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EE C245 - ME C218 Introduction to MEMS Design Fall 2010

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Lecture Module 15: Gyros, Noise, & MDS

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Lecture Outline

- Reading: Senturia, Chpt. 14, Chpt. 16, Chpt. 21
- Lecture Topics:
 - ↳ Gyroscopes
 - ↳ Gyro Circuit Modeling
 - ↳ Minimum Detectable Signal (MDS)
 - Noise
 - Angle Random Walk (ARW)

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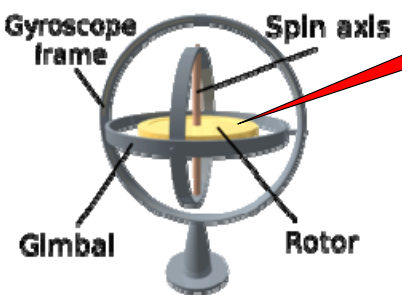
Gyroscopes

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Classic Spinning Gyroscope

- A gyroscope measures rotation rate, which then gives orientation → very important, of course, for navigation
- Principle of operation based on conservation of momentum
- Example: classic spinning gyroscope



Rotor will preserve its angular momentum (i.e., will maintain its axis of spin) despite rotation of its gimbled chassis



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Vibratory Gyroscopes

- Generate momentum by vibrating structures
- Again, conservation of momentum leads to mechanisms for measuring rotation rate and orientation
- **Example:** vibrating mass in a rotating frame

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Basic Vibratory Gyroscope Operation

Principle of Operation

- Tuning Fork Gyroscope:

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Basic Vibratory Gyroscope Operation

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Vibratory Gyroscope Performance

Principle of Operation

- Tuning Fork Gyroscope:

$$\bar{x} = \frac{\bar{F}_c}{k} = \frac{m\bar{a}_c}{k} = \frac{\bar{a}_c}{\omega_r^2} \quad \bar{a}_c = 2\bar{v} \times \bar{\Omega}$$

Beam Mass Beam Stiffness Sense Frequency Driven Velocity

- To maximize the output signal x , need:
 - ↳ Large sense-axis mass
 - ↳ Small sense-axis stiffness (Above together mean low resonance frequency)
 - ↳ Large drive amplitude for large driven velocity (so use comb-drive)
 - ↳ If can match drive freq. to sense freq., then can amplify output by Q times $\rightarrow x \propto \frac{Q\bar{v}_c}{k_r}$

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MEMS-Based Gyroscopes

Tuning Fork Gyroscope [Ayazi, GA Tech.]

Vibrating Ring Gyroscope [Michigan]

Nuclear Magnetic Resonance Gyro [NIST]

Labels in diagrams: Central Post, Proof Mass, Laser, Polarizer, Rb/Xe Cell, Photodiode, 3.2 mm, 1 mm, $\dot{\theta}$.

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MEMS-Based Tuning Fork Gyroscope

Labels: Sense Electrodes, Drive Electrode, Tuning Electrodes, Proof Mass, Anchors, Quadrature Cancellation Electrodes, Sense Electrodes.

Drive Mode

Sense Mode

- In-plane drive and sense modes pick up z-axis rotations
- Mode-matching for maximum output sensitivity
- From [Zaman, Ayazi, et al, MEMS'06]

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MEMS-Based Tuning Fork Gyroscope

Labels: Drive Voltage Signal, Drive Electrode, Drive, Sense Electrodes, Sense, Tuning Electrodes, (-) Sense Output Current, (+) Sense Output Current, Drive Oscillation Sustaining Amplifier, Digital PLL, VCD, VOA, Differential TransR Sense Amplifier, Instr. Amp, Demodulator, EPF, Rate Out.

[Zaman, Ayazi, et al, MEMS'06]

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MEMS-Based Tuning Fork Gyroscope

Labels: Sense Electrodes, Drive Electrode, Tuning Electrodes, Proof Mass, Anchors, Quadrature Cancellation Electrodes, Sense Electrodes.

Problem: if drive frequency changes relative to sense frequency, output changes \Rightarrow bias drift

Need: small or matched drive and sense axis temperature coefficients to suppress drift

Graph: Amplitude vs ω . Shows Drive Response and Sense Response curves. Resonance frequencies $f_0(@T_1)$ and $f_0(@T_2)$ are shown. Temperature points T_1 and T_2 are indicated.

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Mode Matching for Higher Resolution

- For higher resolution, can try to match drive and sense axis resonance frequencies and benefit from Q amplification

Problem: mismatch between drive and sense frequencies \Rightarrow even larger drift!

Need: small or matched drive and sense axis temperature coefficients to make this work

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Issue: Zero Rate Bias Error

- Imbalances in the system can lead to zero rate bias error

Mass imbalance \Rightarrow off-axis motion of the proof mass

Drive imbalance \Rightarrow off-axis motion of the proof mass

Output signal in phase with the Coriolis acceleration

Quadrature output signal that can be confused with the Coriolis acceleration

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Nuclear Magnetic Res. Gyroscope

- The ultimate in miniaturized spinning gyroscopes?
- from CSAC, we may now have the technology to do this

Better if this is a noble gas nucleus (rather than e-), since nuclei are heavier \Rightarrow less susceptible to B field

Soln: Spin polarize Xe¹²⁹ nuclei by first polarizing e- of Rb⁸⁷ (a la CSAC), then allowing spin exchange

Challenge: suppressing the effects of B field

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MEMS-Based Tuning Fork Gyroscope

Drive Oscillation Sustaining Amplifier

Differential TransR Sense Amplifier

[Zaman, Ayazi, et al, MEMS'06]

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