Study of Effect of Number of Fingers in a Mems Differential Capacitive Accelerometer

S sunithamani, T.Yamini Priyanka, p. Bhanu, n. Sudharshan reddy

Abstract*:This paper is about the study of MEMS capacitive accelerometer for dual axis sensing. For the accelerometer design a capacitive approach is used and this depends on number of fingers attached to the proof mass. We have used a comb structured differential capacitive accelerometer and are studied with different fingers. We have studied and simulated a MEMS differential capacitive accelerometer using COMSOL Multiphysics.

Index Terms:capacitive accelerometer, dual axis, differential capacitive sensing, MEMS.

I. INTRODUCTION

Micro-electro-mechanical system (MEMS) Accelerometer is some of the first sensors, whose miniaturization and subsequent cost reduction have paved the way for their use in a number of applications. From the past decades broad efforts are being made to develop effective, powerful and small scaled machined inertial sensors primarily accelerometers and gyroscopes [1].An accelerometer measures acceleration forces as it is an electro mechanical device. These may be static forces like the constant force of gravity pulling at our feet, or they can be dynamic, which are caused by moving or vibrating the accelerometer. As MEMS accelerometers have small size, light weight, low cost and low energy consumption, MEMS are widely used in smart phones, automobile, toys, aerospace and many other applications which lead their demand [2]. An accelerometer modelling can be done in different ways. Depending on the requirement voltage or resistance or capacitance there are different MEMS accelerometer. Some of the accelerometers are piezo resistive, electromagnetic, piezoelectric, ferroelectric, optical, thermal, electrostatic and capacitive can be used [3].

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The most powerful techniques are Capacitive and piezo resistive sensing techniques and the other less dominant techniques are piezoelectric, thermal, optical and current tunneling. Capacitive accelerometers have low temperature dependency and low power dissipation. Also we can integrate them into cost sensitive commercial devices like smart phones and robots. Because of these advantages and with the advancement of MEMS. MEMS Capacitive accelerometers are very attractive for high performance applications [4]. Unlike piezoelectric accelerometers capacitive accelerometers are optimal as they are less prone to noise and temperature. Capacitors can be used both as sensors and also actuators. They have exceptional sensitivity and the transduction mechanism. Sensing of Capacitance is autonomous on the base material and relies on the variation of capacitance when the geometry of the capacitor is changing [5]. Difference in acceleration is due to the change in capacitance between thefingers attached to the poof mass.When there is change in force applied the position of plate changes [6].

The research in this paper is designing of 3D capacitive accelerometer in COMSOL Multiphysics. This differential capacitive accelerometer is capable of measuring acceleration in two axes. Force can be applied in two directions. For different Eigen frequencies displacement and electric potential are calculated.

Compared to piezoelectric accelerometers capacitive accelerometers are ideal enough since they are less prone to noise and temperature. Capacitors can operate both as sensors and actuators. They have excellent sensitivity and the transduction mechanism. Capacitive sensing is independent of the base material and relies on the variation of capacitance when the geometry of the capacitor is changing [5]. The acceleration determination is based on the change of capacitance between the capacitors plates when an acceleration/displacement producing force changes the plate positionschanges [6].

The research in this paper is designing of 3D capacitive accelerometer in COMSOL Multiphysics. This differential capacitive accelerometer is capable of measuring acceleration in two axis. Force can be applied in two directions. For different Eigen frequencies displacement and electric potential are calculated.

II. THEORETICAL ANALYSIS

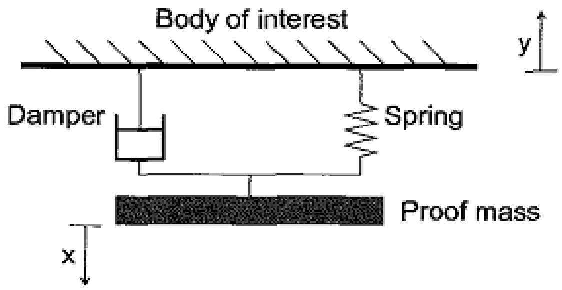

Fig 1. Accelerometer model.

When a force is applied to the accelerometer it will be excited towards its sensing axis. Because of theinertial forces, the proof mass always moves in opposite direction of force applied. The mechanical sensitivity of an accelerometer can be described by the displacement of proof mass per unit of gravitational acceleration.

III. PROPOSED ACCELEROMETER MODEL

This paper is about a differential capacitive accelerometer with dual sensing application. The sensing axis depends upon the number of axis an accelerometer can be freely displaced upon the application of force. Variation in capacitance dependson the variations inarea of overlapping fingers or may be due to the change in distance between fingers. Below mentioned is a comb shaped capacitive accelerometer.

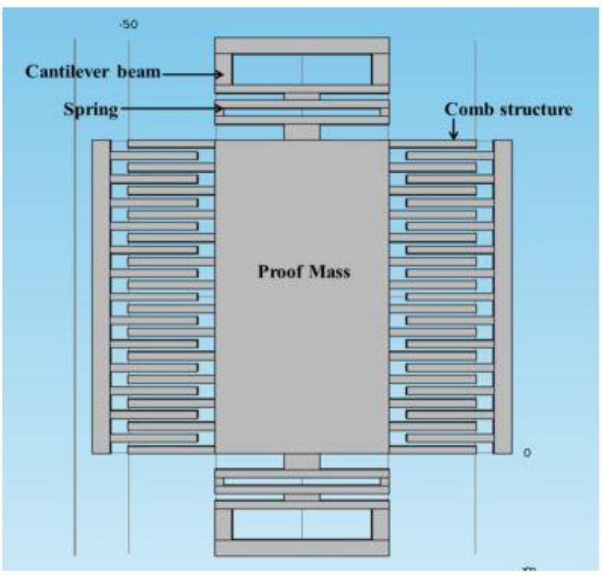

Fig.2. Proposed Comb shaped capacitive accelerometer model.

Force is applied at the rectangular proof mass which is placed at the Centre of the design. As it is a dual axis sensing accelerometer force can be applied on both ends of the proof mass. Comb structure and spring support series are directly attached to the proof mass on the both sides of the proof mass. For transversal changeof proof mass the maximum displacement has to be less than the gap between the fingers or capacitive plates.These comb fingers are attached in a series for sensing the change in capacitance and the capacitance assimilated for a pair of fingers gets increasedwiththe quantity of fingers. These comb-drive accelerometers consistof two finger structures, one is fixed fingers series and the other is movable fingers series. Fixed finger series is attached to the accelerometer where as themovable fingers series are attached to the proof-mass which are suspended by flexible elements to the frame. An external acceleration is provided to the device which is transferred to the proof-mass through the flexible elements like springs. Springs are attached at the both ends of the device. Springs deform on the application of force and would return to its original form. But if the force is beyond limit spring will not return to its original position. So we have used piezo electric material. Piezo electric materials act as spring.When a force is applied both the proof mass and the movable fingers displace in the direction of applied body force, but the fixed series of comb fingers remains constant. This variation in displacementgives a change in capacitance of both fixed and movable fingers. This change of capacitance depends on the change in overlapping area of plates or may be due to the change in distance between plates.

A. Proof mass support modelling

As mentioned above proof mass is designedwith two supports, which is a combination of beam and a spring. Spring accelerationcannot be effected bythe support of beam.But its effect can't be ignored when movement is with beam support.

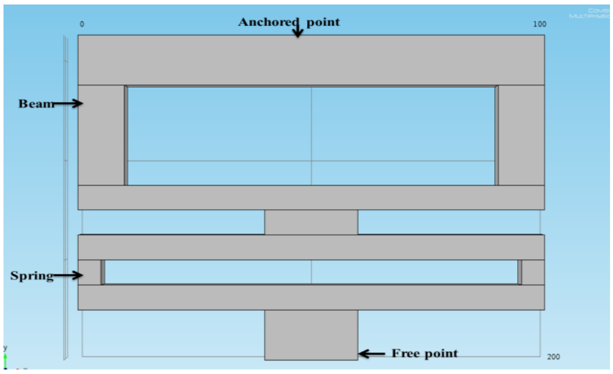

Fig.3. Spring and beam support provided to proof mass

Anchored point is stationary. Force is applied at the anchored point. To the other end of the anchored point spring is attached and at the free end of the spring proof mass is attached.

Table.1 Proof mass support parameters

Parameters	Beam	Spring
Length	20	10
Width	10	5
Height	10	10

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B. Accelerometer modeling

An accelerometer designed in COMSOL software is shown below. This model is having a structure with 52 fingers.

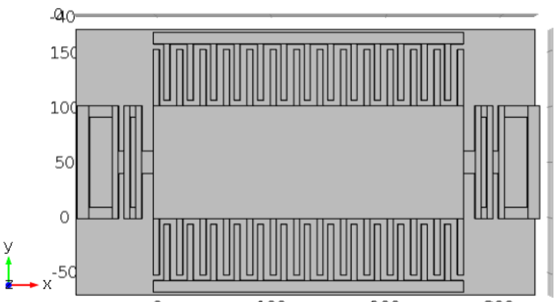

Fig.4.Accelerometer with 52 fingers

Table.2.Accelerometer Parameters for 52 fingers

Parameters(µm)	Comb	Proof Mass
Length	-	200
Width	-	100
Finger length	50	-
Finger width	5	-
Finger gap	40	-
Capacitor pair	52	-
Height	-	10

C. Materials used

Table 3.Design Materials

Block	Material
Cantilever beams & supporting blocks	Gold (Au)
Piezoelectric	Zinc oxide (Zno)
Proof mass with attached fingers	Gallium arsenide (GAs)
Fixed fingers	Aluminium Nitride
Plate	Silicon

We have used gallium arsenide and aluminium nitride for the dielectric which are having high conduction levels, also require young's modulus. These dielectric capacitance storages also give better performance. These materials resonance frequency is also more with the less force and more displacement. Gallium arsenide and aluminium nitride is very low expensive whereas gold is much expensive than the two semiconductors.

Eigen frequency analysis:
Eigen frequencies are distinct frequencies at which object vibrates. At a particular Eigen frequency structure of the body deforms into different shapes. This analysis is for determining the system displacement at different frequencies.

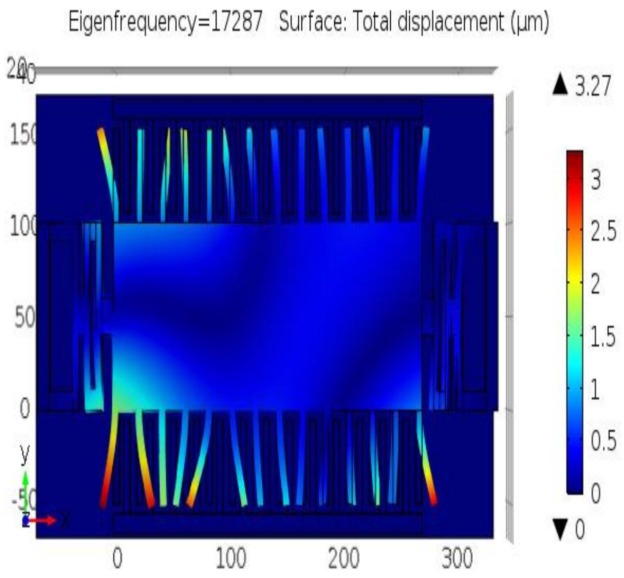

Fig.5. Eigen frequency 17.29KHZ and maximum displacement is 3.27

In the above design more deformation is occurring which is a disadvantage for the structure. So, a similar structure with more spacing is designed which shows less deformation than the previous.

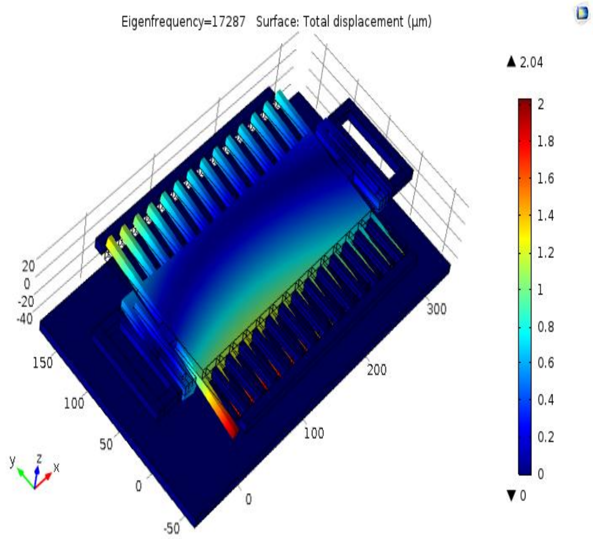

Fig.6.Maximum displacement is 2.04µmat Eigen frequency 17.29 KHz

Due to the usage of more fingers and less spacing deformation occur which results in the breakage of the body. If spacing is increased and number of fingers is reduced deformation reduces. So, a model with less fingers and more spacing is simulated for which deformation is less.

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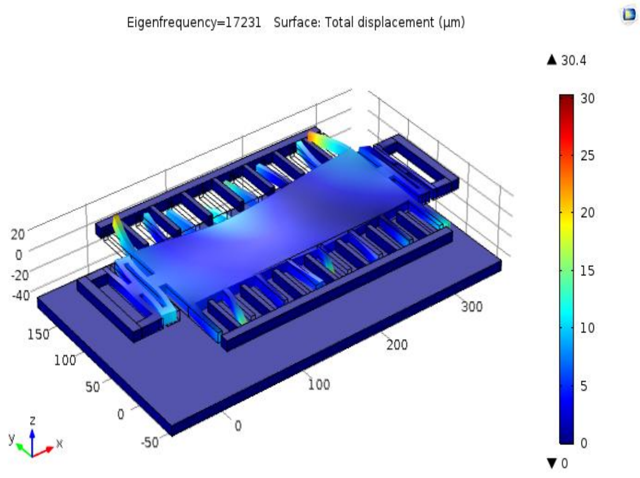

Fig.7. Maximum displacement is 30.4μm atEigen frequency 17.23 KHz

IV. RESULTS AND DISCUSSION

Frequency and Displacement

Table.4.Eigen frequencies maximum displacement with 52 fingers

Frequency(Hz)	Displacement(μm)
17157	6.78
17227	0.01
17247	6.35
17329	4.56
17356	9.4
17395	34.9

Table.5.Eigen frequencies maximum displacement with 32 fingers

Frequency(Hz)	Displacement (μm)
16999	7.75
17019	2.56
17062	5.3
17094	0.06
17150	0.09
17231	30.4

Electric potential

For 52 fingered structure

Table.6.Capacitance constant at voltages for 52 fingers

Capacitance	Voltage
1.38	3
1.38	3.25
1.38	3.5
1.38	6
1.38	17
1.38	18.5

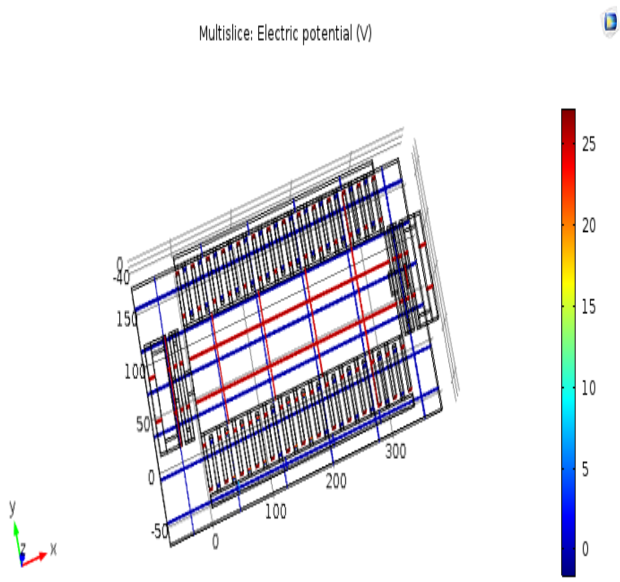

Fig. 8 COMSOL Multislice electric potential

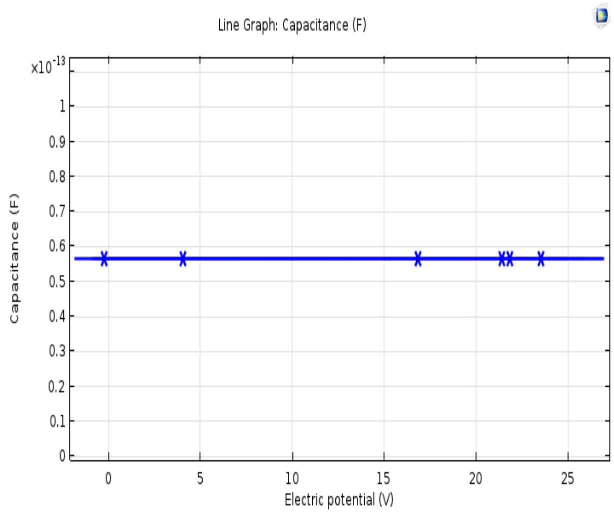

Fig.9. Potential vs capacitance graph

Voltage ranges from 0-25v

For 32 fingered structure

Table.7. Capacitance constant at voltages for 32 fingers

Capacitance	Voltage
0.54	1
0.54	4.5
0.54	165
0.54	21
0.54	23.5

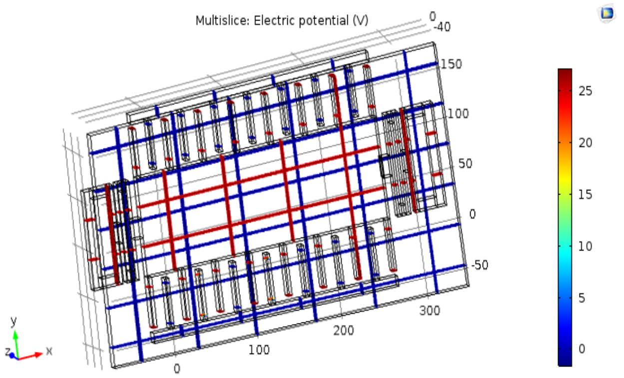

Fig. 10 COMSOL Multislice electric potential

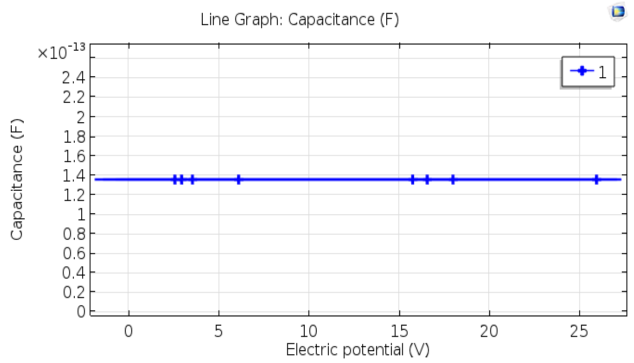

Fig.11. Potential vs capacitance graph

Voltage ranges from 0-27v

The accelerometer sensitivity is directly proportional to the displacement of proof mass from its initial position and inversely proportional to the distance between sensingelectrodes. The more displacement, sensitivity will be high. With the more fingers and less spacing deformation is more and with more spacing deformation is less. But if the fingers are less capacitivity of the structure will be less. Also voltage range will be varied. Capacitive sensing is made differential to increase the sensitivity.

V. CONCLUSION

In this paper, we have studied MEMS differential capacitive accelerometer capable of measuring acceleration in dual axis. By varying number of fingers displacement and voltage at different frequencies are studied. It is observed that if the displacement is maximum it may damage the structure. Always displacement of proof mass has to be lower than the gap between the attached fingers or capacitive plates.This paper helps in further design and study of accelerometers with varying number of fingers.

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