7th International LISA Symposium IOP Publishing
Journal of Physics: Conference Series **154** (2009) 012034 doi:10.1088/1742-6596/154/1/012034

Initial interferometric pre-investigations for LISA

E D Fitzsimons, J Bogenstahl, J Hough, C Killow, M Perreur-Lloyd, D I Robertson, S Rowan and H Ward

Institute for Gravitational Research, Department of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ, UK

E-mail: `e.fitzsimons@physics.gla.ac.uk`

Abstract. LISA, the Laser Interferometer Space Antenna, is a proposed ESA/NASA space based gravitational wave detector. In order to help meet the many technological challenges of LISA, the ESA precursor mission LISA Pathfinder (LPF) will test some of the key enabling technologies for LISA. LPF however will only go so far, and much work is needed to take LPF technology to a state suitable for LISA. One such area is the use of polarising Mach-Zehnder interferometers. We report on the design and initial construction of an experiment to test the use of such interferometric techniques, as well as suitable component mounting mechanisms.

1. Introduction

The LISA Pathfinder (LPF) mission goes some way to testing key technologies for LISA, but there are some elements of the LISA baseline design that LPF will not test. One of these is the use of polarising optics for beam steering. The interferometers used for probing the test masses on LPF are non-polarising Mach-Zehnder interferometers. In LISA it is planned to use a combination of non-polarising and polarising Mach-Zehnder interferometers, with the test mass read-out interferometer in particular being of the latter form [1]. Adopting this design requires that the ~pm stability of polarising optics in the mHz region be tested, and shown to be suitable for adoption in LISA.

2. Experimental concept

2.1. Hydroxide-catalysis bonding

In order to validate polarising interferometry as being suitable for use on LISA, an experiment must measure the stability of such arrangements in a LISA-like configuration. One possible solution is to use a low expansion base plate and hydroxide-catalysis bond components to it to form an interferometer [2]. The required stability of such systems has already been demonstrated, for example by the engineering model of the LPF Optical Bench Interferometer (OBI) [3]. Further more the LISA baseline design calls for hydroxide catalysis bonding as the preferred method of construction for the LISA optical benches [1].

2.2. Interferometer design

An interferometric test bench has been designed for this purpose, consisting of multiple Mach-Zehnder interferometers. There will be two non-polarising reference interferometers, one unequal arm length non-polarising interferometer to measure laser frequency noise [4], and one measurement interferometer into which can be placed polarising optics. The bench consists of a

300 mm square baseplate made of Ultra Low Expansion (ULE) glass ceramic, the top surface of which has been polished locally flat to $\lambda/10$ over any 30 mm length. Fused silica optics are then hydroxide catalysis bonded onto this surface, this is described in Section 4. Light is injected onto the bench through a monolithic fibre collimator as designed for the OBI [5]. Called the 'FIOS' (Fibre Injector Optical Subassembly), it consists of a small fused silica baseplate onto which the main components are attached. The low thermal expansion of the fused silica gives a stable lens-fibre separation, resulting in a stable beam. Two FIOSs are required, one for each of the beams, these will be bonded to either side of a mounting post which is bonded to the baseplate. The layout of the interferometer is shown in Figure 1. The polarising optics will be mounted on a separate small low thermal expansion baseplate (made of ZERODUR), that can be inserted in the measurement path, illustrated in the figure by a dashed box. This introduces a degree of versatility into the measurement capability and will allow a variety of different subassemblies to be tested, enabling, for example, comparison of different mounting techniques for polarising optics.

3. Construction plan

The test bench is being constructed using the same procedures and techniques as the OBI. In doing so there must be a carefully defined order of construction to ensure the alignment of the bench. Broadly, there are three different types of item to be attached to the baseplate, the mirrors and beam splitters, the FIOSs and the photodiodes. The mirrors and beam splitters can be further subdivided into two classes, critical and non-critical. Non-critical components are those that can be bonded down with larger tolerances, and any beam position errors arising from these larger tolerances can be compensated for with the positioning of the critical components. The critical components are M7 and M8 (the input beam steering mirrors for the FIOSs) and BS4, BS6, BS11 and BS12, the four beam recombiners. All other optical components (except the polarising components shown in the dashed box, which are treated separately) are non-critical. The procedure for construction is then: *(a)* template bonding of the non-critical components, *(b)* bonding of FIOS2, *(c)* precision alignment and bonding of M7, *(d)* bonding of FIOS1, *(e)* precision alignment and bonding of M8, *(f)* precision alingment and bonding of the four beam recombiners and *(g)* gluing of the six photodiodes, aligned to beam centres.

4. Construction of the test bench

4.1. Templating

4.1.1. Template design and manufacture The template used for construction step *(a)* is made of brass plate ~ 4 mm thick. It sits on three ball bearings on the top surface of the bench, and locates against the baseplate on a further three ball bearings mounted in blocks under the template. For each component, there is a 'cut-out' in the template, with three ball bearings mounted in holes along two of the sides, one on the short side and two on the long side. In this way, a component placed into a cut out will sit against the three ball bearings. The template itself was manufactured using a 5-axis CNC mill, and after machining, was measured using a coordinate measuring machine (CMM). The positions of all the component locating ball bearings were measured, and the mean deviation of the ball bearings from the nominal positions was $\sim 30\,\mu$m.

4.1.2. Template bonding During template bonding, the baseplate, having been initially cleaned to specifications suitable for bonding (see [2]), was inclined to an angle of $\sim 5°$. The template is designed so that all the component locating ball bearings are to the same side. As a result, the inclination of the baseplate provides a small restoring force which holds the components in place against the ball bearings. The components were bonded in turn, having first been suitably cleaned like the baseplate, using $0.6\,\mu\mathrm{l\,cm}^{-2}$ of sodium silicate solution. The bonds were left

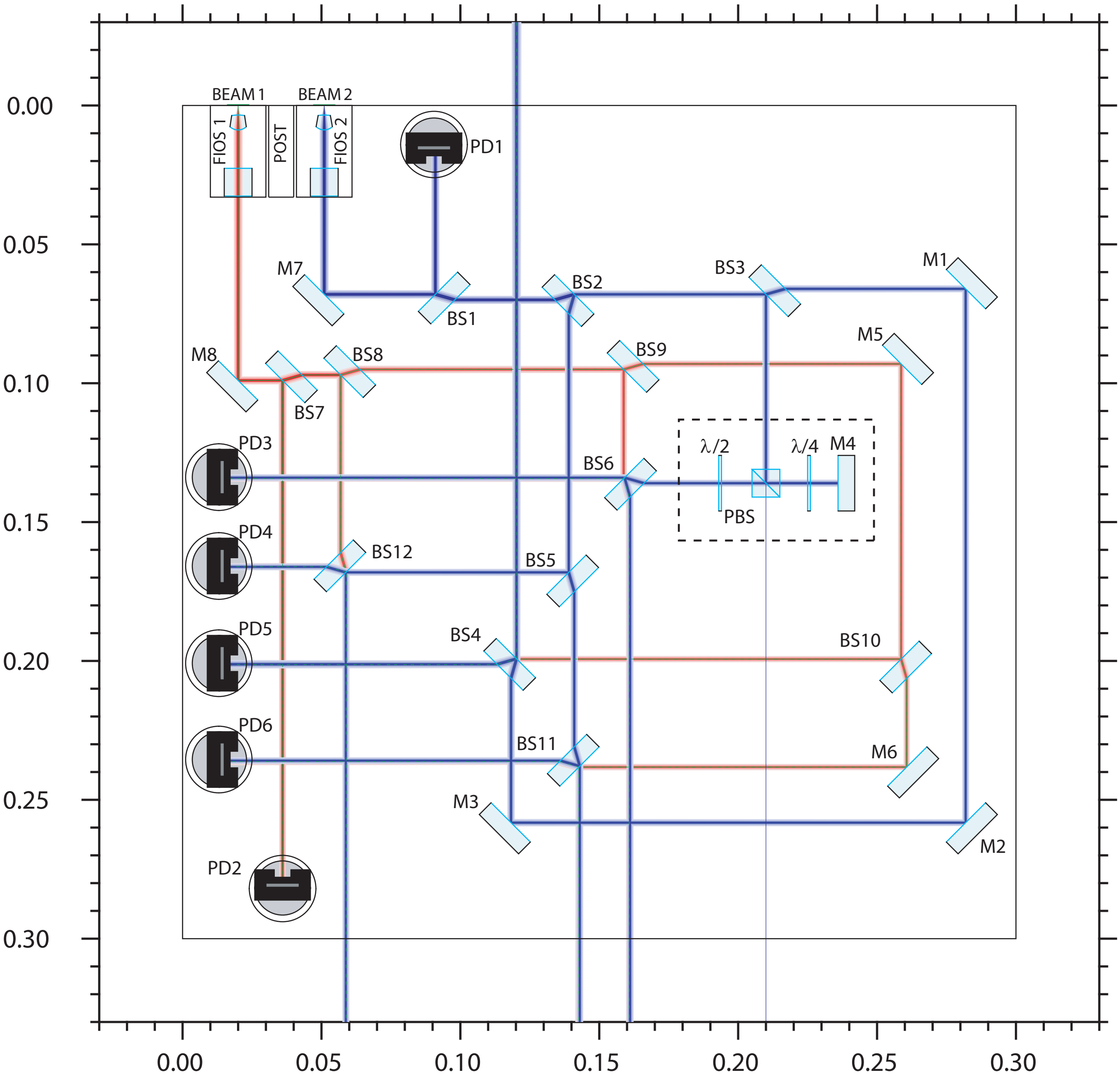

Figure 1. OptoCad [6] representation of the test bench; the polarising optics are shown bounded by a dashed box

to cure for 24 hours before the template was removed, using three screw risers built into the template which raised it above the height of the optics before it was lifted off. In addition to the non-critical mirrors and beam splitters, the FIOS mounting post was also bonded with the template. Figure 2 shows the bench after the templating procedure just prior to the removal of the template.

4.1.3. Component position accuracy After the bonds had thoroughly cured, the components were measured with the CMM to determine the accuracy of positioning. Since it is only the *relative* position of the components that is of interest (alignment to the sides or any other absolute reference frame is not required) the measured positions of the components was optimised by applying small rotations and translations to the measurement coordinate frame, and minimising the square sum of the difference between the altered measured positions and the nominal ideal positions. Translations of the components from the nominal position are largely irrelevant (given the known accuracy of the template), however angular deviations are of interest. Figure 3 shows the angular deviation from a perfect 45° of each component. All of the components fall within tolerances and these deviations can easily be accommodated by precision alignment of the critical components.

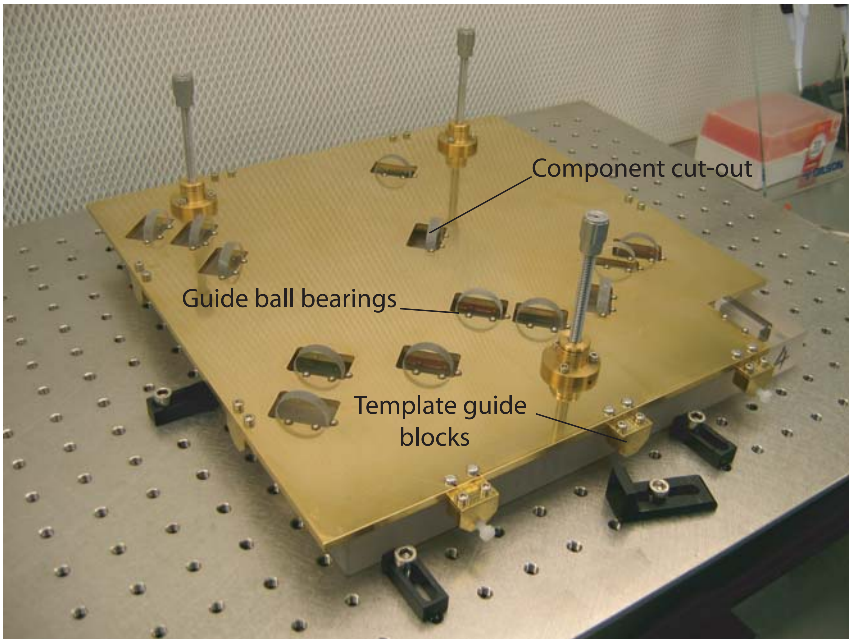

Figure 2. Photograph showing the bench after the template bonding procedure with the template still in place

4.2. FIOS bonding

The test bench is currently in the process of having FIOS2 bonded to the mounting post (step *(b)*). The bench has been incorporated into a mounting jig which holds the bench at a slight angle from vertical, so that the bonding surface of the mounting post is at a slight inclination from horizontal. This, as per the template bonding, is to provide a small restoring force against the actuators that will be used to position the FIOS. The FIOS will be floated on a buffer fluid (typically octane), this prevents optical contacting [7] of the two polished surfaces. The beam from the FIOS is monitored using a pair of quadrant photodiodes mounted in a frame. The position of the photodiode centres with respect to the frame is well known (having been previously calibrated using the CMM), thus by positioning the photodiodes such that the beam is centred on both of them, and measuring the frame with the CMM, the beam vector can be calculated. Since the ideal position of this beam is already known, it is possible to use an iterative alignment technique to position the FIOS in the correct place. The position of the FIOS is adjusted using the actuators which have a sub-micron resolution and contact the FIOS with ruby balls. Once optimum alignment is achieved, the FIOS is lifted off, bonding fluid applied and the FIOS relocated against the ruby balls. By rotating the bench through 180° the same technique can be used for FIOS1. In practice however, after FIOS2 is bonded the input mirror will then be bonded, using the precision actuators with the bench inclined. The beam from FIOS2 will then be fully profiled with respect to the baseplate, such that FIOS1 can be aligned

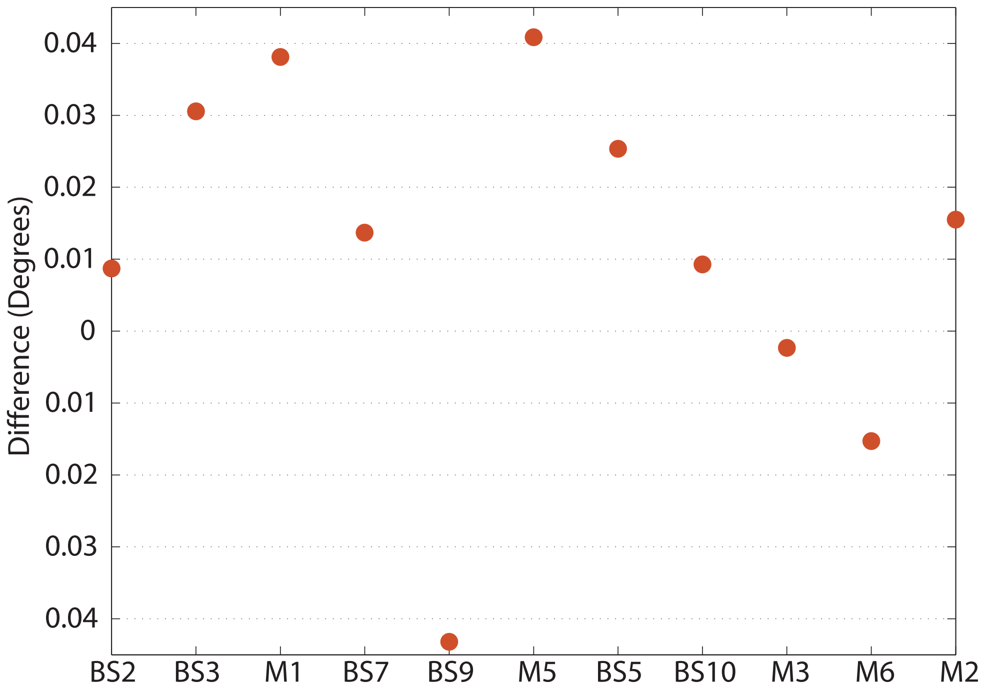

Figure 3. Measured angular deviations of templated components from nominal

to match FIOS2 as well as possible, both in height and vertical angle. After this the second input mirror can be precision bonded. The purpose of the input mirrors is to add a degree of freedom in the horizontal to allow the beams to be steered to the recombining points as well as possible.

4.3. Final construction steps

After the completion of steps *(b)* to *(e)*, the beam recombiners must be bonded. As before, the recombiner will be floated on a buffer fluid to allow adjustment of the component using the precision actuators. Beams will be injected from both FIOSs, and a off-bench photodiode used to measure the recombined beam. The contrast of the interference pattern will be optimised by adjusting the position of the recombiner. Once contrast is maximised, the component will be bonded in place. Only after the four recombiners are in position will the photodiodes be glued in place (step *(g)*), centered onto the recombined beams.

5. Test plan

Once construction is complete, the test bench will be integrated into a vacuum tank. A removable gantry incorporating precision actuators will be used to position the sub assembly containing the polarising optics into position. Laser light will be provided by a pair of Nd:YAG lasers operating at $\lambda = 1064\,\mathrm{nm}$. The lasers will be offset phase locked together, with the slave laser trailing the master by 79.99 MHz. The master laser will then be frequency shifted by an acousto-optic modulator (AOM) by 80 MHz. This will give a 10 kHz offset between the two beams, giving the heterodyne frequency for the experiment. These beams are injected onto the bench through single mode fibres, via a vacuum feedthrough, and onto the bench through the FIOSs. The two beams interfering in each of the interferometers will generate a 10 kHz heterodyne beat note at the photodiodes. By comparing the phase fluctuations of the beat notes of the reference and measurement interferometers, the stability of the measurement path can be established. Additionally, the measurement and reference interferometers all have approximately matching path length mis-matches (measurable by analysis of the heterodyne signals) [4]. This minimises coupling of laser frequency noise into the measurement. The frequency noise monitoring interferometer has deliberately offset arm lengths to exaggerate laser frequency noise and allow it to be compensated for, either in post-processing or by feeding back to the laser, see [4]. Using the replaceable sub assembly in the measurement path, the stability of polarising Mach-Zehnder interferometers can be verified, and a variety of mounting techniques for polarising optics can be tested in order to select the best mounting techniques for LISA.

6. Conclusion

We have presented the design, initial construction of, and future plans for, a hydroxide catalysis bonded test bench designed to test the concept of polarising Mach-Zehnder interferometers for use in LISA. Such investigations are vital in advancing the existing technology developed for LISA Pathfinder towards the more challenging LISA baseline. By applying LISA Pathfinder construction techniques (precision adjustable hydroxide catalysis bonding and monolithic fibre injectors in particular) we ensure the most representative test possible of these optical assemblies.

Referances

[1] D Weise et al. 2008 *See this volume*

[2] E J Elliffe, J Bogenstahl, A Deshpande, J Hough, C Killow, S Reid, D Robertson, S Rowan, H Ward and G Cagnoli 2005 *Class. Quantum Grav.* **22** S257-S267

[3] G Heinzel et al. 2005 *Class. Quantum Grav.* **22** S149-S154

[4] D Robertson, C Killow, H Ward, J Hough, G Heinzel, A Garcia, V Wand, U Johann and C Braxmaier 2005 *Class Quantum Grav.* **22** S155-S163

[5] D Robertson et al. 2008 *See this volume*

[6] OptoCAD by Roland Schilling. http://www.rzg.mpg.de/∼ros/OptoCad, 2008