Design and Analysis of High Precision Opto-Mechanical System for Space Application

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Abstract— Star sensor is one of the Opto-Mechanical systems. Star tracker/ Star Sensor is an aerospace navigation instrument used to provide absolute 3-axis attitude information to the spacecraft. A "Lost–in-space" case may develop if there is no accurate attitude determination. Hence there is a requirement attitude determination device of maximized accuracy, reliability, life time and optimized mass, size and cost. A wide variety of attitude sensor exists but this is a new design of Opto-Mechanical system. Star sensors have numerous advantageous over other attitude detectors because of their ability to provide 3 axis orientation information with high accuracy. Star sensors are the most accurate attitude determining devices. Finite Element Method is used to analyze Opto-Mechanical System which is a part of navigation system. This assembly is analyzed for mechanical loading. Star Sensor is analyzed for 4 mechanical load cases. Geometry and loading are specified by LEOS (ISRO). The displacement and Von-Mises stresses are presented. UG NX 7.5 is used for CAD modeling and Analysis. Maximum stresses are observed at the bolt locations (localized stresses) and can be neglected.

Key words: Opto-Mechanical, Star Sensor, Quasi-Static, Von-Mises, Aluminum 6061, Localized Stress, Deflection

I. INTRODUCTION

Indian Space Research Organization Laboratory for Electro Optics Systems (LEOS) is engaged in design, development and production of Electro-Optic sensors and camera optics for satellites and launch vehicles. The Opto-Mechanical Systems include star trackers/sensors, earth sensors, sun sensors, magnetometers, horizon sensors & processing electronics. [1]

LEOS is actively involved in the development of new technologies for present / future satellites. This includes development of Star Sensor assembly which is a component of the satellite.

Star Sensor is a navigation device which gives attitude information of the space craft. It consists of imaging Charge Coupled Device (CCD) and associated processing electronics. As outcome of advancing state-of-the-art, new generation star sensor features faster, lower cost, power dissipation and size than the first generation star sensor. [2][3]

The camera in the star sensor is used for star image acquisition. The star image is then sent to the onboard computer which processes it to determine star identification. Once the star in an image has been identified, orientation and attitude can be inferred based on which stars are in view and how these stars are arranged in the star pattern.

A star sensor compares predetermined star information stored in a memory and actual star information corresponding to star image signals from an imaging device. A processing device generates an attitude signal corresponding to the attitude of spacecraft with respect to the star when the predetermined and the actual star information substantially coincide. A connecting device connects the predetermined star information when the predetermined star information and the actual star information are not substantially the same.

The basic principle: the energy from the target star is collected by a set of optics and brought to focus for electronic scanning or mechanical modulation. A photo detector then transduced the modulated star energy into an electrical signal that contains information on the star presence and the angle of the star direction relative to the optical axis. The latter is used as a tracking signal. [2] [3]

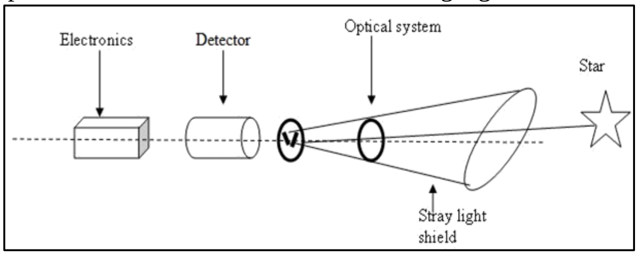


Fig. 1: Basic working principle of star tracker

A. Introduction to UG NX

Unigraphics NX is an advanced CAD product, and not a general purpose CAD solution. NX is used by various diversified industries. Since it is integrated with all stages of product development, it can vastly improve design, simulation and manufacturing productivity. It can help you develop better products much faster. UG-NX Nastran can be used to design, analyze, and optimize structures and mechanical systems. [4]

In this project UG NX 7.5 is used to design and analyze the component. Finite element solution includes Static Analysis.

A typical set of finite elements including shell, solid, bar, scalar mass and rigid elements as well as loads and materials are available for modeling complex events.

II. MESH MODEL DETAILS

The meshing of Star Sensor assembly is carried out in UG NX software. Total number of elements and nodes used to create the FE model of Star Sensor Assembly is 426232 elements and 140693 nodes. Total number of degrees of freedom in the Star Sensor Assembly is 581,262.

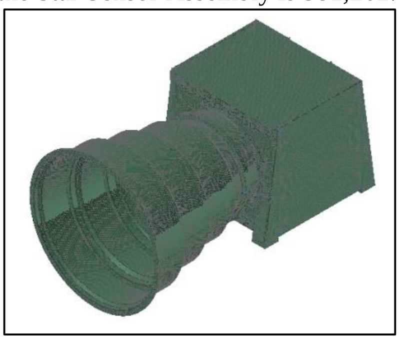


Fig. 2: FE model of Star Sensor assembly

The Star Sensor assembly is modeled with both solid and shell elements, meshed according to the geometry & the components like optics housing, Baffle, are connected to the Structure through the rigid elements at the specified locations and properties are not created for the point mass. During the meshing of the PCB the total mass of the PCB is equally distributed through-out the PCB and the total mass of the optics assembly is equally distributed through-out the optics housing. The total weight considered for the FE analysis is 2221.04 grams. Beam elements along with the rigid elements are used for connecting/fastening baffle assembly and optics assembly to the detector assembly, also the similar type of elements are created at the four mounting points/holes of the detector housing. The FE modeling of Star Sensor assembly is shown below.

Materials	Components	Density (N.sec^2/mm^4) *10-9	Young's Modulus (N/mm^2)	Poisson's Ratio	Thermal conductivity W/mm°k*10^{-3}	Linear Coeff. of Expn *10-6/°k
Aluminum Alloy 6061T6	Detector and baffle housing & Cover	2.71	71000	0.334	204	22.9
FR4	PCB	1.9	61000	0.25	0.28	100
Titanium Ti6Al4V	Optics housing	4.43	11400	0.34	6.6	8.8
Steel	Bolts	7.8	21000	0.3	20	15

Table 1: Material Properties for Structural & Thermal Analysis [6]

A. *Meshing and Element Data*

The table below describes the mesh and element considered for FE Analysis

	Electro-Optical Sensor assembly
No of nodes	140693
No of Element	426232
No of Rigid Element	142
DOF	581,262

Table 2: Finite Element Model Data

B. *Opto-Mechanical System Mass Distribution Calculation*

The below table describes the masses considered for the FE analysis.

Components	Mass
Detector housing	1.1224 kg
Housing	0.816 Kg
Baffle assembly	0.394 kg
Optics assembly	0.305 kg
PCB	0.294 kg
CCD	0.104 kg
Detector Plate	0.135 kg
Top plate	0.045 kg
Bottom plate	0.045 kg
Left plate	0.041 kg
Right Plate	0.041 kg
Star Sensor Assembly total Mass	2.22014 kg

Table 3: Mass of Individual Components used for Opto-Mechanical System

III. FE ANALYSIS

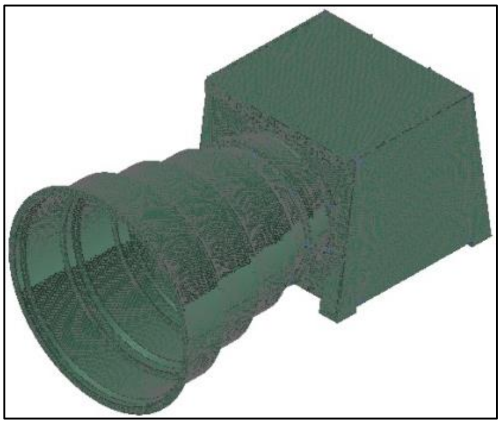


Fig. 3: FE model of Star Sensor Assembly

Electro-Optical Sensor assembly subjected to static loads is analyzed using Finite Element Method and results are presented in this chapter. The FE model of the Star Sensor used to perform the analysis is shown in Figure 3.

A. *Units Followed for FE Analysis*

- Length: mm
- Time: sec
- Mass: Kilogram
- Force: Newton
- Acceleration: mm/sec2
- Stress: MPa
- Temperature: deg Celsius

B. *Assumptions*

- Structure is assumed to be Homogeneous & Isotropic.
- PCB is modeled as shell element because of uniform thickness and behaves like a plate.
- Housing, top cover, bottom cover; side plates are modeled with 3D solid elements to capture the complex shape of the structure (because of thickness variation).
- Bolts are modeled with Elastic beam elements (rigid elements are used for connecting bolt to the housing).

C. *Boundary Condition*

The Opto-Mechanical System is fixed at the four nodes representing the four M6 screws as shown in Figure 4.

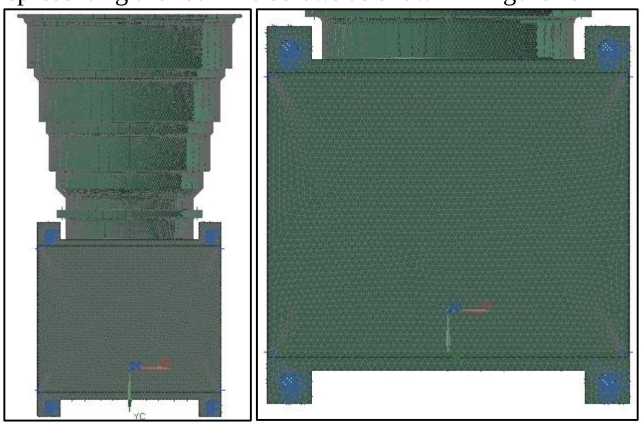


Fig. 4: Boundary condition

IV. QUASISTATIC ANALYSIS

As the cover plates do not carry load they are glued to the housing and simulation is done for 60g quasi static load.

A. *Quasi-Static Load of 60G in X Direction*

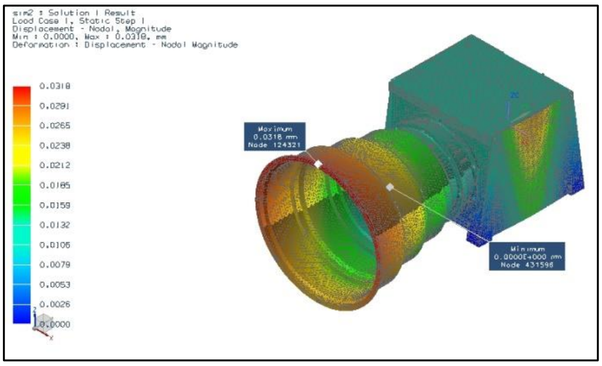


Fig. 5: Displacement contour (Max. 0.0318 mm)

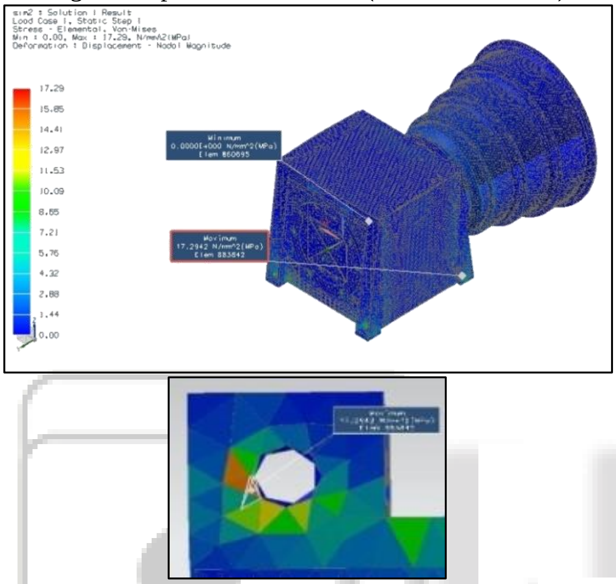


Fig. 6: VonMises stress contour (Max. 17.29MPa)

B. *Quasi-Static Load of 60G in Y Direction*

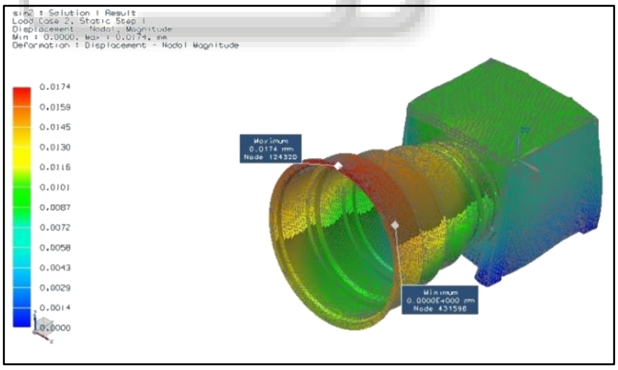
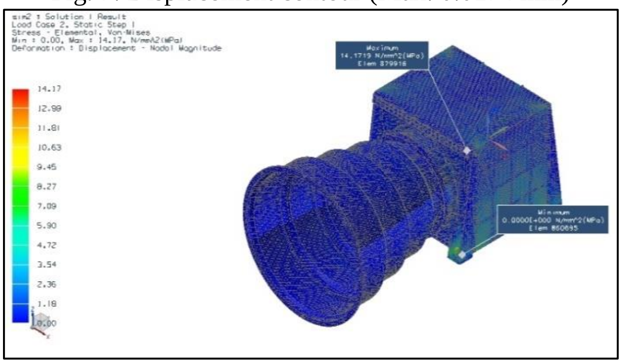


Fig. 7: Displacement contour (Max. 0.0174 mm)



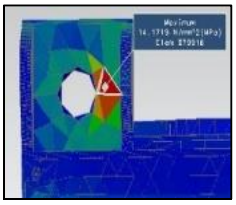


Fig. 8: VonMises stress contour (Max. 14.17MPa)

C. *Quasi-Static Load Of 60G in Z Direction*

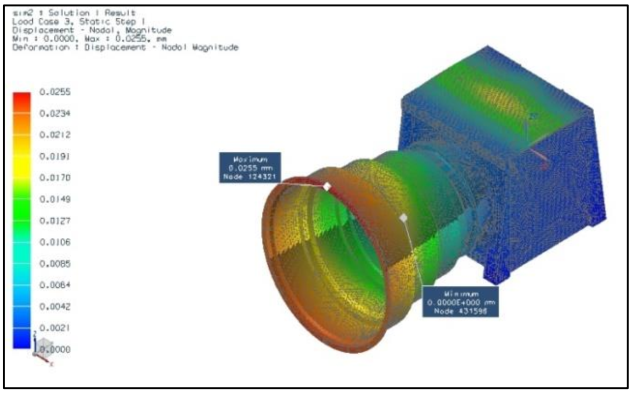


Fig. 9: Displacement contour (Max. 0.0255 mm)

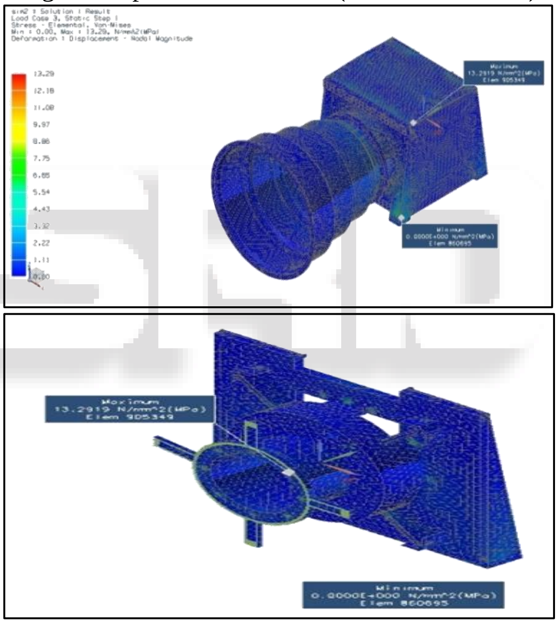


Fig. 10: Von Mises stress contour (Max. 13.29MPa)

V. QUASI-STATIC LOAD OF 60G IN X, Y AND Z DIRECTIONS SIMULTANEOUSLY

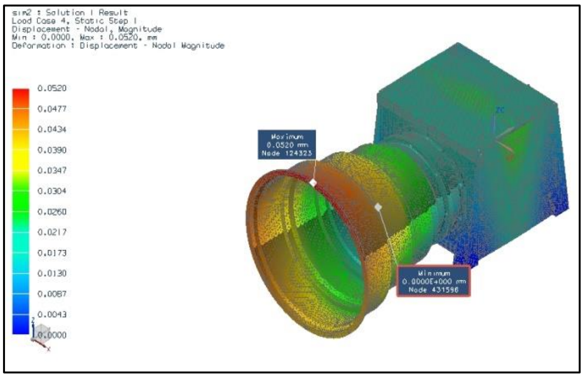


Fig. 11: Displacement contour (Max. 0.0520 mm)

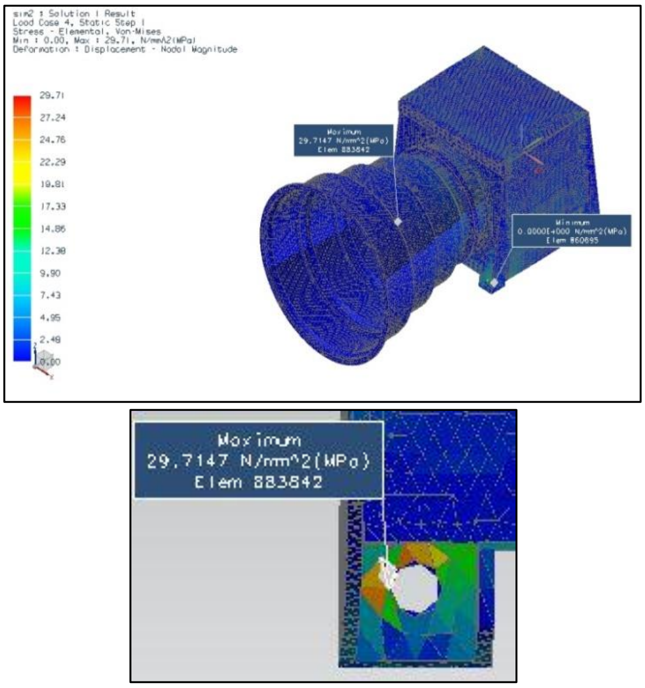


Fig. 12: VonMises stress contour (Max. 29.71MPa)

VI. Observation

The below Table 4 and Table 5 shows the VonMises stresses and displacements respectively in the Star Sensor Assembly.

Von-Mises stresses (MPa)				
	X Axis	Y Axis	Z Axis	ALL Axis
Opto-Mechanical System	17.29	14.17	13.29	29.71

Table 4: Von-Mises Stresses

Displacement (mm)				
	X Axis	Y Axis	Z Axis	ALL Axis
Opto-Mechanical System	0.0318	0.0174	0.0255	0.0502

Table 5: Displacement

VII. Conclusion

Results of the Analysis shows that Maximum stresses, 17.29 MPa, 14.17 MPa, 13.29 MPa, and 29.71 MPa are observed at the bolt locations (localized stresses) and can be neglected and the deflections are optimal.

Acknowledgement

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References

[1] Dr. Carl Christian Liebe. Star Trackers Attitude Determination. IEEE AES Systems Magazine, 0885-8985/95/ $4 00 Q 1995 IEEE,, June 1995.
[2] Brij N. Agrawal, Jae Jun Kim, Jack A. Tappe. Development of star tracker system for accurate estimation of spacecraft attitude, Naval Postgraduate School Monterey, California. December 2009.
[3] J. Bebris, R.F. Bohling, F.J. Carroll, R.L. Cleavinger, T.P. Dixon, C.D. Engel, F.F. Forbes, K.V. Knight, A.R. Lesie, F.D. MacKenzie, J.M. McLaunhlan, T.S. Michaels, G.R. Quasius. Spacecraft Star Trackers. NASA Space Vehicle Design Criteria (guidance and Control), NASA SP- 8026. July 1970.
[4] Ming C. Leu, Akul Joshi, Krishna C. R. Kolan. NX7 for Engineering Design, Missouri University of Science and Technology.
[5] Jorge Padro, Captain, USAF. Development of a star tracker-based reference system for accurate attitude determination of a simulated spacecraft. Air University. AFIT/GAE/ENY/12-M32. March 2012. Pg no. 1.
[6] Lingaiah K. Machine Design Databook. McGraw-Hill Education, 1994
[7] Singiresu S. Rao, Mechanical Vibrations, ©2011 Pearson Education, Inc. Upper Saddle River, ISBN 978-0-13-212819-3 (978-0-13-212819-3, Fifth edition, 2010.