International Journal of Engineering Science Invention
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 5 Issue 10|| October 2016 || PP.01-06

Design and Development of a 3-Axis Micro Gyroscope with Vibratory Ring Springs

B. Sravanthi[1], Y. Vijayakumar[2], Dr P. Ravinder Reddy[3]
[1,2]*Departmentof Mechanical Engineering, J B Institute of Engineering &Technology, Hyderabad, Telangana State, India*
[3]*Departmentof Mechanical Engineering, Chaitanya Bharathi Institute of Technology, Hyderabad, Telangana State, India*

Abstract: *This work presents the design, simulation of a miniaturized 3-axis gyroscope with vibratory ring springs. Its total size is 2 mm x 2 mm. The designed gyroscope has the vibrating ring spring to accomplish all sensing schemes necessary for 3-axis angular rate. The gyroscope is composed of the inner and outer ring springs, the x direction and y-direction driving parts, the rolling sensing, and the pitch sensing and the yaw sensing parts. FEA analysis is performed to get (i) the deflections and stresses induced in miniature gyroscope made of two different materials such as Aluminum alloy and CFRP composite material, and (ii) the modal analysis to get the natural frequencies and mode shapes for both gyroscope made of two materials such as aluminum alloy and CFRP composite material. Further the driving mode and the sensing mode of gyroscope using ANSYS program. The gyroscope was modeled in CATIA and the analysis is performed in ANSYS.*
Keywords: *Catiav5 R20, Modal Analysis, Jacobi Method, Modes, Stability*

I. Introduction

A gyroscope is a device for measuring or maintaining orientation, based on the principle of conservation of angular momentum (/entry/Angular momentum). The key component, a relatively heavy spinning rotor, is mounted with nearly frictionless bearings inside two concentric lightweight rings (gimbals) each of which is also mounted with similar bearings inside the next outer ring, or the support frame in the case of the outer ring. The rotor and the two rings are mounted so the plane of rotation for each is perpendicular to the plane of rotation of the other two. The spinning rotor naturally resists changes to its orientation due to the angular momentum of the wheel. In physics, this phenomenon is also known as gyroscopic inertia or rigidity in space. Thanks to its unique support in the nested gimbals the rotor is able to hold a nearly constant orientation even as the support frame shifts its orientation[1-3]. The gyroscope's ability to hold its axis fixed in a certain orientation, or in some applications to process about an axis, even as its supporting structure is moved into different positions has permitted it to be used in making vast improvements to navigational systems and precision instruments. Early work by Leon Foucault during the mid-19th century explored two different design paradigms for angle measuring mechanical gyroscope based on either a spinning or vibrating mass. While the spinning mass approach was the dominant method of mechanical gyroscope construction from its inception well into the second half of the 20th century, it is not well suited for MEMS implementation due to the technological limitations in the manufacturing of precision, low friction bearings. Few designs of spinning mass MEMS gyroscopes using electrostatic levitation have been reported in the literature without yet achieving commercial success due to the inherent instability of the mechanical system and necessity for a sophisticated control system. The vibrating mass approach, illustrated by the popular Foucault pendulum experiment, exploits the exchange of energy between different axis of vibration due to the Coriolis effect. This architecture, at present referred to as the Coriolis Vibratory Gyroscope (CVG) remained largely a scientific curiosity for almost a century until the introduction of a functional vibratory gyroscope by Sperry in the mid-20th century followed by successful commercialization of quartz tuning fork gyroscopes by BEI Technologies in the late-20th century, and very high volume deployment of silicon MEMS CVGs in the early 21st century. Today, silicon vibratory rate gyroscopes with capacitive transduction comprise the majority of MEMS gyroscopes in development and production, with some research groups and manufacturers pursuing quartz devices with piezoelectric transduction or silicon devices with alternative transduction mechanisms such as inductive or electromagnetic. During World War II, the gyroscope became the prime component for aircraft and anti-aircraft gun sights. After the war, the race to miniaturize gyroscopes for guided missiles and weapons navigation systems resulted in the development and manufacturing of so-called midget gyroscopes that weighed less than 3 ounces (85 g) and had a diameter of approximately 1 inch (2.5 cm). Some of these miniaturized gyroscopes could reach a speed of 24,000 revolutions per minute in less than 10 seconds. Three-axis MEMS-based gyroscopes are also being used in portable electronic devices such as tablets, smart phones, and smart watches. The finite element method is so popular to predict the behavior of materials, testing statically or dynamically for he stability [4-6].

II. Geometric Modeling Of Gyroscope

We can create solid bodies by sweeping sketch and non-sketch geometry to create associative features or Creating primitives for the basic building blocks, then adding more specific features (for example, holes and slots). Sweeping sketch and non-sketch geometry lets us to create a solid body with complex geometry. This method also gives us total control over the editing of the body. Editing is done by changing the swept creation parameters or by changing the sketch. Editing the sketch causes the swept feature to update to match the sketch. Creating a solid body using primitives results in a simple geometry solid body. Making changes to primitives is more difficult, because primitives cannot always be parametrically edited. We can use primitives when we do not need to be concerned with editing the model. Generally, however, it is to our advantage to create the model from a sketch. The geometric model of the gyroscope is shown in Figure1.

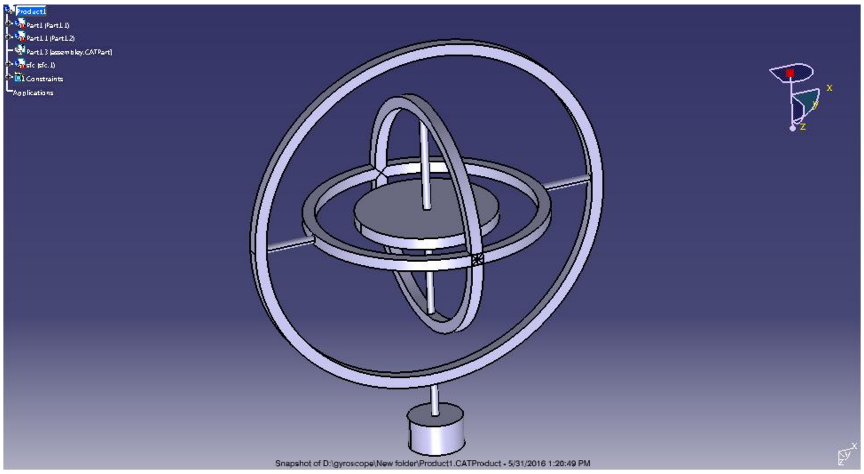


Fig.1: Geometric Model of Gyroscope

III. Finite Element Modeling Of Gyroscope

The model created in CATIA software is imported through the IGES file in to Hypermesh software then geometry clean up is carried out. Using the ANSYS library of elements the cards are prepared. The element selected for meshing the gyroscope is a 10 nodded 3D sold element which is having 3dof/node and 24dof/element, the element has shown in Figure2. After checking the convergence norms the meshed model is shown in Figure3.

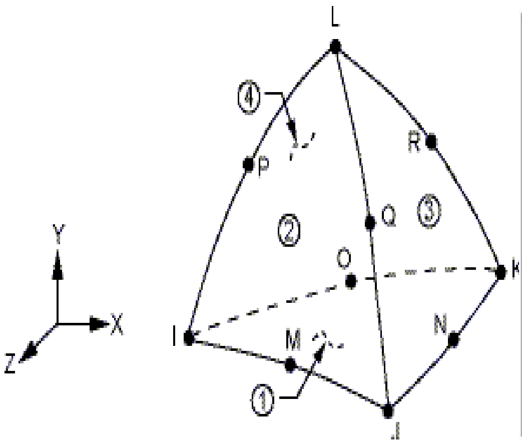


Fig.2: SOLID92 Geometry

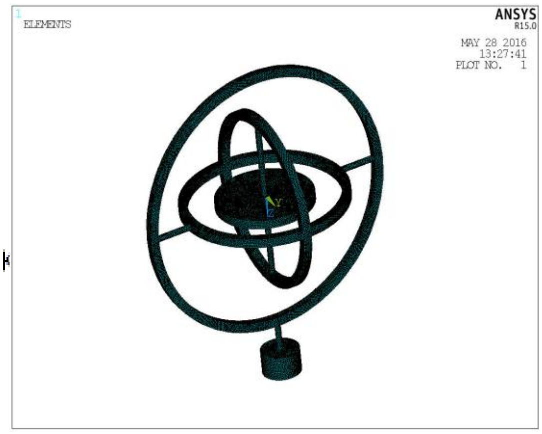


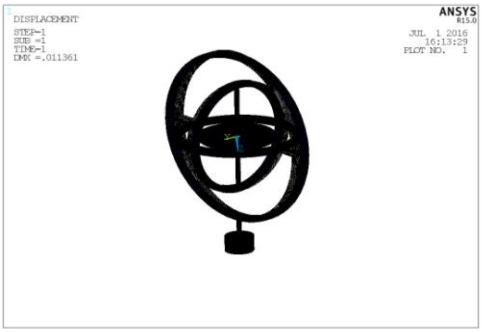
Fig.3: Meshed Model of Gyroscope with Tet Elements

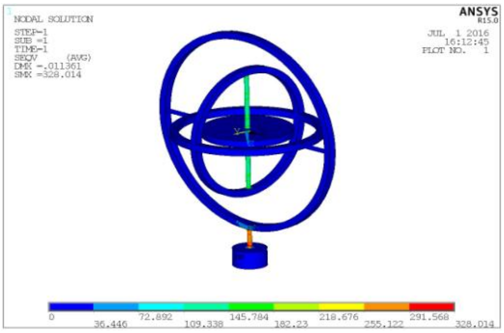
IV. Material Properties

The materials selected for gyroscope are aluminum alloy and CFRP Composites. The properties of these materials are given as here under. Mechanical Properties of aluminum alloy: Young's modulus: 68.9GPa, Poisson's ratio: 0.29 . Mechanical Properties of CFRP Composites are Young's modulus =E_x = 180GPa, E_y = l0Gpa =E_z , Poisson's ratio nu_{xy} = 0.28 , Shear modulus =G_{xy} = 7. 1 GPa, Mass density =1600 kg/m^3 , Damping co-efficient = 0.018.

V. Results And Discussions

5.1 Static Analysis: From the Figure 4a. shows the variation of deformation in the gyroscope due to a torque of 100 N-m is applied, the maximum deformation is observed is 0.011361 mm for the aluminum alloy material.

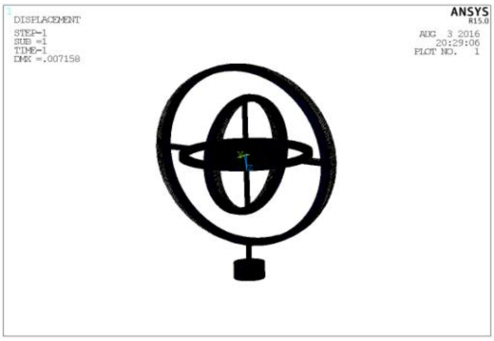


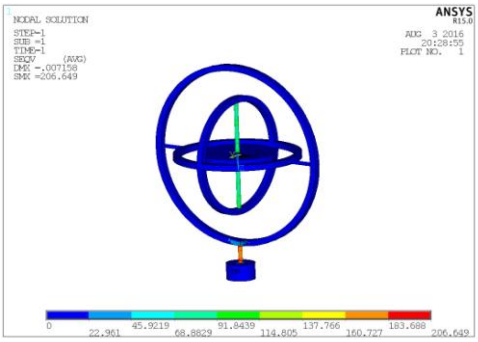


a. Deformed shape, mm b. Vonmises stress induced, MPa

Fig.4: Deformation and vonmises stress induced in the gyroscope made of aluminum alloy with a torque of 100 N-m

The Vonmises stress induced in the gyroscope made of aluminum alloy with a torque of 100 N-m is 328 MPa , which is seen from the Figure4b. From the Figure 5a shows the variation of deformation in the gyroscope due to a torque of 100 N-m applied, then maximum deformation observed is 0.007158 mm for the CFRP material and the corresponding Vonmises stress induced in the gyroscope is 206 MPa, which is observed from Figure5b.



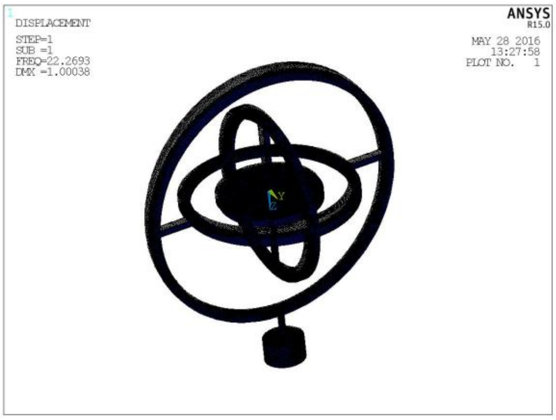


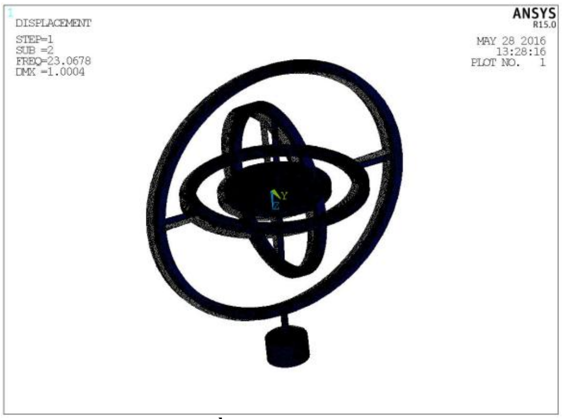
a. Deformed shape, mm b. Vonmises stress induced, MPa

Fig.4: Deformation and vonmises stress induced in the gyroscope made of CFRP composite with a torque of 100 N-m

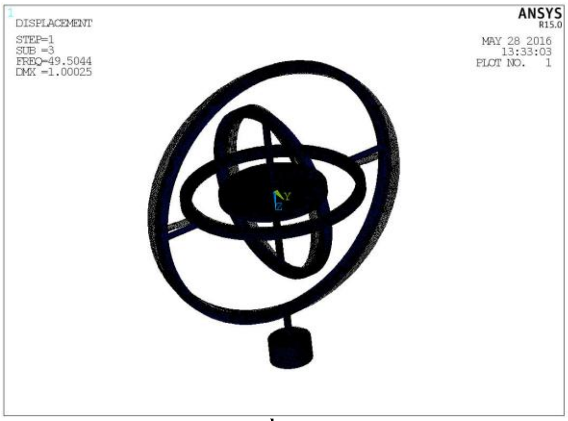
5.2 Modal Analysis of Gyroscope

Modal analysis is carried out for Aluminum Alloy and CFRP Composite Gyroscope. Eigen value analysis is carried out by using Block Lanczo's method. Ten natural frequencies are obtained for aluminum alloy are given in Figure5. Where as Figure6 shows the natural frequencies of Gyroscope made of CFRP composite materials.

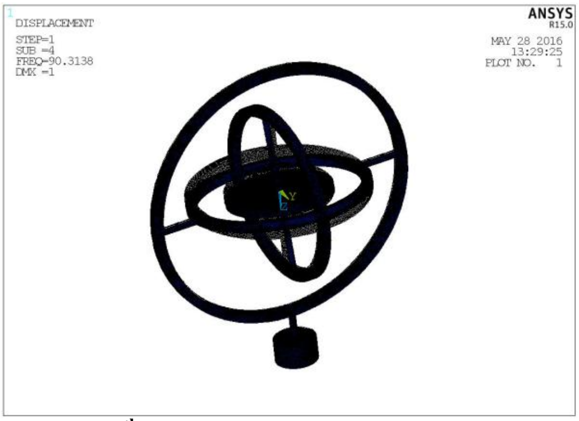




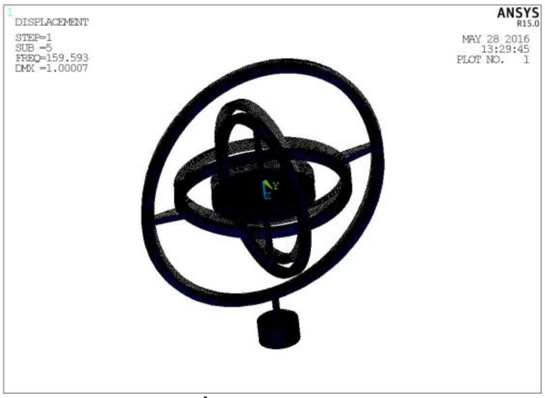
a. First mode (**f_{n1}**=22.269Hz) **b. 2nd Mode** (**f_{n2}**=23.0678Hz)



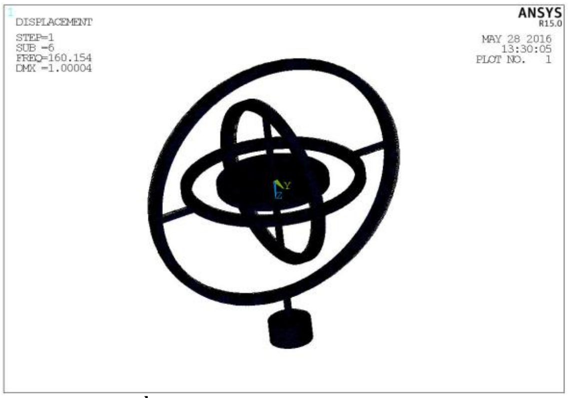
c. 3rd Mode (f_{n3}=49.5Hz)



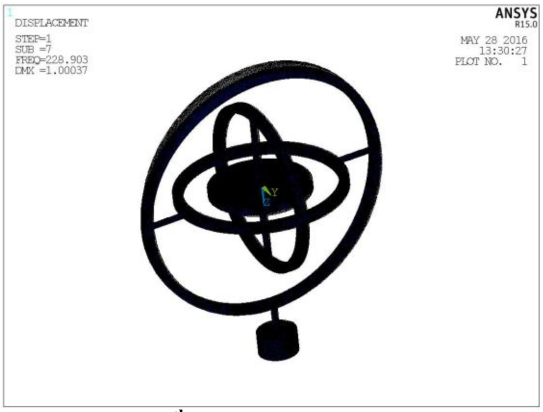
d. 4th Mode (f_{n4}=90.3138Hz)



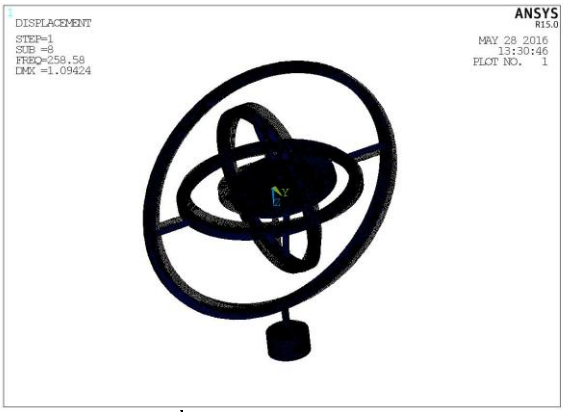
e. 5th Mode (f_{n5}=159.593Hz)



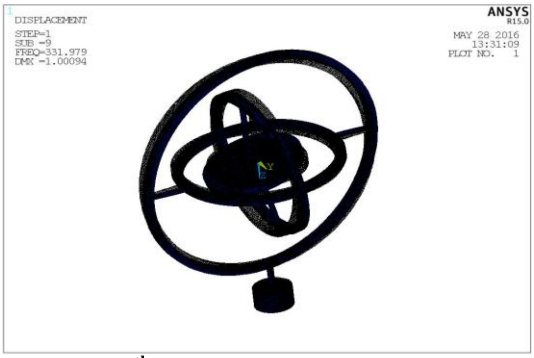
f. 6th Mode (f_{n6}=160.514Hz)



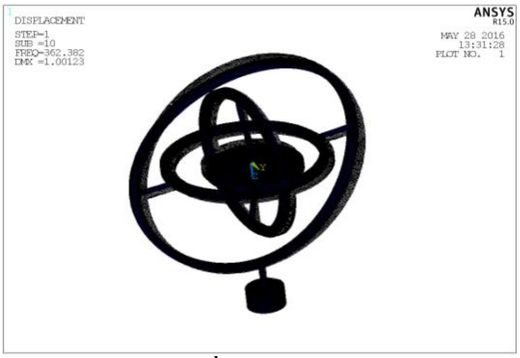
g. 7th Mode (f_{n7}=228.9Hz)



h. 8th Mode (f_{n8}=250.50Hz)

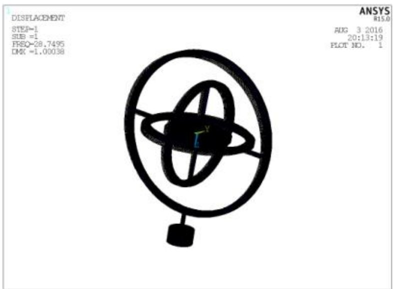


i. 9th Mode (f_{n9}=331.979Hz)

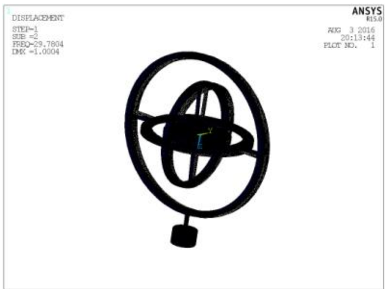


j. 10th Mode (f_{n10}= 362.382Hz)

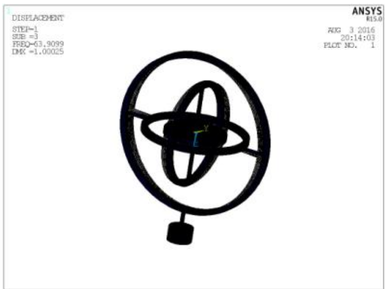
Fig.5: First 10 Natural Frequencies in the Gyroscope made of Aluminum Alloy Material



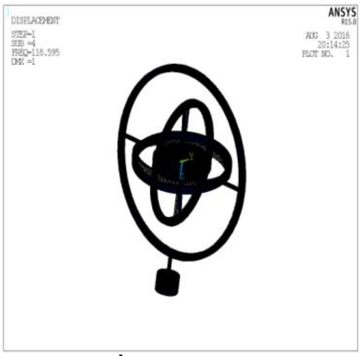
a. 1^{st} Mode (f_{n1}=28.75Hz)



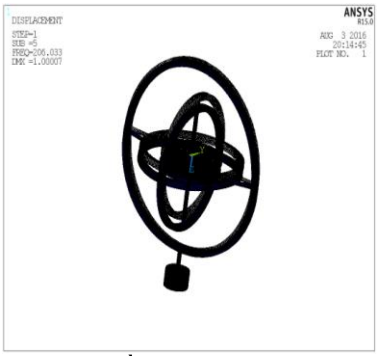
b. 2^{nd} Mode (f_{n2}=29.78Hz)



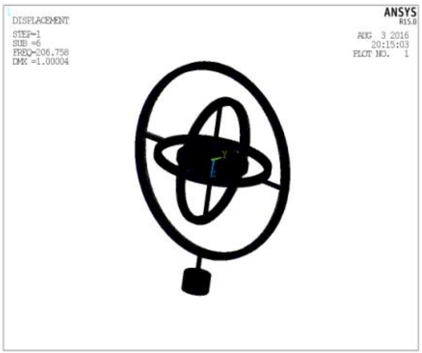
c. 3^{rd} Mode (f_{n3}=63.9Hz)



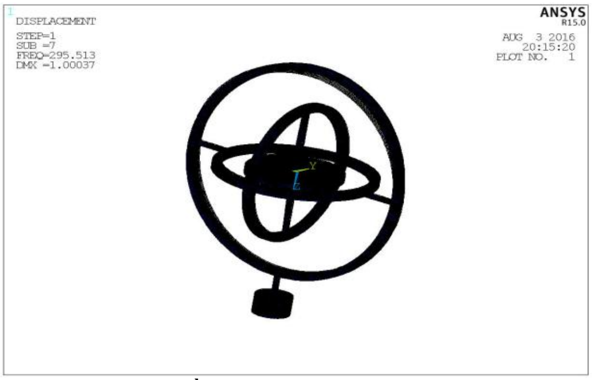
d. 4^{th} Mode (f_{n4}=116.6Hz)



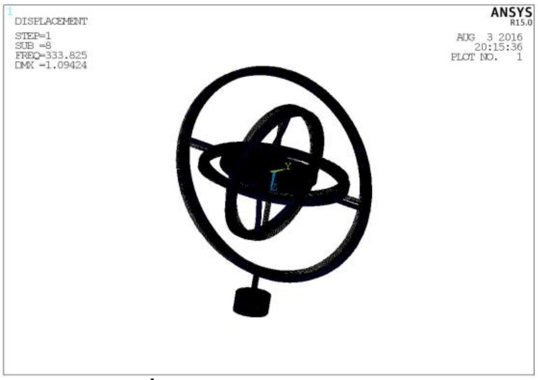
e. 5^{th} Mode (f_{n5}=206 Hz)



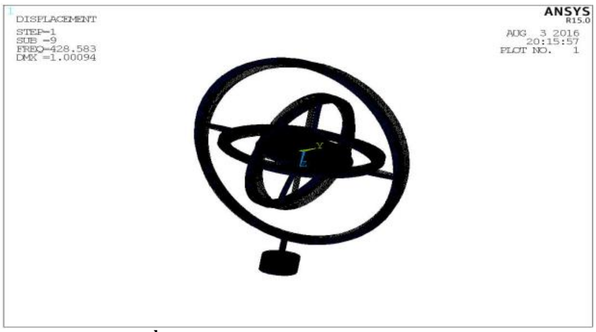
f. 6^{th} Mode (f_{n6}=206.8Hz)



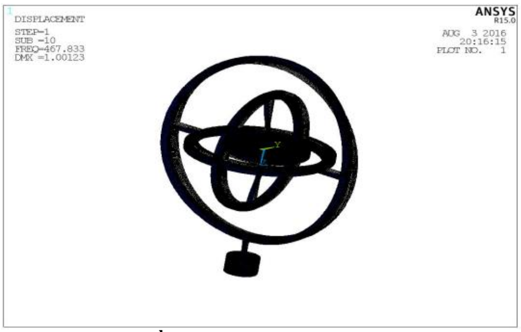
g. 7^{th} Mode (f_{n7}=295.5Hz)



h. 8^{th} Mode (f_{n8}=333.8Hz)



i. 9^{th} Mode (f_{n9}=428.6Hz)



j. 10^{th} Mode (f_{n10}=467.8Hz)

Fig.6: First 10 Natural Frequencies in the Gyroscope made of CFRP composite Material

The maximum deformation and vonmises stress induced in the gyroscope made of aluminum alloy and CFRP material is given table2 and it is observed that deformations and stress induced is more in aluminum material.

Table2: Comparison of Static Analysis Results

	Aluminum Alloy	**CFRP**
Deformation(mm)	0.011361	0.007158
Vonmises stress (MPa)	328.014	206.649

Results of modal analysis of gyroscope is shown in table3. It is observed that the natural frequencies are high in CFRP material as compared to the aluminum gyroscope. Hence the dynamic stability is good in CFRP gyroscope as compared to aluminum gyroscope.

Table 3: Comparison of Modal Analysis Results

Mode shapes	**Aluminum Alloy Gyroscope Frequency(Hz)**	**CFRP Gyroscope Frequency(Hz)**
First mode	22.2693	28.749
Second mode	23.0678	29.7804
Third mode	49.5044	63.909
Fourth mode	90.3138	116.595
Fifth mode	159.593	206.033
Sixth mode	160.154	206.758
Seventh mode	228.903	295.513
Eighth mode	258.58	333.825
Ninth mode	331.479	428.583
Tenth mode	362.382	467.833

VI. Conclusions

The deflection in Gyroscope made of aluminum material is found to be 0.011361mm where as for the CFRP composite material Gyroscope is 0.007158 mm for all layers, which is much less than that of Aluminum alloy Gyroscope. Hence composite material gyroscope is stiffer than aluminum gyroscope. Modal analysis results showed that the natural frequencies of composite Gyroscope were higher than aluminum Gyroscope, which indicates that the dynamic response of composite Gyroscope is much superior to aluminum gyroscope. Static stresses induced in the CFRP Composite Gyroscope is less than that of gyroscope made of Aluminum material. However the stresses induced in both gyroscopes are well within the allowable range. Hence the design of the gyroscope is satisfying the rigidity and strength criteria's.

References

[1]. C. LeFèvre, Hervé, *The fiber-optic gyroscope* (Norwood, MA: Artech House. 1993)
[2]. Machover, Carl., *Basics of gyroscopes vol. 1.* (New York, NY: John F. Rider Publishing 1963)
[3]. Walton, Harry, *The how and why of mechanical movements - exactly how machines work: engines, turbines, transmissions, brakes, clutches, rockets, atomic generators, gyroscopes, guidance systems.*(Tampa, FL: Popular Science 1968)
[4]. P. Ravinder Reddy and J. Pradeep Kumar,Vibration Response of Composite Plate with Delamination using FEA, *International Journal of Applied Engineering Research, 2295)* , 2010,3633–3643.
[5]. S. Khadar Vali, Dr P Ravinder Reddy, Dr P Ram Reddy, Impact Testing of Advanced Ceramic Composites Using Experimental & Numerical Analysis, *International Journal of Technology Spectrum, Research Communication, 2(1)*, 2008, 22-25
[6]. S. Khadar Vali., Dr P. Ravinder Reddy, Dr P. Ram Reddy, Modeling and Analysis of Three Dimensional Carbon Fiber/SiC Composites prepared by Liquid Silicon Infiltration Using FEA, *Global Journal of Engineering and Applied Sciences (GJEAS),3(1),* 2011,133-139.
[7]. ANSYS user manuals, Swansea