Preliminary Investigations of an Optical Assembly Tracking Mechanism for LISA

J. L. Thorpe1, R. Stubbins1, S. Schlummer1, J. Gundlach1
1NASA/GSFC, U. Washington

Abstract
After injection into their specific orbits, the position of the LISA spacecraft (SC) are not actively controlled. Rather the SC are allowed to passively follow their trajectories and the roughly equilateral triangular constellation is preserved. Slight variations in the orbits cause the constellation to experience both periodic and secular variations, one consequence of which is a variation in the interior angles of the constellation on the order of 2°. This variation is larger than the field of view of the LISA telescope, requiring a mechanism for each spacecraft to maintain pointing to its two companions. This Optical Assembly Tracking Mechanism (OATM) will be used to accommodate these variations while maintaining pointing at the Broad/Flat level to the far SC. Here we report on a possible design for the OATM as well as initial results from a test campaign of a piezo-inchworm actuator used to drive the mechanism.

Phase I — Actuator Metrology System
Building a metrology system with the required range and precision is a challenging task in and of itself. For convenience, we decided to split the task between two commercial displacement sensors. The long-range sensor, able to cover the entire actuator range with a precision of 20nm is a Zygo 21000 compact interferometer. The high-precision sensor is a Quensey NG series capacitive sensor, capable of 0.1nm resolution over a 150um range.

To verify the measurement precision of the capacitive sensor, we placed the device in an approximately spherical structure which was then placed in a passive thermal enclosure (i.e. styrofoam). We also developed a data acquisition system consisting of analog and digital anti-aliasing filters. The plot below shows the measured position stability. The sensor is shown to meet the requirements except at the low end of the LISA band. The rise at low frequencies is expected to be driven by temperature coupling through the uncompensated material. It is expected that a better thermal environment (vacuum chamber) will improve the low-frequency performance.

Phase II — Actuator Testing
To test the NEXLINE actuator’s stability, we have designed an assembly whereby two identical actuator move in opposition to maintain a nominal 50um gap. This ensures that the capacitive sensor can be used to measure the positional stability over the entire actuation range. The absolute position is tracked by two Zygo 21000 interferometers as well as encoders internal to the actuators.

Mechanism Design
Each LISA SC contains two identical payload subassemblies for making displacement measurements along the two arms for which the SC serves as a vertex. The assemblies, referred to here as Optical Assemblies (OAs) consist of a gravitational reference sensor, optical bench, telescope, and associated hardware. The OAs are mechanically connected to the SC structure via rotational flex pivots, which allow rotation within the required dynamic range.

We have identified a piezo-electric ‘inch-worm’ actuator, the NEXLINE series by Physik Instrumente, which may have the required range and precision to drive the OATM. Through a series of shearing and clamping piezo motions, the NEXLINE actuator is able to deliver 30pm positioning resolution with a 2cm stroke. This fractional precision (0.7x10^-9) exceeds the angular precision requirement (2°/8 radian = 4x10^-9) but there are no measurements on positional stability in the LISA band. A space-qualified version of the NEXLINE actuator is used in the caging mechanism for LISA Pathfinder, an ESA-led technology demonstrator mission for LISA.

The NEXLINE actuator provides a linear displacement, which can be converted to an angular displacement using a lever as shown in the figure above. Appropriate design of the lever can be used to match the available dynamic range of the actuator with the required dynamic range of the OATM.

Experimental Plan
Phase I: Design and test a metrology system capable of evaluating the actuator stability.
Phase II: Measure the position noise performance, linearity, and other characteristics of the NEXLINE actuator.
Phase III: Implement a candidate mechanism design and measure the angular stability.

Data Acquistion: A custom data acquisition and control system has been developed to operate the actuator test-bed. This system, running on a National Instruments real-time processor, allows the user to control the position of each actuator and record position information from the capacitive sensor, interferometer, and internal actuator encoders. Temperature data is recorded separately by the thermal control system.

Current Status: The system is currently being integrated into a vacuum chamber with both active and passive thermal shielding. This should provide adequate environment stability to reach the required measurement precision across the LISA band.

Preliminary Results: Prior to integrating the system in vacuum, the actuator test-bed was tested in air to verify operation. The plots below show capacitive and interferometric displacement measurements for a case where the actuator was asked to hold position. The displacement measured by the interferometer over long time scales was consistent with that measured by the capacitive sensor except with a 4x greater amplitude. This is consistent with the ratio of effective CTEs for the two measurements, calculated to be ~3.1. The thermal response of the assembly will be further characterized once the system is in vacuum and the temperature diagnostics are operational.

Phase III — Mechanism Testing
The design of the mechanism and the test apparatus is still in its early stages. Progress has been made, however, on an angular position sensor that will meet the precision and range requirements. Developed at U. Washington and based on a classic autocollimator, the new device uses a series of slits and a CCD to improve angular precision. The system is capable of measuring over a 3° range with preliminary noise of a few nrad/Hz.