MSA PROJECT REPORT

Piezoelectric Rate Gyroscope

Group-12

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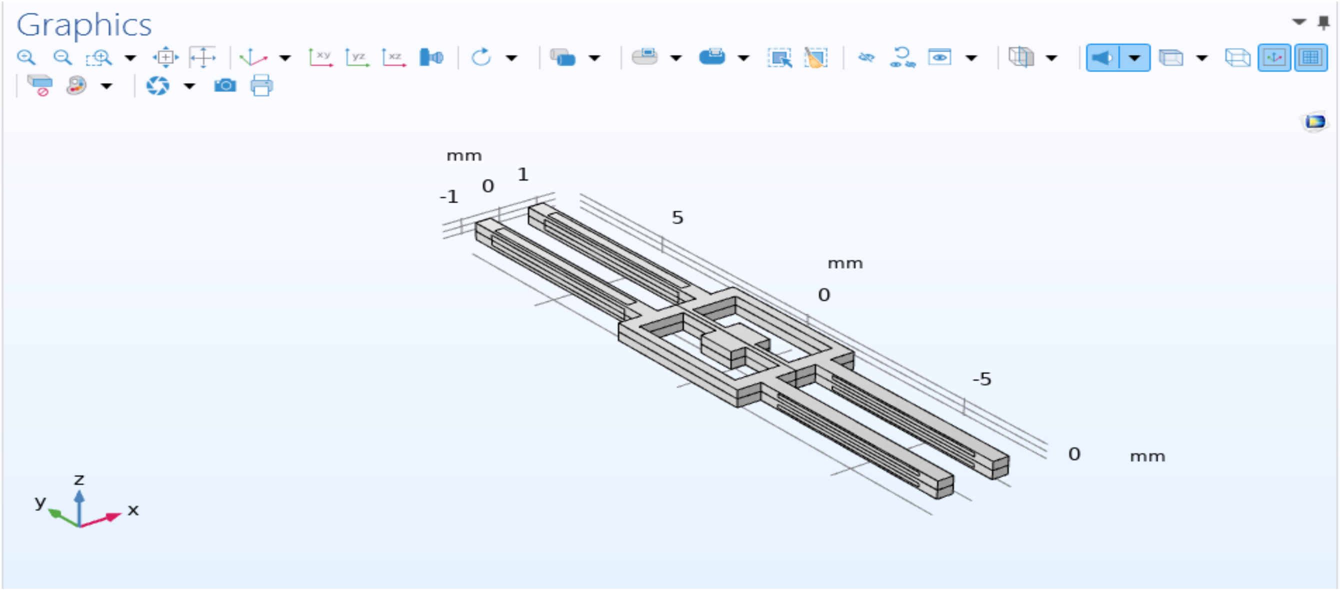
Introduction

Gyroscope is a device that can measure and maintain the orientation of angular velocity of an object. These are more advanced than accelerometer. These can measure the tilt and lateral orientation of the object whereas an accelerometer can only measure the linear motion.



Literature Review

[1].Gyroscope is an instrument used to measure angular velocity and importantly for navigation. Driving mode and sensing mode are the two modes in gyroscopes and Rotary, Vibrating structure and Optical gyroscopes are three basic types of gyroscopes.

[2].The concept of Coriolis force is used in gyroscope sensor. In this sensor to measure the angular rate, the rotation rate of the sensor is converted into a electrical signal.

$$\mathbf{F_{cor}} = \boldsymbol{-2\rho}\Omega\left(\boldsymbol{\frac{du}{dt}}\right)$$

- F_{cor} = Coriolis Force
- Ω = Angular Velocity
- P = Momentum or Density
- (du/dt) = Change in Velocity

[3].When a Piezoelectric gyroscope is excited into vibration in one of the two modes by an applied alternating voltage and attached to a rotating body, Coriolis Force will excite the other mode through which the rotation rate of the body can be detected.

[4].The geometry of tuning forks is designed so that the eigen frequencies of the nearby modes are separated in frequency space. The frequency response of the signal is computed and the rotation rate sensitivity is evaluated.

[5].As for the solid-rate gyroscope we used, the piezoelectric material serves as the excitation source and sensing element simultaneously, so the piezoelectric material should have larger piezoelectric constant and electromechanical coupling constants.

Objective

- Designing a piezoelectric rate gyroscope structure.
- Simulate the design using COMSOL software.
- Compute angular velocity and plot graphs of sense voltage vs angular velocity and sense voltage vs frequency.
- Compare results of two materials Quartz and PZT-5A.

Methodology

- The methodology for simulating a Piezoelectric Rate Gyroscope using COMSOL Multiphysics software has several steps following:
    1. Geometric creation
    2. Material properties
    3. Electrode modelling
    4. Boundary conditions
    5. Meshing
    6. Physics setting
    7. Simulation
    8. Sensitivity analysis
    9. Optimization
    10. Validation

Experimental details

- Mesh profile
  - Sequence type: User-controlled mesh
  - Element size: Finer
  - Element size parameters:
    - Maximum element size = tQz/4
    - Minimum element size – tQz/12
  - Mesh consists of 15630 domain elements, 5220 boundary elements, and 1139 edge elements.
- Material : Quartz LH (1978 IEEE) and PZT-5A

Experimental details

- Parameters

Parameters

Name	Expression	Value	Description
va	64[deg/s]	1.117 rad/s	Rotation angular velocity
tQz	0.5[mm]	5E-4 m	Quartz thickness
w_m	1[mm]	0.001 m	Mount width
l_w	(l_f-w_m)/2-w_tbf	0.0011 m	Wing length
w_w	0.25[mm]	2.5E-4 m	Wing width
l_f	4[mm]	0.004 m	Frame length
w_f	3[mm]	0.003 m	Frame width
w_tbf	0.4[mm]	4E-4 m	Frame top/bottom thickn
w_sf	0.25[mm]	2.5E-4 m	Frame side thickness
l_d	6[mm]	0.006 m	Drive tine length
w_d	0.4[mm]	4E-4 m	Drive tine width
l_s	5.5[mm]	0.0055 m	Sense tine length
w_s	0.4[mm]	4E-4 m	Sense tine width
gap	1[mm]	0.001 m	Gap between tines

Experimental details

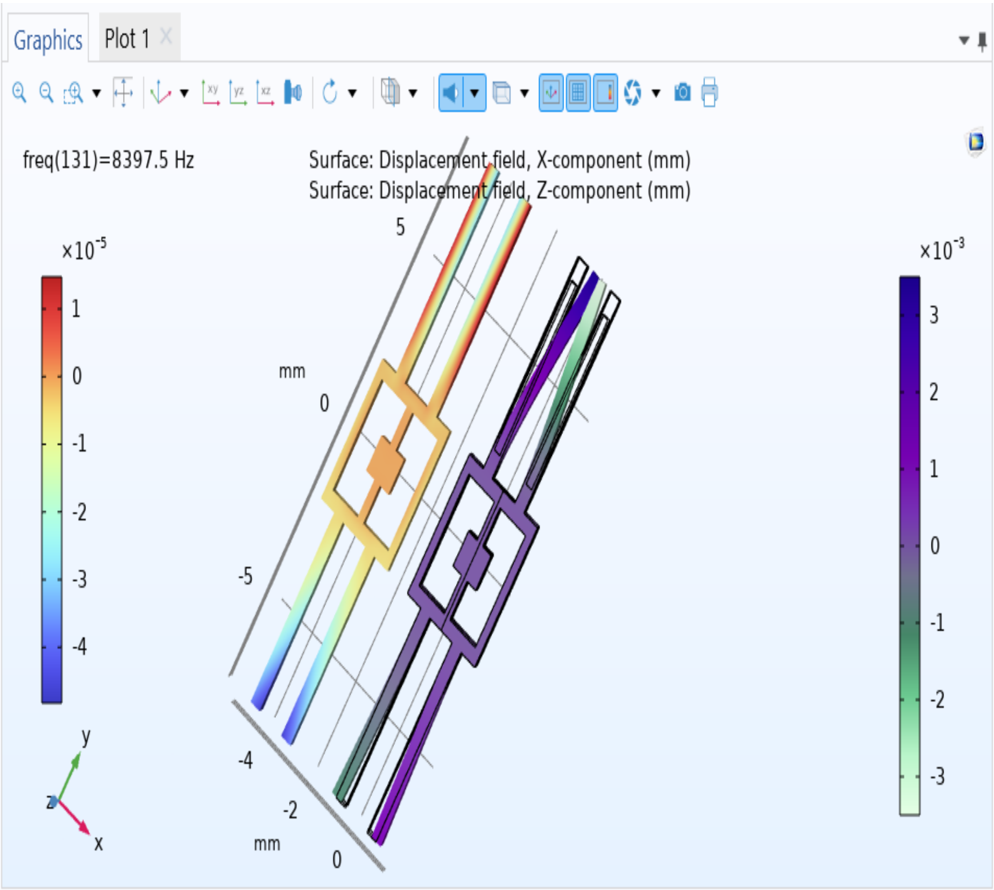
- Eigen Frequencies:

  These are also known as natural frequencies at which a system vibrates or oscillates when it is exited by an external force or disturbance and allowed to freely oscillate.

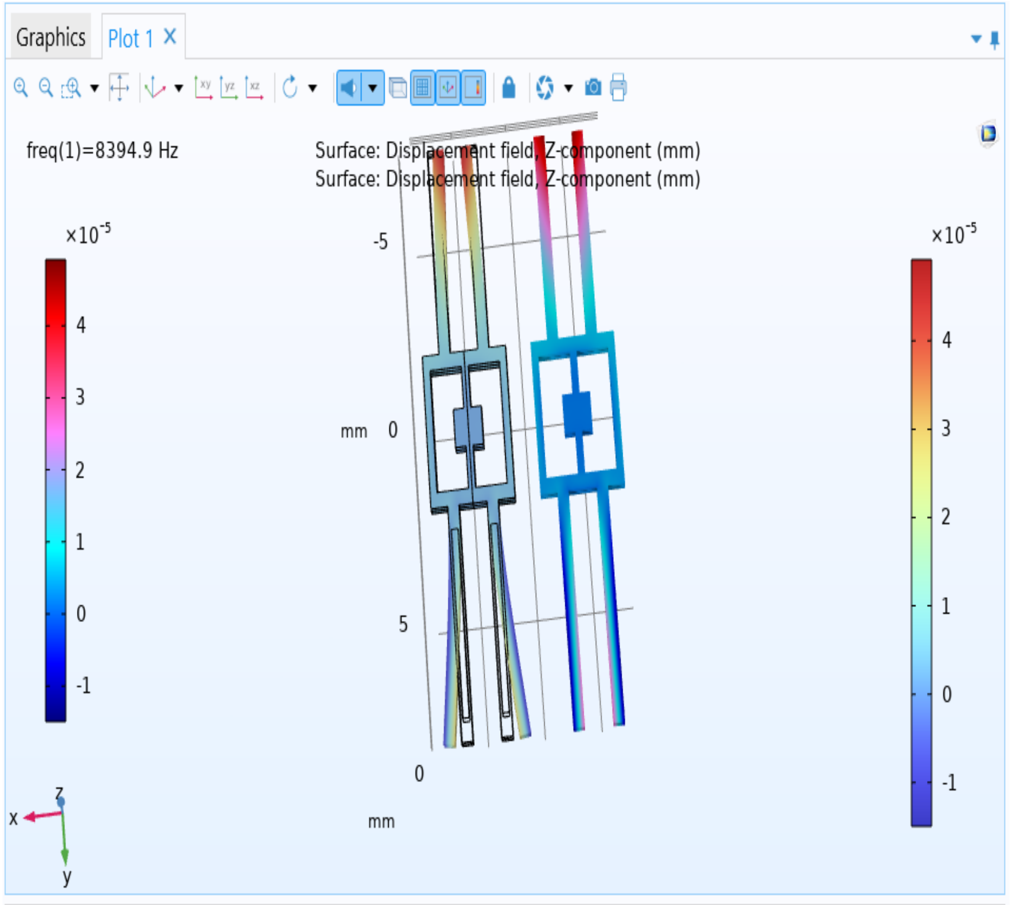
  These are the Eigenfrequencies we used for the study:

Eigenfrequency (Hz)	Angular frequency (rad/s)	Damping ratio (1)	Quality factor (1)
3910.5+0.096934i	24571+0.60905i	2.4788E-5	20171
6173.8+0.15362i	38791+0.96521i	2.4882E-5	20095
7472.7+0.18584i	46952+1.1677i	2.4869E-5	20105
8396.2+0.20848i	52755+1.3099i	2.4830E-5	20137
9225.9+0.22990i	57968+1.4445i	2.4919E-5	20065

Results



Graphics
Plot 1
freq(131)=8397.5 Hz
Surface: Displacement field, X-component (mm)
Surface: Displacement field, Z-component (mm)
×10⁻⁵
×10⁻³
mm



Graphics
Plot 1
freq(1)=8394.9 Hz
Surface: Displacement field, Z-component (mm)
Surface: Displacement field, Z-component (mm)
×10⁻⁵
×10⁻⁵
mm

Discussion

- To determine which is better, we performed simulations for both materials in a piezoelectric rate gyroscope. The selection depends on several characteristics like:

❖ Sensitivity

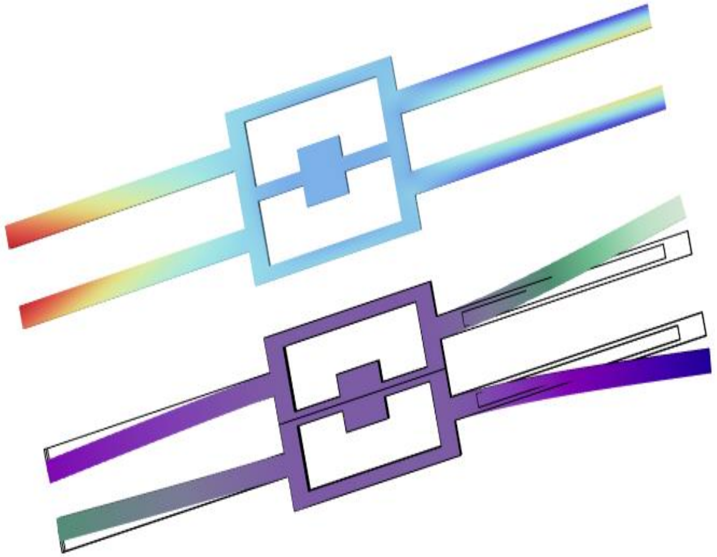
❖ Stability

❖ Frequency range

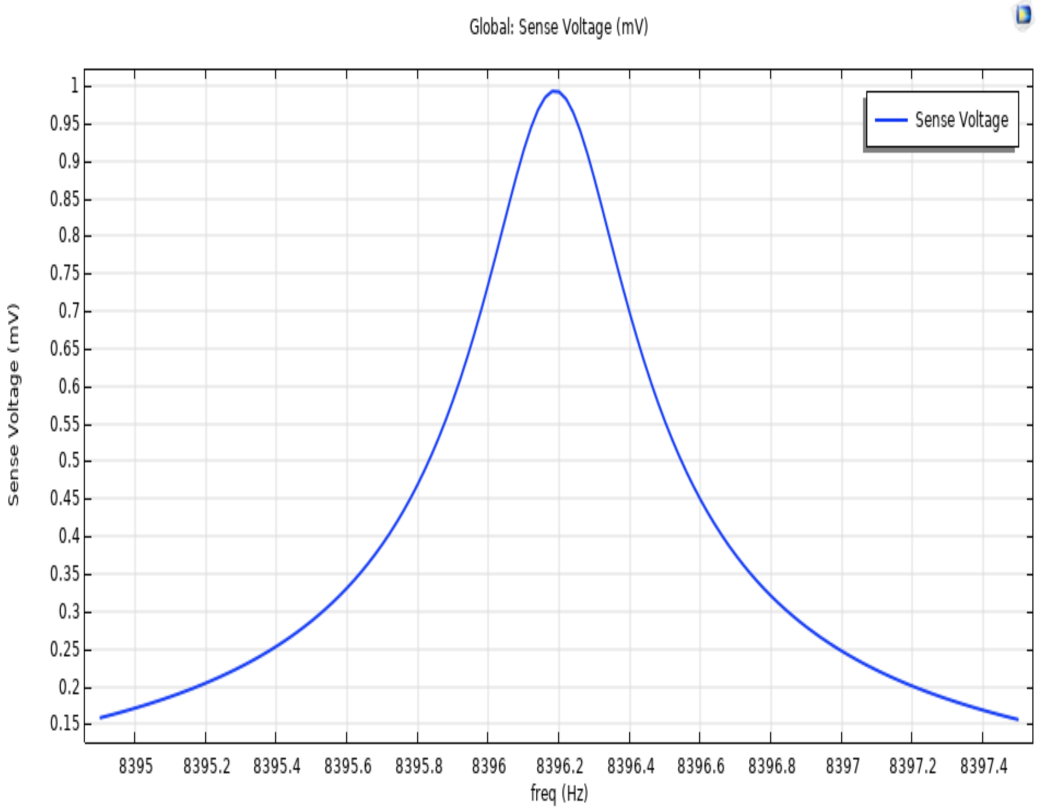
❖ Size and weight

❖ Cost

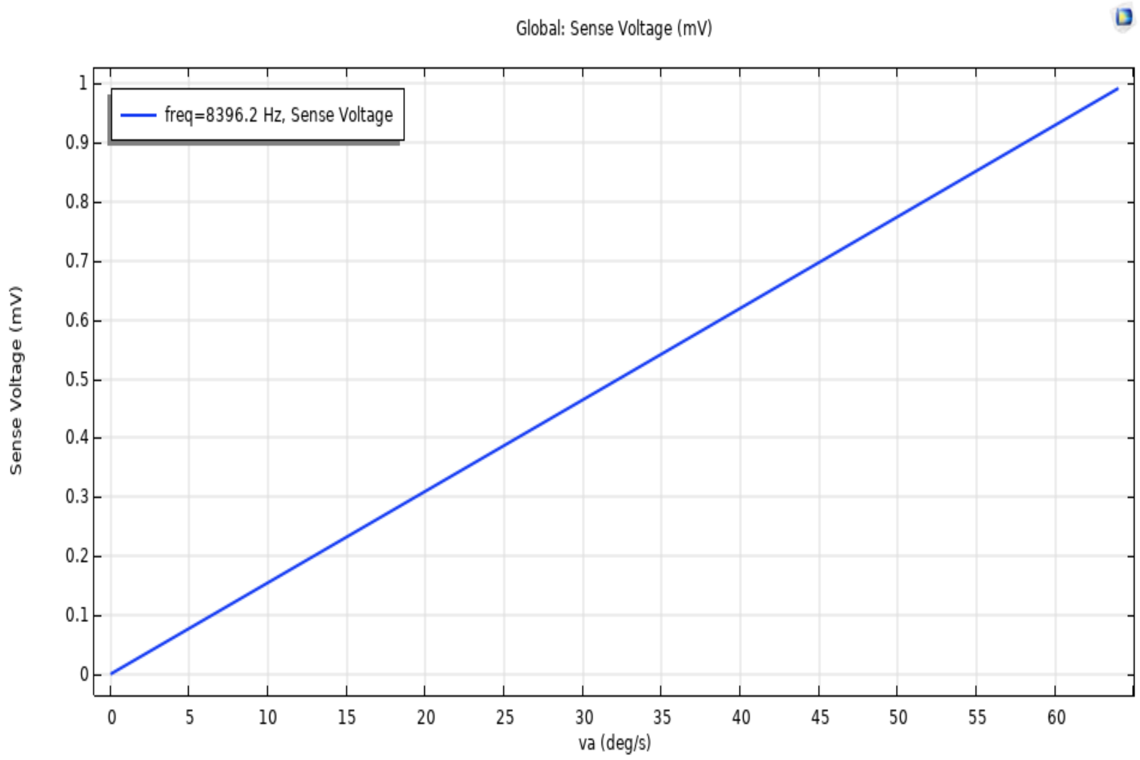
Results



Results



Global: Sense Voltage (mV)
Sense Voltage
Sense Voltage (mV)
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
8395
8395.2
8395.4
8395.6
8395.8
8396
8396.2
8396.4
8396.6
8396.8
8397
8397.2
8397.4
freq (Hz)



Global: Sense Voltage (mV)
freq=8396.2 Hz, Sense Voltage
Sense Voltage (mV)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35
40
45
50
55
60
va (deg/s)

Conclusions

This model shows how to analyze a tuning fork based piezoelectric rate gyroscope. The reverse piezoelectric effect is used to drive an in-plane tuning fork mode. This mode is coupled to an out of plane mode by the Coriolis force and the resulting out of plane motion is sensed by the direct piezoelectric effect. The geometry of the tuning forks is designed so that the eigen frequencies of the nearby modes are separated in frequency space. The frequency response of the system is computed and the rotation rate sensitivity is evaluated.

References

[1].Jacek Nazdrowicz ,Michal Szermer, Adam Stawinski,Andrzej Napieralski, "MEMS gyroscope FEM modelling and simulation",25th International Conference on mixed design of integrated circuits and systems.

[2].Lee,Sang Woo, et al. " a micro rate gyroscope based on the SAW gyroscopic effect." Journal of Micromechanics and Microengineering 17.11(2007); 2272.

[3]. Sato, Kenji, Atsushi Ono, and Yoshiro Tomikawa. "Experimental study of gyro sensor using double-ended tuning fork quartz resonator." Proceedings of the 2004 IEEE International Frequency Control Symposium and Exposition, 2004. IEEE, 2004.

[4].Hu, Xiaojun, et al,"Model design of piezoelectric micromachined modal gyroscope." Journal of sensors 2011 (2011).

[5].Vineela,V., Rao,B.R.,Nath, T.M. and Rao,K.S.,Design and simulation of MEMS piezoelectric gyroscope.

Contributions

- T.V.S.Kalyan: Simulation of Gyroscope with Quartz and PZT-5A.
- C.V.Bhanu Prakash: Verifying Gyroscope properties for different eigen frequencies.
- S.Sai Anirudh: Meshing and referring to base papers.

THANK YOU