Variation of a Resonant Frequency Due to Static Structural Loads on a Ring Laser Gyroscope with Mechanical Ring Dither

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Abstract - *Ring Laser Gyroscope (RLG) has been used as an instrument to measure angular rotation about its axis for inertial navigation system and it operates according to the principle of Sagnac effect. The main problem in ring resonator is at very low rotation rates the frequency coupling of two opposite propagating waves takes place known as lock-in phenomenon. In this region, RLG will not give any phase difference between the two waves and an angular increment is not detected. To overcome this problem Mechanical ring dither is implemented to eliminate lock-in region. This paper presents Variation of a resonant frequency due to static structural loads on a RLG with Mechanical Ring Dither, Modeling and Analysis of a Mechanical Ring Dither is carried out using UNIGRAPHIS(NX) and ANSYS work bench software to evaluate the change in resonant frequency of RLG with the application of boundary conditions and preloads with suitable materials.*

Key Words: **Angular rotation, Saganc Effect, lock-in Phenomenon, Mechanical Ring Dither.**

1. INTRODUCTION

In today's world one of the most difficult sensing is accurately sensing three dimensional movements in a space. An inertial navigation system (INS) is a process monitoring and controlling the air craft position and that uses a computer, linear motion sensors(accelerometers) and rotation sensors(gyroscopes) to continuously calculate via dead-reckoning the position, orientation, and velocity of a moving object without any external references. Gyroscopes are used to determine pitch, roll and yaw(rotation about a corresponding axis) of any object moving in three dimensional spaces.

In past INS were carried out with the mass-spinning gyroscopes by calculating the effects of coriolis inertial forces to determine angular rotation, but in the present scenario all mass-spinning gyroscopes are replaced by (optical) ring laser gyroscopes because of no moving parts and high sensitivity, which works on principle of sagnac effect. Laser beam with ring cavity can be used to measure angular rotation with great accuracy and precision and these sensors show a wide range and fast update rate and it is vibration insensitive and have a long and reliable life about 10 years or operating life 10,000 hours and maintenance free.

1.1 GYROSCOPE

A gyroscope is sensor used to measure angular rotation about its fixed axis. They were first developed for aerospace and military systems but in the present scenario gyroscopes have very wide range of application such as automotive, ships and robots. In 1817 the first gyroscope was invented by German Johann Bohnenberger and he called it as a machine but it was based on a rotating massive sphere. In 1832 American Walter R. Johnson developed similar device based on rotating disc.in 1852 Foucault used an experiment involving the rotation of earth and eventually he found the rotation of the earth.

1.2 RING LASER GYROSCOPE

In 1963 the first ring laser gyroscope was demonstrated in US by Macek and Davis, later Georges Sagnac showed that laser beam is split and sent in two opposite directions around a closed circular path on a revolving platform with mirrors on its perimeter, and then the beams are recombined, they will exhibit interference effects. From this experimental result Sagnac concluded that light propagates at a speed independent of the speed of the source. The motion of the earth through space had no apparent effect on the speed of the light beam, no matter how the platform was turned. The effect had been observed earlier (by Harress in 1911), but Sagnac was the first to correctly identify the cause. This sagnac effect (in vacuum) was theoretically predicted by Max von Laue already in 1911. He demonstrated that such an effect is consistent with stationary ether theories (such as the Lorentz ether theory) as well as with Einstein's theory of relativity. It is normally taken to be inconsistent with a complete ether drag, and also inconsistent with emission theories of light, according to which the speed of light depends on the speed of the source.

1.3 SAGNAC EFFECT

In a Sagnac interferometer, two oppositely propagating beams, i.e. clockwise and counter clock wise are started travelling from same source and propagate inside the interferometer along same closed path . The difference in optical path between the two waves produce output interfere fringe pattern known as phase difference is directly proportional to the rotational rate Ω.

1.4 Working of RLG

RLG works on principle of sagnac effect and it consist of resonator block made in square or triangular shape with a ring cavity. Cathode and anodes are fixed to the resonator to provide gain for the lasing medium. The lasing medium is generally a mixture of helium-neon typically in the range of 5:1 to 20:1 and filled with a pressure 5-10 Torr. Mirrors are mounted on the resonator block as shown in figure1, So that the two beams can be constrained to travel around the cavity. The ring laser cavity size is adjusted to support oscillation at frequencies optimal to the lasing media. This difference in frequency between the two travelling waves is called beat frequency.

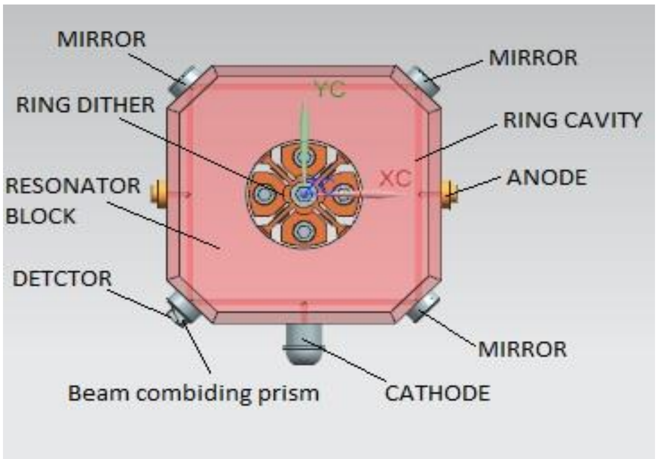

Fig -1: Working of RLG

$\Delta f = 4A\Omega/L\lambda$

Where, A is area of ring laser cavity, L is path length of laser light, λ is wavelength of light in lasing medium and Ω is angular rate of rotation. The ratio $4A/L\lambda$ is known as scale factor of gyroscope. Beat frequency (Δf) is directly proportional to rate of rotation Ω. The output of ring laser gyroscope is developed by use of a combining prism which produces two nearly collinear beams interfering to create fringe patterns sensed by the photo detectors. The number of beats during a time interval is directly proportional to the rotation rate and the direction of fringe movement indicates the rotational direction.

1.5 LOCK-IN EFFECT

At low rotation rates of gyroscope the frequency coupling mechanism arises from back scattering of the mirrors. This effect gives no phase difference and hence there is no detection of angular rotation. The lock-in effect can be removed by using dither mechanism. The dither mechanism is carried out by applying electric filed on piezo plates which are mounted on mechanical ring dither.

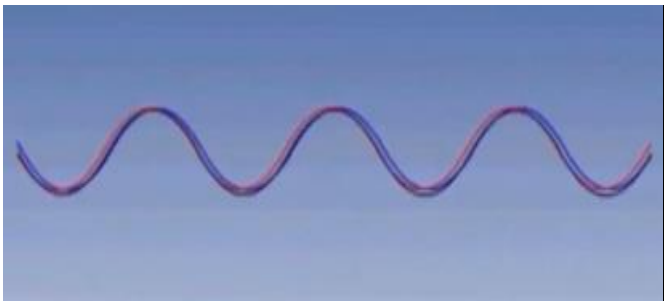

Fig -2: COUPLING OF LASER BEAMS(lock-in)

1.6 ADVANTAGES OF RLG

RLG are vibration sensitive and have a long and reliable lifetime because they have no moving parts compare to spinning gyroscope. The reaction time to respond to rotation rate is quick. They provide digital outputs linear with angular rotation.

1.7 DISATVANTAGES OF RLG

At very low rotation rates, difference in frequency between two beams causes injection locking. RLG assembly time is very high because of its sensitivity. Size and weight are the limiting factors.

2. FINITE ELEMENT ANALYSIS

The FEA was first developed by Richard Courant in 1943. In FEA a complex domain is divided into simple geometric shapes called finite elements and it has several advantages. To reduce the amount of prototype testing and additionally Cost-time are saving. Modeling and FEA of ring laser gyroscope is done using UNIGRAPGHICS (NX) and ANSYS work bench software's.

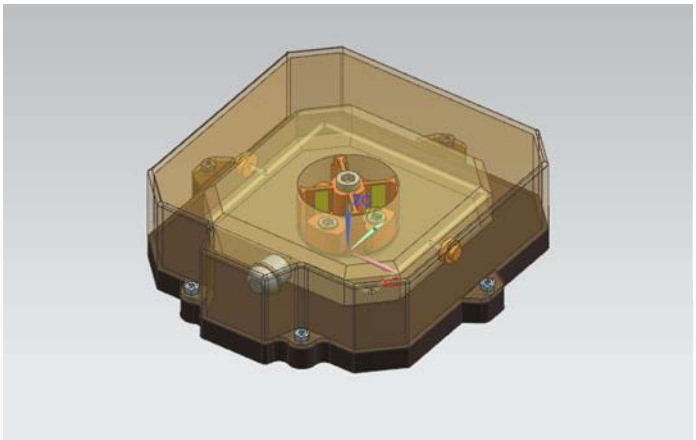

Fig -3: RLG Unigraphic model.

2.1 Steps followed in FEA.

Stesp1: Modal analysis is carried out for the NX model with boundary conditions and suitable materials as show in table1. In this entire analysis element type tetrahedron is used for meshing the model. Modal analysis is very important and preliminary dynamic analysis to determine structures vibration characteristics like natural frequencies, mode shapes, allows the model to vibrate at a specified frequency or to avoid resonant frequency and only first mode frequency is considered. In our case mechanical ring dither has to vibrate at a natural frequency to keep the system in resonant and also gives an idea of how the model will respond with different types of dynamic load conditions.

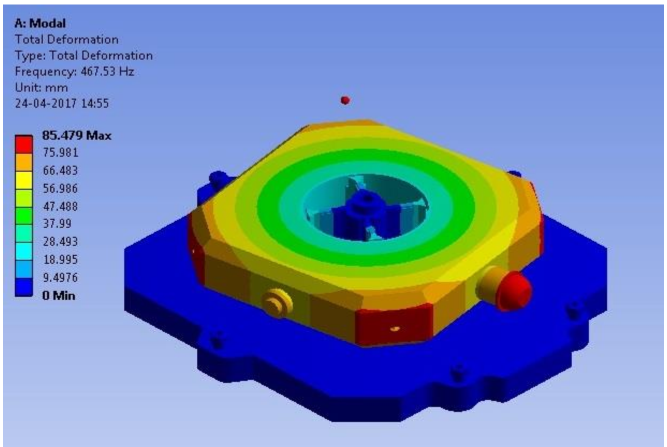

Fig -4: Modal analysis on RLG with 467.53Hz frequency

Table -1: Material Property of RLG

Material property				
component	Material	Density (kg/m^3)	Poisons Ratio	Young's modulus (Gpa)
Resonator block	Zerodur	2530	0.243	90
Dither	Super Invar	8150	0.32	140
Base plate & shield	Aluminum alloy	2794	0.33	73
Piezoelectric ceramic	PZT-SP5A	7650	0.31	70
Electrode (anode)	copper	8912.9	0.31	129

Step2: Static structural analysis is carried out with the same model. In static structural analysis a force of 2142N is applied on the four screws of the mechanical ring dither and another force of 1904N is applied on the center screw in order to develop the pre-stresses in the model. Later the static structural model is further carried out with model analysis to find the variation in a resonant frequency.

Step 3: More accurate results can be obtained by increasing the number of elements in the model. The name for the h-method is borrowed from mathematics. The variable h is used to specify the step size in numeric integration. If a part is modeled with a very course mesh, then the stress distribution across the part will be very inaccurate. In order to increase the accuracy of the solution, more elements must be added by creating a finer mesh. In this analysis element type tetrahedron is selected to generate mesh for the model and separate fine body sizing mesh is given to the dither model as shown in table2 to increase the accuracy of the solution.

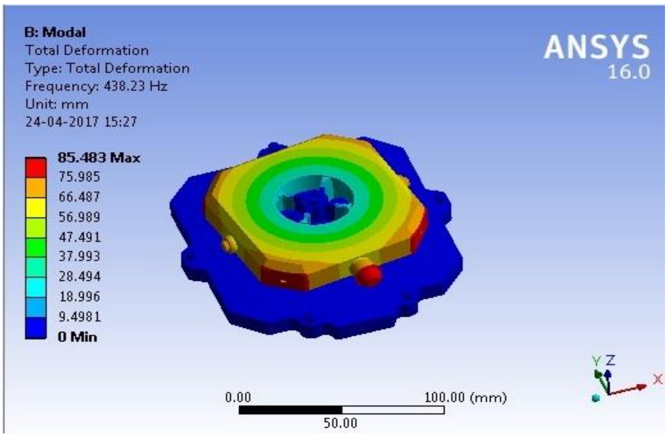

Fig-5: Static structural-model analysis with 438.23Hz frequency

Table -2: Structural resonant frequency with respective to element size

Dither element Size	No. of nodes	Resonant frequency (Hz)
8mm	140569	562.49
6mm	141092	490.06
4mm	141494	478.79
2mm	157266	451.83
1.5mm	178955	455.22
1.2mm	213314	440.66
1mm	262893	438.23

3. CONCLUSIONS

Study carried to find the variation of resonant frequency in modal and static structural analysis, the resonant frequency 438.23Hz will unlock the coupling of the two laser beams and it keeps the system in resonant condition and also from the table 2, it is clear that by increasing the no. of nodes or no. of elements of the model, the solution is moving towards convergence.

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