THE BASELINE METROLOGY SYSTEM OF THE USNO ASTROMETRIC INTERFEROMETER

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Abstract. The USNO Astrometric Interferometer (USNOAI; a subarray of the Navy Prototype Optical Interferometer at Lowell Observatory) is presently under construction and expected to begin limited operations within a year. The main goal of the USNOAI observations is to provide a northern hemisphere catalog of several thousand stars with positions known to a few *mas*. In order to meet this requirement, a baseline laser metrology system must be employed to measure the three-dimensional motions of the baselines with an accuracy better than $\sim 0.1\ \mu m$. The metrology scheme, as presently conceived, represents the largest and most complex high-resolution laser metrology system ever attempted.

Key words: Astrometry:Optical Interferometry - Optical Interferometry:Laser Metrology

1. Introduction

The Mark III Optical Interferometer (MkIII) is a prototype presently operated by NRL and USNO. The astrometric baselines of this instrument are $\sim 12\ m$ long (Mozurkewich *et al.* 1988). Astrometric observations with the MkIII have resulted in corrections to twelve FK5 star positions with ~ 10 *mas* errors (Shao *et al.* 1990; Hummel 1993). There are, however, small systematic effects present in these positions, the most important being the mechanical and thermal motions within the instrument. The USNOAI will eliminate this problem by employing an extensive baseline metrology system.

A simple calculation shows that 1 *mas* astrometry with 20 m baselines requires metrology which is better than $0.1\ \mu m$. This requirement is not easily met, especially for a complicated system consisting of components which are subject to significant mechanical motion and thermal expansion. A brief description on how the USNOAI baseline metrology system overcomes these pitfalls follows.

2. Laser Metrology System Overview

The USNOAI consists of four siderostats arranged in a "Y" configuration with 20 m arms; a more detailed description of the array may be found in Hutter and Hughes (1990). The baselines are defined as the vectors between the siderostat pivot points, which are not stable. The motions of the baselines are measured with respect to the bedrock by means of laser interferometers mounted upon metrology plates (one next to each siderostat), which act as intermediaries in the measurement process. Each plate is made of low-CTE Super-Invar and located in an enclosure which ensures the thermal stability of the reference surface.

The entire baseline metrology system employs about 50 laser interferometers. These laser interferometers are distributed among four baseline metrology subsystems: "siderostat", "master plate", "plate-to-plate", and "slave plate".

J.G. Robertson and W.J. Tango (eds.), Very High Angular Resolution Imaging, 174–176.

The siderostat metrology subsystem is described as follows. A cluster of five laser interferometers, aimed at the hemispherical catseye retroreflector on the nearest siderostat, is mounted on each metrology plate. Thus, the motions of each siderostat are measured with respect to the associated plate. These motions can be extensive (± 50 μm in each dimension) because of the repeatable and non-repeatable motions of the siderostat bearings, the slight misalignment of the siderostat axes, and the thermal expansion of the siderostat components. Note that only three lasers are necessary to determine the motion of each siderostat; the extra two lasers allow for the identification and rectification of laser drop-outs ("glitches") which are produced by imperfections in the catseye reflective coatings.

We know that the plates move with respect to the bedrock, so their motions must be measured. The southeast metrology plate is called the "master plate", and the others are called "slave" plates. The master plate metrology subsystem consists of six laser interferometers which measure its motion with respect to the bedrock directly underneath it. The laser interferometers are arranged into three optical anchor clusters (OACs), the first employing three laser interferometers, the second two, and the last one.

The plate-to-plate metrology subsystem employs ten laser interferometers to measure the *horizontal* motions of the slave plates with respect to a reference point on the master plate. The slave plate metrology subsystem measures the *vertical* motions of the slave plates by using three vertical laser interferometers that are mounted on each plate and tied to the bedrock. Note that the vertical motions of the slave plates are not measured with respect to the bedrock under the master plate, so there may be unremovable systematic effects.

3. Laser Interferometer Corrections

The refractive index of air is a function of temperature, pressure, and humidity. There are empirical formulae for the index of refraction as a function of these environmental parameters (e.g., Edlén 1966), but they are not perfect. Over a large path length ($\sim 1\ m$), employing these corrections may introduce substantial systematic errors. Therefore, evacuated pipes will comprise most of the path length of each interferometer. Also, each laser interferometer has six glass components in its path. Temperature changes not only change the refractive index of glass, but also its physical size. Thus, a small correction must be added for each glass component.

Although the metrology plates are made of Super-Invar and located in thermally stabilzed enclosures, they may still expand slightly. In order to measure this expansion, a single laser interferometer is placed across each plate. These readings are then used to correct the readings of the siderostat laser interferometers.

We suspect that the bedrock is not stable over the entire instrument. Since we do not assume *a priori* stability over this length scale, there is no reason to expect stability over a smaller length scale, say 1 to 2 m. Fluctuations over these smaller length scales can affect the laser readings of the non-vertical OAC lasers on the master plate. A system has been devised to determine the corrections to these laser readings by using an additional laser interferometer on the first master plate OAC.

4. Data Acquisition

The resolution of the displacement measured by each laser interferometer will be $\frac{\lambda}{256}$, where $\lambda = 0.6328\ \mu m$, the wavelength of a visible-band HeNe laser. These lasers will be stabilized to a few parts in 10^9 in order to minimize the metrology errors caused by drift.

Several experiments with laser interferometers have shown that there is an optimum sampling rate for the metrology. For $\frac{\lambda}{256}$ resolution, the power spectrum of laser metrology goes as $P(f) \propto f^{-2}$ for $f \lesssim 50\ Hz$ (after the thermal drift is removed). This spectrum is characteristic of a random walk. For $f \gtrsim 50\ Hz$, the spectrum becomes flat, characteristic of white noise. According to the Nyquist Sampling Theorem, we can get all the information (assuming that the power at high frequencies is small enough for aliasing to be unimportant) if we sample at $\sim 100\ Hz$. For uniformity, we have decided to sample the temperature, pressure, and humidity data at this rate as well.

To get usable laser readings, they must be averaged. The optimum averaging rate will be determined by experience; it will most likely be between 10 and 30 s. The averaging rate will be the same for both the laser readings and the environmental data.

5. Milestones

We have passed several milestones in the construction of the USNOAI laser metrology system. We have created a prototype thermally stabilized chamber and can keep the reference surface to within 0.2 $^\circ C$ of the desired temperature over one night. Also, we have measured the expansion and CTE of a metrology plate and used the same plate to verify the known motions of a test retroreflector.

The core mathematics for the entire metrology system has been derived and most of the low-level metrology routines have been coded. Lastly, metrology tests between the test metrology plate and a test siderostat are underway.

6. Conclusion

Baseline metrology is critical for good astrometry with multiple-baseline baseline interferometers. Without it, systematic errors arising throughout the instrument would seriously degrade the final results.

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