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Design and Simulation of Capacitive Type Comb-Drive Accelerometer To Detect Heart Beat Frequency

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Abstract

MEMS accelerometers are one of the most common inertial sensors, a dynamic sensor capable of a vast range of sensing. The basic principle of operation behind the MEMS accelerometer is the displacement of a small proof mass etched into the silicon surface of the integrated circuit and suspended by small beams. MEMS accelerometers in Structural Health Monitoring systems can be able to measure the range of acceleration ± 4g with increasing sensitivity and decreasing cross sensitivity. In this paper, we have designed and simulated the MEMS capacitive comb drive accelerometer with respect to the vibrational frequency of the chest wall. The design consists of a proof mass (4000 μm × 6200 μm) with movable electrodes (2500 μm × 200 μm), fixed beam of electrodes (2500 μm × 200 μm) and a cantilever beam as a spring (1000 μm × 2000 μm). The Device operates in dynamic mode and simulated using COMSOL MULTIPHYSICS 5.2 version software. The output total displacement at 20 Hz is 1.52E-10 μm and at 40 Hz is 1.45E-9 μm, acceleration at 20 Hz is 9.63E-7 m/s^2 and at 40 Hz is 9.19E-6 m/s^2 is measured. The simulated results are correlated to the modeling results at the range of frequency 20 Hz–40 Hz.

Keywords: Inertial sensors; MEMS Accelerometer; Sensitivity; Capacitive comb drive; Proof mass

Introduction

The cardiovascular diseases generally have no symptoms and it can be identified by chest pain or shortness of breath. The diagnosis of heart diseases is often done by observing the heart beats. These heart beats can be monitored by different structural health monitoring systems. Structural Health Monitoring (SHM) systems collect and analyze information about a civil structure so that indications of a structure distress can be identified early. The existing SHMs ECG, BCG, PPG, UCG are costly devices, contains more number of components and is difficult to handle for long time ambulatory monitoring of heart functions and its motions. Miniaturization of Biomedical sensors has increased importance of Microsystems technology in medical applications. Bio-MEMS sensors play an important role in heart rate monitoring. The optical sensors [1] based on the blood flow, the pressure sensors [2] which transform the vibrations (due to pumping of blood by heart) into electrical signals and body worn sensors using mechanical transducers [3] are the existing designs for monitoring the heart rate. Recent research has shown that accelerometer sensors can be used to reliably detect some physical activity types when tested on small datasets [4].

In this paper, the MEMS inertial sensor called capacitive type comb-drive accelerometer is designed to monitor heart beat frequency with increasing sensitivity (± 4 g) and decreasing cross-sensitivity [5]. The accelerometer is placed on the chest wall a slight variation on the chest surface due to heart beat allows visualizing the heart motion for assisting and understanding heart function. The device produces linearity at the heart beat frequency range.

Design structure and principle of operation

Figure 1 illustrates the MEMS comb drive capacitive accelerometer that can be used prototype design of Multiphysics model [6]. The comb drive structure consists of proof mass with interdigitated fingers extending from the frame. The proof mass is suspended from the fixed beams with two cantilever springs. The capacitor plates are arranged such that there are two types of plates: fixed and movable plates as shown in Figure 1. When the proof mass vibrates with the input vibrations then the movable plates are also moves developing a capacitance with the given voltage of 5 V across the plates (Figures 1 and 2) [7].

According to Newton's second law any external inertial forces due to acceleration displace the supporting frame relative to the proof mass. This in turn applies a force F=ma on the spring with 'm' being the mass of the proof mass and **a** being the acceleration [8]. The spring is deflected until its elastic force equals the forced produced by the acceleration. In the first order force acting on the spring is proportional to its displacement F=kx. Hence,

$$a = \frac{m}{kx} \qquad (2)$$

Where 'a' is the acceleration produced by force,

'm' is proof mass,

'k' is the spring constant.

'x' is the displacement of the proof mass.

Initially when there is no acceleration i.e, a=0, then there is no displacement of the proof mass and electrodes attached to it hence there will be the nominal capacitance about 5.1 pF [9]. When the device is placed on the chest wall and senses any external acceleration changes the displacement of proof mass the changes can be monitored along each axis and then analyzed to provide the information of the heart motion occurring.

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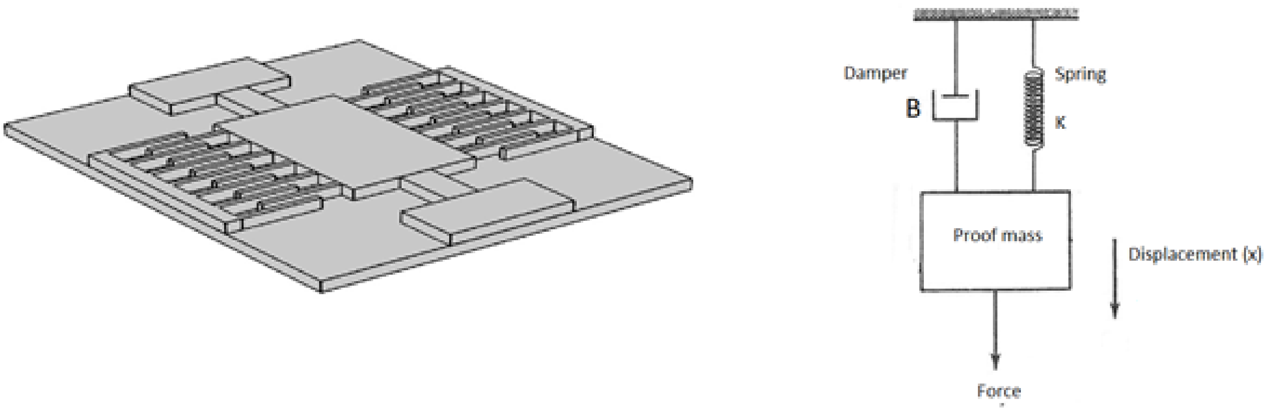

Figure 1: (a) 3D view of MEMS comb-drive accelerometer structure. (b) Mass-Damper-Spring system.

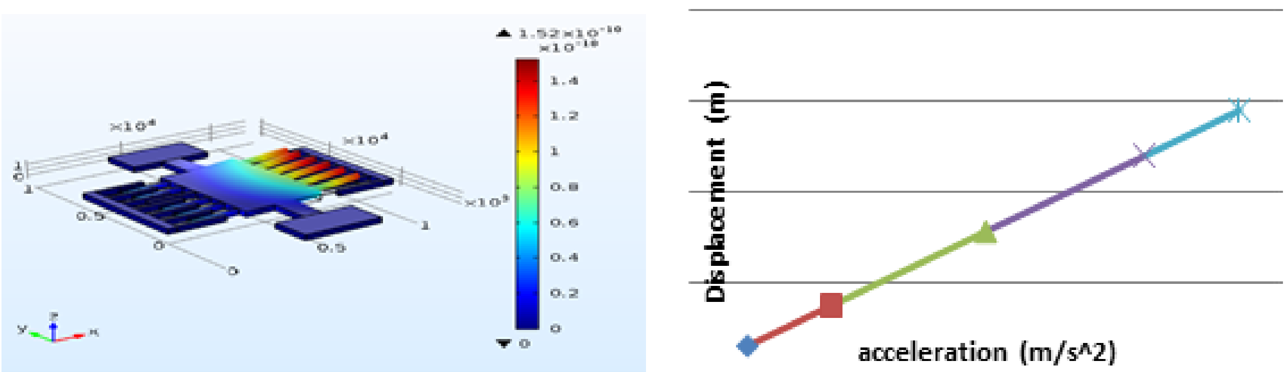

Figure 2: Simulation for total displacement at different heart beat frequencies and graph against acceleration.

Results and Analysis

Displacement analysis

When the device is placed on chest wall, the input acceleration is produced due to vibrations of the chest wall. The total displacement and capacitance at different heart beat frequencies is observed.

Conclusion

In this paper proposed design of comb-drive accelerometer is carried out with suitable capacitive sensing technique. Hence the accelerometer is capacitive type comb-drive accelerometer. The mathematical modeling is done for to find the mass, spring constant and other preliminary parameters. The device is modeled at the resonant frequency 20 Hz hence the device senses the acceleration only between 20 Hz–40 Hz (maximum frequency of heart under stationary condition). The displacement and capacitance values are obtained by simulating the accelerometer in COMSOL Multiphysics software. By obtaining the simulated results it is concluded that when the displacement is in between 1.52e-10 to 1.45e-9 range then the person is in normal heart beat frequency range 20 Hz–40 Hz otherwise the person is affected with Tachycardia or Bardycardia.

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