Design and simulation of MEMS piezoelectric gyroscope Using COMSOL Multiphysics®

T.Madhuranath*, R.Praharsha and Dr.K.Srinivasa Rao

Department of Electronics an instrumentation Engineering

Lakireddy Bali Reddy College of Engineering, Mylavaram-521230, A.P, India

ABSTRACT

Tracking the position of an object is an important engineering problem that finds many application areas including military, industrial, medical, and consumer applications. This problem is effectively solved with gyroscopes, and these sensors find the orientation and angular velocity Knowing linear acceleration and angular velocity in three dimensions is enough to track the motion of the system with the help of additional mathematical operations. solved with gyroscopes, and these sensors find the orientation and angular velocity Knowing linear acceleration and angular velocity in three dimensions is enough to track the motion of the system with the help of additional mathematical operations. MEMS piezoelectric gyroscope is an inertial sensing integrated circuit that measures the angle and rate of rotation in an object or system. Programmable for targeted applications, this technology relies on three dimensional axes of sensing, which are X (pitch), Y (roll), and Z (yaw). In this paper, we have reported the design and simulation of MEMS piezoelectric gyroscope by COMSOL Multiphysics.

Keywords: MEMS, Gyroscope, Piezoelectric devices, Sensors.

INTRODUCTION

Gyroscopes have played an important role in aviation space exploration and military applications. Until recently, high cost and large size made their use in automobiles and other consumer products prohibitive. With the advent of Micro-Electro-Mechanical Systems. (MEMS), gyroscopes and other be inertial measurement devices can now produced cheaply and in very small packages in the micro domain. An example of this are the MEMS accelerometers now used in some automobiles to detect collisions for air bag deployment. In order to estimate the absolute angle, θ , with a traditional MEMS rate-gyroscope, one would have to integrate the angular rate signal Ω with respect to time. The problem with this method is that bias errors in the angular rate signal from the gyroscope will inevitably cause the integrated angle value to drift over time, since all gyroscopes have at least a small amount of bias error in their angular rate signal. This paper develops a sensor design to directly measure absolute angle. The design can also be combined with traditional angular rate measurement to provide a sensor in an integrated package that measures both angle and angular rate. There are a large number of applications where a gyroscope that can measure angle would be useful. A common application is measurement of the heading or orientation of a highway vehicle. The measurement of orientation is useful in computer-controlled steering of the vehicle as well as in differential braking systems being developed by automotive manufacturers for vehicle skid controlAn important additional benefit of the proposed design is that it would also contribute towards improving the accuracy of the regular rate gyroscopes . The proposed design is novel in that it breaks new ground by introducing sophisticated control systems into the MEMS domain. It is the use of advanced control techniques that leads to a new sensor making the measurement of a new variable (absolute angle) possible. A number of researchers and research groups have worked on MEMS vibratory-rate gyroscopes. A good description of the working of a basic angular rate gyroscope can be found in Clark, et.al. Here the gyroscope consisted of a single mass oscillating longitudinally with rotation induced lateral deflections being sensed capacitive. The bulk of literature on MEMS vibratory gyroscopes deals with different embodiments of the above basic sensing concept described in. There are varying designs and implementation using a number of different fabrication processes. Bernstein, et.al demonstrated a tuning fork gyroscope using two masses that oscillate laterally. An external oscillation induced oscillation out of plane of the device. Boeing is now developing a commercial version of this device. Juneau, et. al. demonstrated a dual-axis gyroscope which could simultaneously measure two rotational rates. It consisted of a rotating disk in which deflection induced by rotations about two axes were measured out of plane of the device

Gyroscope History:

In order to discuss MEMS gyroscopes we must first understand gyroscopes in general and what role they play in science. Technically, a gyroscope is any device that can measure angular velocity. As early as the 1700s, spinning devices were being used for sea navigation in foggy conditions. The more traditional spinning gyroscope was invented in the early 1800s, and the French scientist Jean Bernard Leon Foucault coined the term gyroscope in 1852. In the late 1800s and early 1900s gyroscopes were patented for use on ships. Around 1916, the gyroscope found use in aircraft where it is still commonly used today. Throughout the 20th century improvements were made on the spinning gyroscope. In the 1960s, optical gyroscopes using lasers were first introduced and soon found commercial success in aeronautics and military applications. In the last ten to fifteen years, MEMS gyroscopes have been introduced and advancements have been made to create mass-produced successful products with several advantages over traditional macro-scale devices.

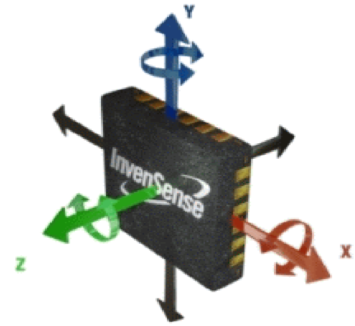
Traditional Gyroscope Function:

Gyroscopes function differently depending on their type. Traditional spinning gyroscopes work on the basis that a spinning object that is tilted perpendicularly to the direction of the spin will have a precession. The precession keeps the device oriented in a vertical direction so the angle relative to the reference surface can be measured. Optical gyroscopes are most commonly ring laser gyroscopes. These devices send two lasers around a circular path in opposite directions. If the path spins, a phase shift can be detected since the speed of light always remain constant. Usually the rings are triangles or rectangles with mirrors at each corner. Optical gyroscopes are a great improvement to the spinning mass

gyroscopes because there is no wear, greater reliability and smaller size and weight.

The Move to MEMS:

Even after the introduction of laser ring gyroscopes, a lot of properties were desired. MEMS vibrating mass gyroscopes aimed to create smaller, more sensitive devices. The two main types of MEMS gyroscope, discussed in Micromachined Vibrating Gyroscopes: Design and Fabrication, are the tuning fork gyroscope and the vibrating ring gyroscope. In this paper, we will look at two other types of gyros; the macro laser ring gyroscope and the piezoelectric plate gyroscope.



WORKING PRINCIPLE:

PIEZOELECTRIC EFFECT:

A. The production of electricity or electric polarity by applying a mechanical stress to certain crystals.

B. The converse effect in which stress is produced in a crystal as a result of an applied potential difference piezoelectrically.

The generation of an electric charge in certain non-conducting materials, such as quartz crystals and ceramics, when they are subjected to mechanical stress (such as pressure or vibration), or the generation of vibrations in such materials when they are subjected to an electric field. Piezoelectric materials exposed to a fairly constant electric field tend to vibrate at a precise frequency with very little variation, making them useful as time-keeping devices in electronic clocks, as used in wristwatches and computers.

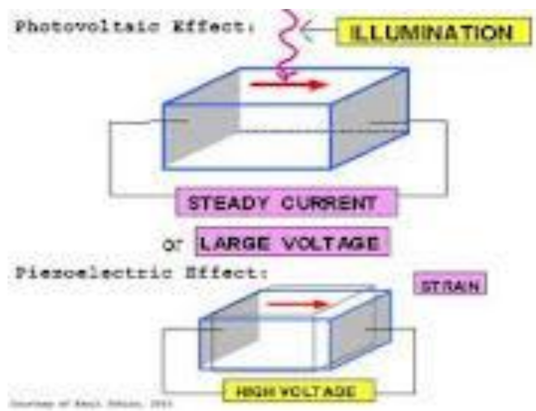


Fig: Piezo electric effect

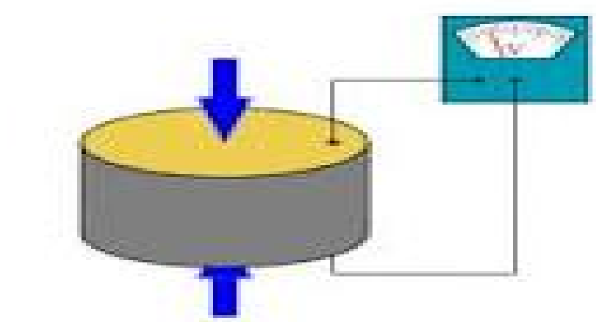


Fig: Reversible Piezoelectric effect

DESIGNING:

Design is done according to the requirement.

MESHING:-

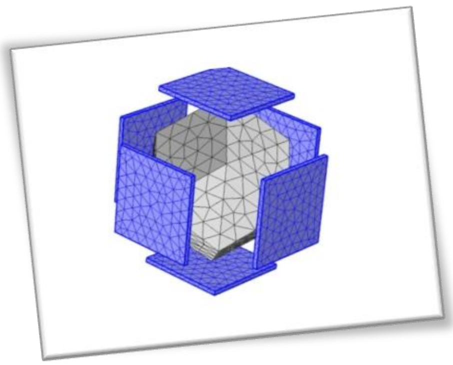
Discretizing of the model into small and simple pieces is called the meshing. For discretization purpose we are using the different shapes and sizes. In this module we are using the FREETETRAHEDRAL, and then distributed to the total module through distribution technique. For applying the meshing we follow the following steps.

Free tetrahedral:-

In the Model Builder window, right-click Model 1>Mesh 1 and choose More Operations>Free Tetrahedral.

Distribution:-

Click the Build Selected button. Total meshed structure is as shown in the following figure.



WORKING:-

When the total device is kept stable and straight, as shown in the figure below. The total weight of the platinum body inside is exerted on the piezoelectric slab under it. Now tilt the device with some angle then the weight of the pt body is shared with other two slabs.

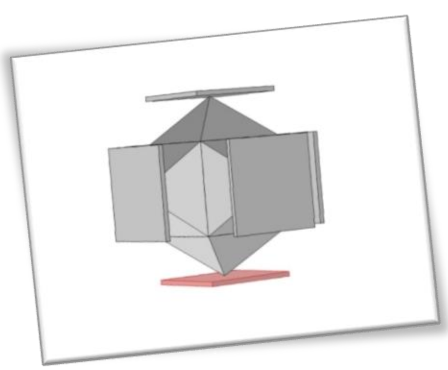


Fig: total weight falling on the down slab

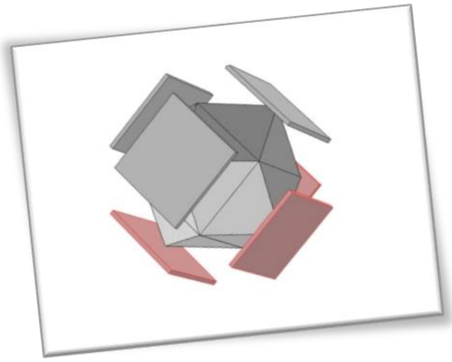


Fig: - Total pt weight falling on lower three slab.

So the piezoelectric slabs which are experiencing weight will deform and produce electric potential.

RESULTS:

For view the output of the device we are using the 3D plot groups. 3D plot group1 is used for the deformation analysis. 3D plot group2 is used to analyze the electric potential produced.

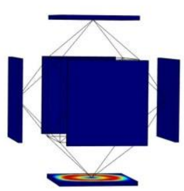


Fig:-3D plot group1

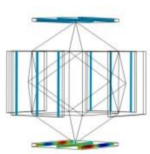


Fig: -3D plot group2

SIMULATION: The performance of the device depends on several design parameters and material properties. Simulation is done by varying density is very high. The obtained are tabulated.

MATERIAL APPLIED FOR THE PROOF MASS	MAX DEFORMATION	POTENTIAL GENERATED
Structural steel	**50x10^-7um**	**0.018v**
Platinum	**25x10^-6um**	**0.083v**

RESULTS AND DISCUSSIONS: -

The design of MEMS based piezoelectric gyroscope was made by using COMSOL Multiphysics software version 4.3a. In which by using electric potential produced in different piezoelectric slabs the angular displacement or orientations of body is calculated.

On the other hand when materials are changed for the inner weighted body platinum gave better result than the structural steel.

CONCLUSION: -

MEMS technology exploits the existing microelectronics infrastructure to create complex machines on a micrometer scale. Extensive applications for these devices exist in Tracking the position of an object is an important engineering problem that finds many application areas including military, industrial, medical, and consumer applications.

MEMS piezoelectric gyroscope used to measure the angle and rate of rotation in an object or system. Programmable for targeted applications, this technology relies on three dimensional axes of sensing, which are X (pitch), Y (roll), and Z (yaw). The devices can accurately track complex motions without being influenced by factors such as magnetic fields. Once occupying transports and vehicles, this technology now turns up in a host of consumer technologies.

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