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

\[ C(t_2) > C(t_1) \]

Basic Vibratory Gyroscope Operation

Principle of Operation
- Tuning Fork Gyroscope:

\[ \dot{\vec{a}}_s \]

Drive/Sense Response Spectra:

\[ f_0(\omega) \]

Vibratory Gyroscope Performance

Principle of Operation
- Tuning Fork Gyroscope:

\[ \dot{x} = \frac{p_x}{k} = \frac{m\dot{a}_s}{k} = \frac{\ddot{a}_c}{\omega^2} \]

\[ \dot{\vec{a}}_c = 2\dot{\vec{v}} \times \vec{\Omega} \]

- 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
MEMS-Based Gyroscopes

Vibrating Ring Gyroscope

- Laser
- Polarizer
- Rb/Xe Cell
- Photodiode

Tuning Fork Gyroscope

- [Ayazi, GA Tech.]

Nuclear Magnetic Resonance Gyro [NIST]

MEMS-Based Tuning Fork Gyroscope

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

- Drive and sense axes must be stable or at least track one another to avoid output drift
- Need: small or matched drive and sense axis temperature coefficients to suppress drift

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

Need: small or matched drive and sense axis temperature coefficients to suppress drift
**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 ⇒ even larger drift!

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

**Sense Electrodes**

**Drive Electrode**

**Tuning Electrodes**

**Quadrature Cancellation Electrodes**

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**Issue: Zero Rate Bias Error**

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

**Mass imbalance** ⇒ off-axis motion of the proof mass

**Output signal in phase with the Coriolis acceleration**

**Quadrate output signal that can be confused with the Coriolis acceleration**

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**Nuclear Magnetic Res. Gyroscope**

- The ultimate in miniaturized spinning gyroscopes?

  - Better if this is a noble gas nucleus (rather than e-), since nuclei are heavier ⇒ 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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**MEMS-Based Tuning Fork Gyroscope**

**Drive Voltage Signal**

**(-) Sense Output Current**

**(+1 Sense Output Current**

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

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*EE 245: Introduction to MEMS*

*Lecture 26m1: Gyros, Noise & MDS*

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