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DESIGNING AND SIMULATION OF MEMS BASED GYROSCOPE

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Abstract: The automotive market is demanding low-cost gyroscopes for sensing yaw rate to compensate braking and suspension systems for driving security and comfort. Technically gyroscope is a device that can measure angular velocity. The gyroscope has been developed for the guidance and control in navigation systems. There are two types of vibrating gyroscope available for orientation and rotational rate control, Type I-angle gyroscope, Type II-rate gyroscope. The rate gyroscope is developed here for sensing the position and orientation for guidance, control and navigation purposes application using ANSYS software. The Coriolis force is used to retain the mass/objects to its initial state, by sensing the acceleration between the drive and sense mode about the z-axis reference frame.

Keywords: MEMS, gyroscope, Coriolis Effect, and navigation system

I. INTRODUCTION

The term MEMS is an abbreviation of micro electromechanical system. MEMS contains components of sizes in 1 micrometer (μm) to 1 millimeter (mm), (1 mm = 1000μm). [1] The MEMS is the miniaturization technique for manufacturing devices and systems, using integrated circuit(IC) fabrication process, such as etching, bonding and so on. MEMS devices (sensors and actuators) have found some applications, such as automobile, aerospace, communication, medical etc., based on high functionality, precision and performance.

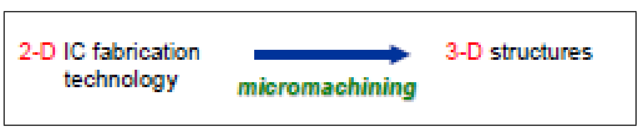

Figure 1: Micromachining Process

MEMS are the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through micro fabrication technology. While the electronics are fabricated using Integrated Circuit (IC) process sequences, the micromechanical components are fabricated using compatible micromachining processes [2].

A. Finite Element Analysis

In essence, the principle of the finite element method (FEM) is "Divide and Conquer" [5]. The very first step in a finite element analysis is to divide the whole solid structure made of continua into a finite number of subdivisions of special shapes (called the elements) interconnected at the corners or specific points on the edges of the elements (called the nodes). A variety of geometry of elements is usually available from the element library offered by most commercial codes.

Credible results forms finite element analysis (FEA) are attainable with intelligent discretization of the structure. Two principle rules need to be followed [6] :

1. Place denser and smaller elements in the parts of the structure with an abrupt change of geometry where high stress or strain concentrations are expected.
2. Avoid using elements with high aspect ratio, of the longest dimension to the shortest one in the same element. The user is advised to keep this aspect ratio below 10.

II. BACKGROUND THEORY

The structure of fly's Halteres is shown in Fig. Each Halteres contains approximately 400 mechano-receptors, mainly campaniform sensilla and chordotonal organs, embedded in the flexible exoskeleton at the Halteres base. Derham was the first scientist to note that with their Halteres removed, flies cannot keep stable and quickly crash to the ground while staying aloft. In reality, those mechanoreceptors at the base of the Halteres function as strain gauges to detect the Coriolis force applied on the Halteres.

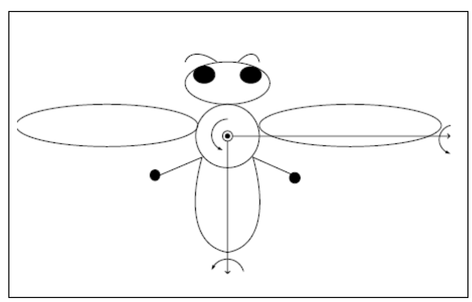

Figure 2: Halteres (Blow Fly)

During flight the Halteres beat up and down in vertical planes through an average angle of nearly 180° anti-phase to the wings at the wing beat frequency[10]. In addition, the two Halteres are not coplanar so that flies can detect rotations about all three turning axes. Assuming no translational motion of the insect, this force can be expressed in vector notation as following :

$$F = mg - ma - m\omega \cdot r - m\omega \cdot (\omega \cdot r) - 2m\omega \cdot v \quad (1)$$

where m is the mass of the Halteres, r, v, and a are the position, velocity, and acceleration of the Halteres relative to the insect body, respectively; ω and ÏĽ'ôĂĂĚ are the angular velocity and angular acceleration of the insect, and g is the gravitational constant. When fly's body rotates, centrifugal (-mω x (ω x r)) and Coriolis (-2mω x v) forces are produced on its Halteres. However, the influence of the centrifugal force to the rotation movement can be neglected. Firstly, the centrifugal force is generally smaller than the Coriolis force and mostly in the radial and tangential directions. Secondly, as it is proportiona1 to the square of angular velocity of the fly, the sign of rotations would not be influenced by the centrifugal force. Thirdly, on the other hand, the Coriolis force is proportional to the product of the angular velocity of the fly and the instantaneous Halteres velocity. The Coriolis force has components in all three directions and contains the information on the axis, sign, and magnitude of the fly's body rotation. The angular acceleration force (-mωôĂĂĚ ÃŮ r) is proportional to the product of the angular acceleration of the fly and the instantaneous position of the Halteres. Due to the 90° phase shift, the angular acceleration and the Coriolis force signals are separable. The primary inertial force (-ma) depends on the Halteres acceleration relative to the fly's body. This force is orders of magnitude larger than the Coriolis force and also has only radial and tangential components. The gravitational force (mg) is always constant and depending on the Halteres position and the fly's body attitude in space, and its distribution varies in the three directions. However, because it is a tonic lateral component, the effect of this gravitational force on the angular velocity sensing is negligible. For this reason, the gravitational force can be considered as DC offset on the Coriolis force and can be removed easily by the subsequent signal processing step.

A. Structural Design

In this study, a vibratory gyroscope is designed consisting of two circular diaphragms with a club shaped structure placed over one of them. The inspiration comes from insects having specialized structure called halteres, which are sensitive to Coriolis force [11]. The driving force is given in the y-direction and the displacement due to the Coriolis effect is sensed in the x-direction.

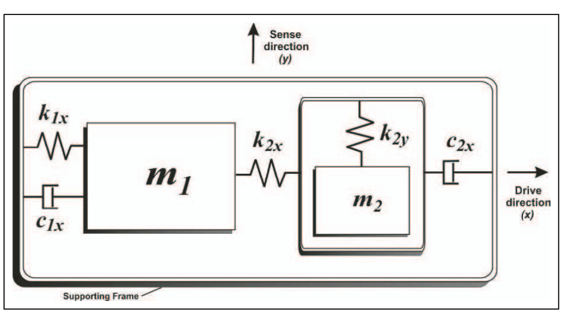

Figure 3: Type I and II Gyroscope's Mass Spring System

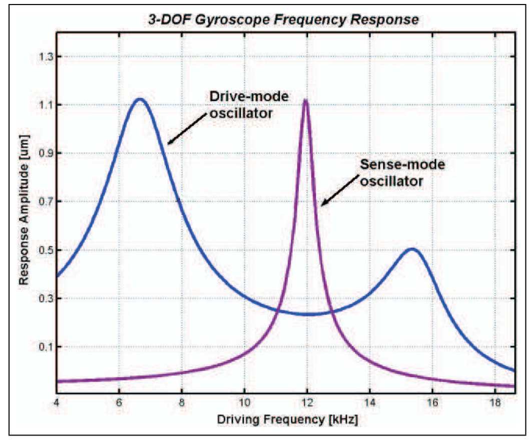

Figure 4: Plot of the combined system

B. Finite Element Simulation

The suspension thin layer of membrane was defined to be clamped along its edges with the surrounding chip substrate [13, 14]. The applied pressure PCF on the right face of the head of the hammer-shape structure is to simulate the stress distribution on the suspension thin layer of membrane which is caused by Coriolis force, the applied pressure is to simulate the electrostatic driving force which would actuate the gyroscope with a swinging model.

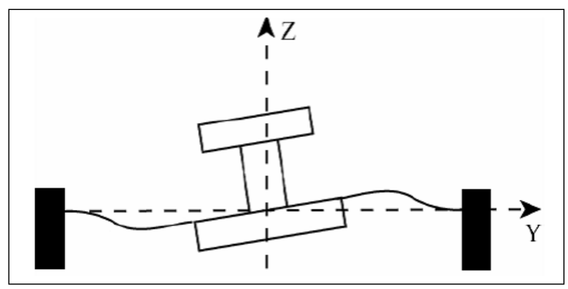

Figure 5: Swinging model for z-axis

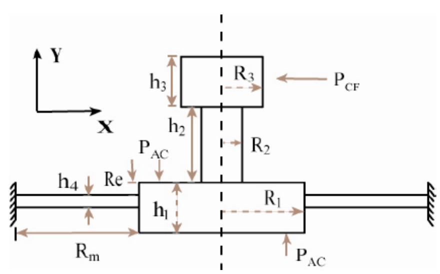

Figure 6: Implementation structure for FE element

The simulations were implemented with the applied pressure PCF and PAC separately [12]. By doing this, the comparison between the results would indicate the momentum amplification property of the biomimetic hammer-shape structure. If the piezoresistive sensing method will be used on the suspension thin layer of membrane of this bio-inspired gyroscope ,then

SYMBOL	DESCRIPTION	QUANTITY (μm)
h1	Thickness of Thick Membrane	5
h2	Height of Pillar	30
h3	Height of Head	15
h4	Thickenes of Thin Membrane	2
R1	Radius of Thick Membrane	20
R2	Radius of Pillar	10
R3	Radius of Head	20
R_m	Radius of Thin Membrane	40
P_{cf}	Applied Pressure from an assumed Coriolis force	5 M Pa
P_{AC}	Applied Pressure from an assumed actuation force	5 M Pa

Table 1: Specifications.

von Misses stress distribution along the suspension thin layer of membrane will be used as the figure of merit.

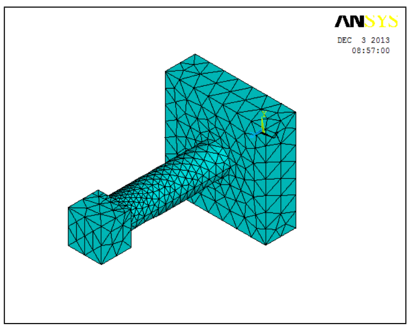

Figure 7: Design of vibratory Gyroscope

III. RESULTS AND DISCUSSIONS

The model above shown measures the angular displacement and angular rate and provides useful information in the field of industrial applications. The inertial sensor can be used either as a sensing device or as an actuating element. Here the gyroscope acts as an actuator, which provides information for future measurements.

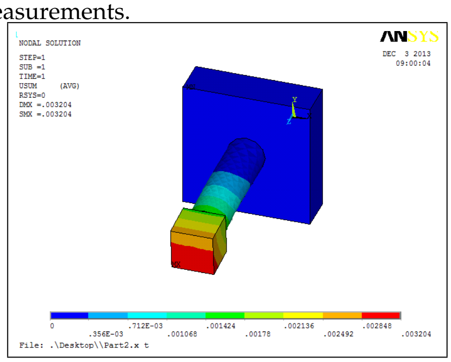

Figure 8: Finite Element Model-input load

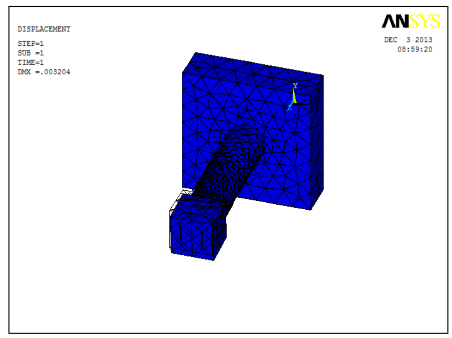

Figure 9: Displacement of Gyroscope

The pressure or external force is given as load, so that the gyroscope will get displaced, from which the rate of velocity can be measured. From velocity measured, angle and rate can be calculated. The external force which is applied as load generates Coriolis force, when the gyroscope displaces having base/x-axis as its reference frame. The generated Coriolis force retains the initial state of the gyroscope. The top of the gyroscope is red in color which indicates that the load is applied on the top axis, which makes the intermediate element to oscillate by vibratory motion

Physics Used :
The solid mechanics physics in terms of boundary load was applied to the required boundary. The MEMS based vibratory gyroscope was modeled and simulated using ANSYS Multiphysics. The materials defined are thicker and thinner membranes were made of steel.

IV. CONCLUSION

The purpose of the research was to develop an effective gyroscope for navigation systems. The simulated results show the displacement due to Coriolis Effect. These results let us to a conclusion, that the gyroscope would provide valuable information for navigation systems

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