Simulation of Piezoelectric in MEMS Gyroscope

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Abstract **- In this paper, piezoelectric gyroscope based on Micro electro and mechanical system (MEMS) was presented using Ansys software. The design of piezoelectric gyroscope is based on parameter and structure which have selected from previous research and journal. The structure and the design of piezoelectric gyroscope have different output such as frequency, displacement or voltage output. It focused on quantitative indicator which is displacement ratio based on different length, width, depth and voltage apply on piezoelectric after the vibration and use Taguchi method to get the optimum performance from the best combination experiment. The result of this experiment shows the combination of 5x4x5mm with voltage applied 5v will give the optimum performance for the displacement ratio between y-axis, x-axis and z-axis which 0.3618 and 0.1180 for A and B respectively.**

Keyword: MEMS, gyroscope, piezoelectric

I. INTRODUCTION

As used in MEMS, it makes the material useful is in micro size. The process of piezoelectric MEMS is micro scale fabrication use to know as microfabrication. Elements in MEMS consist miniaturized structures, sensors, actuators and microelectronic [1].

MEMS gyroscopes have their application. Draper turning fork, laser ring, and piezoelectric plate is MEMS gyroscope application. The main focus gives in this project is piezoelectric in MEMS gyroscope. Gyroscope is a device used to measure angular velocity. Usually it is used for the sailor as sea navigation in foggy condition. MEMS gyroscope uses vibrating mechanical element to sense angular velocity [2]. It also can use in harsh environment with high temperature and humidity, high-G mechanical shock or drop, high radiation, high magnetic and electric field [3].

Piezoelectric in MEMS gyroscope use the vibration occurs in piezoelectric plate to produce some output voltage. At micro level, it has advantages over the common vibrating gyroscope only required small voltage so that it is readable. A simple vibrating piezoelectric plate had been discovered by Hansjoachim [4]. It explains that thickness shear vibration of piezoelectric plate to measure the input rotation rate.

The main focus in this project is about displacement ratio in the piezoelectric gyroscope of MEMS. After getting all the materials needed and the parameters, using Taguchi method, the mathematical equation can be defined so that it can design the experiment using Ansys software.

Ansys software is finite element software which can simulate a MEMS structure. It suits with the entire range of physics and any field of engineering simulation. Ansys software had been chosen because it able to apply technology depends on size of the problem.

II. LITERATURE REVIEW

Semiconductor devices had been introduced in electronic industry a long time ago. After time being, people starts make a research about micro or nano technologies so that it can compatible in millennium era with the sophisticated electronic devices. Gyroscope is one of MEMS application. MEMS gyroscope use vibration behavioral in order to produce output voltage. With MEMS gyroscope, it gives big advantages to laboratory experiment because it can replace expensive and time consuming. After get the value of mass, spring stiffness and damping coefficient, it make easy to solved by developed method. All the simulation had been through till now to get the best result for MEMS technology.

Gyroscope used to determine the angular velocity and it rotational. As a piezoelectric in

MEMS gyroscope, it has own characteristic. One of the advantage is it can lower drive voltage. Versatility of piezoelectric gyroscope and can measure rotation in two direction is other advantage that it has. This device also can operate with integrated circuit(IC) and can be controlled to do more things with other gyroscope application. Piezoelectric in MEMS gyroscope is much closer with ideal gyroscope output which is zero volts although it still up to 100milivolts.

MEMS gyroscopes have unique advantages which is low price, small size, low energy consumption and easy integration. Piezoelectric gyroscope operate when two vibration modes of a vibratory piezoelectric body where the particles move perpendicular directions. When it start to be excited into vibration in primary mode where alternating voltage applied and attached at rotating body, Coriolis force will excite at secondary mode. It also include flexural vibrations in two perpendicular directions of beams and tuning fork [5-8], thickness-shear vibrations in two perpendicular directions of plates [9,10], radial and torsion vibrations of circular cylindrical shells [11], and degenerate modes of circular disk, shells and rings [12-14].With different perimeter, the data of piezoelectric MEMS gyroscope will give different output either in frequency, stability, voltage out or charge.

In this paper, we more focus on displacement ratio for each design. Every axis of the design gave different displacement and by using the displacement value obtained from the kinetic energy of the piezoelectric, value of A and B need to calculate. The displacement ratio equation is obtained from [15] which show the last equation for A and B are as follow:

$$A = \frac{\sum E_{Yi}}{\sum E_{Xi}} = \frac{\sum A_{Yi}^2}{\sum A_{Xi}^2},$$

$$B = \frac{\sum E_{Yi}}{\sum E_{Zi}} = \frac{\sum A_{Yi}^2}{\sum A_{Zi}^2}.$$

A_{xi}, A_{yi}, and A_{zi} is the value obtain from Ansys and they are relative values because modal analysis does not give us absolute values generally. When the value A and B is bigger, it means the movements of mass elements are more obvious at Y direction which leads to higher sensitivity and lower deviation.

III. METHODOLOGY

The research used to understand three different things before combining it all in one title which is MEMS, gyroscope and piezoelectric. These three things have different characteristic need to be understood. Flow charts below show step this project start until it finish it.

The information related about this piezoelectric MEMS gyroscope is obtained from IEEE journal, conferences, website and book at research step. With the parameter obtained, the gyroscope of MEMS start to design based on the previous experiment data and reconstruct again with the new experiment to obtain the data. Taguchi method [16] uses to obtain best performance between the designs with different parameter.

Ansys software had been chosen to because the capability to design this micro structure. Material selection for piezoelectric is PZT850. PZT850 is made from Lead Zirconium Titanate. Usually, piezoelectric ceramic made of PbO2, PbZrO3, and PbTiO3. The PZT850 material constant used in this paper is as follow; material mass density (ρ): 7600 kg/m^3, permittivity (ε): ε_x = 947, ε_y = 947, ε_z = 605, the piezoelectric constant (*e*): $e_{31,}$ e_{32} = -8.02 C/m^2, e_{33} = 18.31 C/m^2, $e_{25,}$ e_{16} = 12.840 C/m^2, the elastic constant matrix (*c*): $c_{11,}$ c_{22} = 9.7 x 10^{10} N/m^2, c_{12} = 4.9 x 10^{10} N/m^2 , c_{13} , c_{23} = 4.4 x 10^{10} N/m^2, c_{33} = 8.4 x 10^{10} N/m^2 , c_{44} = 2.4 x 10^{10} N/m^2, c_{55} ,c_{66} = 2.2 x 10^{10} N/m^2. The maximum voltage applied for this material is in between 5-7V [17].

Using this parameter, 16 piezoelectric using PZT850 material was design. We can define that every design from different characteristic will give different output. Every height, width and depth varies from 2mm till 5mm and for voltage applied is from 4V to 7V. The design of piezoelectric follow the factor and level as shown in table 1.

Table 1: Level and factor for piezoelectric design

Factor / Level	A Length (y-axis) mm	B Width (x-axis) mm	C Depth (z-axis) mm	D Voltage V
Level 1	2	3	4	4
Level 2	3	4	5	5
Level 3	4	5	2	6
Level 4	5	2	3	7

Using the method of vibration based on gyroscope, we fixed one surface of the piezoelectric like figure 1.

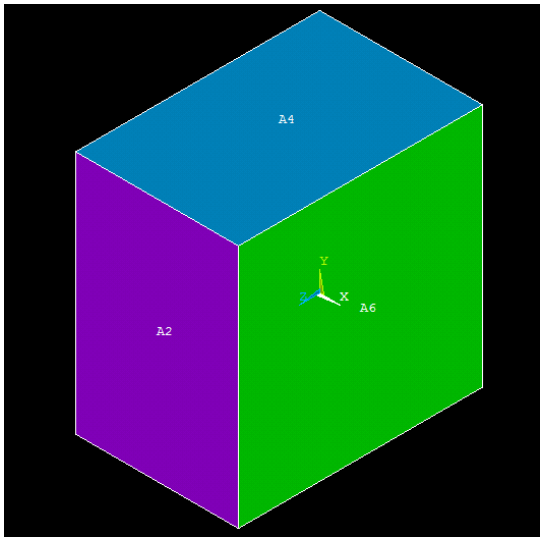


Figure 1: Label for each surface piezoelectric

At surface A4, that is the fixed point where when the vibration applies on this piezoelectric body, it will move from y-direction. The temperature for every design is 30° C. When the vibration complete, Ansys will produce result displacement at every axis for every design. The displacement value is in positive and negative value since but the polarity can be ignored because it only shows direction. All the data will be tabulated and the graph will be plotted to know which design will give the best performance of piezoelectric. Step doing this paper is following this flow chart which shows steps how this piezoelectric is designed.

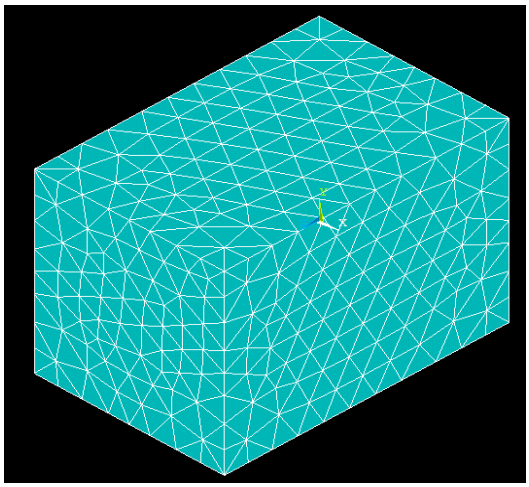
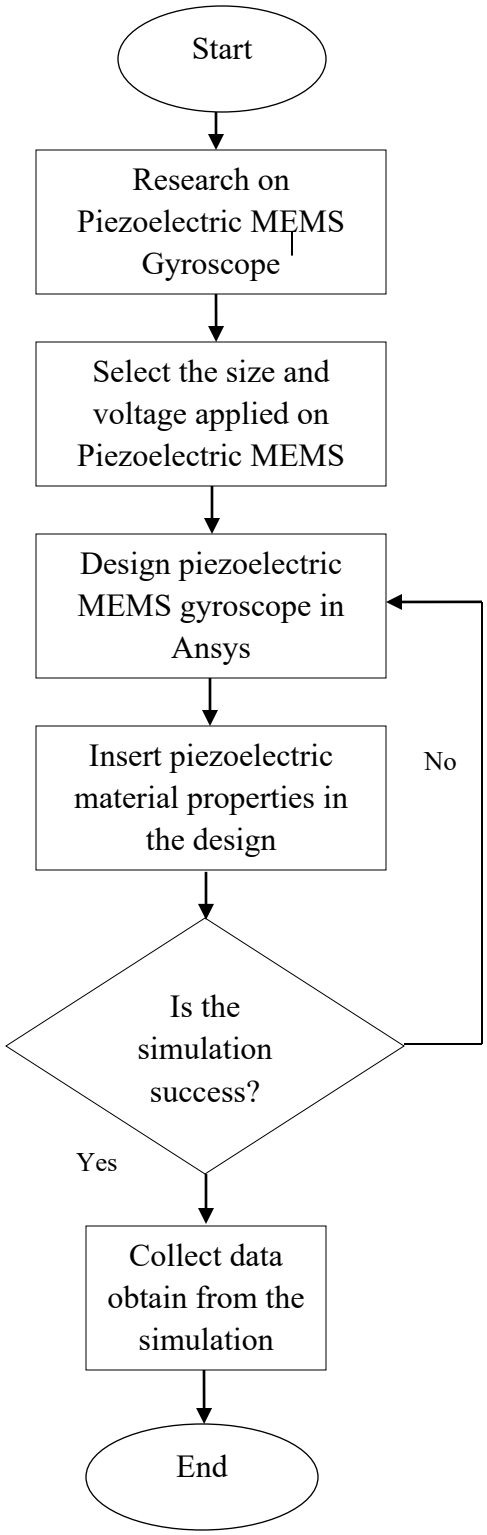


Figure 2: Meshing point at the piezoelectric design

For the simulation design, mesh is the important step to determine the stress of the design in each node. From figure 2, the line in the piezoelectric body show how the meshing line is connected to the all node in the design.



IV. RESULT AND DISCUSSION

After designing the piezoelectric, it can start simulate and did the vibration as figure 3 and 4.

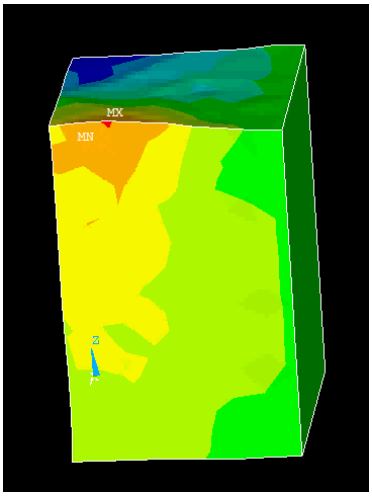


Figure 3: Vibrational mode in 3D view

Figure 3 and 4 shows the vibrational mode of piezoelectric in 3D and 2D view respectively after simulation. From both figure, what we can say is the simulation is moved toward y-axis. As in figure 3, the smaller value of mesh will give more accurate movement in particle of piezoelectric body.

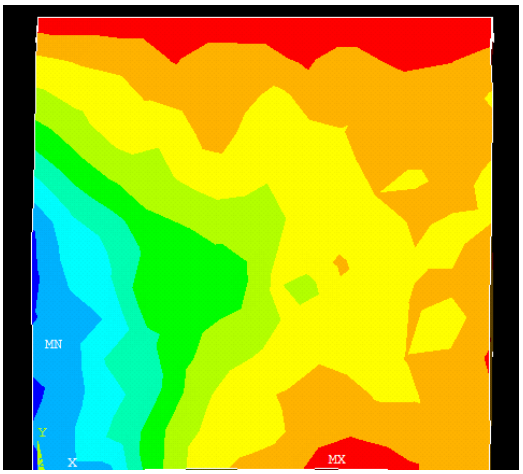


Figure 4: Vibrational mode in 2D view

All the 16 design of piezoelectric will be analyzed to get the best performance from using Taguchi method as in table 2. As the result in table 2, the displacement value is in range 10^{-11} till 10^{-15} meter. Since the result obtain is from the Ansys software, we can assure that value is accurate with the parameter and material used. The negative value of displacement can be ignored because in displacement, the negative shows direction only. Since the final result is the displacement ratio, value A and B doesn't have any unit.

Table 2: Displacement obtain after the simulation

Experiment	Designation	Displacement (meter)			Displacement ratio	
		A_X	A_Y	A_Z	A	B
1	A1B1C1D1	0.12239E-12	0.22104E-12	-0.16186E-11	3.2617	0.0187
2	A1B2C2D2	0.45526E-13	-0.29029E-12	0.13180E-11	40.6579	0.0485
3	A1B3C3D3	0.62801E-14	-0.97172E-14	-0.18185E-11	2.3941	0.0001
4	A1B4C4D4	-0.31329E-12	-0.16898E-12	-0.77322E-12	0.2909	0.0477
5	A2B1C1D1	-0.12393E-12	0.68957E-13	0.18380E-11	0.3043	0.0014
6	A2B2C2D2	-0.43424E-13	-0.21098E-12	-0.11304E-11	23.6060	0.0348
7	A2B3C3D3	-0.21686E-12	0.20076E-12	-0.26709E-11	0.8570	0.0057
8	A2B4C4D4	-0.41861E-12	-0.92616E-15	0.20175E-11	4.8949E-6	0.2107E-6
9	A3B1C1D1	-0.63431E-13	0.11488E-13	0.37681E-11	0.0328	9.949E-6
10	A3B2C2D2	-0.76441E-13	0.51644E-13	0.94328E-12	0.4564	0.0030
11	A3B3C3D3	0.24545E-12	0.49935E-13	-0.96925E-12	0.0414	0.0027
12	A3B4C4D4	0.28440E-13	-0.27106E-12	-0.30336E-11	90.8389	0.0080
13	A4B1C1D1	-0.12804E-12	-0.32382E-13	0.20168E-11	0.0640	0.0003
14	A4B2C2D2	0.44216E-12	0.26594E-12	-0.24507E-11	0.3618	0.1180
15	A4B3C3D3	0.30072E-13	-0.28782E-12	0.14800E-11	91.6046	0.0378
16	A4B4C4D4	0.61026E-13	0.14599E-13	-0.20615E-11	0.05722	0.0001

From table 2, A and B is the displacement ratio calculating for each design. In order to get best performance between 16 designs of experiment, the maximum value of A and B must be reached simultaneously. For the maximum value of A, experiment 15 get the highest value which is 91.6046 meanwhile for maximum value of B is experiment 14 which is 0.1180. For experiment 8, design A2B4C4D4 gives the lowest value among the others which only give 4.8949E-6 and 0.2107E-6 for both A and B respectively. All value at B is less than 1 which shows the value a Y-axis is high than y-axis and z-axis because the design was vibrated in y-axis so that more kinetic energy will produce at y-axis.

The data calculate from table 2 had be plot in the graph as in figure 5 and 6 for A and B values respectively. The graph obtained is to determine which design will give the best performance. The best performances determined by the value of A and B is nearest with each other. From the graph obtained, we can know that every design will give different displacement ratio either it too high or too low.

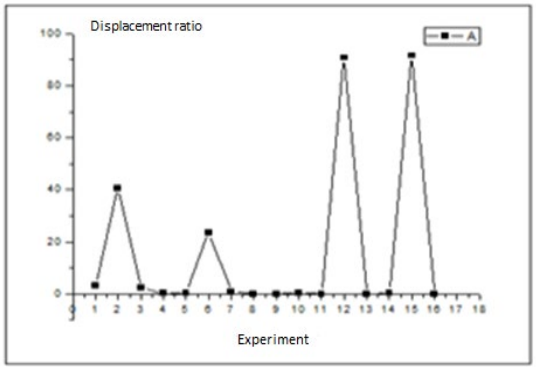


Figure 5: Value of A versus number of experiment

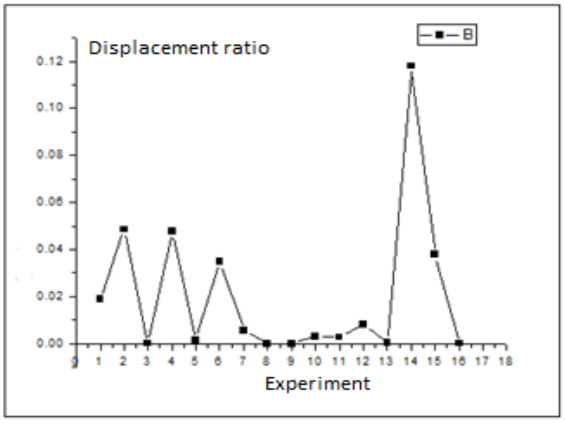


Figure 6: Value of B versus number of experiment

V. CONCLUSION

Structure of piezoelectric in MEMS gyroscope is a unique because it has larger stiffness, resulting in resist to shake and strike. In this paper, the best operation of piezoelectric was determined from displacement ratio which is the design from Experiment 14 with size 5x4x5mm with voltage applied 5v. The ratio of this design is 0.3618 and 0.1180 for A and B respectively which is not too high or too low compares to others design.

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