

Basic Vibratory Gyroscope Operation

Principle of Operation

- Tuning Fork Gyroscope:

Drive/Sense Response Spectra:

$\vec{a}_c = 2\vec{v} \times \vec{\Omega}$ (where $\omega \times \epsilon$ depends on amplitude!)
 $\vec{F}_c = \frac{m\vec{a}_c}{k} = \frac{\vec{a}_c}{\omega_r^2}$

Labels in diagram: Input Rotation, Driven Vibration @ f_0 , Amplitude, Drive Response, Sense Response, f_0 (@ T_1), ω , Coriolis (Sense) Response, \vec{a}_c , Driven Velocity, Rotation Rate, Coriolis Acceleration, $\vec{a}_c = 2\vec{v} \times \vec{\Omega}$, Coriolis Force, $\vec{F}_c = \frac{m\vec{a}_c}{k} = \frac{\vec{a}_c}{\omega_r^2}$, Coriolis Displacement, Beam Stiffness, Beam Mass, Sense Frequency, Coriolis Torque.

EE C245: Introduction to MEMS Design LecM 15 C. Nguyen 11/18/08 7

Vibratory Gyroscope Performance

Principle of Operation

- Tuning Fork Gyroscope:

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

Labels in diagram: Input Rotation, Driven Vibration @ f_0 , Amplitude, Drive Response, Sense Response, f_0 (@ T_1), ω , Coriolis (Sense) Response, \vec{a}_c , Driven Velocity, Rotation Rate, Coriolis Acceleration, $\vec{a}_c = 2\vec{v} \times \vec{\Omega}$, Coriolis Force, $\vec{F}_c = \frac{m\vec{a}_c}{k} = \frac{\vec{a}_c}{\omega_r^2}$, Coriolis Displacement, Beam Stiffness, Beam Mass, Sense Frequency, 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

EE C245: Introduction to MEMS Design LecM 15 C. Nguyen 11/18/08 8

MEMS-Based Gyroscopes

Tuning Fork Gyroscope [Ayazi, GA Tech.]
Vibrating Ring Gyroscope [Michigan]
Nuclear Magnetic Resonance Gyro [NIST] (3.2 mm, 1 mm)

EE C245: Introduction to MEMS Design LecM 15 C. Nguyen 11/18/08 9

MEMS-Based Tuning Fork Gyroscope

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]

EE C245: Introduction to MEMS Design LecM 15 C. Nguyen 11/18/08 10

MEMS-Based Tuning Fork Gyroscope

Drive Voltage Signal

Drive Oscillation Sustaining Amplifier

Differential Transresistance Sense Amplifier

sense amplifiers

GHFB & surface oscillation

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

EE C245: Introduction to MEMS Design LecM 15 C. Nguyen 11/18/08 11

MEMS-Based Tuning Fork Gyroscope

- 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 => bias drift

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

EE C245: Introduction to MEMS Design LecM 15 C. Nguyen 11/18/08 12

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

EE C245: Introduction to MEMS Design LecM 15 C. Nguyen 11/18/08 13

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

Drive imbalance => 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

EE C245: Introduction to MEMS Design LecM 15 C. Nguyen 11/18/08 14

Nuclear Magnetic Res. Gyroscope

UC Berkeley

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

Atoms
Aligned
Nuclear Spins

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

3.2 mm
1 mm
 $\dot{\theta}$

Challenge: suppressing the effects of B field

EE C245: Introduction to MEMS Design LecM 15 C. Nguyen 11/18/08 15

MEMS-Based Tuning Fork Gyroscope

UC Berkeley

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

EE C245: Introduction to MEMS Design LecM 15 C. Nguyen 11/18/08 16