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Electrostatically Levitated Rotational Gyroscope

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1. Introduction

Various applications such as advanced automotive safety and comfort systems, virtual reality, people-to-device communication, robotics and medicine increases the demand for low cost angular rate sensors with high accuracy. The aim of our project is the development of a micromachined levitated rotational gyroscope, which has small size and high sensitivity [1,2]. In principle, a levitated rotational gyroscope can eliminate a mechanical friction and yield high sensitivity. Nevertheless, the levitation of the rotor requires high voltage [3], which limits its applications. MEMS technology can miniaturize the structure and provide a solution to this problem.

In this work, we present operation designs, the fabrication and experimental results of the micro levitated gyroscope.

2. Operation Principle

Gyroscope Principle

A schematic drawing of the principle of a micro gyroscope is shown in Fig. 1.

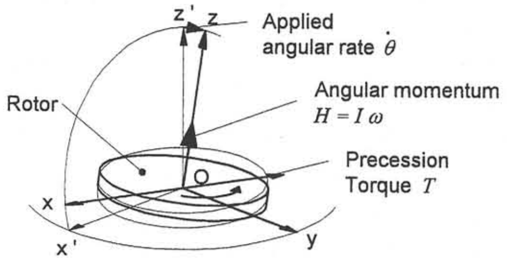

Fig. 1 Principle of the gyroscope

It consists of a spinning rotor and a stator that maintain the rotor at its null position by the levitation control. When out-of-plane angular velocity (θ or ϕ) is applied, the rotor tends to maintain its position in space. Due to the closed loop control, an applied angular rate generates a perpendicular torque to the applied velocity and spinning axis, i.e. a precession torque returns the rotor to the null position. In this way, the angular rate $\dot{\theta}$ is determined by detecting the magnitude of the precession torque. For a rotor shaped a disk plate, a formula below gives the magnitude of the precession torque T, as a function of the rotational speed of the rotor ω, the mass of the rotor m, the radius of the rotor r and the angular rate $\dot{\theta}$.

$$T = \frac{m}{2} r^2 \omega \dot{\theta}$$

Sensor Geometry

The schematic view of the micro gyroscope is shown in Fig. 2. The device consists of three layers. Central silicon is forming a rotor and a frame. Top glass and bottom glass plates have common electrodes, control electrodes and rotational electrodes. These electrodes are used for capacitive detection of rotor position and for electrostatic actuation. The diameter of the rotor is 5 mm and the thickness about 200 μm

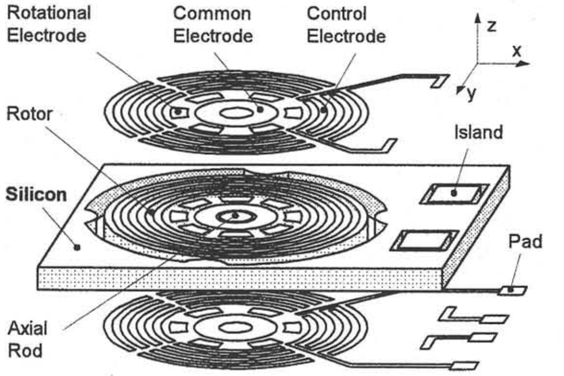

Fig.2 Schematic view of the gyroscope

Control electrodes in quadrant configuration are arranged symmetrically as shown in Fig. 2. These electrodes on glass plates constitute concentric array electrodes and form capacitors with teeth and notches on both sides of the silicon rotor. The symmetrical design of the device allows the measurements of differential capacitance in three axes (x, y, z) and two rotational axes (ϕ, θ).

Levitation Principle

Figure 3 shows the block diagram of the levitation system for z-axis. It is designed for sensing differential capacitance using frequency multiplex method to monitor the position of the rotor in all axes [1,2,4].

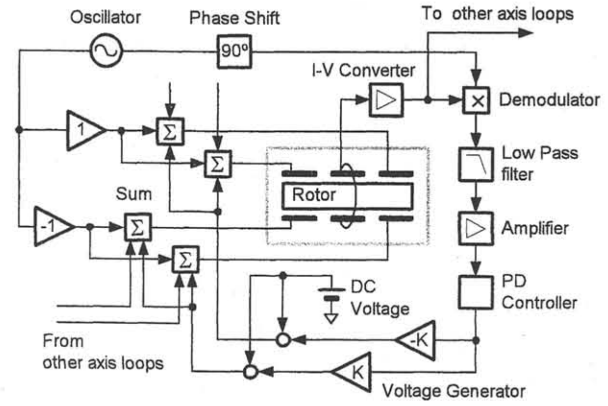

Fig. 3 Diagram of the levitation system for z-axis

Rotation Principle

The rotation of the micro gyroscope is operated with a principle based on a planer variable capacitance motor [5]. The silicon rotor rotates in 3-phase with 12-pole stator (rotational electrodes, shown in Fig. 2) and 16-pole rotor. The rotation system of the micro gyroscope is shown in Fig. 4. The rotor angle is detected by differential capacitance between two stator (A, B) and the rotor. The capacitance changes periodically as the rotor rotates and the frequency of the cycle indicates the rotational speed of the micro gyroscope. The rotational speed is compared with a reference speed. Feedback voltages are synchronized with the rotor position and generate torques to maintain the rotational speed.

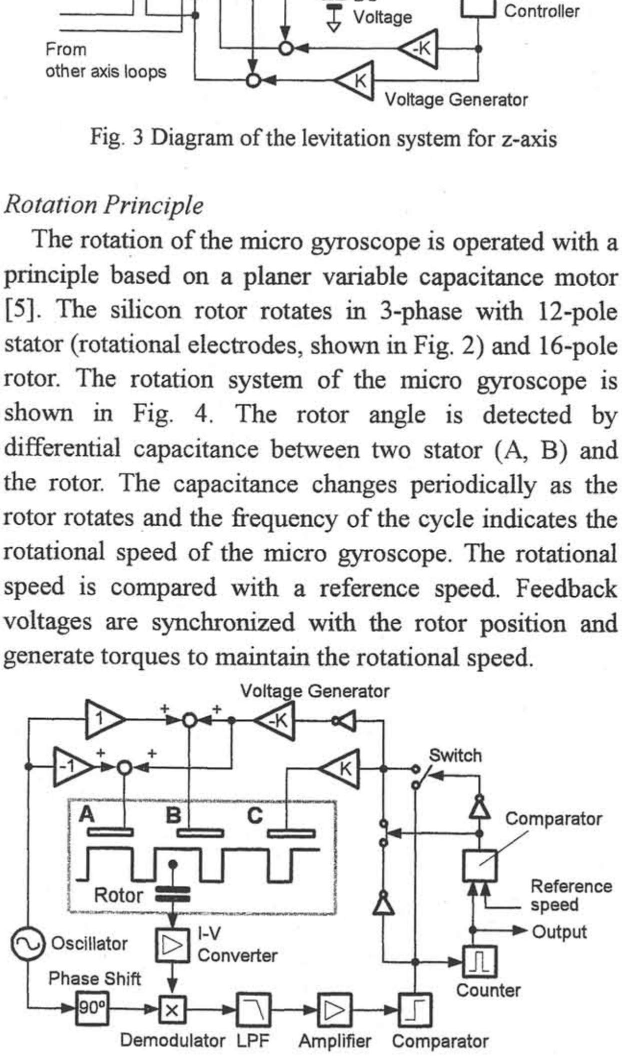

Fig.4 Diagram of the rotation system

3. Experimental Results

The performance of the micro gyroscope has been tested using a rollover setup with two reference accelerometers and a reference vibratory gyroscope. The micro gyroscope was characterized in a vacuum chamber. The rotational speed of the gyroscope was maintained to 5000 rpm by the rotational control. An example of the measurement results obtained is shown in Figure 5. As can be seen, the micro gyroscope showed almost identical measurements with those of reference sensors. The sensitivity of the feedback voltage with ±30 V DC supply was 13 V/G to the axial acceleration, 62 V/G to the radial acceleration and 8.7 mV/deg/sec to angular velocity respectively.

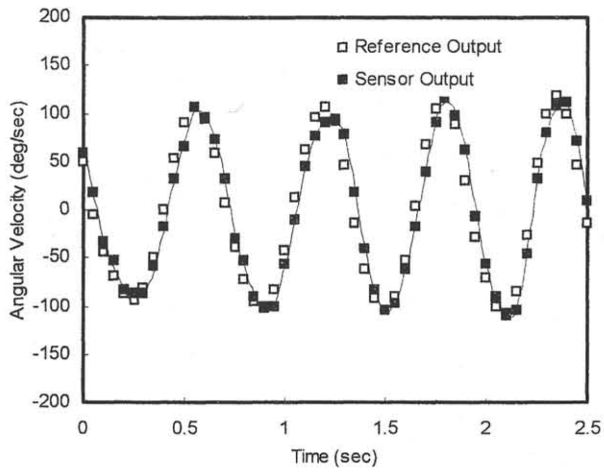

Fig. 5 The measured gyroscope response

4. Conclusion

An electrostatically levitated rotational gyroscope was successfully fabricated and characterized. The closed-loop operation of the rotation was demonstrated. Characteristics of tri-axis accelerometer and dual-axis angular rate sensor have been obtained, which means a five-degree of freedom inertia sensor could be realized.

Acknowledgements

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