Design and Simulation of MEMS Based Gyroscope for Vestibular Prosthesis

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Abstract: The primary function of the vestibular system is to provide the brain with information about the body's motion and orientation. The absence of this information causes blurred vision and spatial disorientation, vertigo, dizziness, imbalance, nausea, vomiting, and other symptoms often characterize dysfunction of the vestibular system. Our aim is to design vestibular prosthesis using COMSOL Multiphysics 4.2a. In this model there are two modes –driving mode and sensing mode. The driving force is given in the x-direction and the displacement due to the Coriolis effect is sensed in the y-direction. In the prosthesis, the three semicircular canals are replaced by 3-axis MEMS gyroscopes. The microscopic gyroscope senses angular motion of the head and generates voltages proportional to the corresponding angular accelerations. Then, voltages are converted into electric current pulse relating angular acceleration to spike count in vestibular nerve.

Keywords: MEMS, Gyroscope, Coriolis Effect, Vestibular prosthesis.

1. Introduction

A gyroscope is a device that can measure angular velocity. MEMS piezoelectric gyroscopes aim to create smaller and more sensitive devices. Fundamental to an understanding of the operation of a vibrating structure gyroscope is an understanding of the Coriolis force. Coriolis force is the force exerted on a body when it moves in a rotating reference frame. It is caused by rotation of earth and inertia of mass. It acts perpendicular to rotation axis and velocity of body in rotating frame and is proportional to rotation rate.

MEMS vibrational gyroscopes provide a low cost inertial measurement of rotation rate by sensing the effects of the Coriolis force in a rotating system. A vibrational gyroscope can be understood by considering a mass attached to a rigid frame by springs (Fig 1).

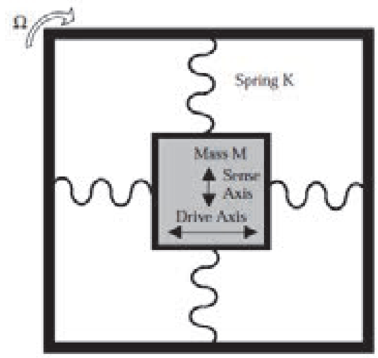

Figure 1: Basic Vibrational Gyroscope

Sensory prostheses to artificially replace lost sensory function for a number of sensory systems are currently under investigation. For example, cochlear implants use electrical stimulation to restore hearing and provide some relief for patients suffering profound sensorineural hearing loss. Using similar principles, a vestibular prosthesis could provide head orientation information to the nervous system for patients suffering from peripheral vestibular disorders. The vestibular organ of the inner ear is the major anatomical system to sense motion. The primary function of the vestibular system is to provide information to the brain about the body’s motion and orientation. It measures six quantities concerning the spatial orientation including 3-axes angular acceleration and 3-axes linear acceleration. Diminished balance ability, often seen in older adults, poses a serious health risk due to the increased likelihood of the falling. Several approaches can be considered for improvement of balance sensation and postural control. Appropriate drugs could relief some of the symptoms. Non-invasive exercise has relatively low risk and may also lead to improvement of the vestibular function. If the natural tactile sensitivity and balance control cannot be improved using non-invasive methods, prosthesis might be an alternative way to restore balance function. In balance related prosthetics, sensors such as gyroscopes and accelerometers can sense the motion and provide patients with information about body’s orientation. Such a device could be used as a temporary aid during recovery from ablative inner-ear surgery and as a permanent prosthesis for those elderly prone to falls[1].

2. Background Theory

The properly functioning vestibular system is responsible for a number of reflexes and reactions critical for achieving and maintaining equilibrium of the body and stabilization of images on the retina as the head and body are moved. The vestibular system comprises the non-acoustic portion of the inner ear and consists of three semicircular canals and two otolith organs called the utricle and the saccule. The sense organs of the semicircular canals detect rotational head movements, while the sense organs of the saccule and utricle detect linear movements of the head. All of these organs have small sensory hair cells that send pulses through the nerves to the brain, where information about head movement is combined with information from the eyes, muscles, and joints, which is then interpreted[2].

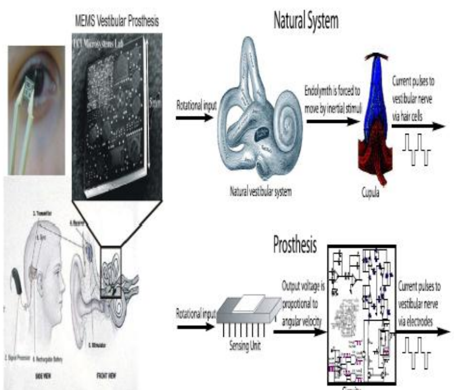

Figure 2: A conceptual model of a totally implantable vestibular prosthesis. The implant is based on 3-axes micro size gyroscopes integrated alongside with signal conditioning electronics on the same silicon chip; MEMS-based neural vestibular prosthesis is mimicking functionality of the natural vestibular end-organ

Angular accelerations stimulate the semicircular canals. The semicircular canals are three approximately circular canals whose planes are mutually orthogonal. Each canal is filled with fluid, endolymph, which, by virtue of its inertia, flows through the canal whenever an angular acceleration in the plane of the canal is experienced by the head. Flow of the endolymph deflects the cupula, a flapper-like valve which seals an expanded portion of each duct called the ampulla. Displaced endolymph Bends the tiny hairs of sensory cells (stereocilia) inside the canals and chambers, initiating nerve impulses that pass along the vestibular nerve to the brain. The impulses provide information to the brain about changes in head position.

3. Structural Design

In this study, MEMS based Gyroscope was designed, consisting of a proof mass and four fixed arms. The purpose of the semicircular canal prosthesis is to restore balance function. The prosthesis should be able to sense motion with sufficient precision and to deliver information to the central neural system in the same form as the natural organ would transmit.

Vestibular Prosthesis Application

Figure 3 shows the functional diagram of the vestibular prosthesis. The device includes three main functional units - a sensing unit, a pulse generator, and a stimulator. The device also includes two supporting units: a power supply and an external controller and charging unit. The sensing unit includes 3-axis accelerometers and 3- axis gyroscopes. These devices sense linear and angular motion of the head and generate voltages proportional to the corresponding linear acceleration and angular velocity. Then, voltages are sent to the pulse generating unit where angular velocities (or linear accelerations) are translated into voltage pulses. In the stimulator, the voltage pulses are converted into current pulses and are delivered through specially designed electrodes to stimulate the corresponding vestibular nerve elements. Each functional block of the chip consumes electrical power. For long term autonomous operation of the implantable device, it is required to supply power externally. Additionally, the implant should be able to communicate with an external controller and charging unit.

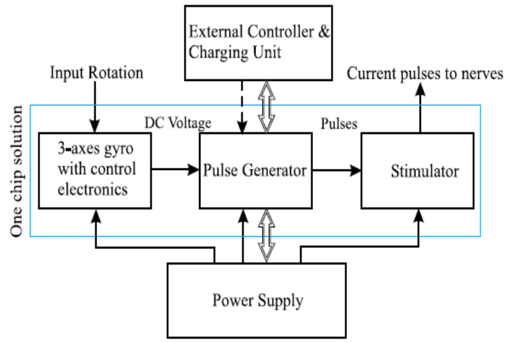

Figure 3. Functional diagram of the vestibular implant

4. COMSOL Multiphysics Analysis

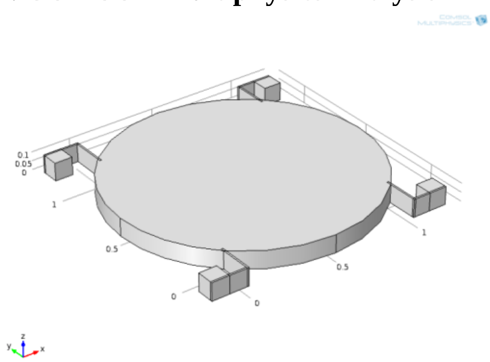

Figure 4: 3D Model of MEMS based Gyroscope

This MEMS based vibrating gyroscope was modeled and simulated using COMSOL Multiphysics 4.2 a - MEMS module.

Materials defined: Zinc Oxide

Physics Used: The Piezoelectric devices physics in terms of boundary load was applied to the required boundary. In case of electric field the load was applied to opposite sides of the thicker membrane.

5. Results and Discussion

The simulated results show that the Coriolis force input on the structure, would cause larger displacement on the suspended thin layer of membrane than the applied pressure, which was defined to simulate the electrostatic driving force. **Figure 5** shows the Displacement due to Coriolis Force in 3D model. **Figure 6** shows the Displacement due to Electric field in 3Dmodel.

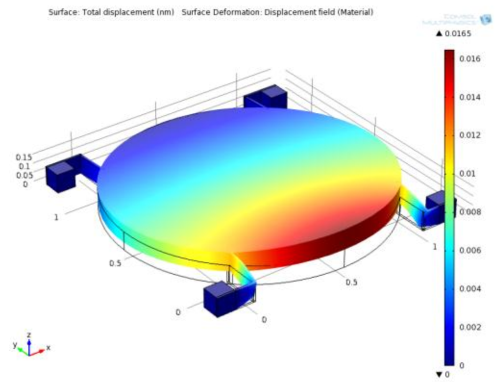

Figure 5: Displacement due to Coriolis Force in 3D model

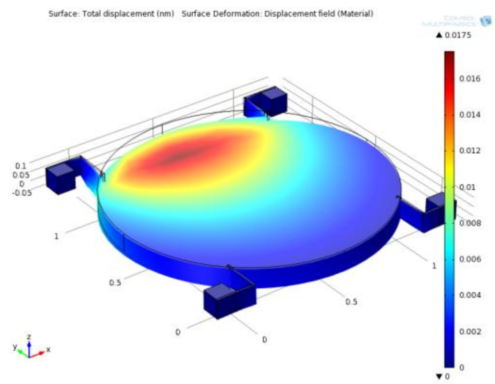

Figure 6: Displacement due to Electric field in 3Dmodel

6. Conclusions

The purpose of the work was to develop an effective gyroscope for vestibular prosthesis. The simulated results show that the displacement due to Coriolis effect, used for body balance by providing stimulus to the nerves. To restore the position of the gyroscope electric potential is applied. These results let us to a conclusion, that this gyroscope would provide information to brain about the body motion and orientation. MEMS based Gyroscope using COMSOL provide design of bio-compatible package for the prosthesis, and interface of the prosthesis with neurons. Benefiting from the unique capabilities of the MEMS technology, this vestibular implant will be small and consume little power, and can be potentially manufactured in large quantities at low cost.

7. References

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2. Timothy G. Constandinou,"A Neural Implant ASIC for the Restoration of Balance in Individuals with Vestibular Dysfunction",2009 IEEE.

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