Synopsis of:

New isostatic mounting concept for a space born Three Mirror Anastigmat (TMA) on the Metrosat Third Generation Infrared Sounder Instrument (MTG-IRS)
Maximilian Freudling ; Jesko Klammer ; Gregory Lousberg ; Jean-Marc Schumacher ; Christian Körner
Proc. SPIE 9912, Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation II, 99121F (July 22, 2016)

Eduardo Marin
OPTI521

Abstract

This paper is an overview of the paper "New isostatic mounting concept for a space born Three Mirror Anastigmatic (TMA) on the Metrosat Third Generation Infrared Sounder Instrument (MTF-IRS)" appearing in the proceedings of the SPIE July 2016. The paper discusses the design of a new isostatic mount for a space based three-mirror anastigmatic telescope. I chose this paper because it goes over many of the topics we have covered in class, especially in terms of the selection of different materials and how they interact when placed together in a complete system design.

Introduction

The Metrostat Third Generation Infrared Sounder Instrument (MTG-IRS) is a geostationary satellite used to gather meteorological and climate data in a cooperation between European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) and the European Space Agency (ESA). The goal is to provide 4 imaging satellites and 2 sounding satellites (MTG-S), which will ensure an operational lifetime of more than 20 years for the MTG system.

The MTG-S has a Fourier transform interferometry based Infrared Sounder (IRS). This instrument will provide4-demeisnal resolved water vapor and temperature structures of the atmosphere. The design is such that a Back Telescope Assembly (BTA) will really the interferogram beam in the cold optics and the focal plane. The BTA is based on a new isostatic mounting concept for a space born Three Mirror Anastigmat (TMA) telescope, based on a light weight-all aluminum design. A TMA telescope uses 3 curved mirrors to control optical aberrations of astigmatism, thus the name anastigmat.

The BTA is a design where both the structure and the mirrors are made of aluminum. Making the entire structure of aluminum and the mirrors as well was selected to prevent any stress from CTE mismatches between the structure and the mirrors. Additionally the use of aluminum means that well-known design and manufacturing process can be used. The disadvantage of using aluminum is hat main structure of the IRS is made of CFRP (Carbon-Fiber Reinforced Polymer). In order to compensate for the larger difference of the CTE this new isometric mounting was developed. See Figure 1 for a view of the BTA.

Additional to the large CTE mismatch another important limitation to using standard isostatic mounts is the small space envelope. The volume allowed for the BTA is in fact only a few centimeters larger than the volume used for the optical beam of the TMA. The mounting must also compensate for the transition from an integration temperature of 20C to the operating temperature of 0C. The first Eigen-Frequency of the BTA must be above 200Hz.

The challenging part of this mount if the different CTE of the materials aluminum is about 23 ppm while CFRP is between 0 and 2 ppm, resulting in a mismatch of about 20 ppm. The TMA is also expected to work at about 0C. Using this information the temperature transition from integration to operation results in a length change just larger than 150 microns (the BTA size is 330mm).

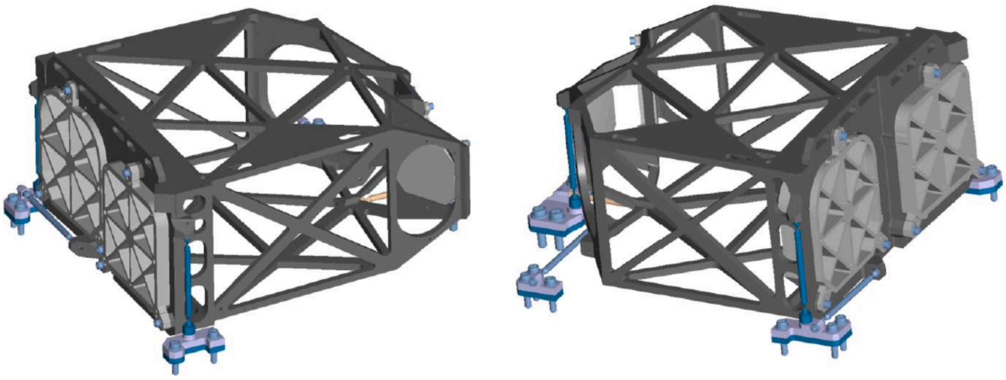

Figure 1: TMA with mirrors in gray

The mounting concept

The mount concept is based on six independent interface elements, called needles, each blocking on degree of freedom but providing high flexibility in the other degrees of freedom. The elements themselves are made out of titanium in order to be able to sustain the high stress of launch into orbit. See figure 2 for an example of the needle.

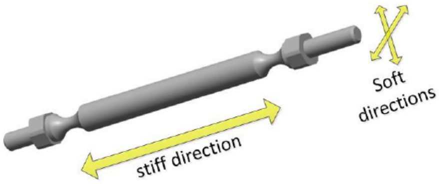

Figure 2: Needle

The first and largest issue to address is the large length change in between the TMA and the main structure of the IRS caused by the CTE mismatch. In order to do this three needles are used to hold the TRA parallel to the mounting plane. This fixes out of plain movements (Z position and rotation about X and Y). Two more degrees of freedom are fixed by using two needles parallel to the Y-axis, preventing lateral displacement in Y and also rotation in X. Lastly one more needle is mounted in the X-axis fixing lateral displacement about X. Figure 3 shows the needle placements.

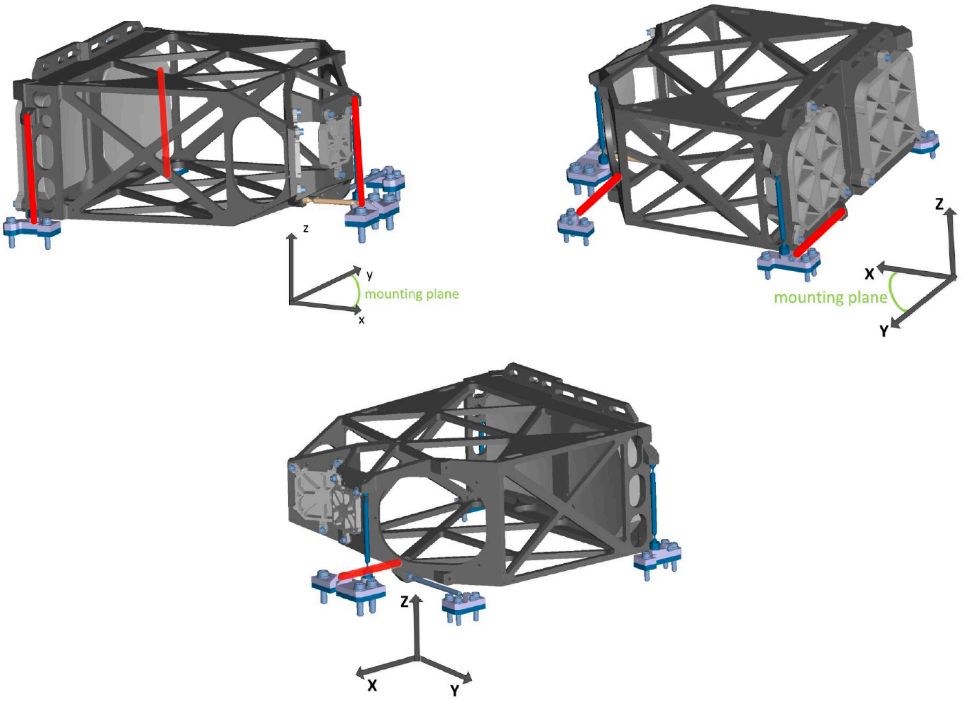

Figure 3 Mounting points of 6 needles

Optimization

As part of the design it had to be determine what the optimal placement and length of the needles would be. This is very important because of the different CTE of the materials used. The BTA is made of aluminum, while the IRS main structure is CFRP and the needles themselves are made of titanium. The most important requirement is that the BTA line of sight not deviate from the on-ground characterized LOS while in orbit.

In order for the optical axis to remain as stable as possible it is necessary that the change in length between the needed fixation at the structure be compensated by the change in length of the needed itself. See equation 1.

$$\Delta optical\ axis = \Delta C_{20^\circ C \rightarrow 0^\circ C} - \Delta l_{20^\circ\mathrm{C} \rightarrow 0^\circ\mathrm{C}}$$

The goal is to get the change in the optical axis to be as close to zero as possible. In this case the change delta C is the change of the position of the fixation calculated using the CTE of aluminum and the change delta l is the change in length of the needle using calculated using the CTE of titanium. Figure 4 provides a pictorial representation. The change in the mounting is in the opposite direction as the change in the length of the needed. This analysis is applied to all 6 needles to find the optimum location for the fixation as well as the optimum length of the needle.

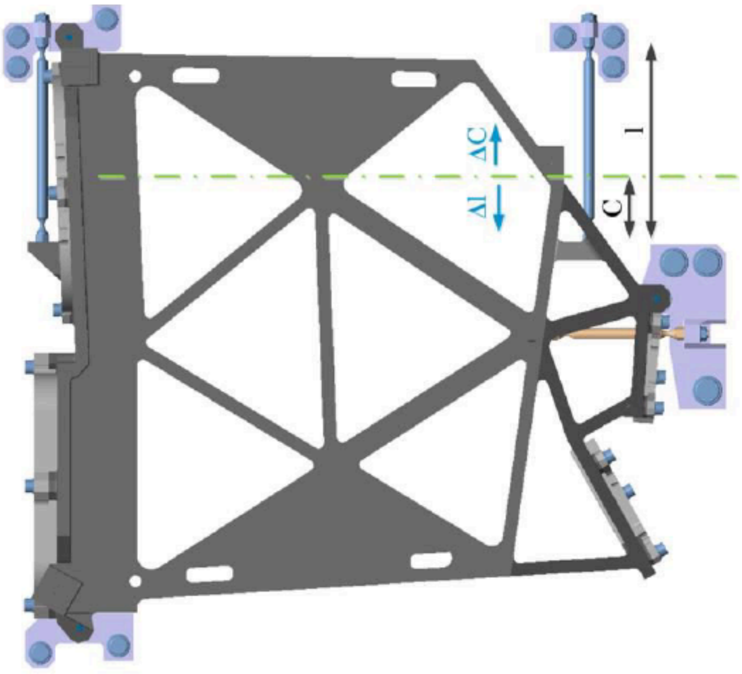

Figure 4: Change of length due to temperature change

It is also important to look at the diameter of the needle. The entire assembly must be able to take a force of 47g which is the force applied during launch into space. In order to model this a FEM was made of the BTA with the established needle location and lengths calculated from the thermal expansion calculations done before. The maximum stress of the titanium used is about 700Mpa. Given that it is possible to see the maximum axial force that can be applied given the diameter of the needle. Figure 5 is the result of this modeling. From the model it can been seen that a diameter of 2mm the requirement of 47g is met. Finally an X-diameter of 2.0mm, Y= 1.5mm and Z= 1.6mm was chosen as sufficient to meet the requirements.

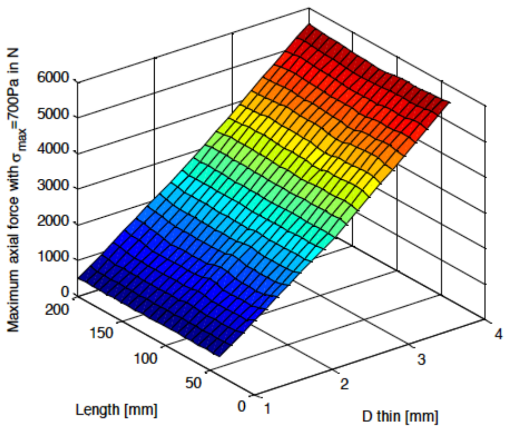

Figure 5: Maximum axial force as a function of diameter

Along with the force calculation the minimum Eigen-frequency must be at least 200Hz. Assuming the BTA to be a single mass oscillator the needed stiffness can be calculated using in any direction by dividing it by the number of needles in that direction. The results using the diameters calculated before and the lengths calculated before is a first Eigen-Frequency of 225Hz which meets the requirements.

Results

The mounting concept that is being proposed for this system behaves well in simulation. The resulting WFS error from the CTW mismatch is 22nm which is less than 1% of the specified WFE od 180nm. The line of sight stability of the TMA when going from the integration temperature of 20C to the operational temperature of 0C is also within the requirements as it is calculated to be 1.2 arcseoncds that is only 4% of the required stability.

Despite the use of materials with very different CTE, the design allows for the TMA to be mounted isostatically while in orbit. Meeting all requirements within 50% of the margin.

The manufacturing of the BTA qualification model is currently underway and it is expected that test results will be available later in the year.

Conclusions

The authors of this paper present a new mounting concept that will work to in their telescope despite the large differences in CTE and the small space envelope provided. As well as explaining how the mount works to keep the telescope isotactic, they preform analysis to make sure that it can take the loads induced by thermal stresses and the launch of the steatite.

Referances

All figures are taken directly from the article itself.