

Classic Spinning Gyroscope

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- 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 gimballed chassis

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Vibratory Gyroscopes

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- 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

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Principle of Operation

- Tuning Fork Gyroscope:

Side View: *force cancel*

Top View: *radiated anchor loss very small if motion cancel here*, *Compound measure rotation*

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Basic Vibratory Gyroscope Operation

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Principle of Operation

- Tuning Fork Gyroscope:

Drive/Sense Response Spectra:

Amplitude vs ω

Drive (y -direction)

Sense Response (x -direction)

f_0 ($@ T_r$)

Coriolis Acceleration $\vec{a}_c = 2\vec{v} \times \vec{\Omega}$

Driven Velocity

Rotation Rate

Coriolis Force

Beam Mass

Coriolis Displacement $\vec{x} = \frac{\vec{F}_c}{k} = \frac{m\vec{a}_c}{k} = \frac{\vec{a}_c}{\omega_r^2}$

Beam Stiffness

Sense Frequency

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Vibratory Gyroscope Performance

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Principle of Operation

• Tuning Fork Gyroscope:

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

Beam Mass Beam Stiffness Sense Frequency Driven Velocity

Input Rotation $\vec{\Omega}$ Driven Vibration @ f_o \vec{v}

Coriolis (Sense) Response \vec{a}_c

Coriolis Torque

• 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 $\rightarrow \vec{x} = \frac{Q\vec{F}_c}{k}$

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MEMS-Based Gyroscopes

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Tuning Fork Gyroscope [Ayazi, GA Tech.]

Vibrating Ring Gyroscope [Najafi, Michigan]

Laser Polarizer Rb/Xe Cell Photodiode

3.2 mm 1 mm 1 mm

Nuclear Magnetic Resonance Gyro [NIST]

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MEMS-Based Tuning Fork Gyroscope

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Sense Electrodes Drive Electrode Tuning Electrodes Proof Mass Anchors Quadrature Cancellation 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

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Sense Electrodes Drive Electrode Tuning Electrodes Drive Voltage Signal

(-) Sense Output Current (+) Sense Output Current

Drive Oscillation Sustaining Amplifier

Differential Sense Amplifier

From Sense Instr. Amp Demodulator LPF Rate Out

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

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MEMS-Based Tuning Fork Gyroscope

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- Drive and sense axes must be stable or at least track one another to avoid output drift

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

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Mode Matching for Higher Resolution

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- 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

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- 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

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- The ultimate in miniaturized spinning gyroscopes?
- \Leftarrow 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 Xe^{129} nuclei by first polarizing e- of Rb^{87} (a la CSAC), then allowing spin exchange

Challenge: suppressing the effects of B field

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