Structural Analysis and Optimization of Fiber Optic Gyro based Sensor Package Unit (FSPU) for Missile Control Applications

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Abstract

Opto-mechanical packaging Fiber Optic Gyroscopes (FOG) and systems based on FOG is a big challenge of today's world owing to the complicated and extremely stringent end use requirements. In this paper we describe the step by step procedure involved in the development of mechanical package for FOG based Sensor Package Unit (FSPU) for missile control applications. FSPU consists of three single axis control grade FOGs and two dual axes MEMS accelerometers mounted in an orthogonal triad. In the preliminary FSPU designed, one of the FOG outputs shifted from the mean to an intolerable level, during random vibration test, indicating higher responses at that FOG mounting location. Limitations and faulty designs under lied in the initially designed unit were unearthed through actual dynamical testing and verified through FEM analysis. Based on it, certain modifications are made in the design through FEM analysis. Modified package was put to random vibration test and higher amplification observed in the initial design was brought down to acceptable level. Optimization of the package was also done for reducing weight, increasing strength, better thermal management of PCBs and power supplies, high structural integrity and enhancing flexibility in packaging. Different materials are also taken into considerations for better damping conditions and low weight. Detailed analysis and test results are included in the paper.

1. INTRODUCTION

A sensor package unit (SPU) based on fiber optic gyroscope (FOG) meant for control application in a missile system has experienced severe amplification of vibration levels in the structure and intolerable performance degradation when subjected to random vibration excitation. The package consists of three FOGs and three MEMS accelerometers receives the dynamic acceleration load in form of vibration, which originates from the aerodynamic forces and propellant thrust during flight. One of the FOGs mounted along the yaw axis experienced a vibration level of 111 g_{rms} for an input of 23 g_{rms} showing amplification factor of 5 when it is tested in random vibration environment and its output mean value shifted drastically during vibration. After exploring through different possibilities of structural modification an optimum package configuration has been arrived at through successive iterations making use of Finite Element Method (FEM). The package is re-fabricated by incorporating the recommended modifications and tested for better structural dynamics. From the analysis of proposed configuration the amplification factor is observed to be 1.3 indicating the design is safe.

2. DESIGN REQUIREMENTS OF THE SPU

- The vibration level on any of the FOGs should not exceed 30 g_{rms} since the light source used in FOG may malfunction at higher vibration levels
- There should not be any appreciable amplification on PCB mount in order to ensure safe functioning of the electronics.

3. PACKAGE DETAILS

Total package comprises of three control grade FOGs mounted over mounting panels along three orthogonal directions, two dual axis MEMS accelerometers strapped down on a rigid rectangular blcok, DC-DC convertor, driving and processing electronics and interfacing connectors. Exploded view of the initially designed package is shown in fig 1

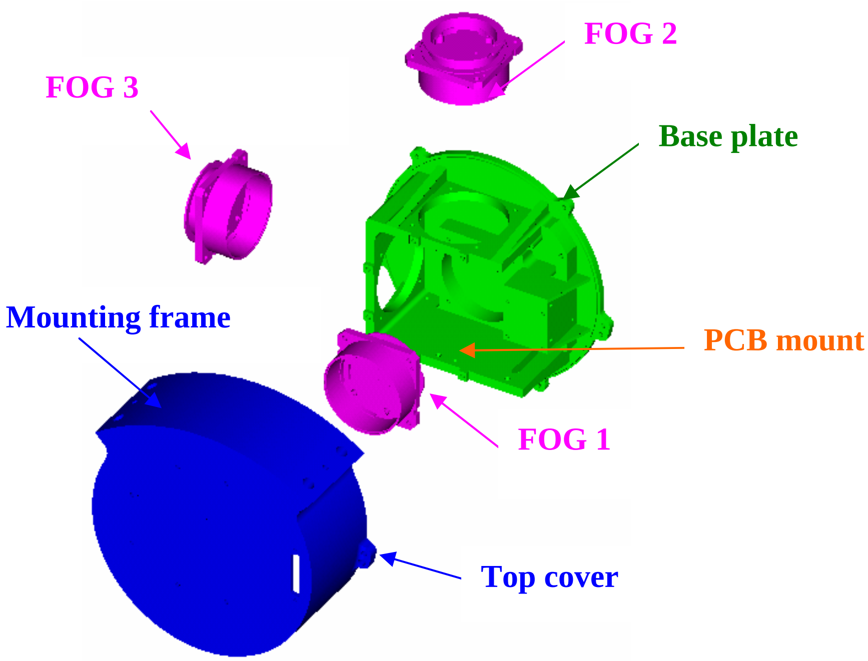
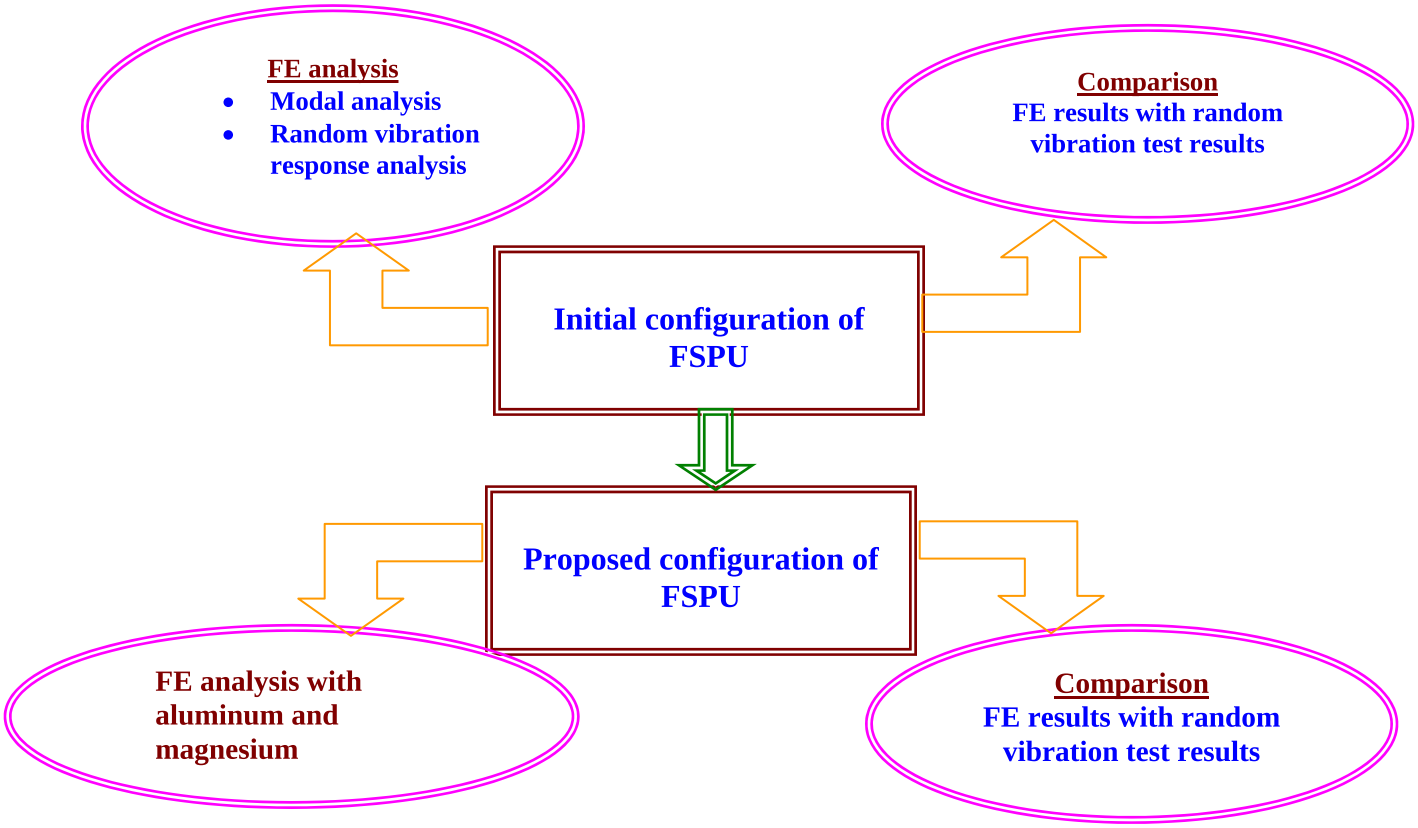


Figure 1 Exploded view of FSPU (initial design)

4.0 ANALYSIS APPROACH

The analysis approach is represented in form of flow chart as shown below.



5.0 ANALYSIS OF SENSOR PACKAGE - INITIAL CONFIGURATION

Random vibration response analysis is carried out using Finite Element Method (FEM).

5.1 FE Modeling

Most of the subsystems of the assembly are discretized using linear 4-nodded quadrilateral shell elements having six DOF per node, where as the mounting frame and supporting wall for FOG 1 are discretized using 10 nodded solid parabolic tetrahedron elements. Restraint set has been defined at 6 holes on the periphery of base plate to represent mounting of the sensor package to the airframe. Aluminum alloy material properties are considered for the FE model.

5.2 Modal analysis

The FE model is solved for modal frequencies using Lanczos iteration method and all the modes are extracted with in the frequency range of 20-2000 Hz. The linear behaviour of the structure is assumed in the selected frequency range of interest. The fundamental frequency is found to be 514 Hz. The FE model and first mode shape associated with fundamental frequency are shown in Figure 2.

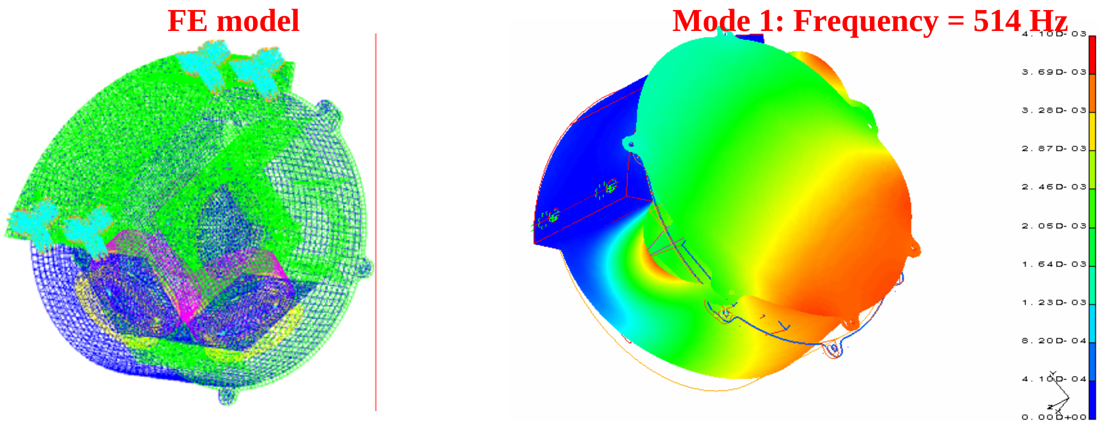


Figure 2 -FE model and first mode shape of the package

5.3 Random vibration response analysis

The same FE model of the package used for modal analysis is extended for random response analysis. The input spectrum is applied as base excitation at those 6 locations where it is mounted on to airframe in a direction normal to the base plate. A constant damping ratio of 0.5 %, which is observed from the modal test, is considered for the analysis. Random vibration responses are obtained on all three FOGs units and PCB. The input spectrum and typical response spectrum obtained on FOG 1 is shown in Figure 3.

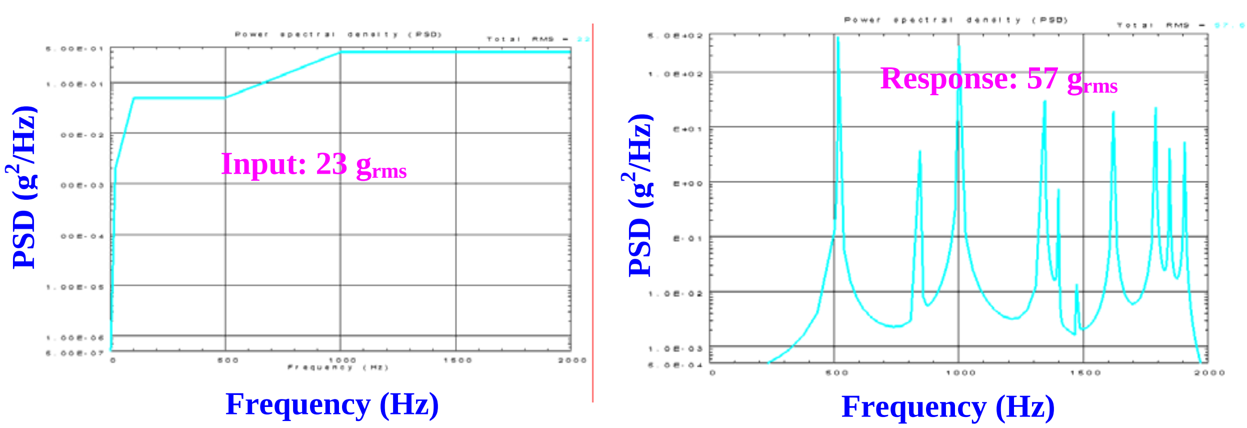


Figure 3 – Comparison between the input and response vibration spectra

The response levels obtained using FEM are compared with that of random vibration test as shown in Table 1.

Table 1 Comparison between FEM and test results

	FEM		Random vibration test	
	Response	**Frequencies (Hz)**	**Response**	**Frequencies (Hz)**
FOG 1	57 g_{rms}	514,844,1345, 1842	41 g_{rms}	500,700,1300, 1850
FOG 2	48 g_{rms}		43 g_{rms}	
FOG 3	116 g_{rms}		111 g_{rms}	
PCB mount	37 g_{rms}		34 g_{rms}	

5.4 Observations

- The vibration response levels obtained using FEM and random vibration test are in good agreement.
- It is observed that the top cover being the weakest link is driving the base plate at high frequency, as the mounting frame is integral to the top cover.
- A maximum amplification of 5 times is noticed in vibration response measured on FOG 3 as shown in Figure 4.
- As the mounting frame is near to FOG 2, PCB mounting wall which is on other side is experiencing cantilever action due to which the response is high (34 g_{rms}) against the design constraint (30 g_{rms}).

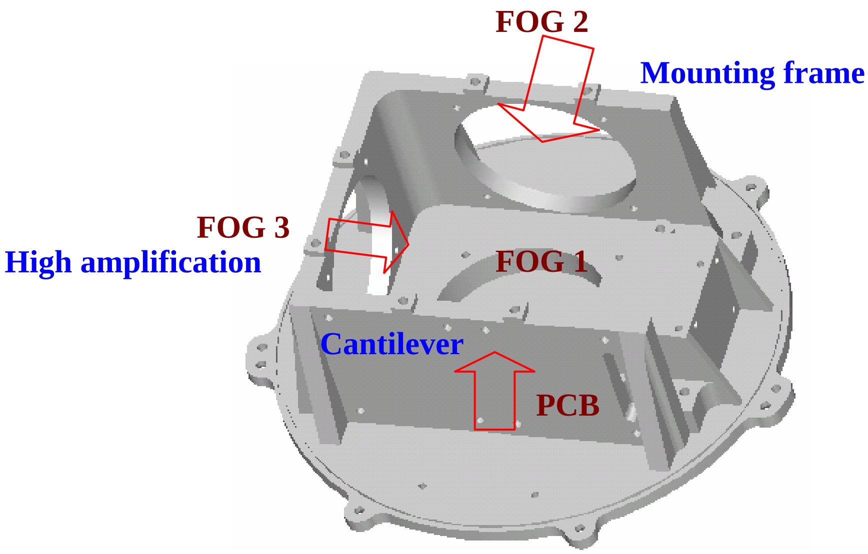


Figure 4 - Location of maximum amplification

6.0 PROPOSED CONFIGURATION

As the vibration levels observed in earlier configuration of the FOG based sensor package unit (FSPU) are not meeting with design requirements, the design of top cover and base plate are suitably modified. The mounting frame is relocated from top cover to the base plate as the top cover is observed to be the source of excessive vibration. While changing the mounting frame from the top cover to the base plate it has been relocated from FOG 2 side to PCB side to avoid the cantilever action noticed on PCB in the earlier configuration. In addition to this PCB mounting wall is supported on either side from mounting frame. Earlier and proposed configurations of base plate and top cover are shown in Figure 5.

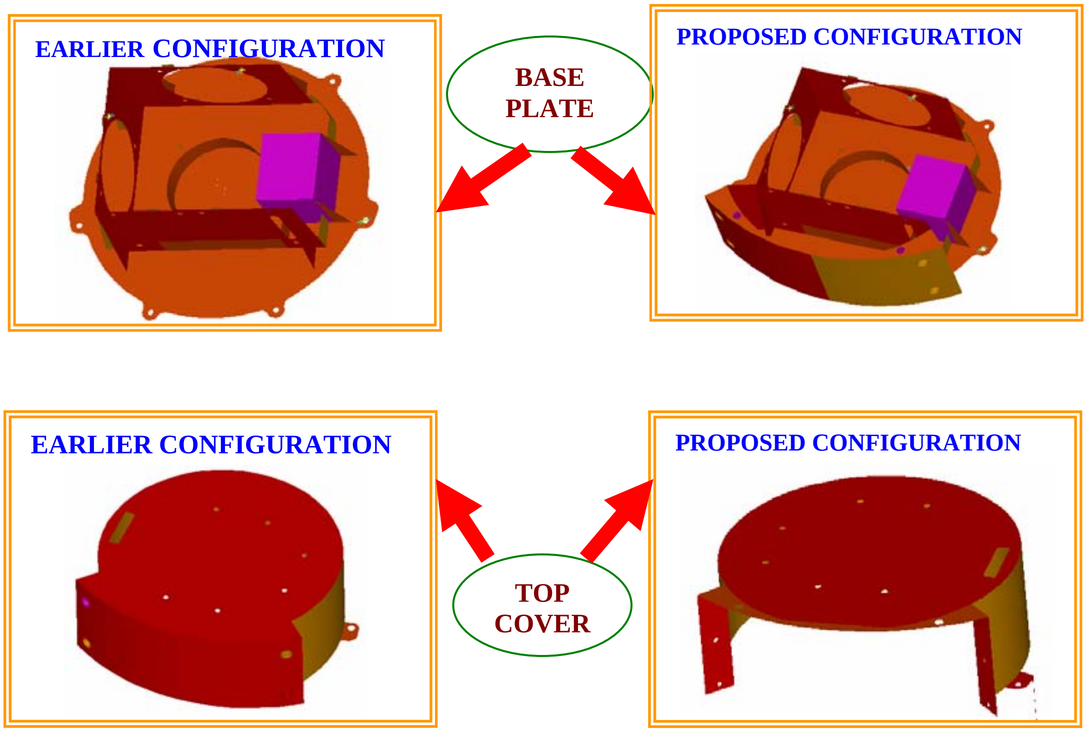


Figure 5 -Earlier and proposed configurations of base plate and top cover

6.1 Analysis of FSPU - Proposed configuration

Proposed configuration of FSPU is analyzed for random vibration response using Finite Element Method (FEM). FE modelling details are same as that of earlier configuration. Analysis has been carried out by considering both aluminium and magnesium as package materials. The FE model is solved for modal frequencies and the fundamental frequency of the structure is found to be 569 Hz. The same FE model is extended for random vibration response analysis against the specified input same as that applied for earlier configuration. The package is re-fabricated with aluminium while implementing the recommended modifications and tested. The responses obtained using FEM for proposed configuration of the package are compared with that of the earlier configuration in Table 2.

Table 2- Comparison of vibration responses between earlier configuration and proposed configuration of FSPU

Component	**Earlier Configuration – FEM (Aluminium)**	**Proposed Configuration**		
		FEM (Aluminium)	**Vibration Test (Aluminium)**	**FEM (Magnesium)**
FOG 1	57 g_{rms}	47 g_{rms}	25 g_{rms}	30 g_{rms}
FOG 2	48 g_{rms}	30 g_{rms}	38 g_{rms}	27 g_{rms}
FOG 3	116 g_{rms}	40 g_{rms}	51 g_{rms}	23 g_{rms}
PCB mount	37 g_{rms}	23 g_{rms}	27 g_{rms}	23 g_{rms}
Weight	2.89 Kg	3 Kg		1.9 Kg

6.2 Observations

- The vibration response levels obtained using FEM and random vibration test for aluminum based SPU are in good agreement.
- FEM analysis showed excellent results for Magnesium based FSPU package, as expected, owing to higher material damping of Magnesium alloy.
- The discrepancy in response level observed on FOG1 may be due to discretization of the supporting wall for this unit with solid elements.
- Though the FE analysis of proposed configuration with aluminum did not exactly meet the design requirement, test is carried out to study the influence of structural modifications as the fabrication with magnesium is in progress.

7.0 CONCLUSION

The FOG based sensor package when tested in random vibration environment has shown five times amplification of vibration levels and performance degradation of the individual FOGs. Based on the FEM analysis the structural modification has been carried out by changing the unit mounting from the weaker element (cover plate) to stronger structure (base plate). When modified package made of Aluminium alloy was tested for the same input spectrum, amplification levels reduced drastically and the test results were well in agreement with the finite element analysis results. Optimization of the package to reduce the weight has been achieved by selecting Magnesium alloy as the package material, which also helped to further bring down the response level through its higher damping characteristics.

FUTURE WORK

Proposed configuration of the sensor package unit with Magnesium alloy will be tested for random vibration environment, as the actual model is ready.

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