LTP fibre injector qualification and status

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Abstract. This paper presents the current state of the LISA Technology Package (LTP) fibre injector qualification project in terms of vibration and shock tests. The fibre injector is a custom built part and therefore must undergo a full space qualification process. The mounting structure and method for sinusoidal vibration and random vibration tests as well as shock tests will be presented. Furthermore a proposal will be presented to use the fibre injector pair qualification model to build an optical prototype bench. The optical prototype bench is a full-scale model of the flight model. It will be used for development and rehearsal of all the assembly stages of the flight model and will provide an on-ground simulator for investigation as an updated engineering model.

1. Introduction

The LTP optical bench interferometer (OBI) will be built at the Institute of Gravitational Research (IGR), University of Glasgow. The aim of the OBI is to measure displacements of two test masses [1]. To do this it uses four heterodyne interferometers, two of which have beams reflected from the test masses. Figure 1 shows the optical layout created by OptoCAD [2] of the OBI. The optics have to be bonded [3] to the ultra stable bench to achieve the desired performance [4]. Silicate bonding is a technique which has been used as part of a previous space mission [5]. As part of the LTP OBI two customised ultra-stable fibre injectors are attached to the bench by monolithic joints. These fibre injectors have been developed and will be built at the IGR. The fibre injector consists of glass components which are either glued or silicate bonded together and an optical fibre which includes strain relief cladding. The design and construction process of the fibre injector are subject to space qualification. Vibration and shock tests are part of the qualification tests. It has to be demonstrated that the tests cause no significant changes of the optical performance of the fibre injectors. A fibre injector pair qualification model will be built to the same requirements using the same processes as the proto flight model. This fibre injector pair will be bonded to a representative prototype Zerodur® baseplate for the qualification process.

2. Fibre Injector Qualification

The fibre injector optical sub-assembly (FIOS) consists of the fibre with part of the cladding stripped which is attached to a ferrule and then glued into a hole in a fibre mounting cube. There is also a strain relief at the fibre input side. The fibre mounting cube is polished flat and silicate bonded onto the FIOS baseplate. The collimating lens is first glued into a fused silica U-groove and this assembly precision bonded to the FIOS baseplate. Finally, a polariser to maintain the correct polarisation is glued onto the FIOS baseplate. The FIOS baseplate will be silicate bonded onto a post which is also silicate bonded onto the OBI Zerodur® baseplate. A complete assembly of two FIOS and their mounting post is shown in Figure 1. To have a fully representative FIOS qualification process, a FIOS pair will be bonded onto a prototype Zerodur® baseplate of the same dimension as the OBI baseplate and at the same location. The Zerodur® baseplate will be used as reference baseplate for optical performance testing before and after the FIOS pair are subjected to environmental tests.

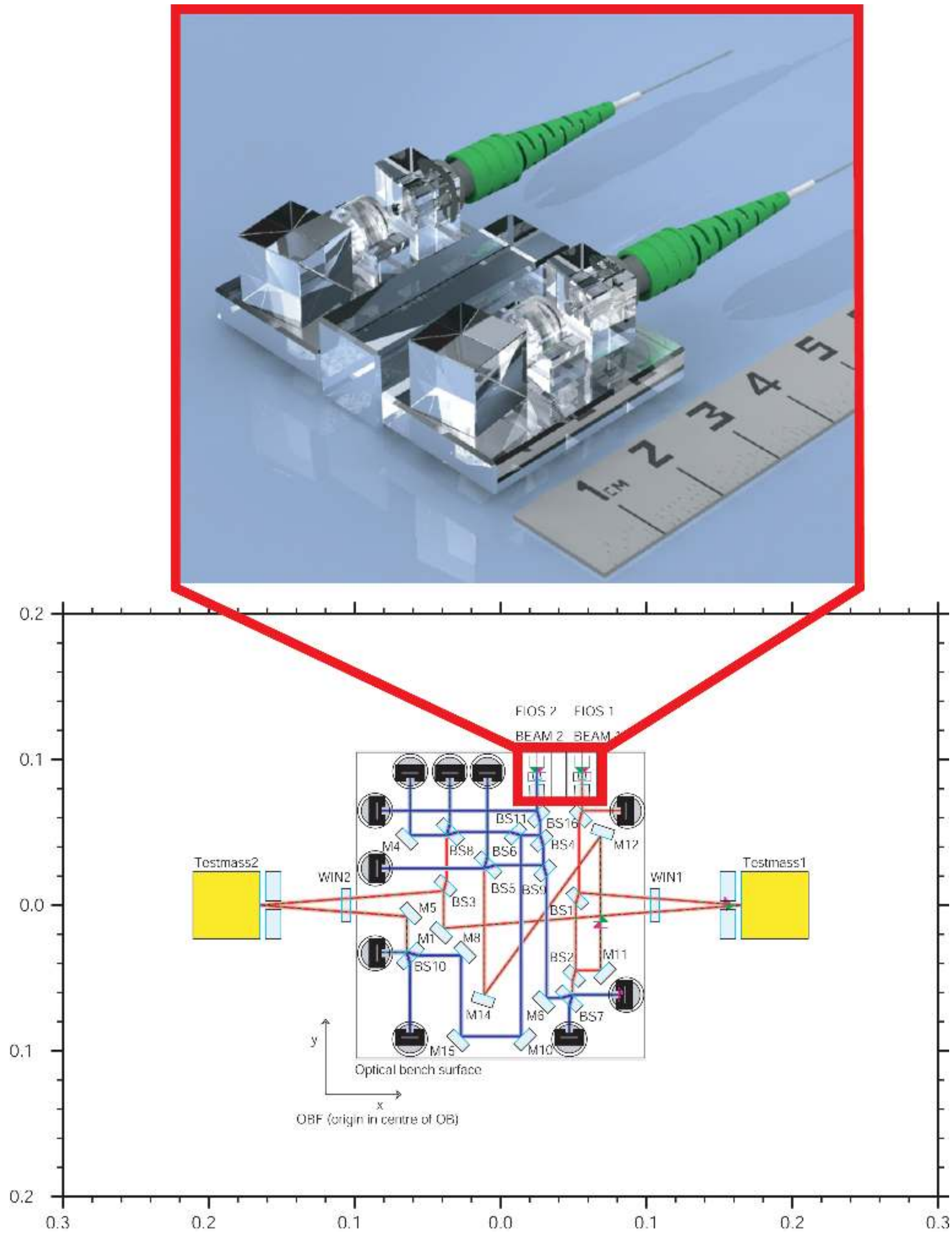

Figure 1. Optical layout of the LTP optical bench interferometer with a CAD rendering close-up of the FIOS pair

2.1. Qualification plan of vibration and shock tests

The main stress for the optical bench assembly is during the launching process. Part of the vibration will be absorbed by the spacecraft and the loading structure. Nevertheless, the requirements for the LTP OBI and therefore for the FIOS qualification are demanding. The qualification process of the fibre injector involves sinusoidal tests, random tests and shock tests along all three axes. During the sinusoidal tests the FIOS will experience an acceleration of up to 40 g at frequencies up to 100 Hz. The random test loads are in the frequency range 100 - 500 Hz with $0.5\,g^2/Hz$ with a RMS acceleration of 20 g. A shock response spectrum (Q=10) of 750 g at 10 kHz and 1.5 kHz and 20 g at 100 Hz has to be demonstrated. In the case of the LTP OBI environmental shaking tests the bench will be mounted using specially engineered inserts, however the prototype Zerodur® baseplate does not have inserts, therefore another way of mounting the baseplate has to be found.

2.2. Mounting technique

A suitable mounting structure is needed, which holds the prototype Zerodur® baseplate and can be easily mounted onto the vibration table. To mount a Zerodur® baseplate into this mounting structure a strong but temporary joint is needed. Waxes are commonly used to mount glass for polishing and cutting, therefore different waxes were tested in small shear tests, of which *Logitech Quartz* wax [8] seemed the most suitable for this application. Large scale tensile tests were carried out using two 10 cm diameter discs, which had been wax bonded together and were then pulled apart. The six test runs measured forces of 8.4 ± 1.2 kN. This equates to $\sim 10\,kg/cm^2$, shown in Figure 2. These measurements show that the wax-bond would be strong enough to hold a Zerodur® baseplate under the toughest load of 40 g. But the behaviour of the wax-bond is unknown during vibration and shock tests, therefore a test run with a wax-bonded dummy load was carried out.

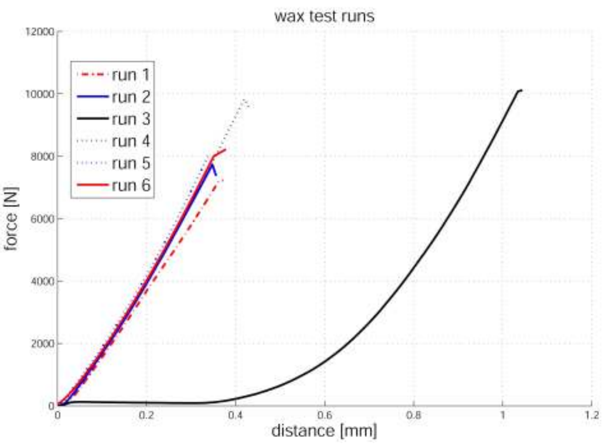

Figure 2. Graph of measured force of tensile tests

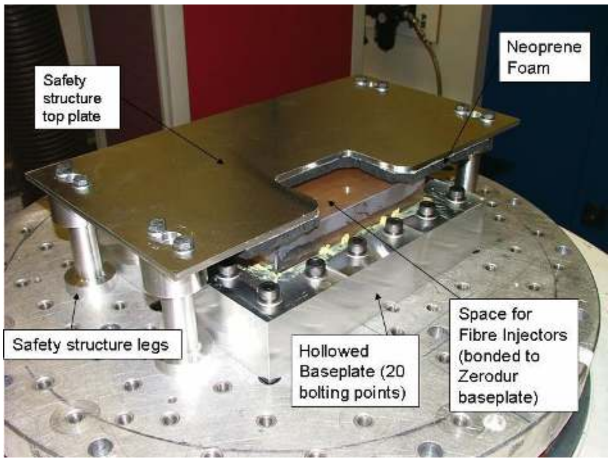

Figure 3. Picture of mounting structure on vibration table

Figure 3 shows the dummy Zerodur® load wax-bonded into the hollowed aluminium adapter plate and the safety structure top plate. Using finite element (FE) analysis [7], the hollowed adapter plate and safety structure were modelled. A hollowed adapter plate of 60 mm thickness, hollowed out to a depth of 20 mm to the size of the Zerodur® baseplate, has a first resonance mode over 2000 Hz. The safety structure has a first mode of 163 Hz, therefore the safety structure is placed over the Zerodur® baseplate with a gap and is never in contact with the Zerodur®

baseplate. The limiting factor for the thickness of the hollowed adapter plate is the mass - the vibration table has a mass limit of 20 kg for our vibration requirements.

2.3. Results of Pre-tests

The pre-tests of a dummy Zerodur® baseplate (without the FIOS pair) wax-bonded into the mounting hardware have been conducted and the results were successful. Figure 4 shows the graph of the sinusoidal vibration test in the horizontal direction. Three accelerometers were mounted onto the Zerodur® baseplate, the hollowed adapter plate and the top plate. It is easy to see that the acceleration of the Zerodur® baseplate and hollowed mount are similar. The acceleration of the top plate is increasing with frequency, due to the fact that the top plate resonance mode is lower and easier to excite, and the top plate shows in Figure 5 the first resonance mode as simulated at 163 Hz. The Zerodur® baseplate and the hollowed adapter plate are showing in Figure 5 the desired effect of behaving like a monolithic entity with the predicted first resonance mode at 2.1 kHz.

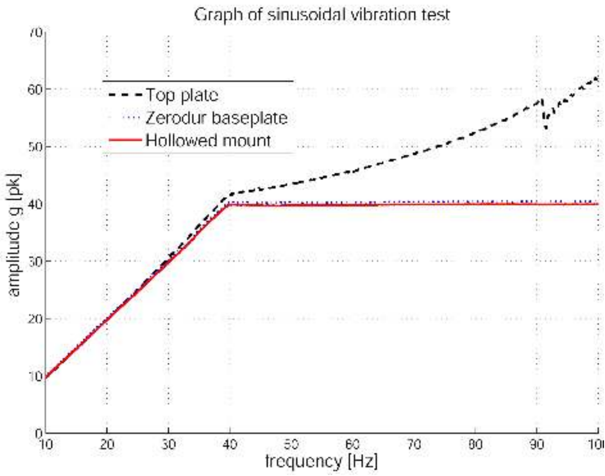

Figure 4. Graph of sinusoidal vibration test

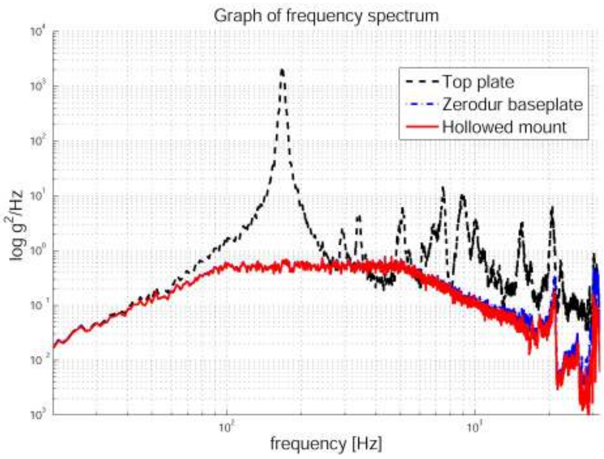

Figure 5. Graph of frequency spectrum

The shock tests were even more challenging than the vibration tests. The wax-bond was not renewed before the shock tests were carried out. During the pre-test, damaged areas of the wax-layer were detected after 6 shocks (2×3 shocks in vertical orientations). Afterwards three further shocks in horizontal orientation were carried out and two more in vertical orientation before the wax-layer and the Zerodur® baseplate became loose. The Zerodur® baseplate was left undamaged. As a summary, it can be said that the wax-bond fulfilled the requirements for a suitable joining technique, because after each shock the wax-layer could be examined and if necessary the wax-bond could be redone by heating the structure to re-form it. This was demonstrated by placing it onto a heat plate and re-melting the wax. The pre-tests of the mounting structure and the wax-bond technique was successful.

3. LTP OBI optical prototype bench

The aim of building an LTP OBI optical prototype bench is to have an exact optical copy of the flight model, including the same design of fibre injectors and therefore similar beam performance. In such a way, the optical prototype bench will be the replacement for the engineering model [9], and can be used for ground-based readout experiments. It can also be used as a dummy bench for flight model OBI performance procedure set-ups. Furthermore, the construction of the optical prototype bench provides practice for the assembly stages of the flight model and will provide feedback to prove the optical bench alignment tools at every construction step.

3.1. Realisation plan

Some optical components do not require high precision location and can be placed within $\sim 50\,\mu$m precision using templates. Some other optical components have to direct the beam to certain points, for example the beams have to hit the test masses accurately in the middle of the front face with a maximum error of $\sim 25\,\mu$m. Using micro precision tools the optical components can be manipulated. This will be done in real time having a beam which will be aimed onto a target consisting of a pair of calibrated quadrant photodiodes (CQP). The CQP will be used to steer the beam to a pre-calculated position of the beam vector and will also be used to measure the position of the final beam after each step, and in this way to provide feedback for the simulation program that generates the next corrected optical target point. The CQP consists of two quadrant photodiodes and a beamsplitter, which splits the beam into two paths with a pathlength difference of 44 cm, shown in Figure 6. The CQP is constructed on a stable Invar structure. Using two quadrant photodiodes the beam position can be detected using the first photodiode and the beam angle using the second photodiode. The readout precision of the quadrant photodiodes is better than $1\,\mu$m. Modulated light is used to reduce the sensitivity to DC offsets on the photodiodes and electronics. For calibration it is necessary to use a stable beam, therefore a FIOS engineering model was glued to a Zerodur® block. Using this stable beam the quadrant photodiode pair was calibrated by centring it to this beam and measuring the position of the stable Invar structure. This process was repeated in the same manner several times at different distances and angles with the non-changed stable beam. In such a way the quadrant photodiode pair was calibrated with a remaining uncertainty of $\pm 3\,\mu$m and $\pm 30\,\mu$rad per single measurement.

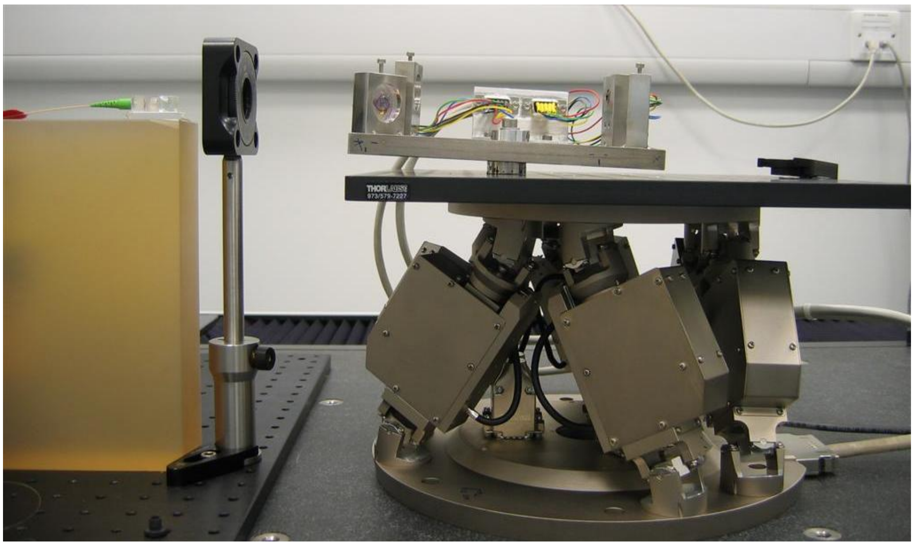

Figure 6. Calibration of the CQP using a stable beam from a FIOS engineering model. The CQP is aligned on a six-dimension micron-precision stage.

4. Conclusion and Acknowledgement

A test procedure to qualify the fibre injectors for LTP has been presented. The mounting hardware has been built and successfully demonstrated. The CQP fulfils the necessary specifications. We wish to acknowledge the support of STFC and the University of Glasgow. We would like to thank SELEX-Galileo (Edinburgh) for their assistance. Furthermore, we would like to thank the Albert Einstein Institute Hannover for their contribution to the LTP OBI optical prototype bench.

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