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AIDAinnova

Advancement and Innovation for Detectors at Accelerators
Horizon 2020 Research Infrastructures project AIDAINNOVA

MILESTONE REPORT

PLAN OF INVESTIGATION AND PROTOTYPING FOR DEVELOPMENT OF MIRRORLESS FSI

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Abstract:

This report details the plans for the investigation of mirrorless FSI within the framework of the AIDAinnova programme. We discuss the recent upgrade of the FSI system at the University of Oxford, which offers more channels (up to 16), and, more importantly for the studies planned here, the option to operate these channels at higher laser power. Finally, we give an overview over existing structural prototypes, which we will use to investigate mirrorless FSI.

AIDAinnova Consortium, 2022
For more information on AIDAinnova, its partners and contributors please see http://aidainnova.web.cern.ch/

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Executive summary

Our programme to work on minimizing retroreflectors for the use with Frequency Scanning Interferometry is continuing. Progress ahs been made with small spherical glass retroreflectors and we could demonstrate their use for obtaining displacement data in the Oxford vibration setup.

A recent upgrade of our FSI system to higher power will give us the capability to investigate mirrorless operation. To demonstrate this we have a number of realistic prototypes available. We will also investigate surface reflectivity enhancements like reflective tapes. We are confident that we will make progress on mirrorless FSI within the framework of this project and produce results which will be relevant for the field, but also lead to technologies that will be used by industry.

1. INTRODUCTION

Frequency scanning interferometry has originally been developed for the alignment of the ATLAS SCT [1]. The technology has been further developed [2], and spun out to industry [3]. This conventional version of the technology provides an absolute distance measurement between a collimator/beam splitter assembly and a retroreflector with nm precision.

One application of FSI, which was developed within the AIDA 2020 programme was the use of FSI for vibration measurements of novel light-weight structures for future tracking detectors under controlled vibrational loads (ground vibrations and air flow). The main drawback of conventional FSI for these measurements is that the retroreflector affects the dynamic response of the structure due to its weight, and provides a significant obstacle to air flow, affecting the local flow patterns, and thus the cooling performance and the mechanical loads onto the structure.

2. IMPROVEMENTS TO RETROREFLECTORS

As part of the AIDAinnova programme we have made already significant progress in reducing the size of retroreflectors. For this we are using glass spheres with an index of refraction $n \approx 2$, which are commercially available [4] and are widely used for launching light into a fibre. The high index of refraction, in the visible range, allows focusing the beam onto a small spot. By coating one hemisphere of the ball lenses with gold (300 nm) using thermal deposition these can be effectively transformed to retroreflectors. The principle was initially tested using 5 and 10 mm diameter ball lenses and at a later stage 1mm diameter ones. The benefit of such small sized retroreflectors is twofold. Firstly, the reflector size is of the same order as the launch beam and hence no light is lost outside the reflector. Secondly, a smaller reflector introduces minimal weight onto the device under test (DUT) and it minimises the effects of dispersion $n(\lambda)$ in the wavelength range where the FSI system operates (1520-1580 nm). This in turn minimises the differences in total path length attributed to different wavelengths. Figure 1 shows the 1 mm diameter gold-coated ball lens with a mass of 3 mg used in the setup.

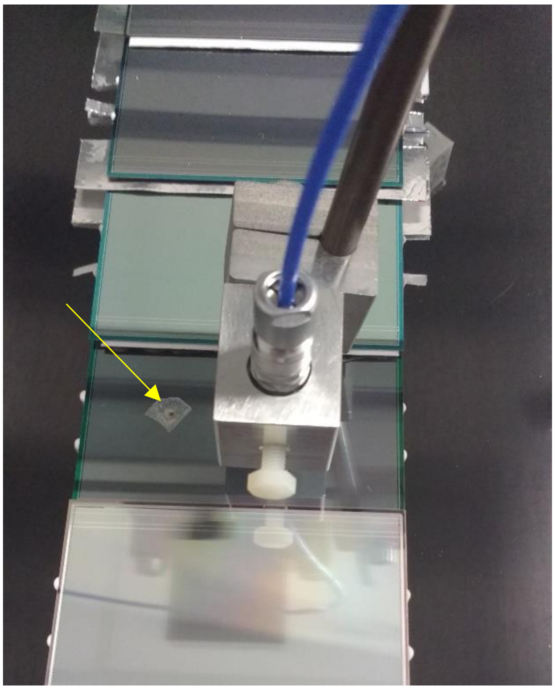


Figure 1: Displacement sensors used in the Oxford structure characterisation facility: the sensor with the blue cable is a capacitive displacement sensor (diameter 10 mm). To the left of the aluminium holder for this sensor the 1 mm diameter spherical glass retroreflector can be seen (indicated by arrow). The structural prototype is a mechanical prototype of the CBM-STS loaded with dummy silicon sensors.

One potential issue with this spherical glass retroreflector is the dispersion of the index of refraction, resulting in insufficient reflected light reaching the collimator. However, at the moderate distances required for the deformation measurements in our vibration and air flow setups, dispersion effects did not affect the operation of the FSI measurement (Figure 2).

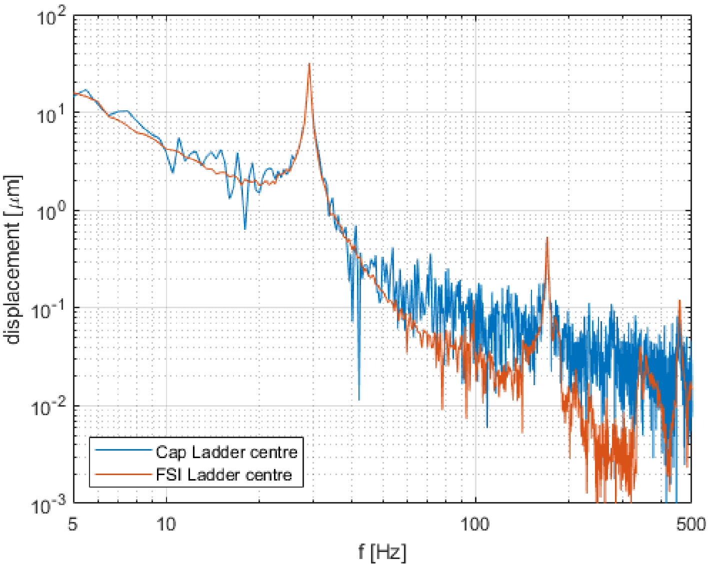
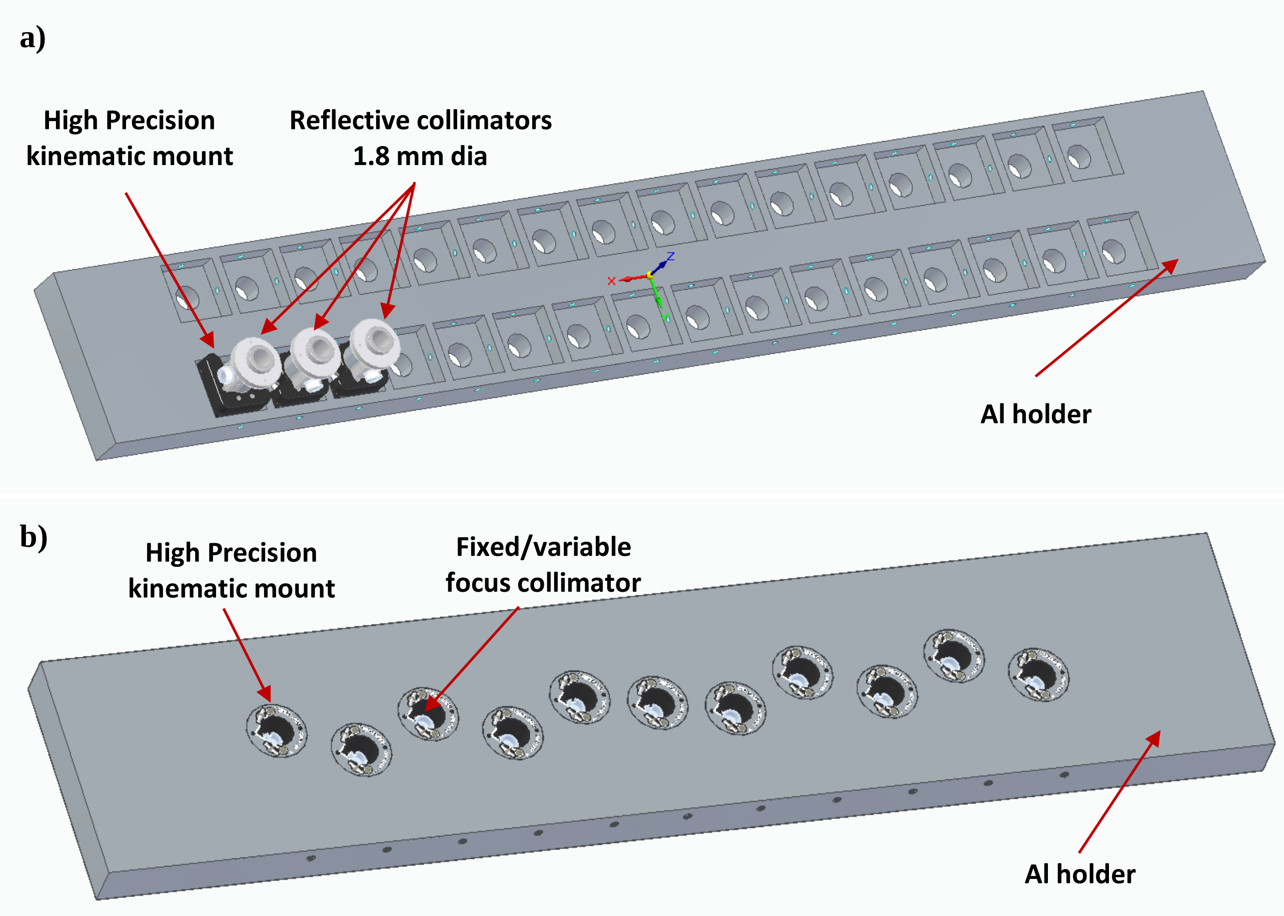


Figure 2: Comparison of absolute displacements of the centre of an ATLAS strip stave core as measured with the capacitive and the FSI measurement systems as a function of the excitation frequency. The FSI data were taken with the 1 mm diameter glass sphere retroreflector. Note that while the 1st mode at about 29 Hz is resolved by both system, the FSI system has a much better resolving power at the 3rd and 5th mode frequencies of 170 Hz and 456 Hz, respectively

One remaining field of study for these retroreflectors is the optimization of the mounting. First prototypes have been glued with superglue onto microscope cover glass shards. We will be investigating alternative methods, like for example double-sided adhesive film or optical waxes.

3. HIGH-INTENSITY FSI UPGRADE

The initial purchase of the multiline FSI system only included 4 channels of which 2 were used to monitor the displacements at the clamping points of the DUT for background subtraction, one for the reference interferometer and one to monitor the vibrations of the DUT at the midpoint over an excitation frequency range of up to 500 Hz. Moreover, the maximum power output of the system was 60 µW per channel. The system has now been upgraded using other Oxford funds to a total of 16 channels. In addition, we have added erbium-doped fibre amplifiers (EDFAs), which can boost the total power to 200 mW (12.5 mW per channel). The higher channel count increases the number of points on the DUT where the displacement can be monitored, thereby allowing the detection of more complex motions under the loading scheme, while the higher power aims to improve on the signal quality and ultimately upgrade the system to one that does not require the use of reflective optics (see next section for more details). Figure 3a below illustrates the design of the collimator structure that will accommodate the 16x lines for the DEPFET detector ladders. The holders vertical can be varied from 10 to 250 mm with respect to the DUT.



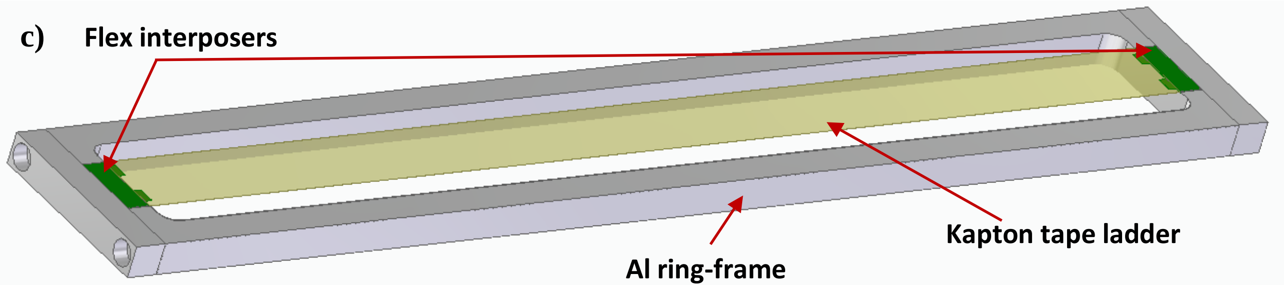


Figure 3:a) Design for new collimator support for the DEPFET detector ladders. The 32 square slots allow for flexible positioning of the 14 channels. b) Collimator support for the Mu3e ladder. c) Mu3e ladder and its ring-frame support.

4. MIRRORLESS FSI STUDIES

Table 1 lists the structural prototypes we currently have available for these studies. As can be seen, we have prototypes with several important surface materials, which will allow us to make representative measurements. Also, the range of dimensions, weights and geometries will provide us with a range of response amplitudes and mode shapes to explore. One of the main drawbacks of the current FSI system is the requirement for coaxial illumination/observation. As the ultimate improvement to the current system would be to relax the need for retroreflector optics, a variety of surface coatings such as reflective paints and/or powders will be tested with the aim to increase the diffuse reflectivity of the test surfaces with collimated beams of 1.8 mm diameter. Moreover, a variety of retroreflecting tapes that are widely available will also be tested in order to improve the reflectivity of otherwise poorly reflecting surfaces such as naked carbon fibres. The aforementioned, will constitute the 1st step towards mirrorless FSI studies and will require the use of the EDFAs in order to increase the beam power (12.5 mW per channel with 10 mW being the limit of class 1 laser for a 1.8 mm diameter beam). The 2nd step of investigations will involve the use of variable focus collimators which will be used to further reduce the beam diameter by focussing the beam to a point like region on the surface of the DUT. This approach will reduce effects caused by surface roughness (roughness is known to be linked to power envelop fluctuations on the recorded interference signal) or inclination of the DUT during the loading scheme. Different sizes of this type of collimators will be trialled in order to find the optimum solution – Larger sizes and hence higher NA allow smaller focal spots as well as larger portions of reflected light to be captured.

Table 1: Prototypes to be used for mirrorless FSI studies.

Device	Manufacturer	Length	Weight[1]	Surface material
ATLAS barrel strip stave core	Oxford	1130 mm	350 g	Cu/Kapton tape
PLUME detector ladders	Bristol	150 mm	~10 g	Silicon, electrical components

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[1] Weight is not directly comparable because of inert material (modules, supports, cables) mounted on some prototypes. Listed to demonstrate scale of dynamic variations.

DEPFET detector ladders	Valencia	70-80 mm	1-2.5 g	Silicon, electrical components
CBM-STS bare truss structure	GSI Darmstadt	550 mm	10 g (est’d)	Carbon fibre
CBM-STS loaded mechanical prototype	GSI Darmstadt	550 mm	+101 g	Silicon
Mu3e ladder	Oxford	373.4 mm	1.5 g	Kapton tape

5. SCHEDULE

Table 2 gives a tentative schedule for the R&D we are expecting to perform (with the usual caveats). With the progress so far we are confident that we will have satisfying results at the end of the programme on low-mass retroreflector and mirror-less FSI at the end of the programme.

Table 2: Tentative schedule for research programme.

<table>
<tr><th>Period</th><th>Vibration setup</th><th>Air flow setup</th></tr>
<tr><td>Q4 2022</td><td>Small retroreflector studies, commisioning of EDFAs</td><td></td></tr>
<tr><td>Q1 2023</td><td>Commisioning of EDFAs</td><td>Small retroreflector studies</td></tr>
<tr><td>Q2 2023</td><td>Mirrorless FSI, reflective tapes</td><td>Small retroreflector studies</td></tr>
<tr><td>Q3 2023</td><td colspan="2">Small retroreflectors/mirrorless FSI, reflective tapes</td></tr>
<tr><td>Q4 2023</td><td colspan="2">Small retroreflectors/mirrorless FSI, variable focus collimators</td></tr>
<tr><td>Q1 2024</td><td colspan="2">Small retroreflectors/mirrorless FSI, variable focus collimators</td></tr>
<tr><td>Q2 2024</td><td colspan="2">Small retroreflectors/mirrorless FSI</td></tr>
</table>

6. REFERENCES

[1] Coe, P., Howell, D. and Nickerson R. (2004) Frequency scanning interferometry in ATLAS: remote, multiple, simultaneous and precise distance measurements in a hostile environment, *Meas. Sci. Technol.* **15** 2175.

[2] Dale, J., Hughes, B., Lancaster, A. J., Lewis, A. J., Reichold, A. J. H., & Warden, M. S. (2014). Multi-channel absolute distance measurement system with sub ppm-accuracy and 20 m range using frequency scanning interferometry and gas absorption cells. Optics Express, 22(20), 24869-24893. doi:10.1364/OE.22.024869

[3] https://www.etalonproducts.com/en/products/absolute-multiline-technology/

[4] https://www.edmundoptics.co.uk/p/10mm-diameter-s-lah79-ball-lens/7166/

ANNEX: GLOSSARY

Acronym	**Definition**
FSI	Frequency Scanning Interferometry
EDFA	Erbium-doped fibre amplifiers
DUT	Device under test
DEPFET	Depleted p-type field effect transistor
PLUME	Pixelated Ladder with Ultra-Low Material Embedding
CBM-STS	Compressed Baryonic Matter experiment - Silicon Tracking System