Simulations of Microgyroscope Dynamics

Oscar Vargas

Major: Mechanical Engineering

Mentor: Laura Oropeza-Ramos

Advisor: Kimberly L. Turner

July 28, 2005

➢ Goals of the research

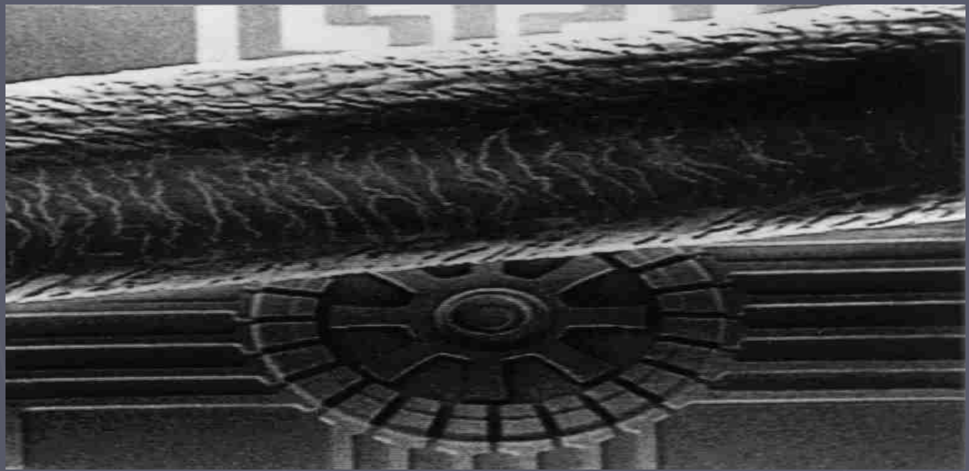
- Analyze non-linear micro-gyroscope dynamics through numerical simulations in MATLAB

➢ Activities

- Understand MEMS principles
  - ✓ Reading from books, papers and discussions
- Understand Linear and Nonlinear Micro-gyroscopes
  - ✓ Dynamics of gyroscopes - Coriolis effect
  - ✓ Study principles of vibration (parametric oscillation)
- Use MATLAB
  - ✓ Create numerical simulations for different parameters values, mostly stiffness and mass

What is MEMS?

Micro Electro-Mechanical Systems



http://www-bsac.eecs.berkeley.edu/archive/users/hui-elliot/mems.html

Benefits of MEMS?

- Low cost
  - Batch fabrication
  - Less material
- Smaller – Less Energy
  - Less energy
  - Miniaturization

What is a gyroscope?

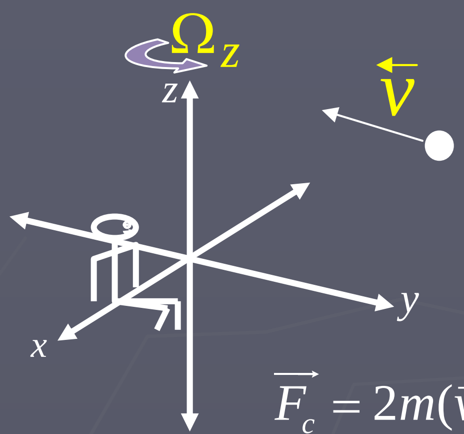
- Macro-gyroscope
- Micro-gyroscope

Applications

- Ships
- Planes
- Cars
- Toys

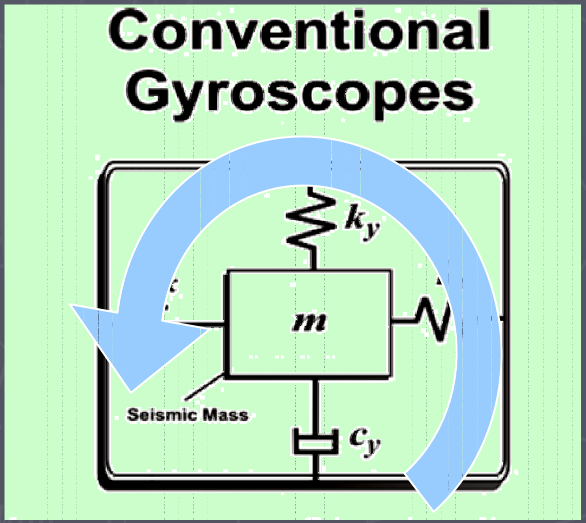
http://www.bridgedeck.org

Coriolis effect



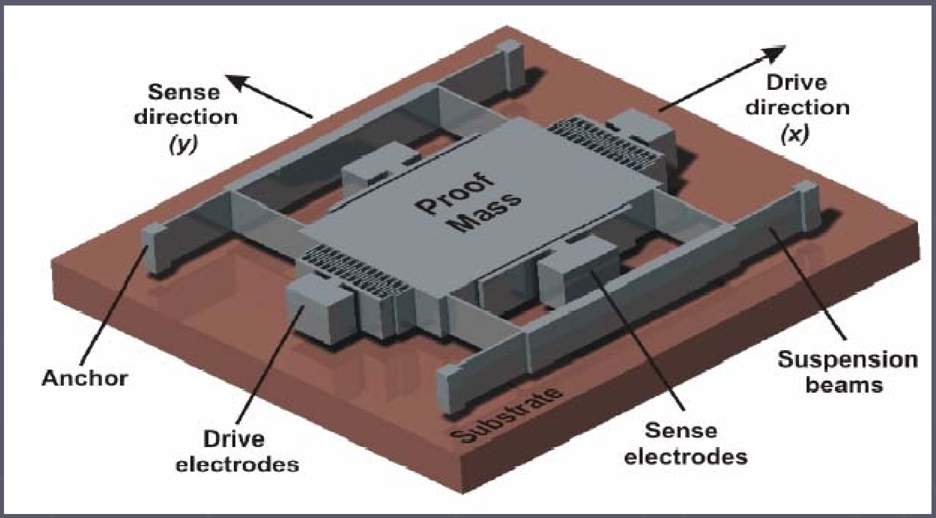
$$\vec{F}_c = 2m(\vec{v} \times \vec{\Omega})$$

- A person looking at a ball traveling parallel to the y axis as he rotates



Robust Micromachined Vibratory Gyroscopes by Cenk Acar

Drawing of a micro-gyroscope



Robust Micromachined Vibratory Gyroscopes by Cenk Acar

Dynamics

$$m\frac{d^2x}{dt^2} + c_x\frac{dx}{dt} + k_x x = F_e + 2m\Omega_z\frac{dy}{dt}$$

$$m\frac{d^2y}{dt^2} + c_y\frac{dy}{dt} + k_y y = -2m\Omega_z\frac{dx}{dt}$$

m = mass

c = damping

F= external force

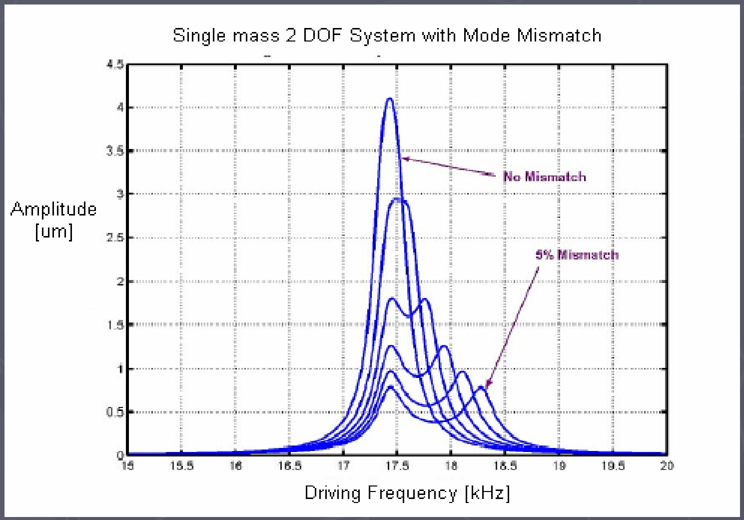
Ω = angular velocity

k = linear spring coefficient

Using Parametric Resonance to Increase Sensitivity

- Interdigitated comb-fingers

Harmonic oscillation

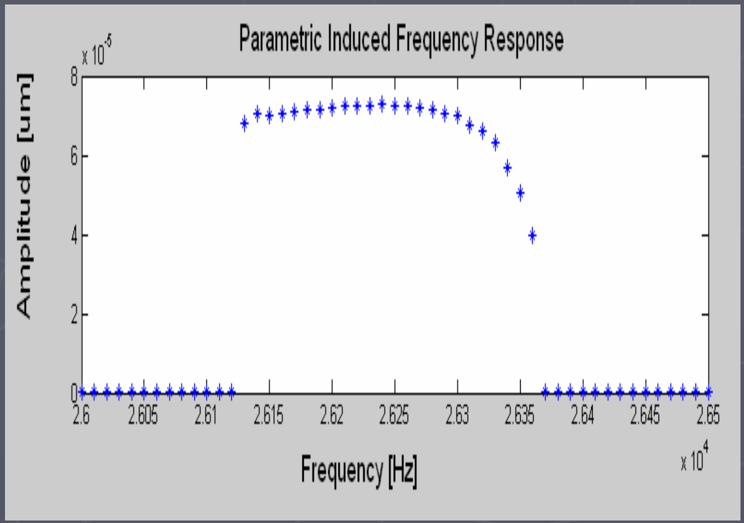


Robust Micromachined Vibratory Gyroscopes by Cenk Acar

Induced frequency response in a harmonic gyroscopes

- Non-interdigitated comb-fingers

Parametric oscillation

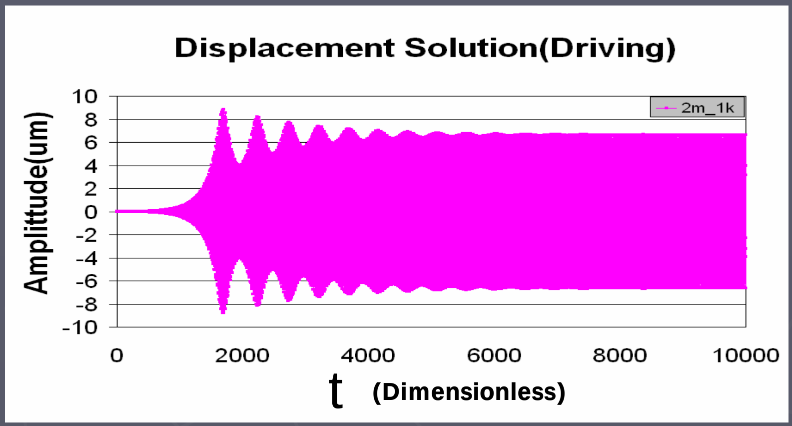


Induced frequency response in a parametric gyroscopes

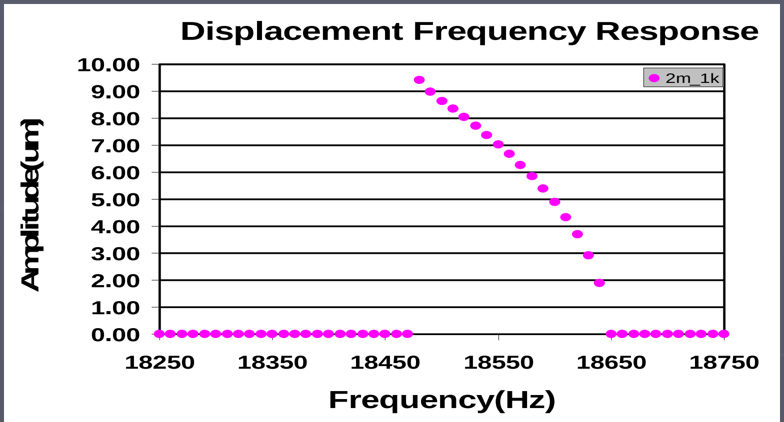
- Parametric resonance has a high amplitude for longer bandwidth

- Parametric resonance is less sensitive to changes in parameters thus gyro more robust

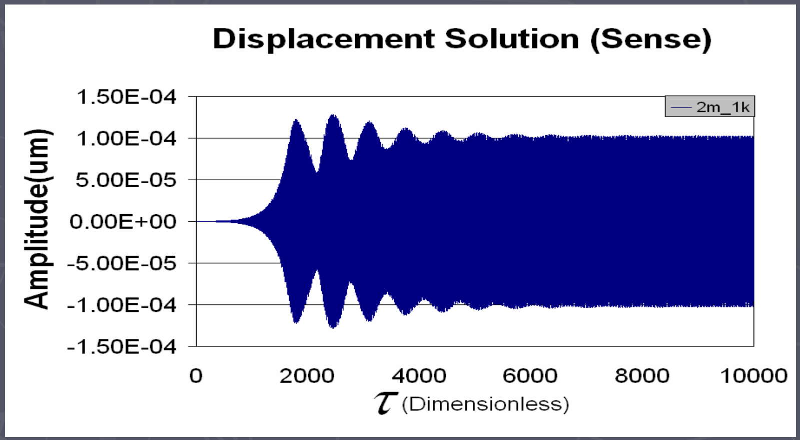
Results of numerical simulations



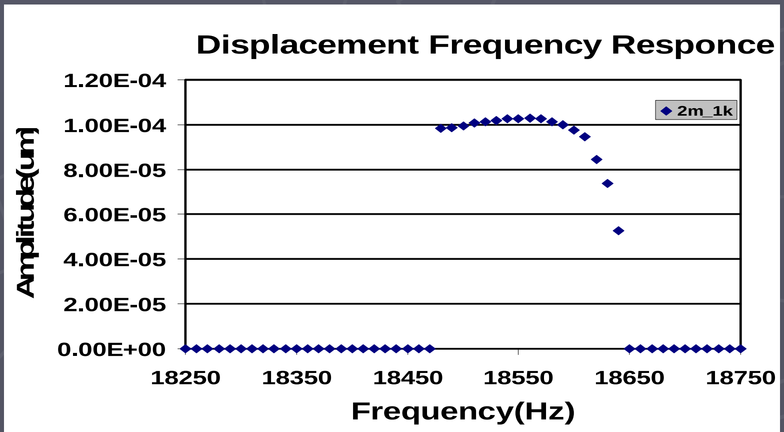
- Amplitude in the x axis, actuated direction



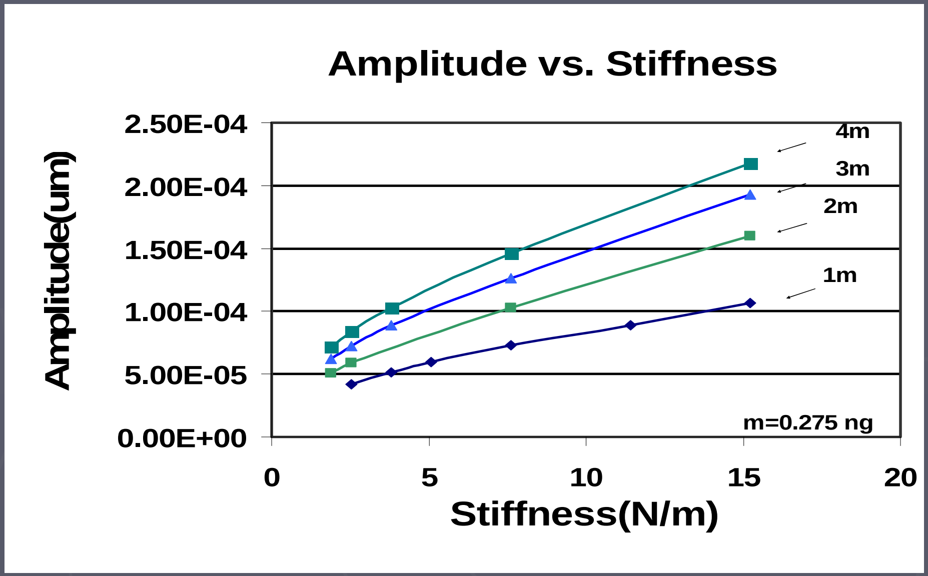
- Response in the x direction, driving direction



- Amplitude in the y axis, induced direction



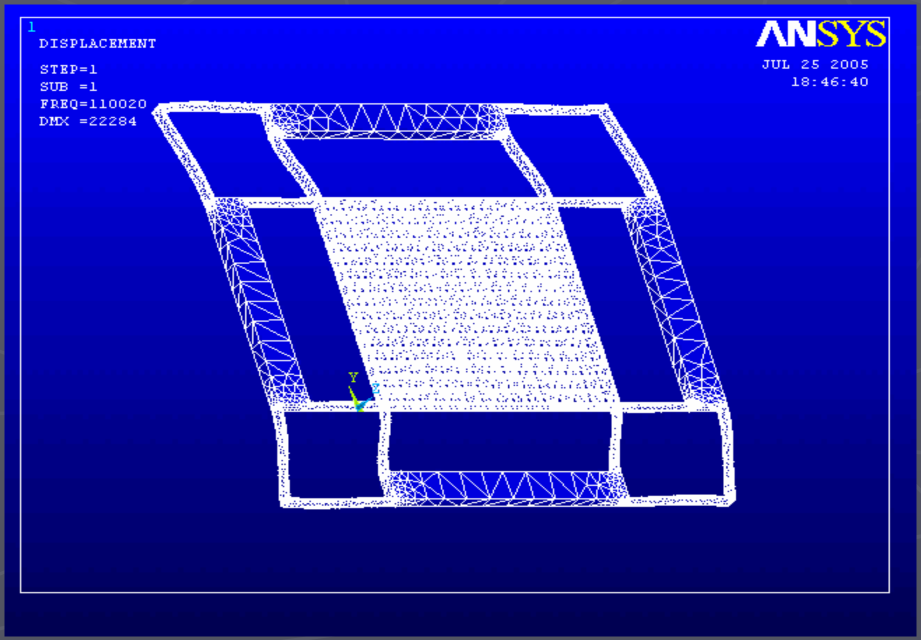
- Response in the y direction, sensing direction



➢Maximum amplitude vs. stiffness for different masses

Future Work

➢Structure of a micro-gyroscope



Thank you

Trevor Hirst

Liu-Yen Kramer

Nick Arnold

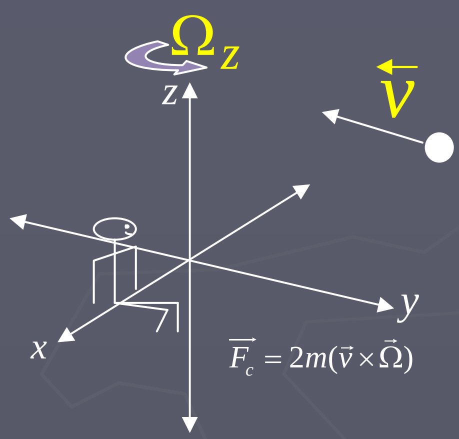
Michael Northen

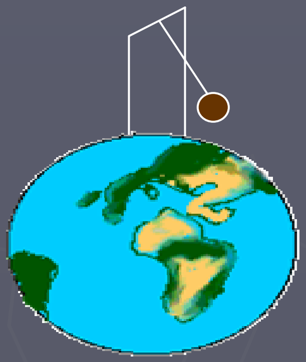
Laura Oropeza-Ramos

Kimberly L. Turner

Turner group

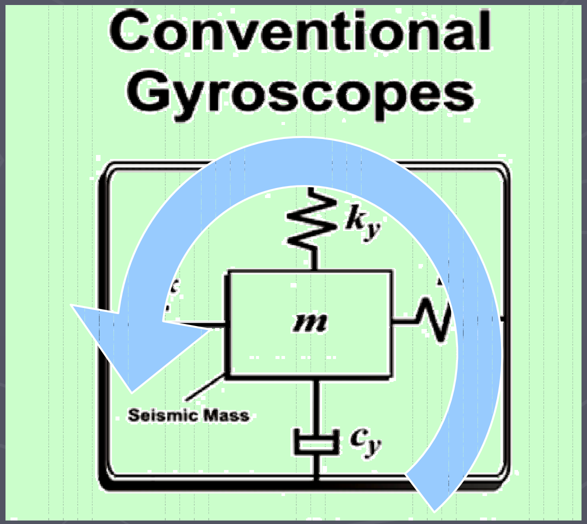
Coriolis





http://www.uvi.edu/SandM/Physics/dave/DavesArchives/111003/Phys211NetPlay.html

- A person looking at a ball traveling parallel to the y axis as he rotates
- Foucault Pendulum swinging on the north pole



Robust Micromachined Vibratory Gyroscopes by Cenk Acar

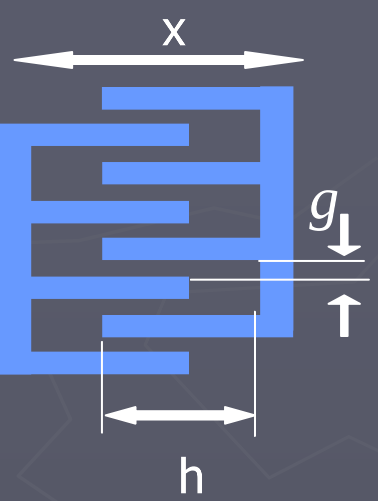
Scaling

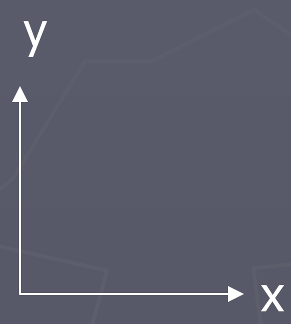
- Time: 1^0
- van der Waals: $1^{1/4}$
- Diffusion: $1^{1/2}$
- Distance: 1
- Velocity:1
- Surface tension: 1
- Electrostatic force: 1^2
- Muscle force: 1^2
- Friction: 1^2

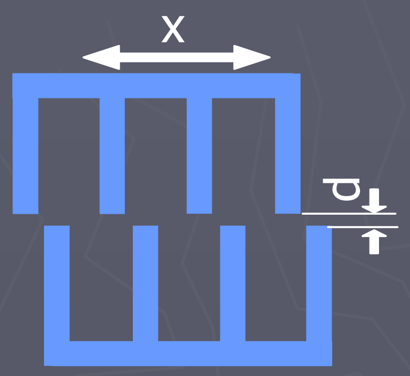
- Friction: 1^2
- Thermal losses: 1^2
- Piezo-electricity: 1^2
- Mass: 1^3
- Gravity: 1^3
- Magnetics: 1^3
- Torque: 1^3
- Power: 1^3

Two Type of Actuators

- Interdigitated comb-fingers
- Non-interdigitated comb-fingers







$$F_e = \frac{N\varepsilon h V^2}{g}$$

$$F_e = -(r_1 x + r_3 x^3)V^2$$

$$m\frac{d^2x}{dt^2} + c_x\frac{dx}{dt} + k_x x = F_e + 2m\Omega_z\frac{dy}{dt}$$

$$m\frac{d^2y}{dt^2} + c_y\frac{dy}{dt} + k_y y = -2m\Omega_z\frac{dx}{dt}$$