New Diagnostic System for Alignment of Cryogenic Optomechanical Assemblies

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Abstract

Figure 1: Typical flat diffraction grating

A novel method utilizing diffraction has been proposed to provide a more efficient, and possibly more accurate method for aligning optomechanical assemblies that will experience the extreme temperature conditions of space. To simulate the foreign space environment, instrumentation is placed into thermal-vacuum chambers. Metrology under operating conditions (very low temperature) remains extremely limited for most assemblies at Goddard Space Flight Center, because most chambers are not properly equipped for large-scale optical alignment. To avoid the addition of expensive and cumbersome hardware and machining, the use of diffraction simplifies the measurement of each degree of freedom needed to determine the alignment of the instrumentation.

Background

Structures built in Earth's ambient temperature, but headed for the cold of space will manifest measurable aberration and adjustment due to the change in temperature when they reach space. Presently, high-grade, sensitive reflective alignment cubes are placed throughout the structures. In large dewars, the instruments are subjected to environmental changes that simulate what will occur before and after flight. With theodolites (Figure 3), the degree of cube orthogonality may be accurately measured; however, this requires that at least two holes be cut in the dewar structure and that two different theodolites be used in measurement. Moreover, this cumbersome arrangement requires the incorporation of cold shutters that manage temperature contamination of the dewar.

Figure 2: Far Ultraviolet Stellar Explorer (FUSE) was not precalibrated. This necessitated ingenious coding techniques to gather photons misplaced by assembly deformation.

Motivation

A new alignment method is crucial for cold optical instruments due to the following requirements and implications

- Multiple theodolites required (Figure 3)
- High-quality, highly-orthogonal alignment cubes are required (Figure 3)

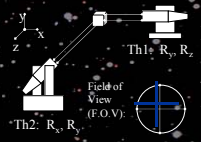


Figure 3: Alignment setup utilizing high-quality alignment cube. Theodolites are as perpendicular to each other as the cube surfaces

- Multiple holes in dewars and thermal-vac chamber

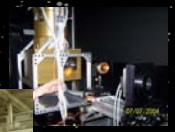
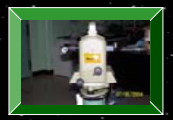


Figure 4: Small dewar (above) currently used in microshutter experiments; thermal-vacuum chamber (left) for diagnostics of larger instruments

Reticle (cross-hairs)



Theodolite

Figure 7: Simplifying degree of freedom measurement; many wavelengths leave Source Theodolite, and Observing Theodolite receives only green light

Stats: Theodolite and Setup

- Theodolites: F.O.V.: ~ 2 arcmin
- Grating: G (= 1/d) = 1162 grooves/mm
- Diffraction scheme: for first maximum (m = 1) and green light (at 540 nm), $m\lambda = d \sin(\theta)$: $\rightarrow \theta \sim 40^\circ$

- Scientific Implication: Better science from James Webb Space Telescope (JWST) and Integrated Science Instrument Module (ISIM) (Figure 6)

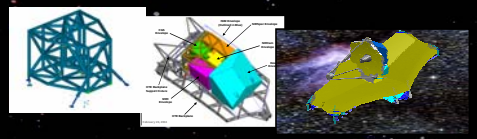


Figure 6: ISIM (left and middle) and artist's rendition full JWST architecture in space (right)

Solution

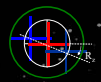


Figure 8: Diffraction profile in observing Theodolite

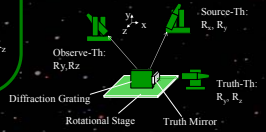
Measure the second degree of freedom in the same plane as the first degree of freedom with made-to-order diffraction grating

- Bending of assembly revealed through measurement of R_z, via diffracted reticle

Resolution limitations

- Human eye : centroiding error bar is 2 arcmin
- Realignment requires ±5 arcsec resolution in R_z

Figure 9: Three theodolites in alignment with cube grating on rotational stage, prepared for method truth test–lab setup (above) , diagram (below)



Current Results: Method Truth-Test in Progress

- Theodolite setup
  - Source theodolite provides diagnostic reticle diffracted by observing theodolite
  - Observing Theodolite receives diffracted reticle at 40° from incident
  - Truth Theodolite (True-Th) measures pitch angle from right
- Grating rests on an adjustable stage: as the roll is adjusted, the diffraction pattern shifts through an arc, R_z
- Observation Theodolite realigns with new position of reticle. Preliminary tests show good correlations between diffraction observed and pitch measured by Truth Theodolite

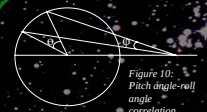


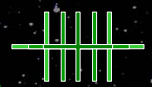
Figure 10: Pitch angle-roll angle correlation

Remaining work

- Grating Design: geometry to meet the resolution requirements
- Grating Fabrication: Single-Point Diamond Turning (SPDT) will provide, to design specifications, a nanometric diffractive surface aluminum
- Thermal-vacuum tests will occur in a small dewar, cooling to 30 K
- Calculation: Still must relate pitch angle, φ (Truth-Th) to roll angle (Observe-Th), φ—Figure 9

Mother of Invention

Figure 11: Diffuse reticles



- New obstacle: extremely faint return of reticle's vertical axis observed—blurring via dispersion (Figure 9)
- Solution: lower dispersion of grating

- Resulting obstacle: loss of resolution in grating
- New solution: Maximize resolution and minimize dispersion by considering geometry of grating, particularly the teeth.

- Implication: Lower dispersion may allow use of only one theodolite (Figure 11)

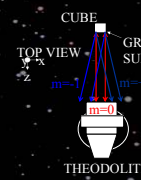


Figure 12: Heaven = only one theodolite necessary for alignment

Further Scientific Impact:

Upcoming space interferometers will require the most precise and intense alignment to maximally reduce error. These missions include Fourier-Kelvin Stellar Interferometer (FKSI), Terrestrial Planet Finder (TPF)

Figure 13: Artist's rendition of the multicomponent TPF

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