

Design and Simulation of Comb Drive Capacitive Accelerometer by Using MEMS Intellisuite Design Tool

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ABSTRACT: This work describes of a novel,three direction MEMS capacitive accelerometer for various applications.INTELLISUITE was used to study the working principle and the dynamic performance of the accelerometer.The accelerometer has only one proof mass, symmetrically suspended by four cantilevers. The displacement change of the proof mass is converted to the change of differential capacitance between the proof mass and adjacent fixed electrodes. In order to establish the mechanical characteristics of the accelerometer in this equivalent electrical model, we use the so-called analog behavioral modeling library to describe the mechanical part of the system.A modal analysis was also used to find the fundamental modes of vibrations and frequencies, in order to avoid resonance and identify the device range of operation.we get the system-level model of the MEMS comb accelerometer. The simulation results are in good accordance with theoretical analysis.

KEYWORDS: Micro accelerometer,INTELLISUITE, capacitive sensing, static and frequency analysis.

I. INTRODUCTION

Now, micro-machined accelerometers are widely used in many different aspects of inertial navigation system as well as the center of the vibration examination system for their small size, low cost and low power consumption [1]. There are many different types of micro-machined accelerometers, such as piezoresistive, piezoelectric, and capacitive accelerometer. But, most accelerometers use the capacitive- based mechanism because of its structural simplicity, high accuracy, low temperature sensitivity, low noise performance, good DC response, and compatibility with CMOS readout electronics. Capacitive accelerometers are typically implemented as a differential capacitance [2, 3]. Moreover, force-balance MEMS accelerometers based on capacitive mechanism can improve the system stability and widen the measurement range using a closed loop structure [4]. [1]Reducing costs and design time is the most important advantage of this method. Different methods to model the micro sensors have been mentioned [5]. Commercial software's like INTELLISUITE and COVENTORWARE have been widely used in the simulation of MEMS devices. INTELLISUITE has the most advantages in the process simulation of MEMS devices, such as bonding, anisotropic etching and so on. COVENTORWARE is famous for the system level simulation of many MEMS devices, such as the micromirror and microgyroscope. But the elementary parts like beam and anchor are custom, and cannot be revised according to the needs of users. Especially for the integral simulation of a MEMS comb accelerometer, the Feedback voltage is continuously applied to the proof mass of accelerometer proportional to the output signal and cannot be accomplished by COVENTORWARE.[6]

MEMS comb accelerometer with one proof mass and symmetrical structure, to achieve the desired performance and it is necessary to ensure that the proof mass moves smoothly and the cross axis sensitivity is low. The capacitive accelerometer converts the displacement signal into an electrical signal.

In this paper we report, To minimize the off axis deflection by using the simple beam and folded beam is designed the proof mass is suspended by four cantilevers beam anchored to a fixed frame. The beam shape physical parameters such as the shape, geometry and material(POLY SI) used in this device need to be carefully considered because these properties will influence the stiffness of the beam.

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II. OPERATION PRINCIPLE OF MEMS COMB ACCELEROMETER

A simplified schematic of a capacitive microaccelerometer is presented in Figure 1. The central part of the accelerometer is a suspended micromechanical proof mass, which acts as the sensing element. When an external acceleration is applied, the proof mass will move with respect to the moving frame of reference. The external acceleration is inferred from the displacement of the proof mass which can be measured by several means. For the capacitive sensing approach that we use in this paper, the displacement is detected by measuring the capacitance change between the proof mass and adjacent fixed electrodes. For the capacitive sensing approach that we use in this paper, the displacement is detected by measuring the capacitance change between the proof mass and adjacent fixed electrodes.

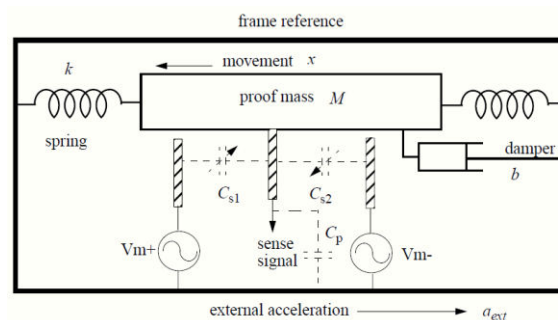


Figure 1. Schematic of a MEMS comb accelerometer

The structure design of a MEMS comb accelerometer is shown in Figure 2. Lateral accelerometers have been developed using comb electrodes and differentially detecting parallel electrodes to obtain linear output. The movable parts of this MEMS comb accelerometer consist of four cantilevers which also can be thought as two double-end fixed beams, a proof mass and some movable fingers. The fixed parts include four anchors and fixed fingers. The central proof mass is connected to four anchors through four cantilevers.

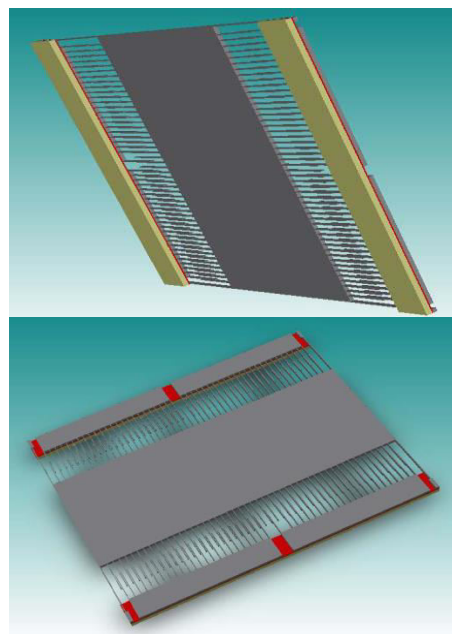


Figure 2. The structure of comb accelerometer

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III. PERFORMANCE ANALYSIS OF THE DEVICE

When an acceleration a along the horizontal direction parallel to the device plan is applied to the accelerometer, the beam deflects under the effect of inertial force. The deflection of beam is in opposite direction of the applied acceleration. The displacement sensitivity of the device is defined as the displacement of the movable mass (and movable fingers) per unit gravity acceleration g ($1g=9.8m/s^2$) along devices sensitive direction. The beam-mass structure of the accelerometer can be treated as a simplified spring-mass model. The four folded-beam can be treated as four springs connected in parallel. For each folded-beam, both sections of the beam can be treated as two springs connected in series. Each beam section can be treated as double-clamped beam model.

Assume for each section of the folded-beam, the beam width and length are W_b and L_b separately. The width and length of central proof mass are W_m and L_m separately. The device thickness (thickness of the poly-silicon layer) is t . There are totally N_f finger groups, among which there are N_s sensing finger groups and N_d driving finger groups ($N_f=N_s+N_d$). For each movable finger, the finger width and length are W_f and L_f separately. When there is no acceleration, the capacitance gap between each movable finger and its left (right) fixed fingers is d_0 . The density ρ and Young's modulus E of poly-silicon material are given as below.

The density of poly-Si is $\rho=2.33 \times 10^3 / \text{kg m}^3$

Young's modulus of poly-Si is $E=1.70 \times 10^{11} \text{Pa}$.

When there is no acceleration, the static sensing capacitance of the MEMS comb accelerometer is

$$C_1 = C_2 = C_0 = \frac{\epsilon \cdot N_s \cdot L_f \cdot t}{d_0} \quad (1)$$

where ϵ is the dielectric constant of air.

Assume there is acceleration along left direction horizontally, the movable mass experiences an inertial force toward right by x , the left (right) capacitances (C_1), (C_2) are ,

$$C_1 = C_0 \cdot \left(1 + \frac{x}{d_0}\right) \quad (2)$$

$$C_2 = C_0 \cdot \left(1 - \frac{x}{d_0}\right) \quad (3)$$

The differential capacitance change ΔC is,

$$\Delta C = C_1 - C_2 = 2C_0 \cdot \left(\frac{x}{d_0}\right) \quad (4)$$

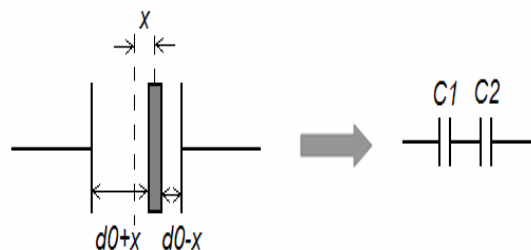


Figure 3: Differential capacitance of MEMS comb accelerometer

From above equations we can see that for small deflection approximation, differential capacitance change is directly proportional to the displacement x of the movable fingers. Because of the capacitance signal's change is very small; the corresponding interface circuit must have enough resolution to the small capacitance. The use of the interface circuit is to detect the differential capacitance change ΔC , thus measuring the magnitude of the external acceleration signal.

IV. FOLDED BEAM DESIGN

The beam width of the folded beam accelerometer is a highly sensitive parameter to adjust the sensitivity of the device. A folded beam accelerometer of desired sensitivity can be designed by adjusting beam width.

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The movable parts of this MEMS comb accelerometer consist of four folded-beams, a proof mass and some movable fingers. The fixed parts include two anchors and some left/right fixed fingers. The central movable mass is connected to both anchors through four folded beams. There are many movable fingers extruding from the both sides of the central mass. In the right and left side of the each movable finger, there are left and right fixed fingers. The movable fingers constitute the differential capacitance pair C1 and C2 with left and right comb fingers. When there is no acceleration, the movable fingers are resting in the middle of the left and right fixed fingers. In this way, the left and right capacitance pairs C1 and C2 are equal. If there is any acceleration along a horizontal direction parallel to the device plan, the proof mass M_s experiences an inertial force ($F_{inertial}$) along the opposite direction. As a result, the beams deflect and the movable mass and movable fingers move for a certain displacement x along the direction of the inertial force. The left and right capacitance gaps are changed, hence the differential capacitances C1 and C2 will also be changed. By measuring this small differential capacitance change, which is known the value and the direction of the experienced acceleration, is the working principle of the MEMS comb accelerometer. The comb accelerometer design also supports in-field built-in self-test feature. Among these capacitance pairs, most capacitance groups act as the sensing capacitance and other few capacitance groups act as built-in self-test capacitance. The built-in self-test feature allows the device to be self-tested during in-field usage using electrostatic force. In test mode, when there is no acceleration, a driving voltage V_d is applied to the left or right fixed driving fingers. The electrostatic force will attract the movable fingers toward the left or right direction. By measuring this displacement and comparing with good device response, one knows whether the device is good or faulty [4]. This self-test feature is especially important for the safety critical applications such as automobile airbag deployment.

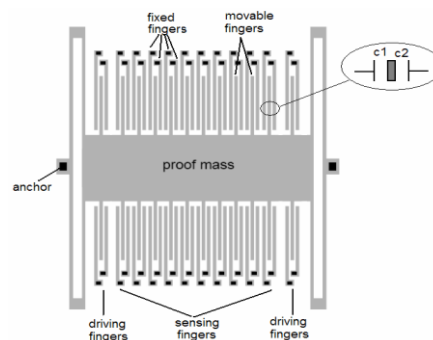


Figure 4. Structure of folded beam

The above theoretical analysis predicts the relationship between device sensitivity and various design parameters (such as beam width, beam length, mass width and length). However, the theoretical analysis is based on the simplified spring-mass model. INTELLISUITE model (after meshing) for an optimized design of the MEMS comb accelerometer is shown in Figure 5. The INTELLISUITE command line programming is used to build the device model and perform the capacitive accelerometer simulation. Here only the movable parts (folded-beams, movable mass and movable fingers) and the anchor are shown. The fixed comb fingers are not involved in the displacement of the movable parts, thus they are not shown.

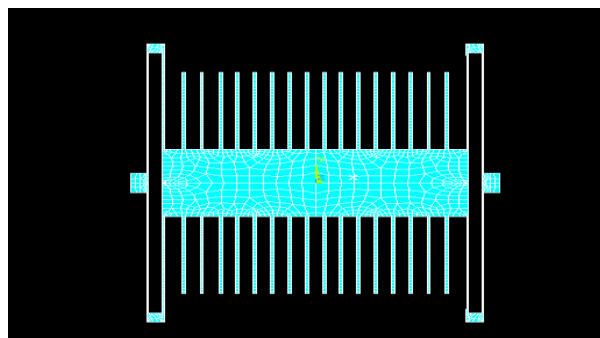


Figure 5. Model of Optimized Design

V. SIMULATION RESULTS

A. OUTPUT RESPONSE OF THE FOLDED BEAM

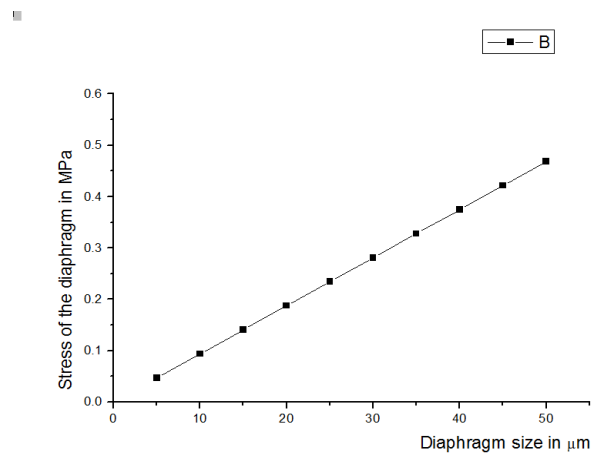


Figure 6. Displacement sensitivity vs acceleration

From the above simulation results, we can see the device sensitivity can be adjusted by the design parameters such as beam width, beam length, mass width and mass length. Thus balanced device sensitivity and linearity is achieved. Here 'B' denotes the device sensitivity.

B. OUTPUT RESPONSE OF THE CAPACITANCES OF C_1, C_2

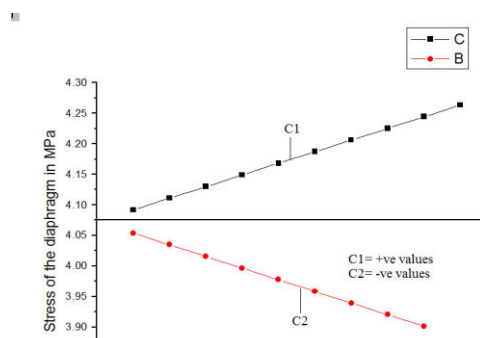


Figure 7. Acceleration vs capacitances (C1, C2)

Further, the relationship between acceleration and capacitances (C1, C2) is simulated. The capacitance (C1) is denoted the positive acceleration values and its denoted by 'C' and similarly capacitance (C2) is denoted the negative acceleration values and it is denoted by 'B'. The device linearity between acceleration input and differential capacitance change will be degraded if the maximum displacement of the movable fingers exceeds 5% of the capacitance gap.

C. OUTPUT RESPONSE OF DIFFERENTIAL CAPACITANCE (ΔC)

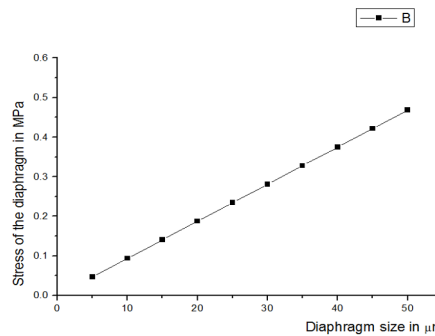


Figure 8. Acceleration vs Differential capacitance

Based on INTELLISUITE simulation results, the sensitivity is by increases the number of fingers with the increments of beam length and acceleration. Based on the above output response differential capacitance is measured and the linearity of the output response is observed. Here , the observed linearity is denoted by ‘B’.

VI. CONCLUSIONS

In this paper based on the MEMS comb accelerometer, a folded beam structure of capacitive accelerometer has been designed and it is simulated. The simplified spring – mass model is used to predict the device sensitivity .Based on theoretical analysis , INTELLISUITE simulation was used to extract the relationship between the device sensitivity and various design parameters, such as acceleration, differential capacitance and linearity. The two main functions were performed in this accelerometer design. Firstly, the sensing region was designed to measure the acceleration, which produced a change in displacement of the proof mass, which changed the distance between electrodes and it produced a change in capacitance – easily measured. Secondly, the static and modal analysis are performed and calculated the differential capacitance.

REFERENCES

[1] JiaYubin, HaoYilong 2005 Bulk Silicon Resonant Accelerometer Chinese Journal of Semiconductors 26 281.
 [2] Yazdi N., Ayazi F. and Najafi K., “Micromachined Inertial Sensors.” Proc. of the IEEE, Vol. 86, no. 8, pp. 1640-1659, Aug 1998.
 [3] J. Bernstein, “An Overview of MEMS Inertial Sensing Technology,” Sensors Magazine Online, Feb 2003.
 [4] Van Kampen, R. P. and Wolffenbuttel, R. F. “Application of electrostatic feedback to critical damping of an integrated silicon accelerometer.” Sensors and Actuators, A 43, pp. 100-106, 1994.
 [5] Senturia S D. CAD challenges for microsensorsmicroactuators and microsystems. Proceedings of the IEEE, 1998, 86:1611
 [6] Yong Zhou, Layout Synthesis of Accelerometers, “Master of Science Project Report”, Department of Electrical and Computer Engineering, Carnegie Mellon University, August 1998.
 [7] Chen Hao, Chen Min, Zhao Wenjing, XuLimei, “Equivalent Electrical Modeling and Simulation of MEMS Comb Accelerometer”, Institute of Astronautics and Aeronautics, University of Electronic Science and Technology of China, DOI 10.1109/ICMTMA.2010.589