9th LISA Symposium, Paris
ASP Conference Series, Vol. 467
G. Auger, P. Binétruy and E. Plagnol, eds.
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Interferometric Characterisation of Path Length Errors Resulting from Mirror Surface Topography with Sub-nm Reproducibility

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Abstract. We present the results of our experimental characterisation of path length errors, caused by beamwalk over the surface topography of laser mirrors. These path length errors can have a major influence on the accuracy of the LISA measurement instrument in Astrium's alternative payload concept with In-Field Pointing. Our measurement setup uses a highly sensitive heterodyne interferometer for measuring the path length error amplitudes, generated by the topography of a moving, $\lambda/10$ test mirror.

1. Introduction

In the LISA space mission, the triangular satellite formation is subject to seasonal changes in shape, caused by the individual orbit dynamics of its satellites. A compensation is in particular required for angular changes of the formation. In the alternative payload concept with In-Field Pointing (IFP), developed at Astrium GmbH, a small actuated mirror, positioned in one of the telescope's pupil planes, is used for this compensation (Weise et al. (2009)). During its actuation by the In-Field Pointing Mechanism (IFPM) the laser beam scans over the surface of the optical components in its path, which leads, due to the surface topography, to path length errors. This paper presents a measurement setup, developed for the investigation of such surface induced path length errors, whose results will be used for a future estimation of their noise impact in the required picometer measurement accuracy of LISA.

2. Measurement Setup

The used measurement setup shows some resemblance to the setups used in interferometric profilometry and was designed to mimic path length errors caused by beamwalk across mirror surfaces with high reproducibility. Therefore a 1 inch, $\lambda/10$ test mirror is moved perpendicular through the outcoming measurement and reference laser beam of a heterodyne interferometer, rising variations in the measured translation signals, due to the mirror topography. To avoid common mode effects, caused by changes in temperature, the differential translation between both laser beams is used for evaluation.
The heterodyne interferometer, shown in Figure 1 (left), was designed as possible concept for the read-out of the LISA test masses and has highly symmetric optical paths (Schuldt et al. (2009)). The beat signals of its measurement and reference laser beam are detected by Quadrant Photo Detectors (QPDs), that additionally enable tilt measurements, used for the correction of the differential translation, falsified by small parasitic tilts of the pendulum during measurement. For the data processing a digital, FPGA based phasemeter is used, enabling measurement

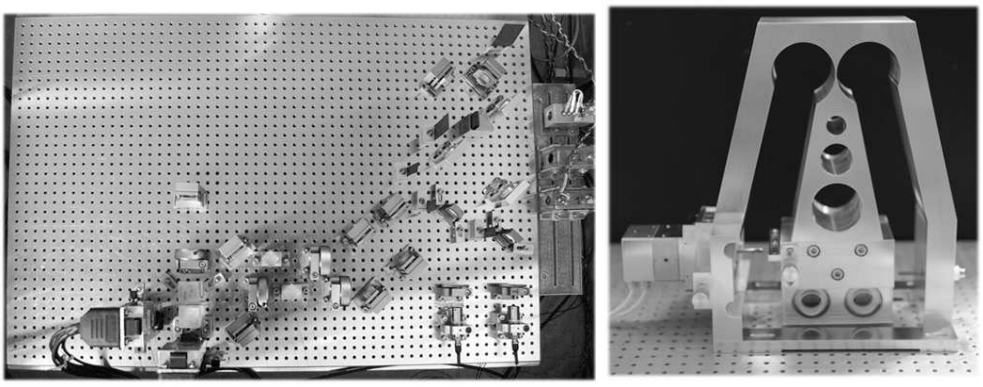

Figure 1. Photograph of the heterodyne interferometer (left) and the pendulum for movement of the test mirror (right).

accuracies of the setup within a few picometer in translation and a few nanoradian in tilt. The test mirror is housed in a mirror support, mounted on a pendulum with monolithic, clearance-free hinge and a highly accurate piezo walking actuator (positioning accuracy 5 nm) for precise and highly repetitive movement. The pendulum with piezo actuator is shown in Figure 1 (right). A pre-adjustment of the pendulum's movement is enabled by two adjustment mechanism, changing the application point and direction of the driving force. This is necessary as the correction of the differential translation, using the tilt signal of the QPDs, is only possible for small parasitic tilts < 1 mrad.

3. Measurement Results

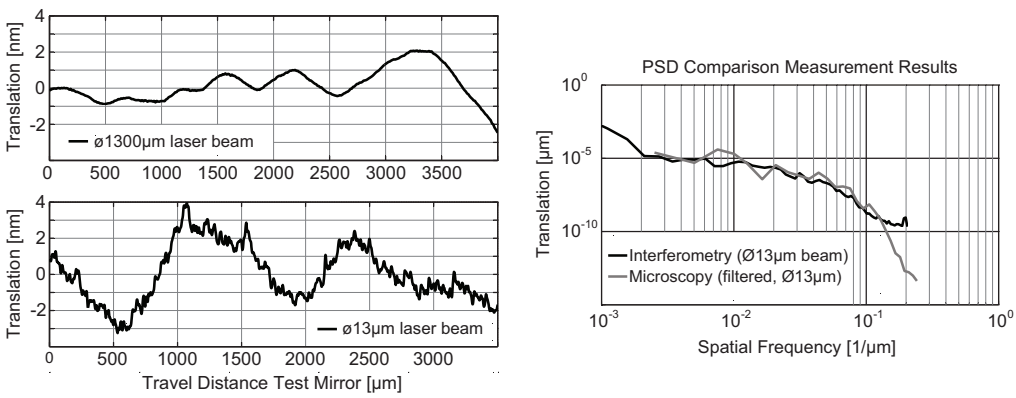

Figure 2. Measurement results of different mirror areas, using a laser beam with $\emptyset \approx 1300\,\mu$m (left, top) and $\emptyset \approx 13\,\mu$m (left, bottom), as well as the PSD of the surface topography for comparison of the results between the interferometric measurements and the comprehensive interference microscopy measurements (right).

Measurements with different beam diameters ($\approx 1300\,\mu$m and $\approx 13\,\mu$m) for the measurement laser beam were performed, leading, due to the averaging of the laser light's wavefront on

the QPDs, to results with different lateral resolutions, shown in Figure 2 (left). The achieved measurement results are highly reproducible with standard deviations from the mean value of 3 different measurement runs < 100 pm and show surface induced path length error amplitudes in the range of some nanometers, which also variate with the used beam diameter.
A validation of the measurement results was realised using comprehensive surface measurements, performed by the Physikalisch Technische Bundesanstalt (PTB) in Germany. They used interference microscopy with phase shifting as measuring method. Comparative results were achieved by multiplying the PTB results with a filter function that simulates the 'low pass' filter effect for spatial frequencies of a laser beam with $\emptyset 13\,\mu$m. A filtering with a simulated laser beam of $\emptyset 1300\,\mu$m seems at least in this case not reasonable as the measured area by interference microscopy is only $416\,\mu$m x $312\,\mu$m. The results of the comparison are shown in Figure 2 (right) as a Power Spectral Density (PSD) of the surface topography. Both measurement methods show a similar curve progression with a decline at $\approx 10^{-2}\,\mu\text{m}^{-1}$, caused by the 'low pass' filter effect of the laser beam.

4. Conclusion and Outlook

Our measurement results demonstrate, that a beamwalk over the surface of a $\lambda/10$ test mirror generates path length errors within some nanometers, depending on the used laser beam diameter. In the next months we will investigate their actual impact in the LISA measurement band, considering the slow movement of the laser beam over the mirror surface in the telescope. Therefore we are developing a theoretical model based on the measurement results demonstrated here. If it is necessary, we will realise a calibration concept of surface induced path length errors, which should be possible with the achieved highly reproducible measurement results.

5. Acknowledgements

This work was funded by the DLR German Aerospace Center using recourses of the federal ministry for economics and technology under funding code 50 OQ 0701 "Untersuchungen zur Systemleistung alternativer Nutzlastkonzepte für LISA".

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