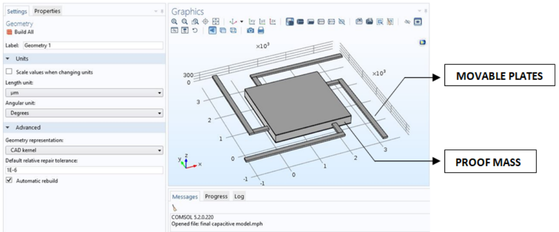

Figure 7. Applied Mesh to the 2-Axis Model

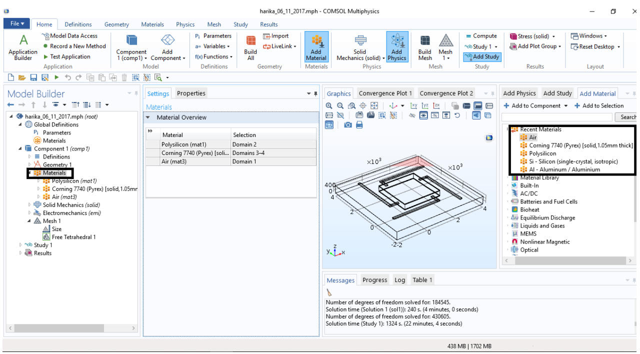

Figure 8. Step:2 Selection of Material

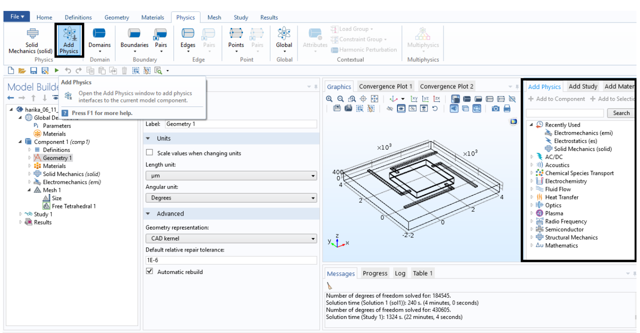

Figure 9. Step:3 Selection of Physics

Step:4 After applying physics,meshing is carried out and solution for the model is obtained. See figure (10) then we have to apply study to get solution for the model.

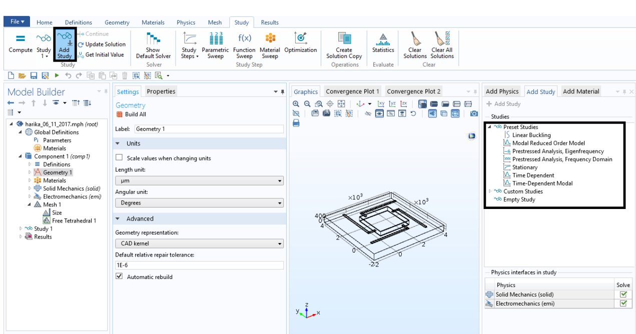

Figure 10. Step:4 Selection of Study

Step:5 The displacement of proof mass is observed and as a result the graph is generated. Figure (11) shows the displacement of proof mass in Z axis and figure (12) shows the displacement in X Y direction in COMSOL window.

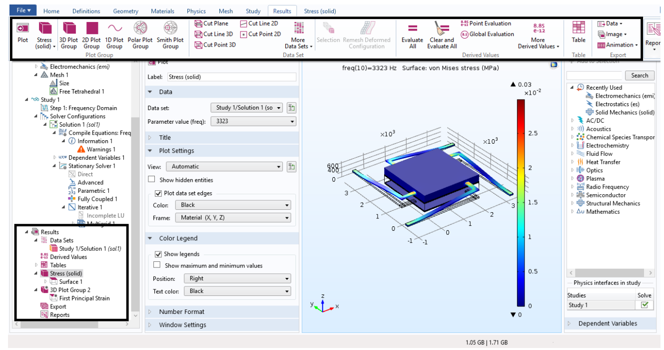

Figure 11. Step:5 Displacement in Z axis

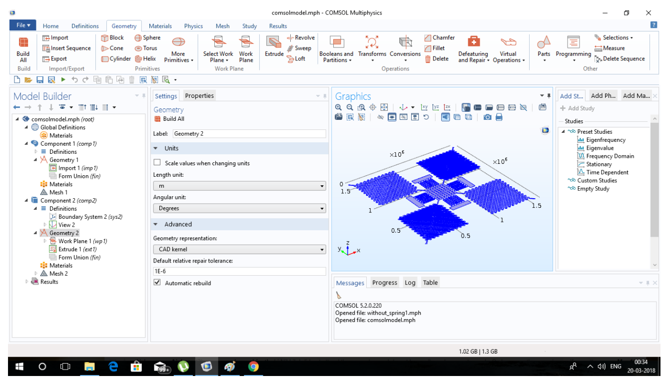

Figure 12. Design for X Y direction displacement

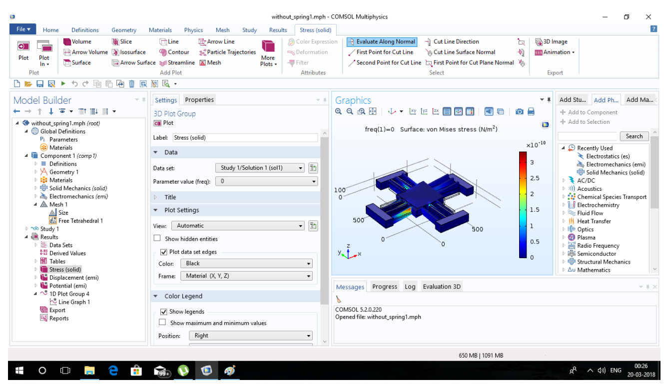

Figure 13. Study of X Y direction displacement

5. RESULT

We have designed the 2-axis and 3-axis capacitive accelerometer using COMSOL Multiphysics. The designs are simulated under the applied force and the study of accelerometer is observed. It is observed that acceleration is linearly proportional to the displacement. The obtained graphs for displacemnt vs. acceleration are shown in bellow figures, Figure (14) graph in Z-axis and Figure (15) graph in X-Y axis.

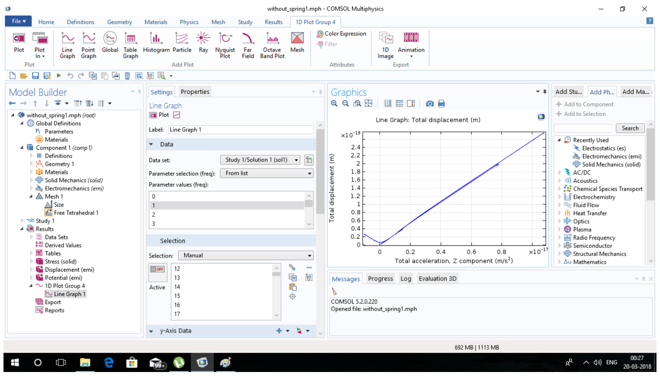

Figure 14. Displacement versus Acceleration Graph in Z axis

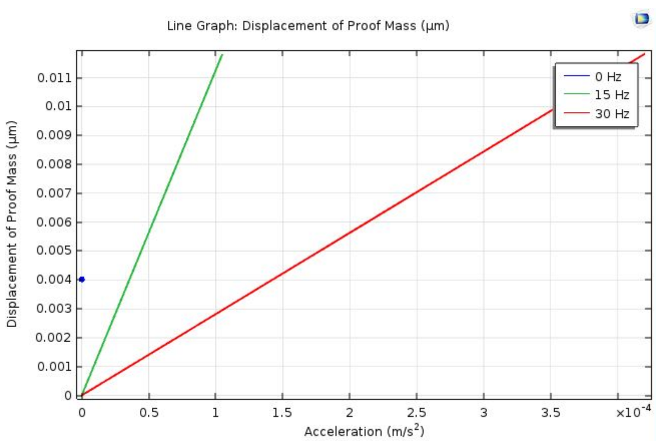

Figure 15. Displacement versus Acceleration Graph in X-Y axis

6. APPLICATIONS

- In the recent years, there has been a lot of development in the medical industry. One such development is the pacemaker. The introduction of MEMS technology has transformed the bulky pacemakers to single-chamber, asynchronous units. In this work the MEMS capacitive accelerometer are used to generate the required voltage for the pacemaker. Whenever there is a vibration in the proof mass , the distance between the capacitive plates change which in turn produces a change in voltage. This vibration is caused by the blood flow in the human body. Therefore, this work proposes to use the body energy i.e. blood flow in the vessels, for charging the pacemaker.
- In addition to the applications in the medical industry, the MEMS capacitive accelerometer has been implemented in many commercial applications, such as automobile air bags, navigation, and instrumentation.
- The MEMS sensor is also used in crash sensing for air bag control in the automotive sector.

7. CONCLUSION

In this paper, the various types of accelerometers and the various materials required in its designing are studied thoroughly. A three-axis MEMS capacitive accelerometer is implemented in COMSOL Multiphysics where we are applying the force in the positive z-direction. The results can be used to calculate the change in distance between the capacitive plates w.r.t change in capacitance which is linear in nature.This has its applications especially in the bio-medical industry where we can use this in pacemakers, eye surgery, kidney dialysis and much more other life-saving operations.

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