ANALYSIS OF RING JET LASER GYRO RESONANT DITHERING MECHANISM

Penumarthi Chandra Sekhar Kumar[1], Bharatam Anil Kumar[2],
Marella Sai Chandra Sekhar[3]
[1]Student, [2]Assistant Professor,
Department of Mechanical Engineering,
Kallam Harinathreddy Institute of Technology, Chowdavaram, Guntur, India
[3]Assistant Professor, Department of Mechanical Engineering,
KKR & KSR Institute of technology and science, Vinjanampadu, Guntur, India

ABSTRACT

This paper presents the design, manufacture, testing and improvement of newly developed piezoelectric torsion actuator which generates angular displacement using piezo ceramics and torsion bar. The proposed piezoelectric torsion actuator generates angular displacement during dithering, directly invoking the shear mode of the piezoelectric material and hence no complicated additional mechanism is needed. The piezo plates are formed from a rectangular PZT material duly poled along the axial direction. The dither mechanism is divided into four segments that are arranged in circular configuration. Each of the segments off our piezoplates is bonded in opposite poling directions with soldering adhesive. The key to design of such an actuator is to match the torsion resonant frequency of the actuator with the excitation frequency. FEA for the Torsion bar is carried out to find the different resonant mode sand mode shapes. Also, a set of torsion bars and resonator are analyzed to evaluate the maximum angular displacement and stresses on torsion bars. An experimental investigation in terms of electrical impedance and angular displacement measurement was conducted to verify the mode analysis. Based on the FEA analysis, a new material for the torsion actuator was selected having high Curie temperature and stable relative dielectric constant so that it has higher tentivity even after bonding the piezo plates on torsion bars and also wire soldering process. The design analysis was verified with the experimental results for incorporation of the selected mechanism for the production of dither in the system.

KEYWORDS: *Dithering Mechanism, Ring jet Analysis, Gyro resonant dithering mechanism, Gyro resonant mechanism*

I. INTRODUCTION

Torsion bars are very important sub-assembly for gyro functioning. During very low rate of rotation, gyro does not give any output due to lock-in of CW and CCW rotating laser beam. In order to overcome this lock-in problem, an artificial rotation is being introduced for proper functioning of gyro at low rotation rates and the same rotation rate will be subtracted from the final output of gyro to get the correct rotation rate. Ring laser gyroscopes are able to detect the rotation rate of their cavity relative to an inertial frame. Their principle of operation exploits the Sagnac effect: rotation causes the length of the cavity as seen by the two counter-propagating running waves in the laser to be slightly different. In the ring laser gyroscope this difference translates directly in optical frequency shift between the two beams. Compared to conventional spinning gyroscopes, a ring laser gyro shows several advantages: they have large dynamic range, high precision, small size, they do not require any moving mechanical part and they are insensitive to translational accelerations. Laser gyros acquire a prominent role in many applications, ranging from inertial navigation system on commercial airliners, ships and spacecraft to geodesy and geophysics, to test of fundamental physics.

II. DESIGN CONCEPT

The newly developed piezo-electric torsion actuator generates angular displacement using Piezo ceramics and a torsion bar. Because of the proposed piezoelectric torsional actuator generates torsional displacement, directly invoking the shear mode of the piezoelectric material, no complicated additional mechanism is needed. The key to design such an actuator is to match the tensional resonant frequency of the actuator with its excitation frequency. Finite element analysis (FEA) of torsion bar is performed to find the torsion bar resonant modes. As a result, a maximum angular displacement of approximately 180 arc seconds was measured. A resonance decreases due to the added mass on the torsion bar is observed.

Piezo electric means having ability to generate mechanical force when electrical field is applied and vice versa. The generating mechanical force is directly proportional to the applied electric field. So that, angular rotation can be controlled by varying the electric field intensity on piezo plates.

The property of the metal that causes to produce mechanical force in terms of VIBRATIONS when voltage is applied. Here the metal is considered as the torsion bar, which produces the vibrations.

Sixteen numbers of rectangular piezo plates are fixed on four torsion bars to generate dithering. Four piezo plates on each torsion bar are soldered as polarity specified in the figure (1).Polarity of piezo plates and position of soldering on flat surface of torsion bar is very important. Electrical inter connectivity is ensured for sixteen piezo plates and electric field specified frequency is applied. Contraction and expansion of piezo plate’s takes place at perpendicular to the electric field applied (i.e.d31mode). The generated forces on piezo plates are transfer to the torsion bar which deflects in the first mode of natural frequency of torsion bar shown in the figure below.

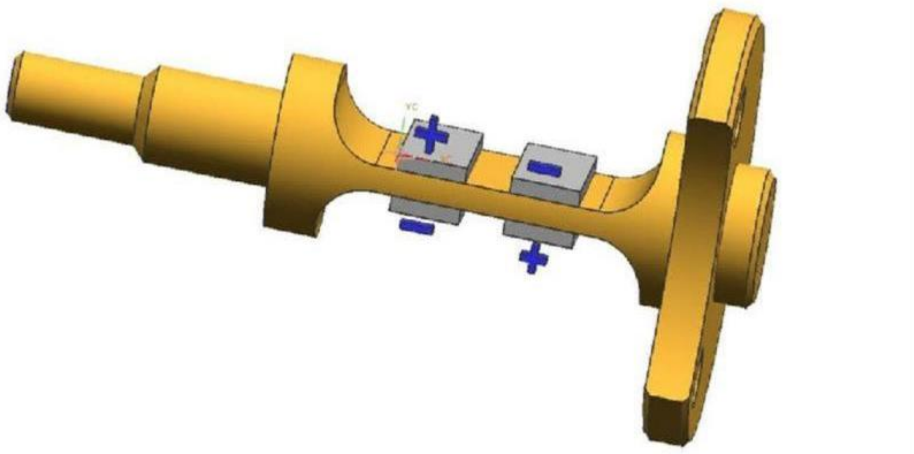

Figure 1: Piezo plates soldering on Torsion bar

The four torsion bars are vertically mounted on a single plane of a circle at 90^o equally.

The vector forces shown in figure (2) indicate the applying forces on four torsion bars and its resultant orthogonal forces. So the applied force will be converted into two orthogonal forces on each torsion bar. The force diagram shows 8 orthogonal forces being generated by four applied forces. The 8orthogonal forces are becoming four synchronized couples and resultant will be an angular rotation.

i.e. couple1 =Orthogonal force C_1 and Orthogonal force C_5
Couple2 =Orthogonal force C_2 and Orthogonal force C_6
Couple3 =Orthogonal force C_3 and Orthogonal force C_7
Couple4 =Orthogonal force $C_4$and Orthogonal force C_8

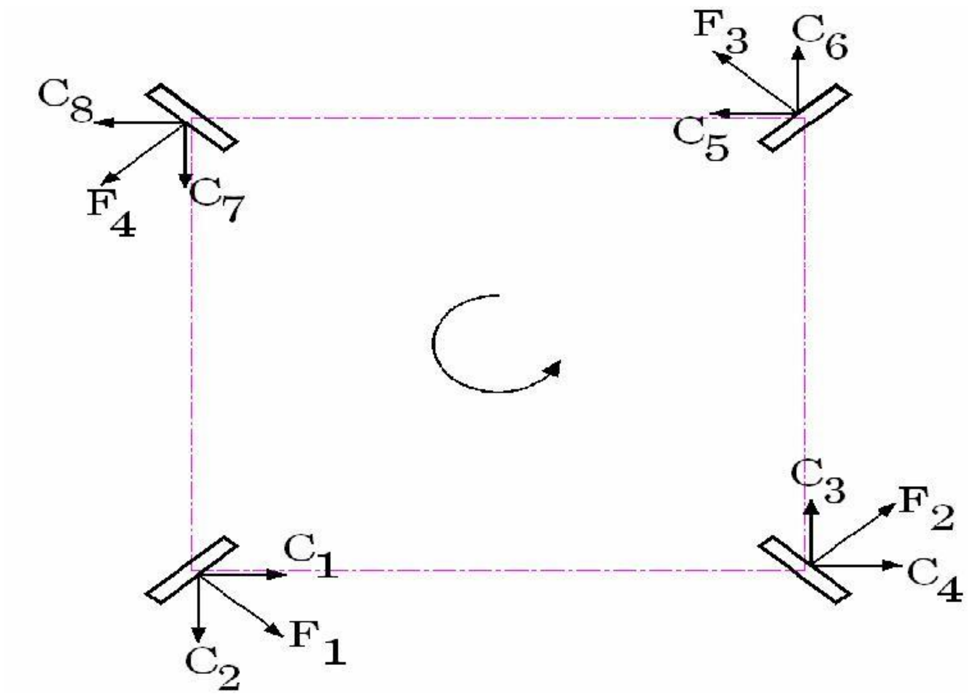

Figure 2: Coupled forces

III. MODELLING AND ANALYSIS

Selection of piezo material:

Specifications of Piezo Plate

- Dimensions : 12 X 5.5X0.35mm
- Piezo Modulus d31 : -240x10^{-12}C/N
- Capacitance : 3000 pF
- Dielectric Loss : 0.028
- Insulation Resistance : 2x108 Ω
- Electrical Strength : 1x106V/m
- Operating Temperature :-60^{o}Cto+100^{O}c
- Voltage frequency ‘f’ : 400Hz

3.1 Torsion bar Material and its Mechanical Properties:

Torsion bars are made of tin free beryllium bronze material. The material properties are high strength and very good durability after temperature cycle, good spring properties, good antifriction properties, and medium electro and heat conductivity.

Mechanical properties of the torsion bar after solution annealed and precipitation- hardened condition are as follows.

1. Tensile strength = 1150- 1305 N/mm^2
2. Yield strength = 1000 – 12050 N/mm^2
3. Modulus of elasticity = 120x10^{3}N/mm^2
4. Modulus of torsion = 47x10^{3}N/mm^2
5. Hardness = 36–39HRc.

3.2 Structural Static Analysis

- Structural static analysis has been done for Torsion bar of thickness 3mm (400Hz).
- Considering the maximum force of 210N

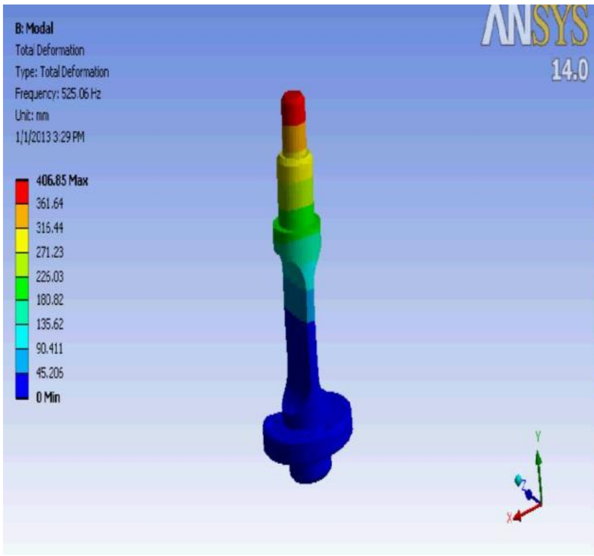

Figure 3: Firstmodenatural frequency and mode shape

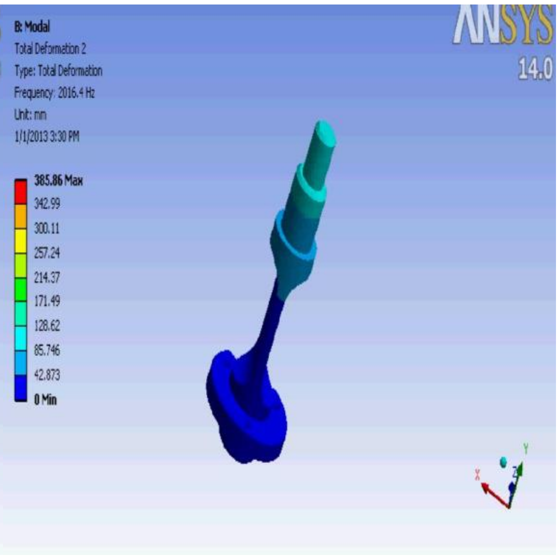

Figure 4: Secondmode natural frequency and mode shape

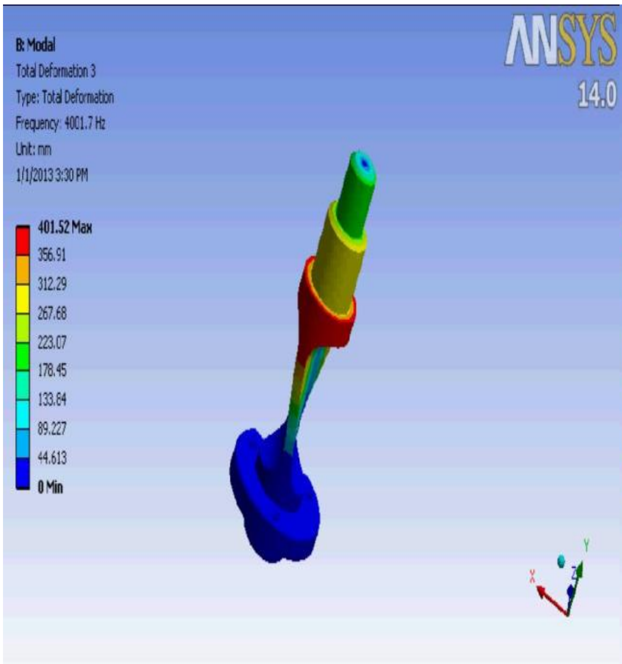

Figure 5: Third mode natural frequency and mode shape

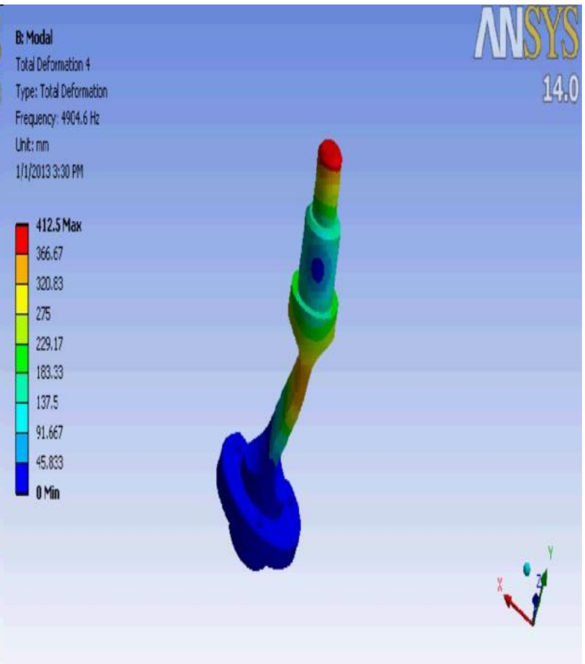

Figure 6: Fourth mode natural frequency and modes hape

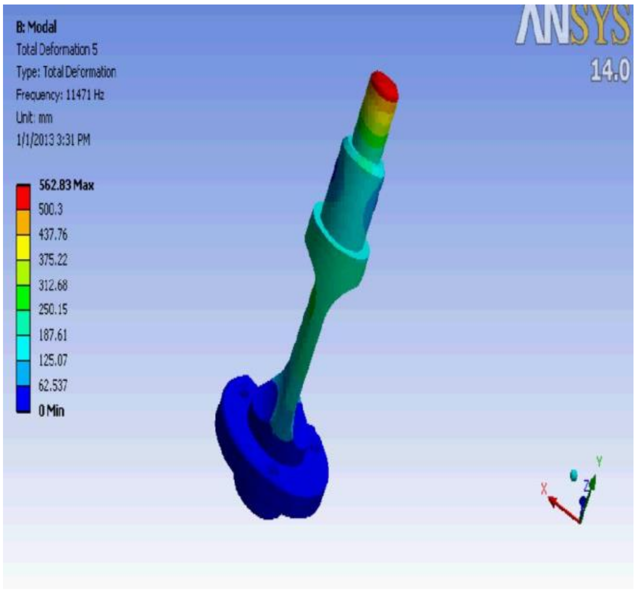

Figure 7: Fifth mode natural frequency and mode shape

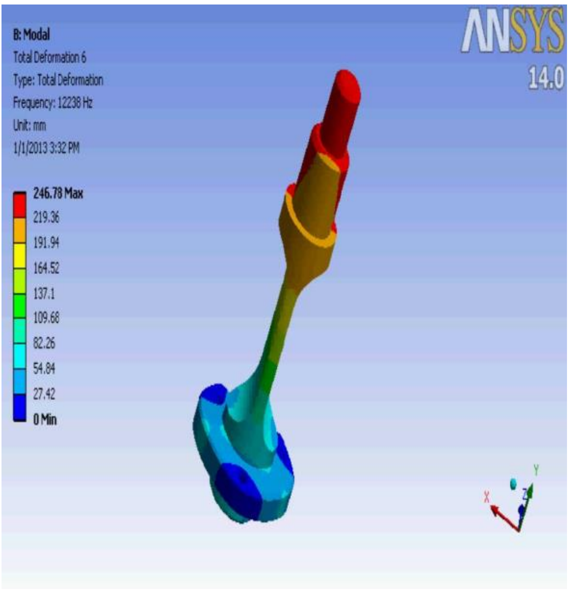

Figure 8: Sixth mode natural frequency and mode shape

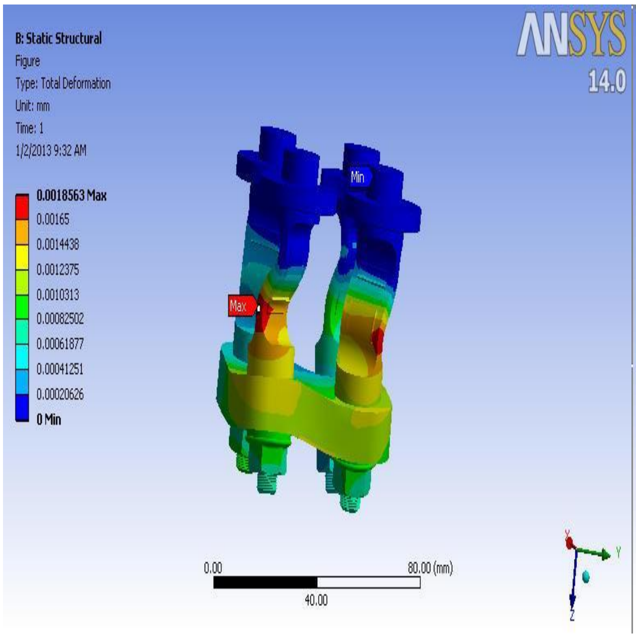

Figure 9: Displacement-Nodal Magnitude

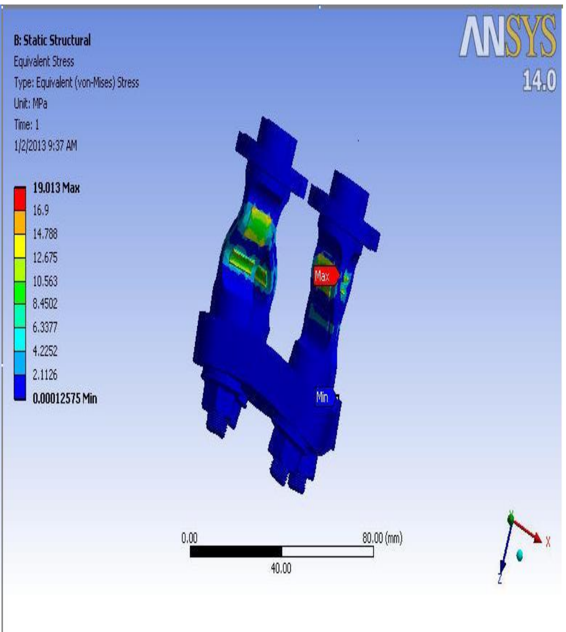

Figure 10: Stress-Element Nodal Von-Mises

IV. RESULTS AND DISCUSSION

Table1. Modalanalysis results

Software Used:	ANSYS14.0WORK BENCH
Solver:	Structures P.E.
Analysis Type:	Structural
Solution Type:	Modal
Linearity:	Linear
Time dependency:	Steady-state
Constraint set	3CSK holes fixed all DOF

Results:	Frequency
Mode1:	525.6 Hz
Mode2:	2016.4 Hz
Mode3:	4001.7 Hz
Mode4:	4904.6 Hz
Mode5:	11471 Hz
Mode6:	12238 Hz

Table2: Material property data

Material name	Material Type	Property	Value
Tin free Beryllium Bronze	Isotropic	Mass Density	8.175e-006(kg/mm^3)
		Young's Modulus	120000000(mN/mm^2
		Poisson's Ratio	0.3

4.1 Dither deflection under static load condition

Table3: Dither deflection under static load condition Solution Summary

Solver:	Structures P.E.
Analysis Type:	Structural
Solution Type:	Linear Static's- Multi Constraint
Linearity:	Linear
Time dependency:	Steady-state
Loads (Piezoplategeneratedforces;Figure10)	210N
Constraints	12CSKholesfixedonfourTorsionbars

Material Summary

Material Name	**Material Type**	**Property**	
Tin free Beryllium Bronze	Isotropic	Mass Density	8.175e-006(kg/mm^3)
		Young's Modulus	120000000 MPa
		Poisson's Ratio	0.3(Unitless)

Results Summary:

Number of Steps in the Scenario Results=1

Step Name	**Displacement**	**Magnitude**	**Direction X**	**Direction Y**	**Direction Z**
Sub case Loads, Constrain1	Maximum	1.8563e-003 mm	1.2638e-003mm	1.9462e-04mm	4.920.31e-004 mm
	Minimum	0 mm	-1.1341e-03mm	-1.4285e-03mm	-6.1775e-04mm

Step Name	**Stress**	**Von Mises**	**Maximum principle**	**Maximum shear**
Sub case-Loads, Constraints1	Maximum	19.013 MPa	20.073 MPa	10.149 MPa
	Minimum	1.2575 e-004 MPa	-1.3276 MPa	7.2219 e-005 MPa

V. CONCLUSION

The Dither mechanism is very compact and provides continuous small rotation rate. The dither rotation rate can be varied by varying the voltage applied on the piezo plates. FEA can be used for designing a complicated torsion bar of nonuniform cross section for different applications.

Scope of Future Work:

We plan to test a new set of four super mirrors. In the same time the cavity will be shrunk slightly, from a side length of 1.40m to 1.35m (to account for radius of curvature of the new mirrors). The new mirrors will be of better quality—with less backscattering—than the current ones, improving the performance of the system. In the end, two ideas are intriguing us: the first is the purchase of a second piezoelectric transducer that could open new possibility. The second is more radical: the change to a passive ring cavity, with a laser externally injected. This should overcome any trouble with backscattering, since of course is a very different system.

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SAMPLE AUTHORS BIOGRAPHY

Penumarthi Chandra Sekhar Kumar was born in Vijayawada, India, in 1991. He received the Bachelor of Technology, Mechanical degree from the Universityof JNTU Kakinada, Vignans Engineering College, Vadlamudi, in the year of 2012, he is pursuing Master degree in Thermal Engineering in Kallam Hrinathreddy institute of technology from university JNTUK. His interests are doing a research in design side.

HARATAM ANIL KUMAR was born in Srikakulam, Andhra Pradesh, India,in 1988. He received the Bachelor inAeronautical Engineering degree from the University of JNTUNIVERSITY, KAKINADA, in 2013 and the Master in Naval Architecture and Marine Engineering degree from the University of Andhra University in 2015. His research interests include in ship structures, CFD and Hydrodynamics.

Marella Sai Chandra was born in Guntur, India, in 1991. He received the Bachelor of Technology degree from the JNTU Kakinada, in the year 2012, Masters Degree (M.Tech) from the JNTU Kakinada, in the year 2016, both in Mechanical Engineering. His research activities are doing the CFD and Design of Machine Components.