Optical Metrology Applications at TAS-I in support of Gravity and Fundamental Physics

Stefano Cesare, Thales Alenia Space Italia, Torino

Workshop “GG/GGG: state of the art and new possibilities”

Pisa, 12 Febbraio 2010
Main research projects and applications of optical metrology at TAS-I:


Collaborations:

- Istituto Nazionale di Ricerca Metrologica
- Politecnico di Torino
- INAF – Osservatorio Astronomico di Torino
Metrology for GAIA astrometric instrument

- **Graph:**
  - x-axis: Time [s]
  - y-axis: Distance variation [m]
  - Graph title: IFR signal: Control error

- **Images:**
  - Diagram of the GAIA astrometric instrument setup.
  - Close-up image of the instrument components.

**GG workshop**
12/02/2010

INTERNAL THALES ALENIA SPACE
COMMERCIAL IN CONFIDENCE
Co-phasing of optical interferometers

Breadboard of a two-aperture optical interferometer with its co-phasing system, for the development project of a synthetic-aperture optical telescope.

Fringe Sensor Unit realized for the co-phasing of the VLTI (ESO). Operative at Cerro Paranal, Chile.
The distance variation between two satellites ($\Delta d$) is measured by a laser metrology system.

The distance variation between the satellites produced only by drag forces ($\Delta d_D$) is measured by accelerometers.

Subtracting ($\Delta d_D$) from ($\Delta d$) the distance variation produced by the gravity acceleration is obtained: $\Delta d_G = \Delta d - \Delta d_D$

Requirement for the laser interferometer measurement noise (relative distance = 10 km)

2.26 nm/$\sqrt{\text{Hz}}$
Michelson-type heterodyne laser interferometer based on polarized beams, with chopped measurement beam to avoid spurious signals and non-linearity caused by the unbalance between the strong local beam and the weak return beam.

Passive retro-reflection of the laser beam on S2: simple solution, suitable for $d$ up to 100 km.
Satellite-to-satellite laser tracking for NGGM

Optical metrology arrangement on the satellites

The non-gravitational accelerations of the satellite COM can be measured by electrostatic accelerometers like those used on GOCE.
Laser interferometer breadboard prepared for the intrinsic noise test (measurement of a constant distance).

In order to achieve the specified measurement performance over a distance of 10 km, the laser frequency shall have a relative stability $\frac{\delta v}{v} \leq 1.4 \cdot 10^{-13}$ Hz$^{-1/2}$.

Spectral density of the distance variation measurement error obtained during the tests and compared to the requirement.
Laser interferometer breadboard under the functional test over a long distance (~90 m) with a moving target. The effectiveness of the measurement beam chopping scheme was successfully verified in this test.
Test of the laser beam pointing control system BB.

Open-loop test of the Lateral Displacement Metrology. Lateral displacement steps (from ±50 µm to ±5 mm) measured by the optical metrology at 10 Hz. Max. measurement error: 0.25 mm (over the largest steps) Max. measurement noise: 14 µm 1σ.

Closed-loop test of the laser beam pointing control system (BSM driven by the Lateral Displacement Metrology measurements). Laser beam pointing stability results.
The Nanobalance is a complete test facility for the direct measurement of the force provided by a micro-thruster along its thrust axis, developed by TAS-I for ESA.
A micro-thruster force $F = 0.1 \, \mu N$ induces a distance variation between the tilting plates $\delta L \approx 14 \, \text{pm}$, corresponding to frequency variation of the laser locked to the Fabry-Perot cavity $\delta \nu_L \approx 40 \, \text{kHz}$. 
Power Spectral density of the measurement force noise after post-processing for removing the low-frequency drift effect.

Measured thrust corresponding to the smallest applied force steps with a voice coil actuator.
Test of a cold-gas thruster

Applications: GAIA, Microscope (backup)

Test of a FEEP thruster

Applications: LISA PF, Microscope, GG

Test of a mini-RIT

Applications: NGGM, GG (backup)