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OPTO - Mechanical Design of Imaging Infrared System

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Abstract: **This paper presents the design of an electro optical imaging system. An electro optical imaging system in the infrared consists of IR transmitting lenses, focal plane array sensor, optional cryogenic cooling mechanism and stray light suppressing structures incorporated in a suitable OPTO mechanical housing. Such systems employed in the military are required to operate over a wide temperature range of -40 to +55Centigrade, imposing a severe penalty on the optical material selection. The effect of temperature on the stability of the image needs to be studied. In this paper an OPTO-mechanical housing unit is designed for an IR transmitting optics provided by the system designer. A suitable stray light suppressing mechanism is designed. The design is analyzed for temperature variations. The effect of material CTE on the image location vis-à-vis FPA plane is analyzed. Thermal analysis is performed and results are included. Materials displacement, stress and strain are plotted against the temperature over the operating range. Structural analysis is performed and strain levels are presented.**

Key words: **Imaging Infrared (IIR), OPTO mechanical system, Thermo-optic analysis, Finite element analysis, Ray tracing**

I. INTRODUCTION

Infrared (IR) systems play an important role in tactical and strategic military applications for target acquisition, identification and tracking. These applications include missile seekers, infrared search and track (IRST), forward looking infrared (FLIR), thermal imaging systems etc. the unique feature of IR is its emission by all objects above absolute zero temperature. It is thus possible to see an object by detecting IR emission, rather than detecting reflected radiations from illuminating source.

The imaging infrared system measures very small relative temperature differences within the scene and converts the same into visible images that are seen through either a viewfinder or monitor.

The detector noise limits the performance in the infra red, thus giving a low contrast image. Temperature variations and material expansions in the infrared optical system can cause the image to degrade rapidly and hence, need to be studied. It is necessary to analyze the thermo-optic effects theoretically, and distinguish the errors caused by thermo-optical effects of optical system.

To analyze the thermo-optic effects, the integrated analysis process by finite element analysis (FEA) and ray tracing must be put forward.

This paper presents an OPTO-mechanical system for an infrared imaging module and describes the integrated analysesof thermo-optic effects on an IIR system in complicated temperature conditions.

I. DESIGN OF OPTO-MECHANICAL SYSTEM

The OPTO-mechanical design of an imaging system considers the optical axis alignment by incorporating all the assembly errors while mounting the lenses and/or mirrors.

Figure1: Optics schematic diagram (as input to mechanics design)

OPTO mechanical design consists of an assembly of various components in one or more housing elements. The stability of the system' line of sight depends on the mechanical stability of the components and optical sensitivity of the system. In general, tilt or decanter motion in an optical element will cause the image to shift. Laterally, the sensitivity to motion of the optical element is usually determined using computer simulation in an optical design code.

The present OPTO mechanical housing is divided into three parts for ease of assembly. The components in the housing are front housing, mid housing, rear housing. Front housing is made of Aluminum HE 15, while mid and rear housings are made of Invar36.

The optics consists of four lenses out of which two are mounted in the front housing and other two are in the rear housing. The lenses in the optical system are made of two different materials, they are silicon (L1, L3, L4), germanium (L2). The lenses are held by lock nuts and separated by push fit spacers. Retainers are provided at either ends of the casing. The function of these retainers is to lock the position of these lenses in the assembly. Baffles are designed to reduce and suppress stray light within mid-section.

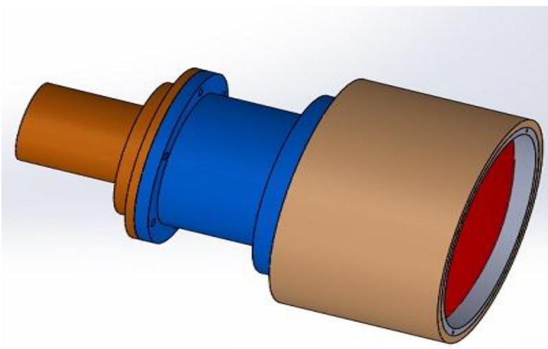

Figure 2: OPTO-mechanical system

Housing has variable diameter at different locations to match the diameter of lenses in the assembly and to reduce overall mass. This casing also acts as thermal wall. Barrel are made of Aluminium HE15 (Al HE15) and Invar.

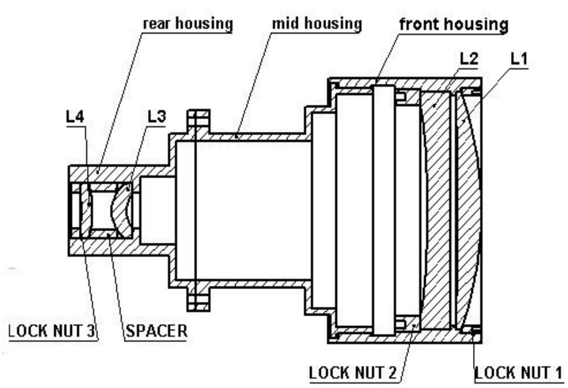

Figure 3: structure of optical system used in IIR seeker

Single scatter stray light occurs when a stray light source such as the sun directly illuminates the optics in the system. Some portion of the light will scatter in a direction that causes it to reach the focal plane. However, it can often be reduced to a level at which it is tolerable. Stray light can be called by another term: optical noise. Just as electrical or acoustical noise can be reduced, optical noise can be reduced by proper design of the OPTOmechanical system.

Table1: Material parameters of optical system

Material	Coefficient of thermal Conductivity (w/mk)	Thermal coefficient of expansion (°C⁻¹)	Young's modulus (Gpa)	Poisons ratio
Al HE15	159	22×10^{-6}	250	0.33
Invar	15	1×10^{-6}	141	0.26
Silicon	149	2.6×10^{-6}	131	0.25
Germanium	60.2	5.9×10^{-6}	102.6	0.26

As there is large variation in the coefficient of thermal conductivity, thermal coefficient of expansion, young's modulus, between aluminium HE15 (Al HE15), invar. So, thermal analysis for focal plane shift and stress analysis for deformation need to be studied.

II. CALCUALTIONS

$\Delta L = \alpha L \Delta T$

ΔL is change in length, α is coefficient of thermal expansion, L is length of the housing, and ΔT is difference in temperature.

III. THERMO-OPTIC ANALYSIS

With the static module of ANSYS, the structure is meshed by high precise element solid 10 nodes tetrahedral. There are 8755 elements and 18273 nodes in the model of the structure, as shown in Figure 4. In the analysis, it is presumed that the reference temperature is 27 °C.

Instead, a hybrid approach was used for generating the initial ANSYS geometry and complex 3D solid parts were modelled in solid works. Solid model saved in neutral format was then imported to ANSYS for assembly meshing.

For the assembly of barrel maximum and minimum temperatures are used at the top and bottom of the barrel respectively. Then analysis was run in ANSYS which generated interpolated temperatures at every node in the model. The output from this run can be used as load input for structural analysis.

The next step was thermo-elastic analysis. The deformations were calculated undergoing the temperature field obtained in this step, and the displacements of FEA elements were obtained.

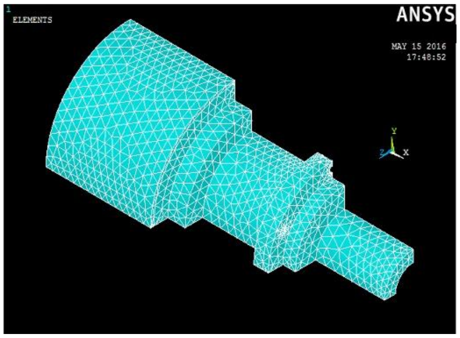

Figure 4: FEA model of optical system.

The thermal analysis is performed from the temperature range -40 to +55 centigrade (233-328K). Analysis was carried out in two steps, from room temperature to maximum temperature and minimum temperature to room temperature.

In the first step outer temperature is taken as 328K and inner temperature taken as 300K. In the second step, outer temperature is considered as 233K and inner temperature taken as 300K.

1.233-300K

2.300-328K

1.233-300K

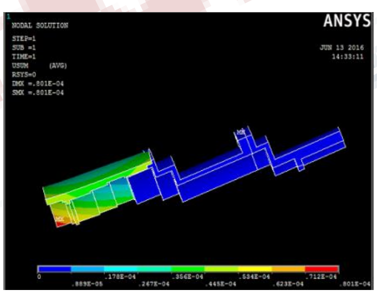

Figure 5: Displacement

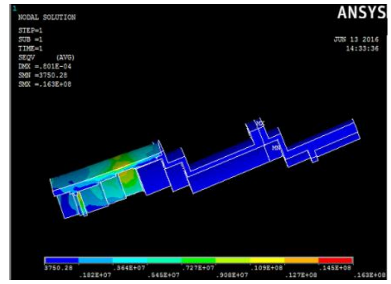

Figure 6: Von MISES stress

Figure 5, 7 shows displacements and strain distribution in the barrel when it is exposed to -40 centigrade temperature.

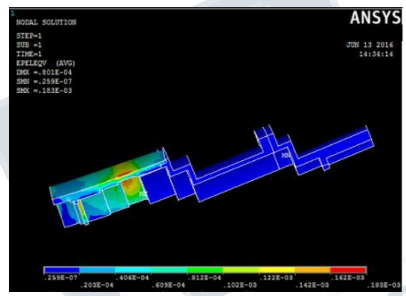

Figure 7: Von MISES Strain

It can be noted from the figures 6 and 7 that von MISES stress and von MISES strain values are small having maximum at gimbals mounting location. When housingisexposed to -40 centigrade system has maximum displacement in axial direction and minimum in lateral direction. There is maximum displacement in the front housing than mid and rear housings because of difference in the coefficient of expansion (CTE).

2. 300-328k

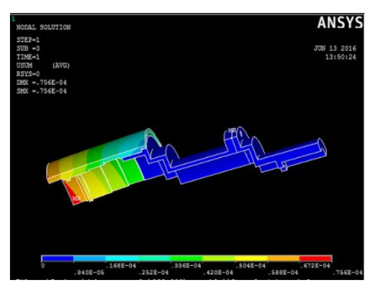

Figure 8: Displacement

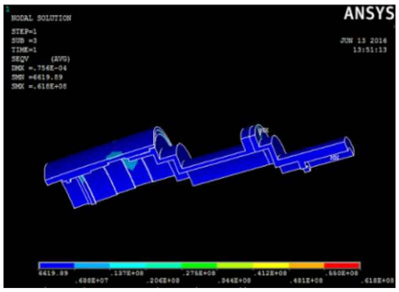

Figure 9: Von MISES stress

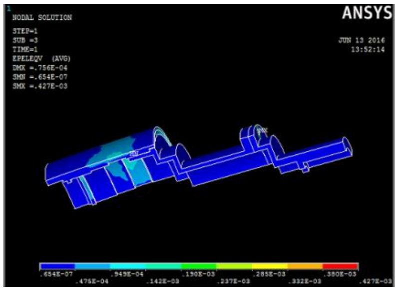

Figure 10: Von MISES strain

Figure 9, 10 shows the von MISES stress and strain distribution in the barrel. It can be noticed from the figures that von MISES stress values is 16.3 Mpa for temperature range 300-328K.which is less than yield stress.

IV. DISCUSSION OF RESULTS

Analysis has been done by exposing system to the temperature -40 to +55 centigrade and computed the elastic deformations and induced stress in the system. Stress computations are used to estimate the potential structural damage under extreme environmental conditions.

Displacements in the individual housing and complete optical system

Table2.Axial displacements of individual housing in optical system

Displacement	Front Housing	Mid Housing	Rear Housing
Axial displacement (µm) (233-300K)	44.2	2.25	1.58
Lateral displacement (µm) (233-300K)	29.5	1.5	1.17
Axial displacement (µm) (300-328K)	20.9	1.04	0.559
Lateral displacement (µm) (300-328K)	10.8	0.18	0.234

Table 3.Displacemnts in complete housing

Displacements	233-300K	300-328K
Axial displacement (µm)	73.2	32.4
Lateral displacement (µm)	22.1	5.01
Von MISES stress (Mpa)	16.3	61.8
Von MISES strain	183×10^{-6}	427×10^{-6}

When the optical system exposed to -40 centigrade the following results can be concluded:Maximum axial displacement is 73.2(µm), lateral displacement is 4.64(µm);the valuesare within the tolerance limits. Von MISES stress induced is 16.3(MPa),whichis less than yield stress. Straininduced in the system due to stress is 183 micronswhichis within the limits.

On analyzing system when it is exposed to the temperature +55 centigrade the results following can be concluded: Maximum axial displacement is 32(µm), lateral displacement is 5.01(µm); the valuesare within the tolerance limits. Von MISES stress induced is 61.8 (MPa), which is less than yield stress. Strain induced in the system due to stress acting on the system is 427 microns is within the tolerance limits.

V. CONCLUSION

This paper presents the design and thermo-optic analyses of an IIR optical system. The displacements, stresses and strains in the optical system are investigatedunderthe operating temperature conditions, and the required temperature scope for the thermal design has been achieved. It provides references in thermal control design of an optical system. The axial displacement and stress values are within the system requirements.

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