Mechanical Stability of optical setup IRIS w.r.t Thermal Cycling

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Abstract*- This paper solely focuses on the stability of opto-mechanical instruments with respect to heat and vibration. Opto-mechanical instruments are sensitive to temperature effects. The optical performance will be influenced by temperature variations within an instrument. Temperature variations can occur due to environmental or internal heat sources. Assembly at a different temperature than eventual operation of the instrument can also influence the performance. The thermal behavior of a system can area-wise be divided in heat source, heat transfer area and place where the optical performance is affected. Placement of the heat source is critical. Using a large thermal capacity, the influence of the source will be minimized. Heat transfer can be controlled by insulation or by good conduction, the latter minimizing the thermal gradient along the thermal path. Thermo mechanical effects on the optical performance can be controlled using a thermal center, a combination of materials with different expansion properties, low thermal expansion materials and scaling effects of the optical design.*

Keywords- Opto-mechanical, thermal expansion, mounts, etc.

I. INTRODUCTION

Some instruments, e.g. those using interferometry, are more sensitive than others because of high stability tolerances. In an interferometer, optical path length differences of nanometer level are relevant. Thermally induced deformation of optical components can have disastrous effects on their performance. In reflective optics, a small displacement of the reflecting surface will induce a change in optical path difference twice that size. Besides misalignment, an instrument can even be destroyed due to high internal stresses, since different materials behave differently to temperature changes. Some materials expand more than others, which can cause high strain and stress.

II. LITERATURE REVIEW

Lake and Hachkowski have written “Mechanism Design Principles for Optical Precision, Deployable Instruments” for a guide for the design of Micro dynamically Quiet” deployment mechanisms for optical-precision structures. Main concern of the study was deployment mechanisms. However, there were some guidelines for optomechanical designs. In the study, it was stated that there should not be any direct load path on the optomechanical structure. Also, it was stated that mechanical interfaces of opto-mechanical mounts should be non-conforming in order to be certain about the stress on the mount. Non-conforming interface geometry was advised since conforming ones were strongly dependent on the match of the surfaces mounted.

III. PRESENT INVESTIGATION

A. Design Criteria

Before the design of a mount is attempted for operating, manoeuvring, test, service, and transportation environments of the mirror must be understood. An optical instrument for use in the earth's gravitational field will be subjected to both dynamic and static loadings during manoeuvre and operation. When an instrument is manoeuvred into position, it usually experiences the most severe loading conditions. These loads are created by accelerations, shock, and vibrations. One way to prevent permanent set in an element is to control the design stress level. If optical tolerances are to be maintained, the stress level of each critical component should be designed to some optimum point below the precision elastic limit of the material used. The precision elastic limit of material is defined as the stress level that will cause a permanent elongation of one millionth of a cm per cm. because of conflicting requirements. On one hand the mount with bonded optics must be robust and strong to survive the launch loads and space environment. This is complicated because generally optical components are made from glass. The strength of glass depends on the random distribution of surface flaws in relation to regions under stress. Fracture of the glass occurs due to uncontrolled crack growth of these flaws under tensile stresses. This results in failure stresses that are much lower than those for metals. The adhesives used to bond the optical component to the mount has nonlinear material behaviour combined and a low strength level compared to metals. On the other hand the mount must not damage or distort the optical components. This limits the forces and moments which can be applied by the mount on the optical component.

B. New Design

The detail design objectives of a mirror-mount system are summarized below:

- Eliminate, or minimize, local mounting pressure and bending moments which might distort the optical surface.
- Transfer the support loads to the supporting structure without distorting the main support structure which maintains the optical alignment of the system.
- Compensate for, or minimize, strains caused by differential thermal distortion.
- Return mirror and mount system elastically to predetermined shape and position after subjection to accelerations, shocks, and vibrations.
- Provide a simple means of aligning and adjusting both the mirror and the mount system that will prevent distortion under all adverse conditions

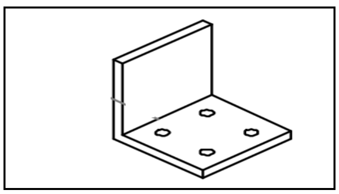

Figure 1.

C. Enhanced Setup Design

The enhanced assembly is a more compact spectroscope, with a manifold reduction in the size of the entire setup. There is absence of extra stabilising elements which reduces the overall dimensions and weight of the setup.

The components used are:

- 7 optically stable mounts
- Laser
- 3 reflective mirrors
- Beam splitter
- Vacuum Chamber for increasing the laser beam's travel distance before it reaches the output wave detector
- Input wave detector
- Output wave detector

The setup is proposed to be available for astronomical applications with it being instrumental in checking the habitability of external planets and life in the outer space.

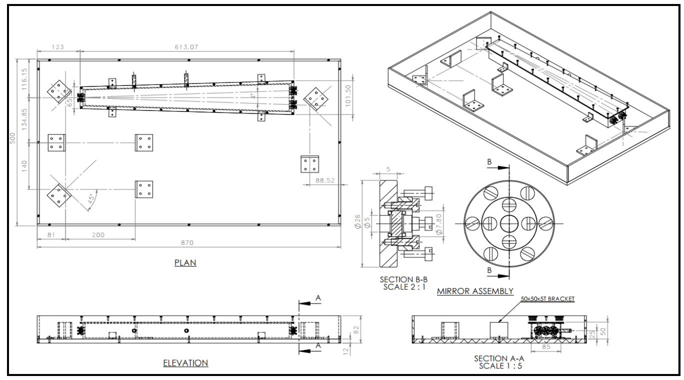

Figure 2. Isotope Ratio Infrared Spectroscopy Setup

D. Vacuum and Thermal Testing

Extreme environmental conditions are simulated during flight-like scenarios to re-create the operational environment that the product will experience in space. These conditions include alternate cycles of extreme heat and cold, pressure extremes, solar radiation levels, and the airless conditions of space.

This is done by subjecting the equipment to elevated temperatures under vacuum which in turn speeds up the diffusion, or molecular outgassing, of volatile material and chemicals. Some products may require an ambient cure or high temperature preconditioning cure prior to bake out.

E. Vibration Isolation

Vertical Isolation

The vertical vibrations are isolated from the optical table by a dual-chamber pneumatic isolation system that requires a constant source of compressed air, such as an air compressor (sold separately). If the source of compressed air is removed, the optical table will lower until it securely rests on the large-diameter cylindrical optical table supports, and the table will no longer be isolated from floor vibrations.

Horizontal Isolation

The horizontal vibrations are isolated from the optical table by mounting the vertical isolation system on a trifler suspension system. This proprietary design eliminates the need to use oil-based damping systems that can leak or degrade over time.

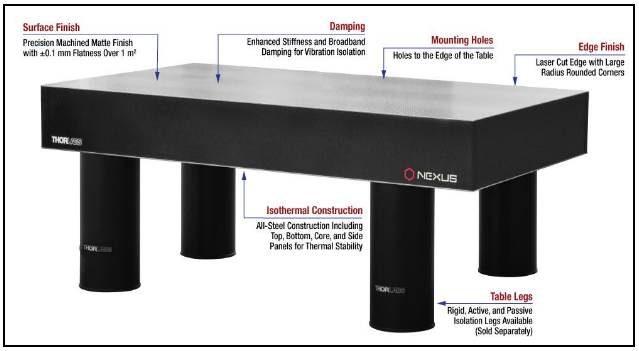

Figure 3. Thorlabs Vibration Isolation Table

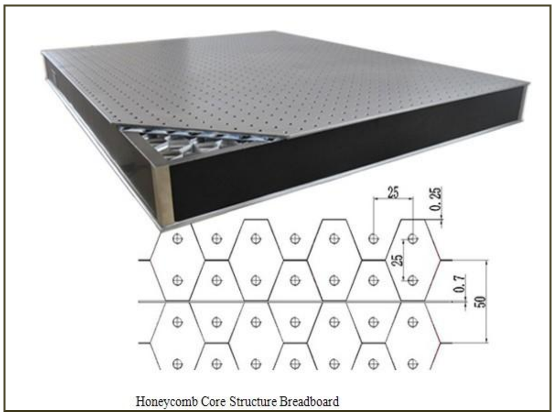

Figure 4. Thorlabs Vibration Isolation Table

IV. RESULTS

The project efforts were successful in achieving the following:

- Vibrational stability

The use of vibration isolators and lesser components led to the enhancement of vibrational stability of the system.

- Thermal stability

Due to reduction in components the new mounts show less angular deviation leading to making the mounts thermally more stable than previous mounts. New mounts are stable to temperature range from 25oC to 40oC. Aluminium is the only material used hence it has only one coefficient of thermal expansion.

- Weight reduction

The use of Aluminium for every part and removal of extra components from the setup optimised the weight of the entire unit and weight of the mount reduced to 60% and made it easy to use and transport from one place to another. The light weight also makes it capable of astronomical applications.

- Compactness

The use of adhesives instead of screws and clamps increased the overall compactness of the setup which made the device smaller than 1 m in length from an earlier length of more than 10 m.

- Accuracy in output

Due to increase in thermal and vibrational stability, the output accuracy of the setup optimised to the degree of 1-2 microRadian from the existing exceeding 20 microRadian. leading to precise readings and more accurate applications.

V. CONCLUSION

With respect to all the discussions and the data presented above, it can be concluded that mechanical stability with respect to thermal cycling and vibrations is of the utmost priority in any optical setup. Therefore, the optical mounts need to be lighter, compact and should have the least angular deviation due to temperature cycling. The angular deviation at the end of the project is aimed to be optimised to the degree of 1-2 microRadian from the existing exceeding 20 microRadian. The mechanical vibrations in the new mounts are aimed to be minimised with respect to the same. This is to ensure minimum mechanical vibrations in the entire setup due to the mounts either absorbing them or transmitting them out of the system effectively.

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