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Using Finite Element Analysis to Determine the Sensitivity of a Triaxial MEMS Accelerometer

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Abstract*: *It is necessary to determine the sensitivity of an accelerometer before building it. To determine the sensitivity of an accelerometer, the Finite Element Method (FEM) is used by the Ansys software. In this work, coupled field static analysis for a triaxial MEMS accelerometer is used to obtain the sensitivity of an accelerometer.

Keywords: Sensitivity, Accelerometer, Finite Element Method, Triaxial, Ansys software, MEMS.

1. INTRODUCTION

An accelerometer is a device used to determine acceleration and the frequency of vibration. The accelerometer was designed using Autodesk Fusion 360 software. The triaxial accelerometer has four cantilever beams, one seismic mass, and four piezoelectric materials. A piezoelectric material is a material that can produce electric charges upon application of mechanical stress. Due to the piezoelectric effect, the mechanical stress developed due to the application of acceleration is in turn converted into an electric charge, which is then fed into an amplifier to amplify the signal, and then the charge is fed into the Data Acquisition System for signal processing. Accelerometers have many uses in industry and science. Highly sensitive accelerometers are used in inertial navigation systems for aircraft and missiles. Vibration in rotating machines is monitored by accelerometers. They are used in tablet computers and digital cameras so that images on screens are always displayed upright. In unmanned aerial vehicles, accelerometers help to stabilize flight.

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The acceleration is measured in terms of g (9.81 m/s^2) and the sensitivity is a property that defines how much voltage is generated per g(9.81 m/s^2). The accelerometer, which has more sensitivity, is preferred in vibration frequency determination, and the accelerometer, which has less sensitivity, is preferred in acceleration detection and condition monitoring, so it is important to find the sensitivity of an accelerometer.

Silicon and the piezoelectric material PZT-5H will be used for the cantilever beam and seismic mass, respectively. In Fig. 1, the accelerometer's design is shown. Since the cantilever beam and piezoelectric material are rigidly sealed together when the acceleration is applied to the system, the seismic mass will cause the cantilever beam to deform. This implies that the deformation of the piezoelectric material causes stress to be induced in the material due to the piezoelectric effect and that the electric charge is developed in the piezoelectric material, which is then used to determine the acceleration. One kind of accelerometer that can measure acceleration in three cartesian axes is the triaxial accelerometer.

2. MATERIAL PROPERTIES

1. PZT-5H:
A.Mass density= 7500 kg/m^3
B. Anisotropic elasticity

126	0	0	0	0	0
79.1	126	0	0	0	0
83.9	83.9	117	0	0	0
0	0	0	23	0	0
0	0	0	0	23	0
0	0	0	0	0	23.5

*unit (Gpa)

C. Anisotropic relative permittivity matrix

1699.7967	0	0
0	1699.7967	0
0	0	1470.5218

*at constant strain

D. Piezoelectric matrix

0	0	0	0	17	0
0	0	0	17	0	0
-6.5	-6.5	23.3	0	0	0

*at constant stress(unit C/m^2)

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Silicon:
A. mass density = 2330kg/m^3
B. Isotropic resistivity = 0.01Ωcm
C. Anisotropic elasticity

166	0	0	0	0	0
64	166	0	0	0	0
64	64	166	0	0	0
0	0	0	80	0	0
0	0	0	0	80	0
0	0	0	0	0	80

*unit (Gpa)

D. Coefficient of thermal expansion at different temperature

Temperature(^{0} c)	Coefficient of thermal expansion (/^{0} c)
20	2.46E-06
250	3.61E-06
500	4.15E-06
1000	4.44E-06
1500	4.44E-06
20	2.46E-06

Design of Accelerometer
The Autodesk Fusion 360 software was used to model the accelerometer, which has dimensions of 5 mm by 5 mm by 0.5 mm. As previously stated, silicon was used in the design of the mass and cantilever beam, and PZT-5H, with a thickness of 0.2 mm, was used in the design of the piezoelectric material. The accelerometer is modeled and then imported into the Ansys software for additional processing.

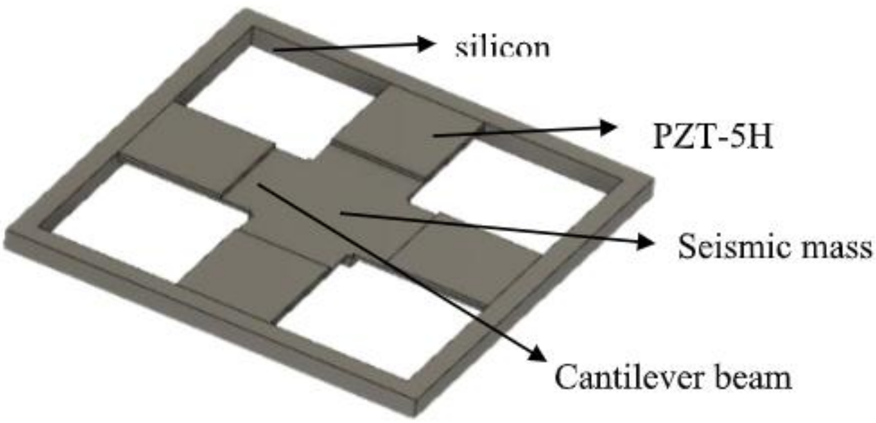

Fig.1. Design of a triaxial MEMS accelerometer

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Analysis of Accelerometer

The previously mentioned design is imported into the Ansys workbench for analysis purposes. The coupled field static analysis system is used for the simulation of the accelerometer to determine the sensitivity. The coupled field analysis system is used when multiple physics factors are taken into account. Since the accelerometer is a device that deals with structural and electric properties, it has been used for analysis purposes.

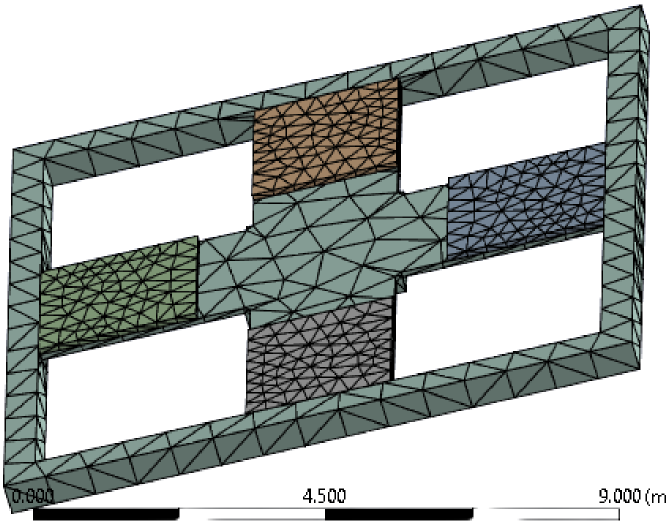

Fig.2. Mesh preview

The material is assigned as PZT-5H for the piezoelectric plate and silicon for the mass and cantilever. The mesh was generated with the tetrahedrons method with quadratic element order to obtain more nodes at the center of the grid lines with an element size of 0.7mm. In coupled field static, the physics region is defined as structural and electric for PZT-5H and structural for silicon. The bottom face of the accelerometer is fixed, and an acceleration of 1 g (9.81 m/s^2) as shown in fig.3. In the solution, the electric voltage is inserted to determine how much voltage is exerted while applying the above input parameters.

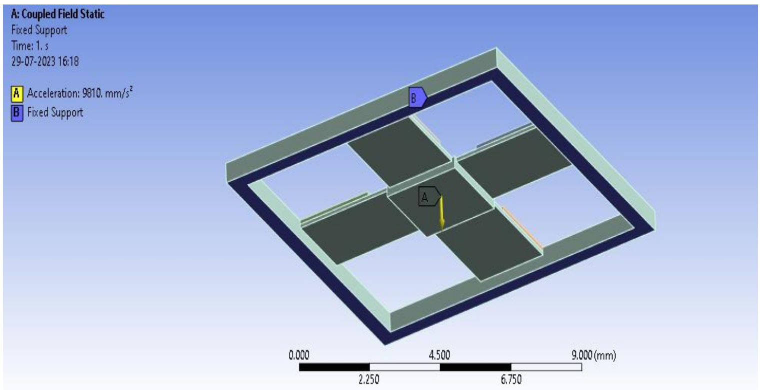

Fig.3. Input parameter and boundary condition

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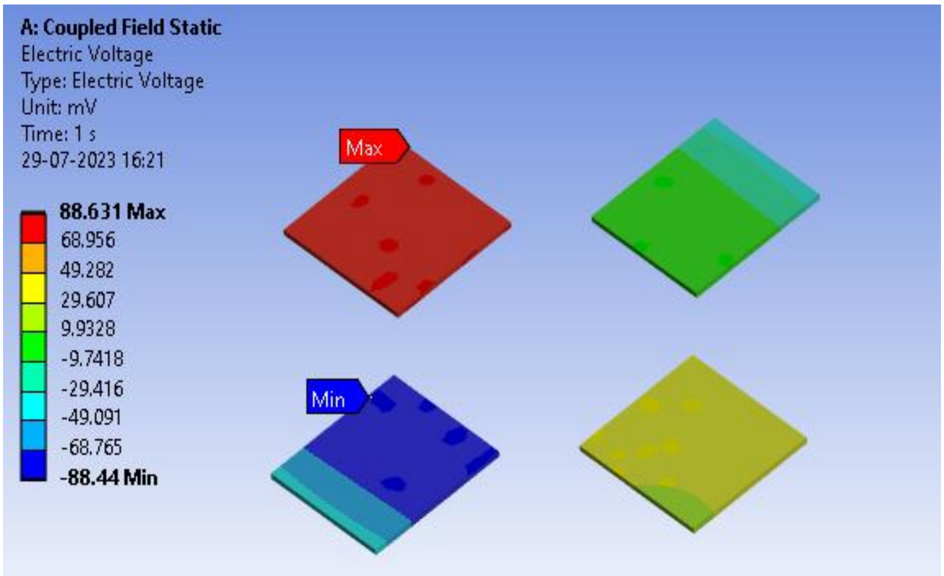

Fig.4. (a) Coupled Field Static

Minimum [mV]	Maximum [mV]	Average [mV]
-88.44	88.631	7.7216

Fig.4. (b) Electric voltage

The average output voltage of 7.7 mV is obtained under the given acceleration of 1 g (9.81 m/s^2), as shown in Fig. 4.

3. CONCLUSIONS

This paper represents the analysis of an accelerometer using the finite element method. The modeling is carried out in AutoCAD Fusion 360 software, and the analysis is done using Ansys software. The resultant sensitivity of the accelerometer is 7.7 mV/g.

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