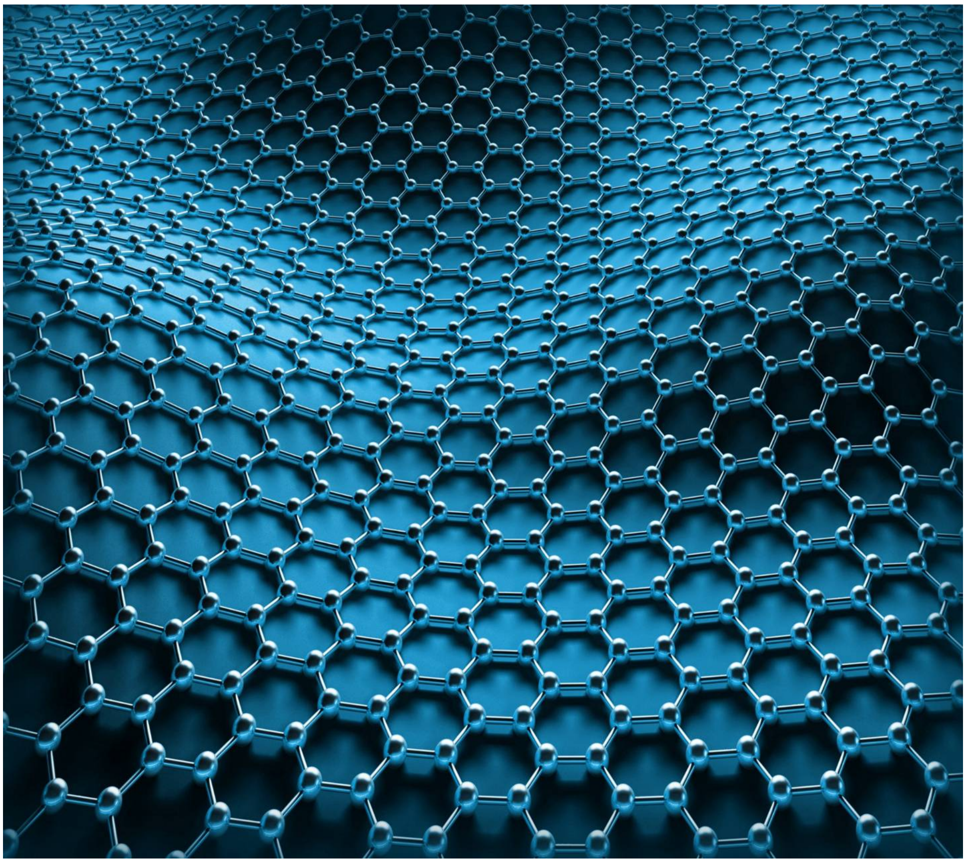
The University of Franche-Comté

Master CompuPhys - Introduction to COMSOL:

Microelectromechanical gyroscope



Chiari Even
Legrand Maxime
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Supervisor : Christophe RAMSEYER
Supervisor : Noah PERREAU

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1 Introduction

The main objective of this practical work is to get deeper into Comsol by studying a microelectromechanical gyroscope. Such a system has been chosen because it illustrates interesting properties regarding the behavior of the angular momentum and its links with the linear momentum.

Question 1:

From what we understood, we inject electricity to the drive tines, which make them vibrate at a certain frequency. On the sense tines, if we rotate the gyroscope, it induces a current by piezoeletric effect.

2 Geometry

Question 2:

This gyroscope is composed of 6 work planes, which are built one by one using the object geometric properties. Two main functions have to be considered here:

- Extrude: Which consists in extracting a 3D object out from a work plane. In fact, it extents the plane by one dimension on a selected range, here the z axis from 0 up to tQz.
- Mirror: Consists in symmetrizing the part with respect to an axis/point.

As the part contains a lot of symmetry planes, the mirror function is often used to build up the entire part starting from the minimum.

3 Boundary conditions

Question 3:

The boundary conditions are **Free 1** and **Fixed Constraint 1**, the first condition specify the absence of boundary conditions this is the default boundary conditions and the second is a condition that make the geometry fixed.

Question 4:

The gyroscope has an angular velocity of 1.117 rad/s around the y axis, counterclockwise.

Question 5:

One creates a potential difference between the two drive terminals by applying respectively $1V$ to the 1st drive and $-1V$ to the 2nd one. Therefore, the extremity of the system is put under an electrical field and starts vibrating by reverse piezoelectric effect.

Question 6:

The sense terminals are here to specify the electric charge of the electrodes for which is $Q_0 = 0$ and this make sense because the tines are here to oscillate when the system has a vibrational speed by the momentum and this is why we have a piezoelectric material because with the oscillations of the tines we have the formation of a electric current.

4 Mesh

Question 7:

The maximum element size and its minimum are defined with respect to the quartz thickness tQz such as its minimum is equal to $tQz/12$ and its maximum equal to $tQz/4$ with $tQz = 0.5mm$. It is useful to define it with respect to the quartz thickness so we can adjust this thickness to perform various simulations.

Question 8:

We have to specify a minimum element because without this the discretization of the surface of the gyroscope can take very small element size and increase the number of degree of freedom in our simulation.

5 Computation and resulting eigenmodes

Question 9: The eigenmodes study tab has several parameters as follows :

- the solver used : $ARPACK$

- the eigen frequencies search method : 9
- Unit : Hz
- search for eigenfrequencies around : $3 \times 10^3 Hz$

With these parameters we think that we should have 9 eigenfrequencies.

Question 10: The report is in the folder $ReportQ10$ under the name $reportfileQ10$.

Question 11:

The report gives us back 9 eigenfrequencies as requested in the eigenstudymodes. The value are in the file 1eigenvalues.txt.

Question 12:

This is useful to have the title to see which plot is related to each eigenfrequencies. At $8396.2Hz$ we can see the behavior of the fork, we have a little oscillation for drive Tines and a bigger range of oscillations for Sense tines.

Question 13:

The displacement field correspond to the range of motion possible for the forks and the eigenfrequency the oscillation frequency of the fork.

6 Frequency response

Question 14:

The Frequency response is computed by forcing the system at a chosen frequency, here the main parameter is the value of the frequency that we have chosen $8396.2 \pm 1.3Hz$.

Question 15:

Comsol pertubed the computed eigenmode with a study of the asymptotic behavior by Asymptotic frequency sweep.

Question 16: The frequency response has the same behavior than a mass-spring system :

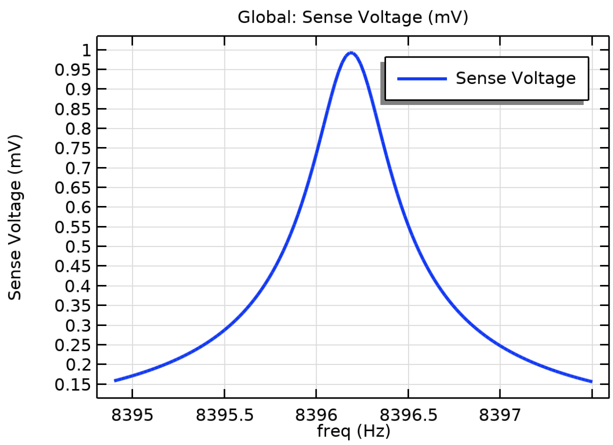

Figure 1: Graph of the frequency response

we can see on this graph that the behavior is quite close to a spring-mass system. The maximum of our Gaussian is for 8396.2 which is our eigenfrequency.

7 Sensitivity

Question 17:

With the parameter and the names of the axis are specified an angular velocity in deg/s and sense voltage mV. The computation should do a rotation of our system and get the values of the voltage. The report is in the folder $ReportQ17$ under the name $reportfileQ17$.

Question 18:

We obtain:

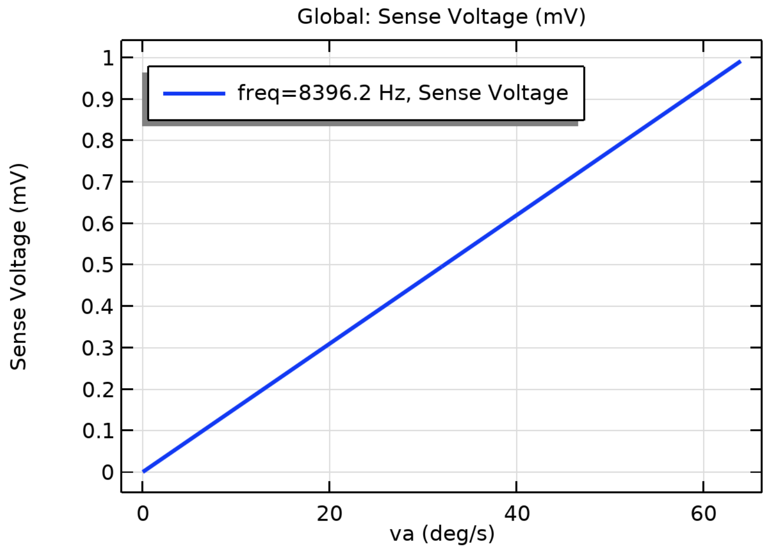

Figure 2: Graph of the sense voltage related to the angular velocity

we can see a line, very simple result that means the sense voltage is related to the angular velocity as we expected. We can't expect a simple result or this relation is constant.

Question 19:

Now that we know the relation between angular velocity and senses voltage is proportional, one could use it to calibrate our gyroscope. We can have the angular velocity when we have the sense voltage by multiplying the value with the slope of the curve.

8 Influence of the tines' length and the mesh quality

8.1 Using a finer and a coarser mesh

Question 20:

By decreasing the element size to $tQz/6$ the time to update the solutions takes 4 minutes and 27 seconds and we have 1147198 degrees of freedom.

Question 21:

The eigenvalues are in $2eigenvalue.txt$, we can see we have the same eigenvalues but with a difference of $20Hz$.

Question 22:

By increasing the element size by tQz we have 123654 degrees of freedom and just 23 second of computation time. Now by comparing the values with the default size mesh we have a difference of $100Hz$. We can conclude by the importance of a good size mesh because we have to be accurate but not with the maximal precision instead the computation time will be too important.

8.2 Changing the length of the tines

Question 23:

The new eigenvalues are in the file $4eigenvalue.txt$, we can see the apparition of new frequencies and some "old" frequencies of the previous length of the sense tines.

9 Conclusion

Question 24:

In this last practical work we have seen the behavior of a gyroscope and studied the behavior of his tines through Comsol, we observed what we have expected but more deeper in the understanding of the properties of the gyroscope. The drives tines can vibrate if we submit them a potential difference, they are here to calibrate our gyroscope, the drives tines give us a current when the gyroscope has a angular velocity. In the both case the response of the gyroscope is possible by the piezoelectric effect.