LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Update on Development of a CO_2 Laser Machine for Pulling and Welding Silica Fibres and Ribbons

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1 Introduction

The purpose of this document is to provide a brief update on the status of the CO_2 laser machine, currently being developed in Glasgow, for the fabrication and welding of fused silica ribbons and fibres for the monolithic suspension stages of advanced gravitational wave detectors. This work is part-funded by the EGO organisation and by PPARC.

With respect to Advanced LIGO the current baseline is to use this machine to fabricate and weld fused silica ribbons to be used in the ETM and ITM suspensions. It can also be used for the fabrication and welding of fibres on the modecleaner and beamsplitter suspensions if required (TBD).

Key reference documents include:

T050206-00-K	*Production and Characterisation of Synthetic Fused Silica Ribbons for Advanced LIGO Suspensions*
T050207-00-K	*Optical Profiling device for Dimensional Characterisation of Ribbons/Fibres*
T050215-00-K	*Monolithic Stage Conceptual Design for Advanced LIGO ETM/ITM*
T050213-00-K	*ETM/ITM Monolithic Stage Fabrication & Assembly*
T040170-01-D	*Advanced LIGO Silicate Bonding, Ears, Ribbon Fiber Status / R&D Plan*
T050212-00-K	*Ribbon Tolerances and Alignment Requirements for Advanced LIGO Optics*
T010103-04-D	*Advanced LIGO Suspension System Conceptual Design*

2 Ribbon / fibre fabrication: process overview

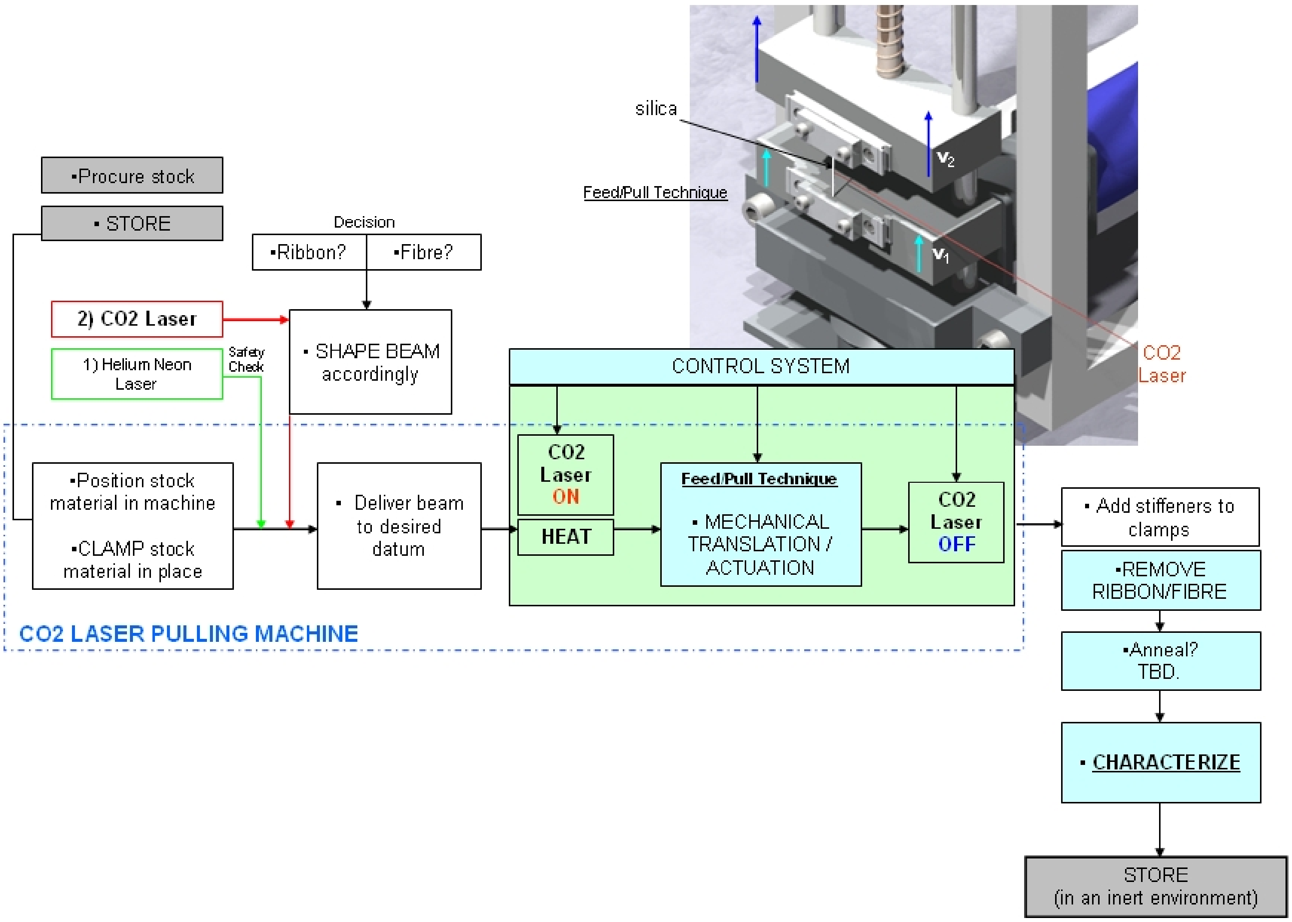

Figure 1 Overview of ribbon/fibre fabrication

3 Feed & pull technique for fibre/ribbon fabrication

The CO_2 laser pulling machine conceptual design is based on the "feed & pull" technique.

Figure 2 gives an overview of the set-up to be used to create a silica fibre, with beam shaping specific to that required for achieving a cylindrical cross section.

Fibre stock (silica rod) is held between the base clamp and upper clamp in the machine. The laser beam is reflected on a rotating 45 degree gold coated mirror onto a pair of conical mirrors. In this way the silica stock material is heated radially. The upper mirror is moved slowly downwards feeding the laser beam into the stock material. The upper clamp moves upwards to draw the fibre.

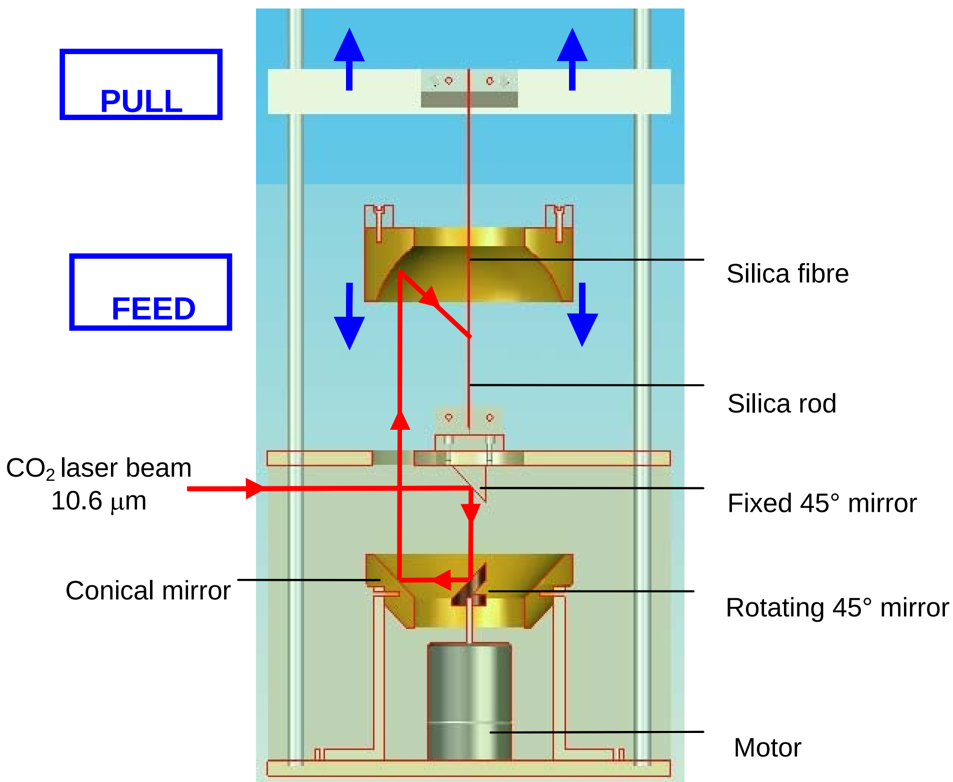

Figure 2 'Feed & Pull' technique.

4 Pre-prototype machine

4.1 Machine layout

A pre-prototype was constructed to verify the concept of 'feed & pull' (*Figure 3*). This prototype was fundamental to the selection of the mechanical actuators for the final prototype machine design.

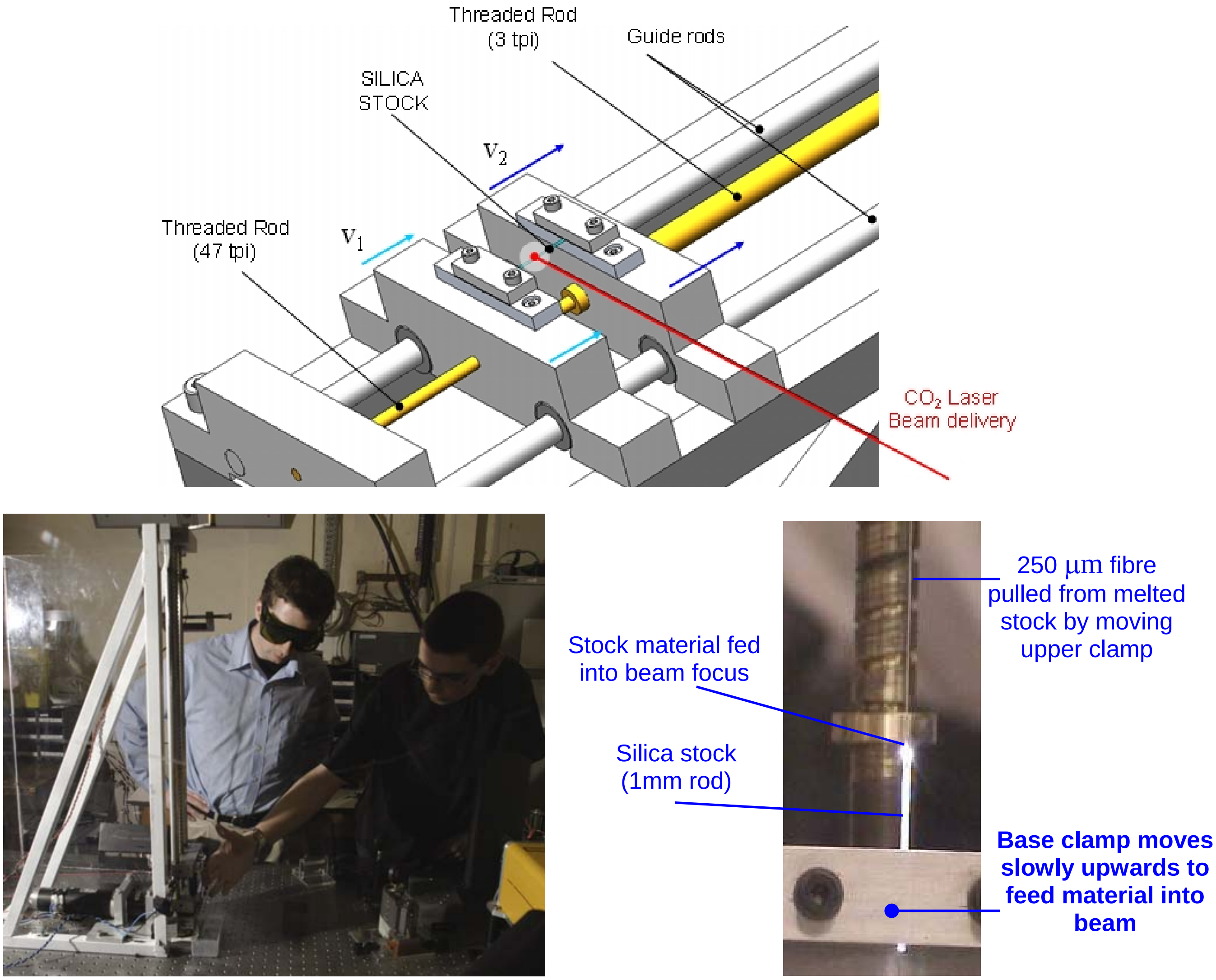

Figure 3 *(a) CAD representation of the pre-prototype set-up; fixed ratio of 'feed' (v_1) to 'pull' (v_2) = 1:16. (b) Pre-prototype set-up in the lab in Glasgow (c) Photograph of the fabrication of a 250 μm fibre - 1 mm silica rod fed into the CO2 laser beam by the slowly moving base clamp as the upper moving clamp draws the fibre.*

4.2 Results from the pre-prototype pulling machine

4.2.1 Fibres

Fibres up to ~580 mm in length were produced using the pre-prototype pulling machine. The following profile characteristics were achieved:

- The first 35 mm were characterized by having the diameter considerably thinner (down to 45 μm) than the rest of the fibre, following the shape typical of the feed and pulling technique
- On 530mm the average diameter was 184μm with a standard deviation of 5μm
- The fibre was reasonably circular (maximum difference measured between two orthogonal diameters 8μm)
- Maximum diameter difference fibre to fibre was15μm (preliminary)
- For future prototypes it is possible to alter the fibre diameter changing the pulling and feeding speeds maintaining fixed their ratio.
- First strength tests on laser pulled fibres yielded a breaking strength of 3 GPa.

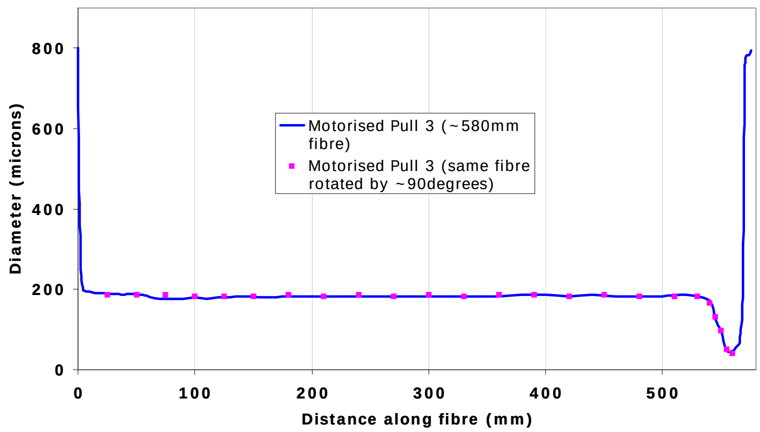

Figure 4 *Graph of dimensional characterisation of a 580 mm long fibre, pulled on the pre-prototype pulling machine*

4.2.2 Ribbons

Early ribbons were fabricated using the pre-prototype motorised feed & pull machine (without laser power stabilization) using stock of 5 mm by 0.5 mm. Typical ribbon dimensions were 4 mm by 150 μm.

A triangular waveform of frequency 10 Hz was used to drive a mirror galvanometer system to dither the beam across the rectangular plate stock material.

5 Prototype machine

Reference documents:

T050206 *Production and Characterisation of Synthetic Fused Silica Ribbons for Advanced LIGO Suspensions*

5.1 Design and development

The key features of the prototype CO_2 laser machine are as follows:

- Vertical double ball-screw unit
- 2 x servo motors with reduction gearboxes
- Beam shaping set-up (separate designs for creating fibres and ribbons)
- Linear encoder sensors (including magnetic tape and readout head)
- LABVIEW control from PC

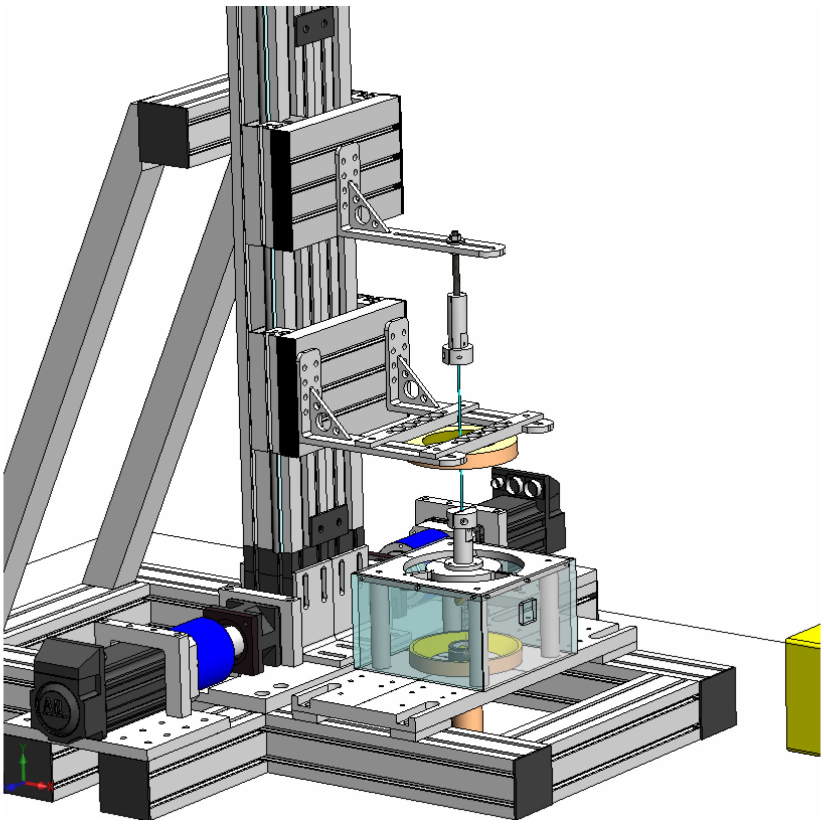

Figure 6 CAD representation of current design (in progress)

The conceptual design and development is at an advanced stage, as can be seen in *Figure 7*.

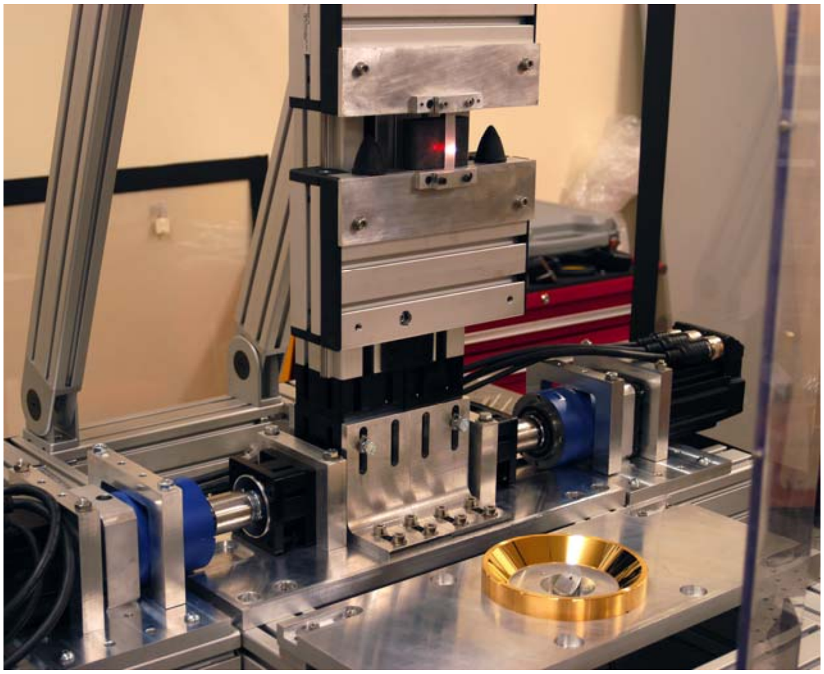

Figure 7 *Ribbon fabrication on prototype machine: silica slide being heated by the dithering of CO_2 laser beam across its width. Gold coated conical mirror used to produce cylindrical fibres also shown.*

Figure 8 illustrates the intended use of the conical mirrors (that appear in *Figure 7*) in the beam shaping set-up for the creation of cylindrical fibres.

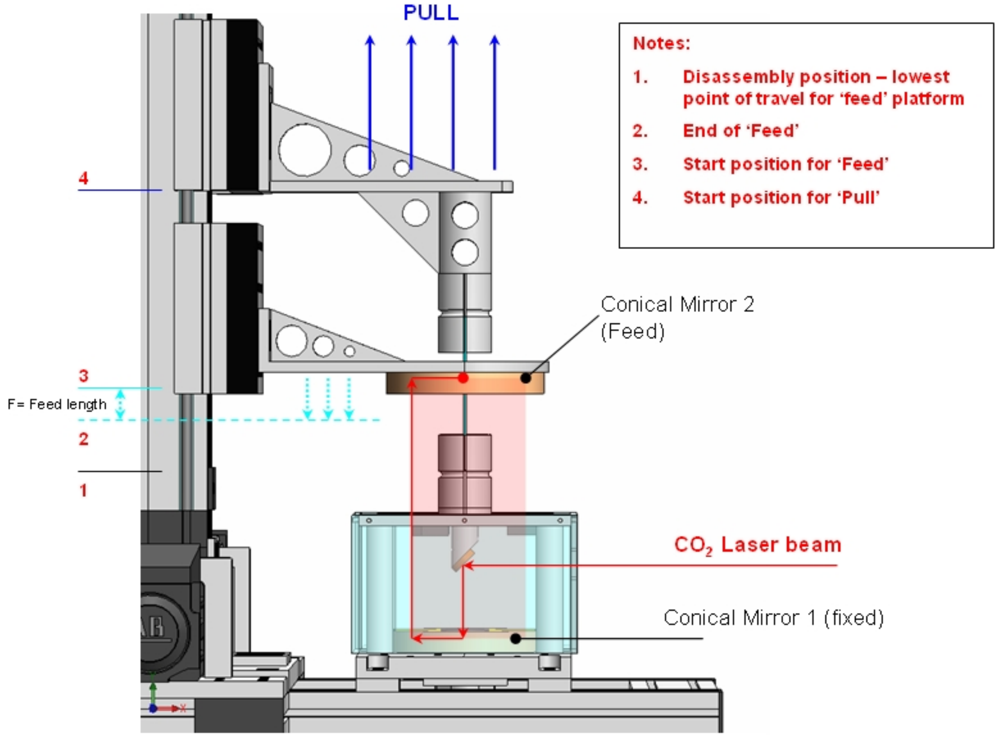

Figure 8 *Feed & pull set-up for production of cylindrical fibres on prototype machine (manufacture and assembly of the beam shaping design in progress)*

5.2 Results: prototype pulling machine

5.2.1 Fibres

Dimensional Characterisation

The first fibres pulled on the new machine show significant improvement on those fabricated with the pre-prototype. The thinner diameter that occurs at the start of the pulling process is far less pronounced on early fibres, which is very encouraging. The mean diameter of the fibre shown in Figure 9, was 406 μm with a standard deviation of 5 μm (on the straight part of the fibre excluding the neck region).

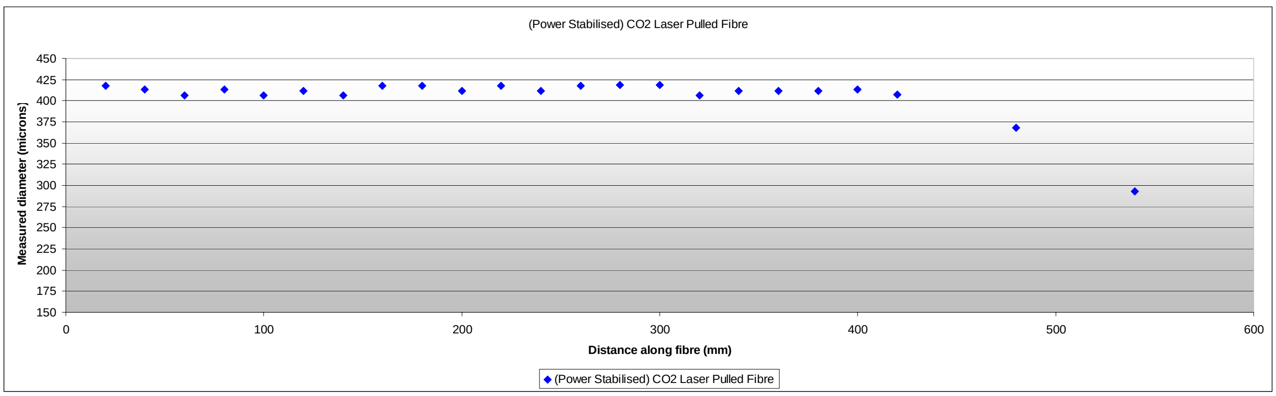

Figure 9 *Dimensional assessment of an early CO_2 laser pulled fibre, pulled on the prototype pulling machine with laser power stabilization.*

6 Welding with CO_2 laser

It has been shown in GEO 600 that welding using a hydrogen / oxygen flame is an effective technique for jointing suspensions. In the case of GEO 600 this was essentially a manual process, performed using a hand held torch. The fibres were cut at the neck and then butt welded onto the ends of the ears. The tension in the fibres was then equalised by allowing a little weight to be put on them and reheating the joints.

Unlike flame welding which is a reasonably skilled task for the operator performing it, welding using a CO_2 laser is fairly simple by comparison. It is done by aligning the pieces to be welded and then exposing them to the laser beam for a period of time until the material has become continuous. As there is no gas being blown at the part to be welded there is less deformation than is associated with a flame. It is also possible to create overlap welds using the laser, which allows for easier alignment of the fibres. While it is possible to weld directly to the fibre, this tends to create a region of high stress, and current plans are instead to weld to the neck region of the fibres (thickened heads).

The beam for welding will be delivered using a 2D galvanometer to allow accurate positioning and dithering across the weld. This has already been tested using a 1D galvanometer, with a 2D giving the possibility to spread the beam slightly and improve the heat delivery.

Basic welding of silica fibres using CO_2 laser radiation has been demonstrated early in the laser pulling/welding machine development. Extensive strength testing of laser welds has not yet been performed. This is planned to be carried out in the near future once the new prototype machine is fully operational and the control over ribbon/fibre neck shape is further advanced.

Welding with laser radiation is further discussed in T050206 *"Production and Characterisation of Synthetic Fused Silica Ribbons for Advanced LIGO Suspensions"* and T050215 *"Monolithic Stage Conceptual Design for Advanced LIGO ETM/ITM"*.

7 Characterisation

7.1 Dimensional assessment

An optical profiling device for dimensional characterization of silica ribbons, fibres and welds is being developed in Glasgow. This device is based on an optical edge detection technique.

The prototype dimensional characterization machine comprises a motorized imaging head made up of a Firewire web camera with suitable lenses to achieve the desired magnification.

The dimensional measurement is achieved using a *LabVIEW* edge detection program which displays an on screen image of the measurement. A typical screen capture is shown below using a CO_2 laser pulled fibre of diameter ~400μm:

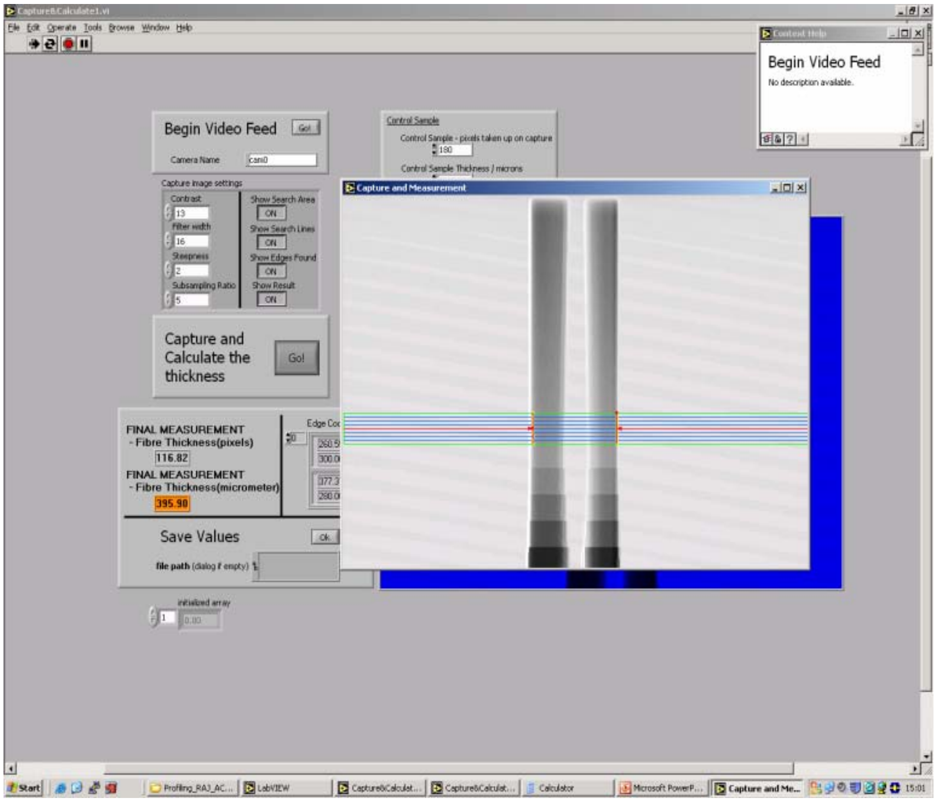

Figure 10 Typical screen capture using a CO_2 laser pulled fibre of ~400μm

The machine is described in greater detail in *"Optical Profiling Device for Dimensional Characterisation of Ribbons/Fibres"*, T050207.

7.2 Q measurements on fibres.

Measurements made on cylindrical flame pulled synthetic fused silica fibres have been shown through many published measurements to have extremely low levels of mechanical dissipation. For example the measurements made on fibres before installation at GEO 600 gave typical material loss values of $\phi_{material} = 1.4\times10^{-7}$. Measurements of mechanical loss performed on silica ribbons have shown them to exhibit a similar level of surface loss to cylindrical fibres. Given that the thermal noise contribution from rectangular fibres is lower than for a similar cross section cylindrical fibre due to the increased dilution effect it is clearly advantageous to pursue this design.

Initial measurements of mechanical loss performed on cylindrical silica fibres produced using the pre-prototype CO_2 laser machine have shown that the surface loss is similar to that of flame pulled fibres. Once the new prototype laser pulling machine is fully operational, loss measurements will be made on sample ribbons and fibres for comparison with flame pulled samples.