Development of Fused Silica Suspensions for Advanced Gravitational Wave Detectors

LSC Virgo Meeting - Pasadena
19th March 2008

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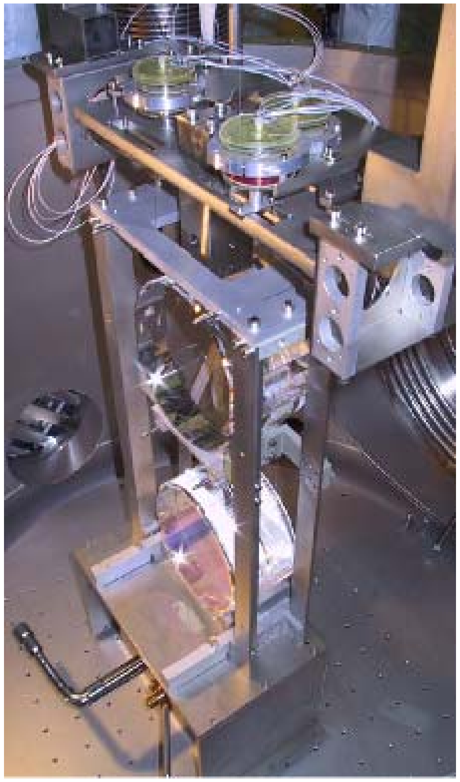
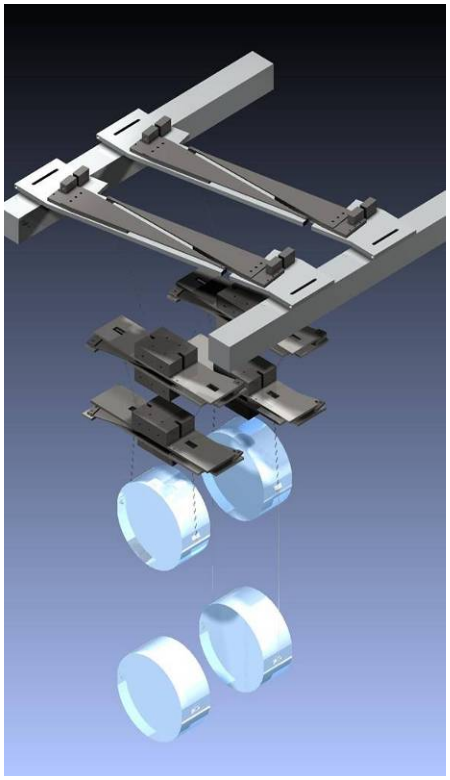
LIGO

Heptonstall, Barton, Cagnoli, Cumming, Faller, Hammond, Hough, Jones, Kumar, Martin, Mittleman, Rowan, Strain, Tokmakov, van Veggel

Monolithic suspensions for advanced detectors

- Development of monolithic suspensions is based on experience from the GEO600 suspensions
- This talk will cover aspects of production and testing of suspension elements suitable for Adv. LIGO and potential upgrades to Virgo
- The criteria that must be met by ribbon fibres for Adv. LIGO:
  - Breaking stress > 2.4 GPa
  - Intrinsic loss $<3 \times 10^{-11}/t$, where t is the thickness of the ribbon
- We will present an update on the status of development since the last LSC





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LASTI Installation – Fibre Pulling Machine

- Installation of the fibre pulling machine began in December 2007
- Main mechanical parts installed over two weeks in December
- Labview / electrical installation completed in January
- Laser stabilisation controller implemented in January
- First fibres produced in February
- Work now progressing on improving the ribbon ‘recipe’

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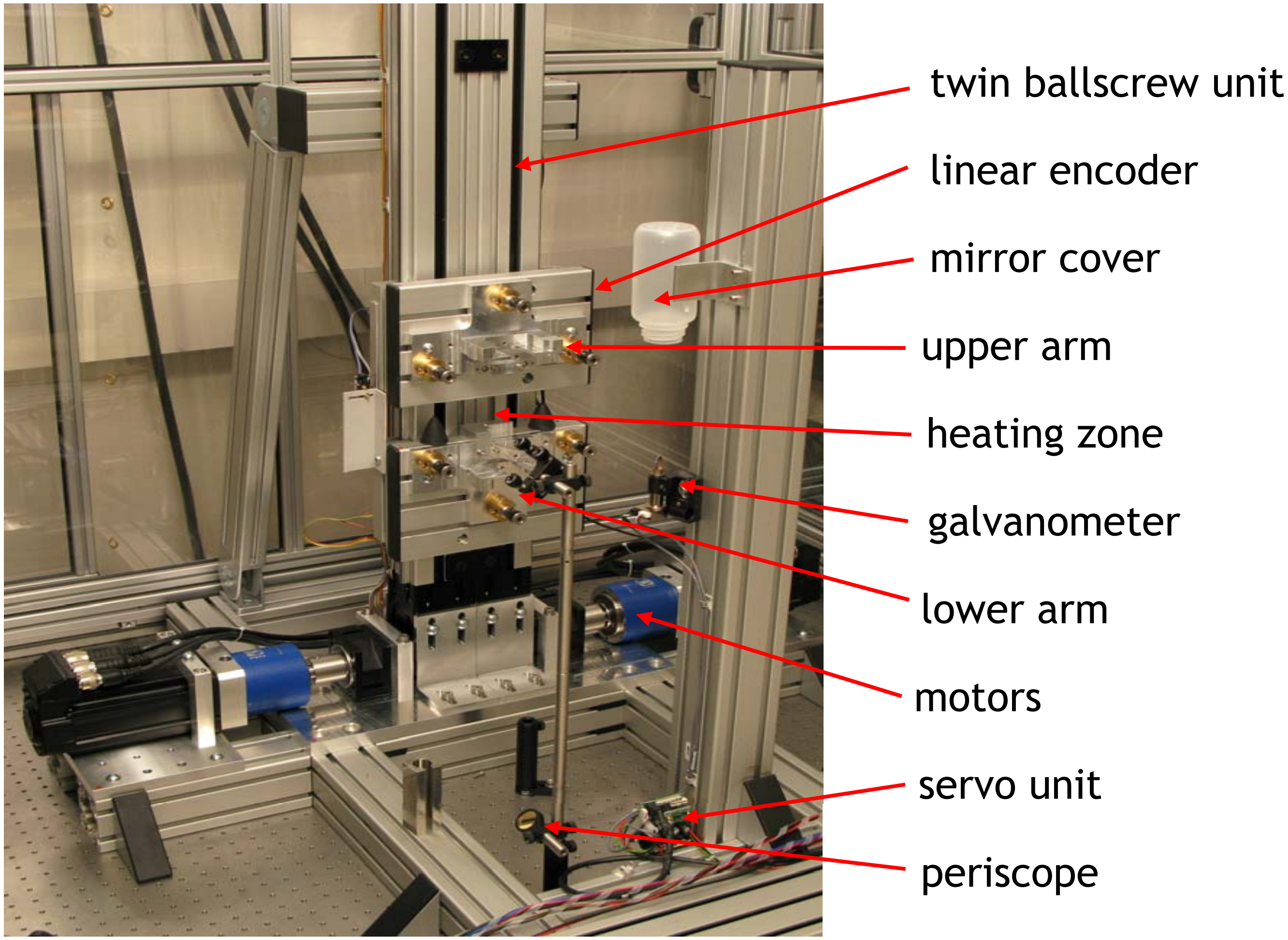
LASTI Installation – Fibre Pulling Machine



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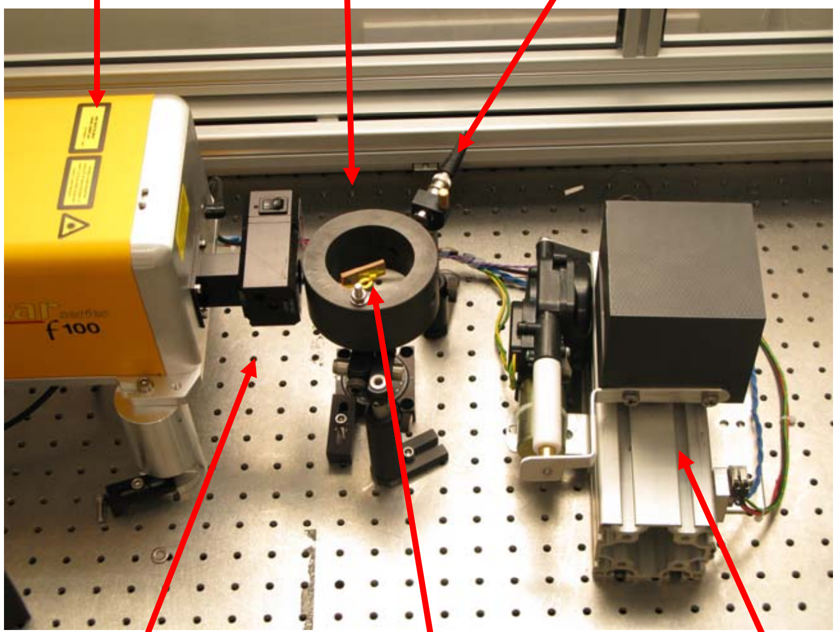
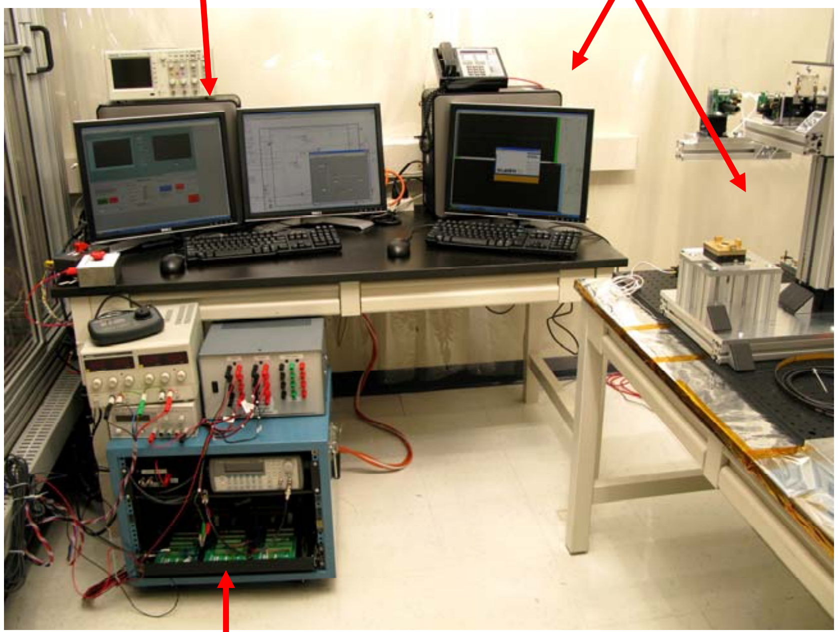
LASTI Installation





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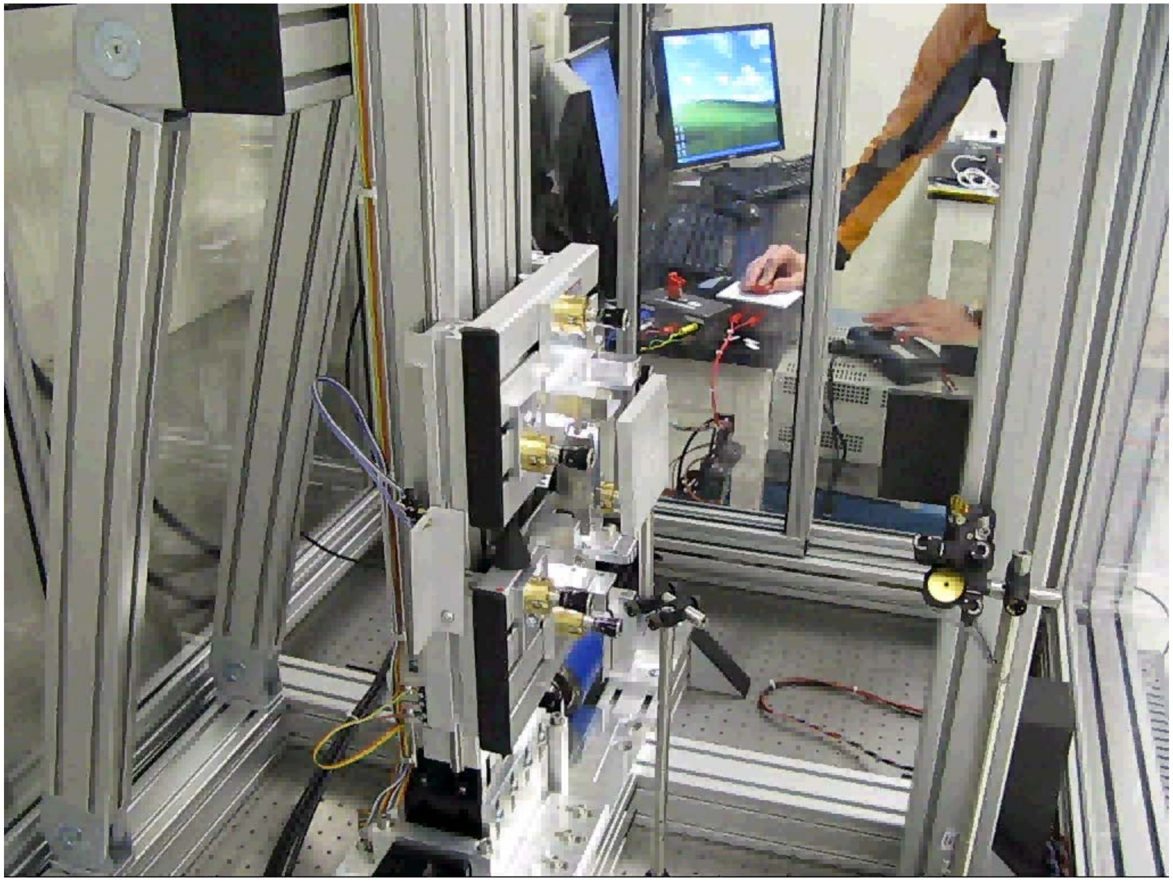
LASTI laser fibre pulling machine



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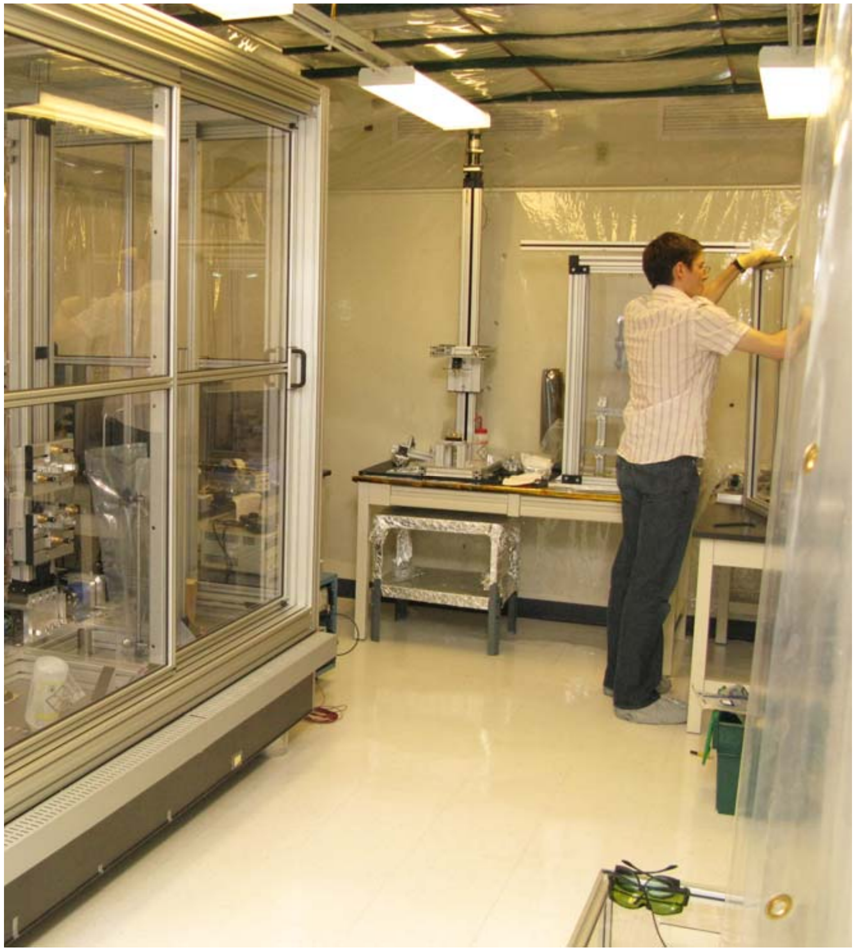
LASTI Installation – Characterisation Equipment

- Parts have been delivered to LASTI for characterisation suite
  - Optical profiler
  - Bounce tester
  - Proof load
- Members of the University of Glasgow group have been installing these systems at the LASTI site
- Over the next month this work will be completed
- A destructive strength tester will also be installed in the coming weeks for further fibre evaluation



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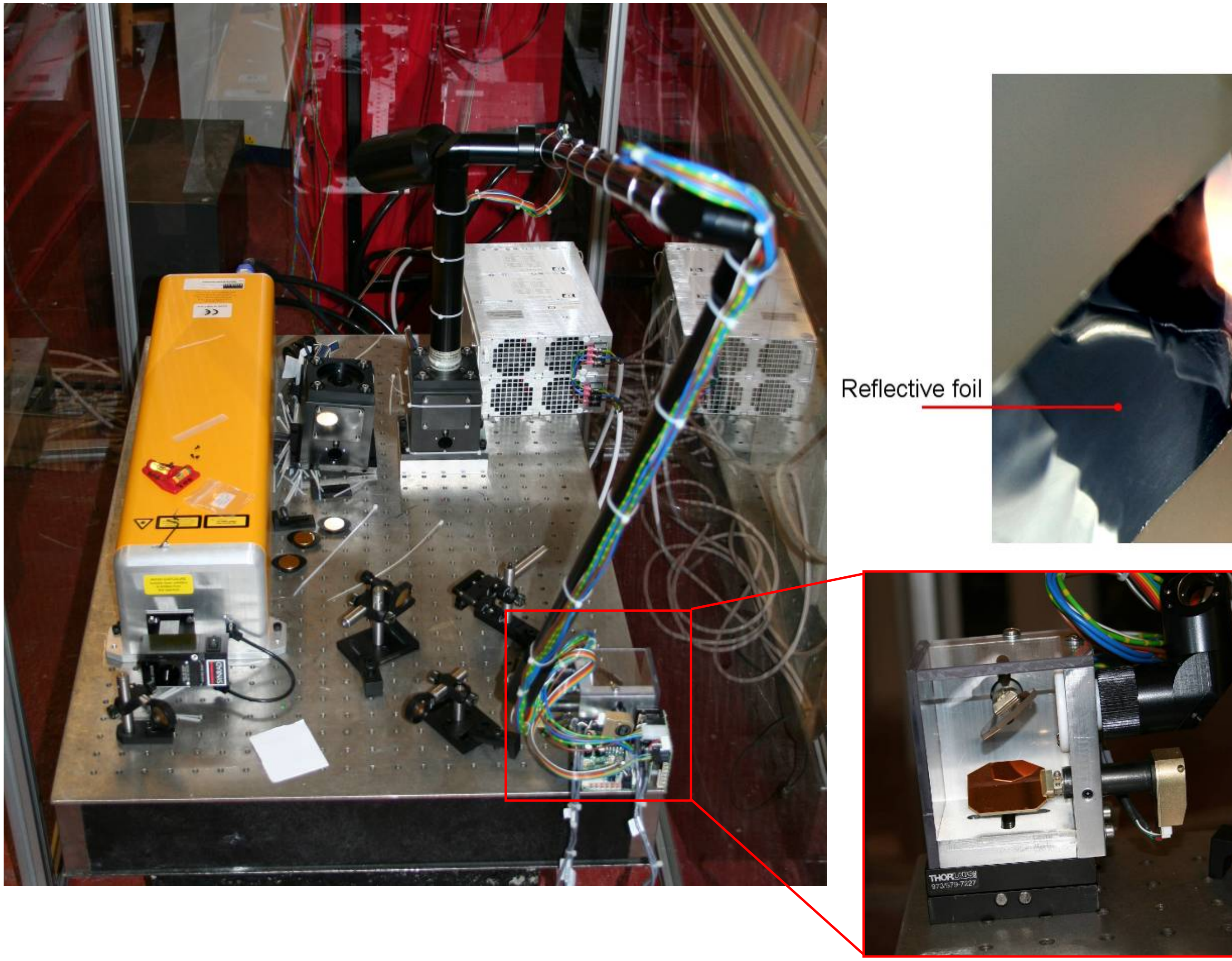
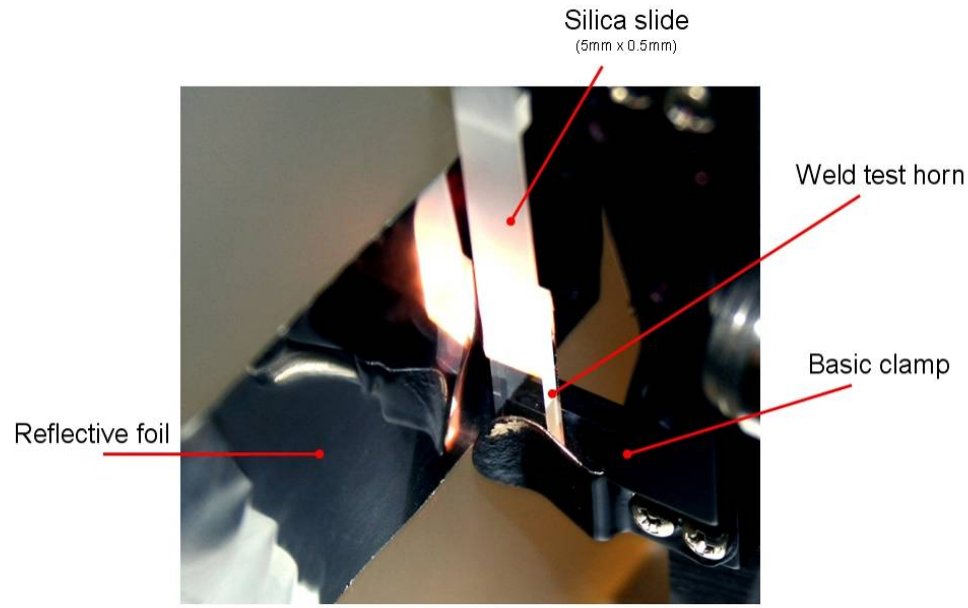
Welding technology in Glasgow





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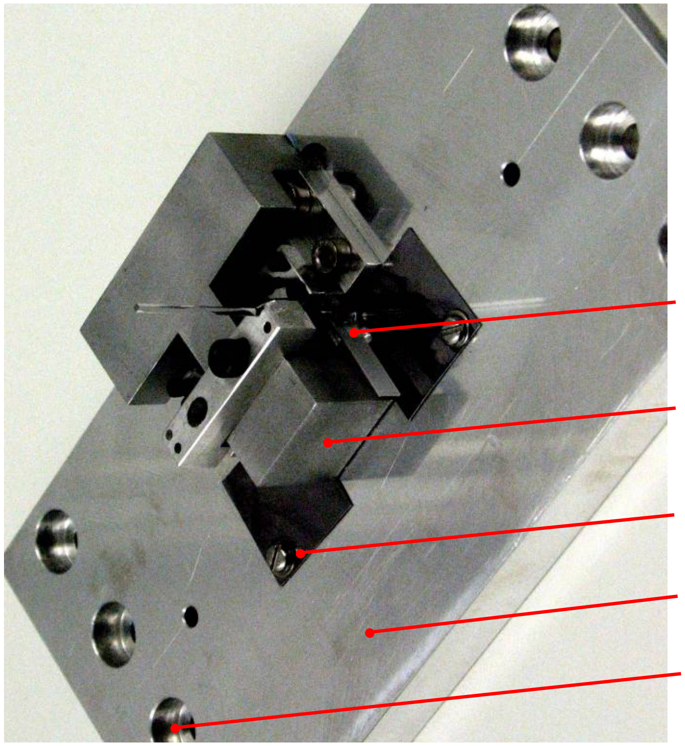
Welding in and around the structure

Main structure

Flat on side of mass



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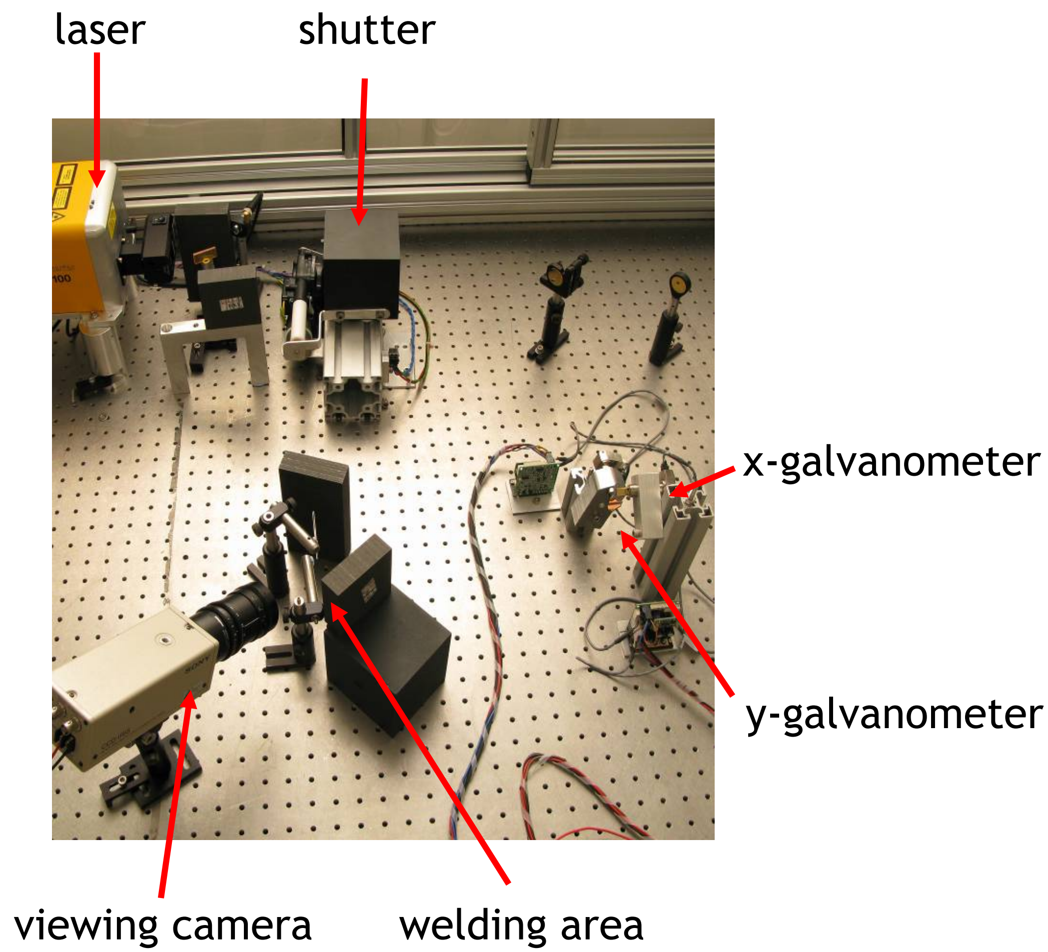
Initial Welding Tests at LASTI

- Mirror galvanometers have been set up on the optical bench, with a Labview control programme
- Preliminary tests on the bench are underway
- The articulated laser arm has been delivered to LASTI
- Designs for the tooling for welding in the structure have been completed
- This tooling is now out for manufacture



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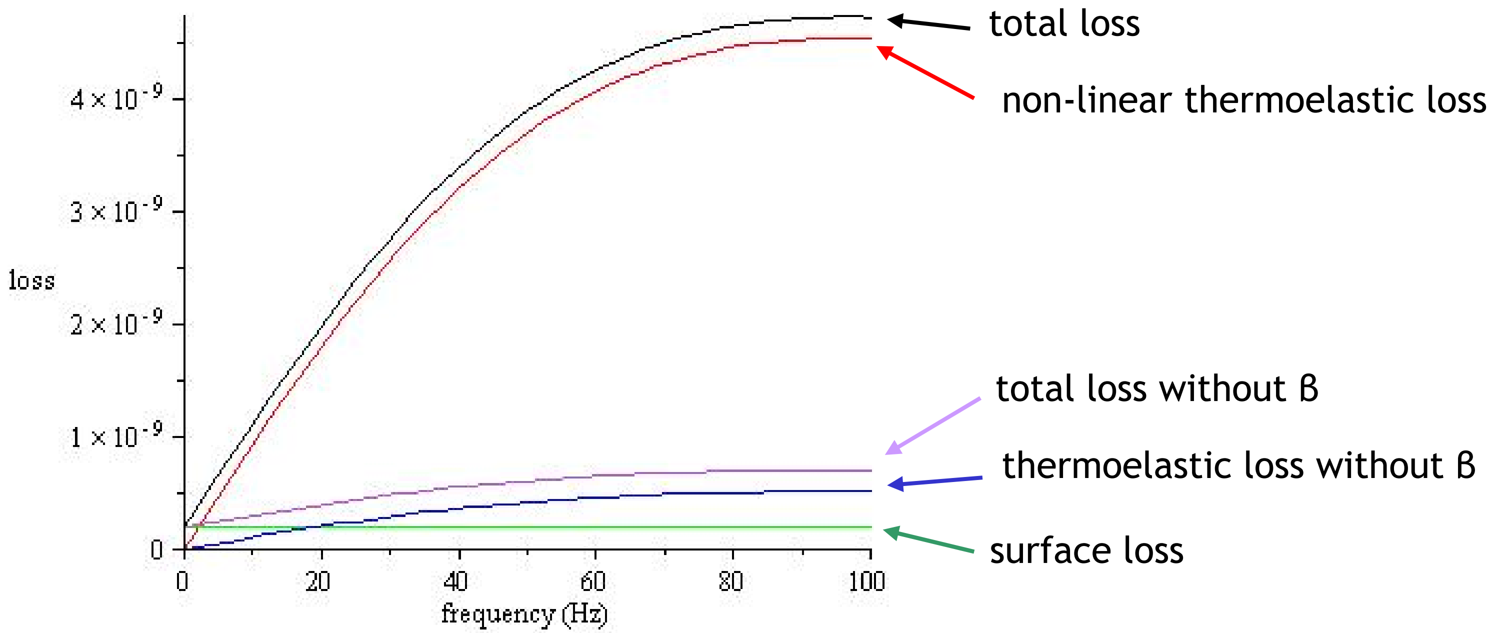
Optimisation of Fibre Shape

- The current baseline uses a ‘thin ribbon’ design (60cm x 1.15mm x 0.115mm)
- This design maximises dilution by minimising stiffness in direction of measurement
- At 20Hz loss is a factor of 6 lower compared to a similar cross section cylindrical
- The plot below show the main sources of loss for a baseline design ribbon
- The dominant source of dissipation is non-linear thermoelastic loss



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Optimisation of Fibre Shape

- Obtaining a high dissipation dilution is not the only critical factor in reducing loss
- We present here initial results of modeling of different suspension fibre geometries to look for optimised shapes for the Advanced LIGO suspensions
- A two stage analytical/FEA computer model is used to look at optimising fibre shape
- We have used a ribbon aspect ratio of 10:1 here
- Included are the effects of surface dissipation, dissipation dilution, non-linear thermoelastic loss and energy distribution in the suspension

$$\phi_{total} = \underbrace{\sqrt{\frac{YI}{Tl^2}}}_{\text{dilution}} \left[\underbrace{\frac{E_{surface}}{E_{bulk}} \phi_{surface}}_{\text{surface loss}} + \underbrace{\left(\frac{YT}{\rho C}\right)\left(\frac{\omega\tau}{1+(\omega\tau)^2}\right)\left(\alpha - \beta\frac{\sigma_0}{Y}\right)^2}_{\text{non-linear thermoelastic loss}} \right]$$

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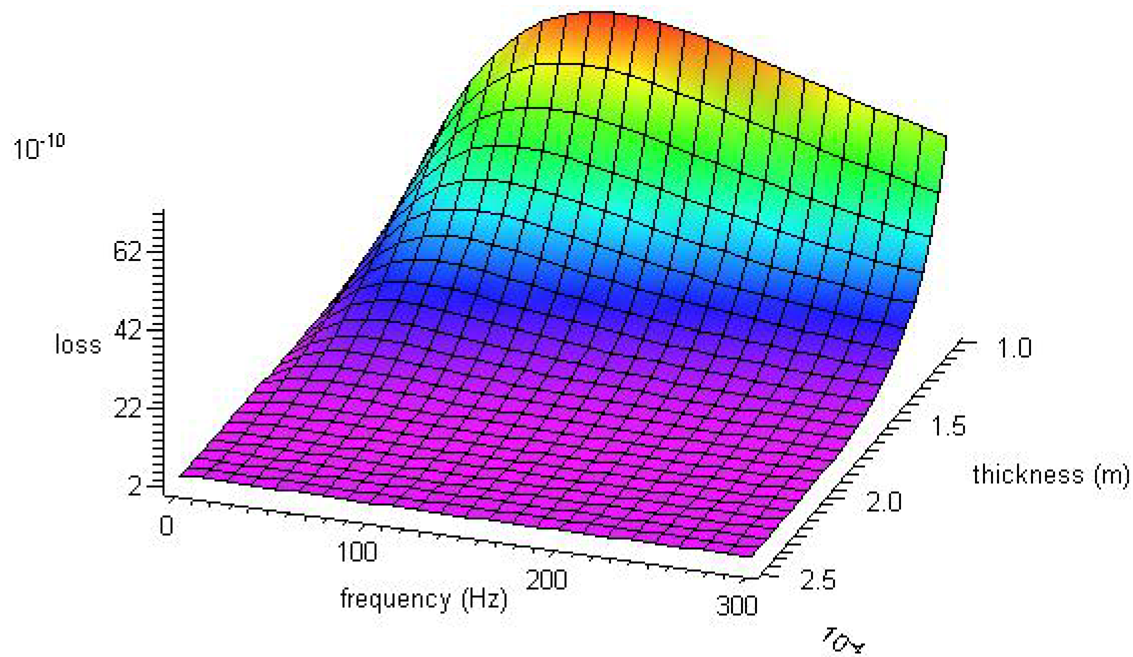
Optimisation of Fibre Shape

- Plotted below is total loss as a function of fibre thickness
- A substantial improvement can be made across a wide frequency range by moving to fibres with thicker flexure regions
- Thicker flexure regions have a reduced stress, and hence a reduced thermoelastic loss



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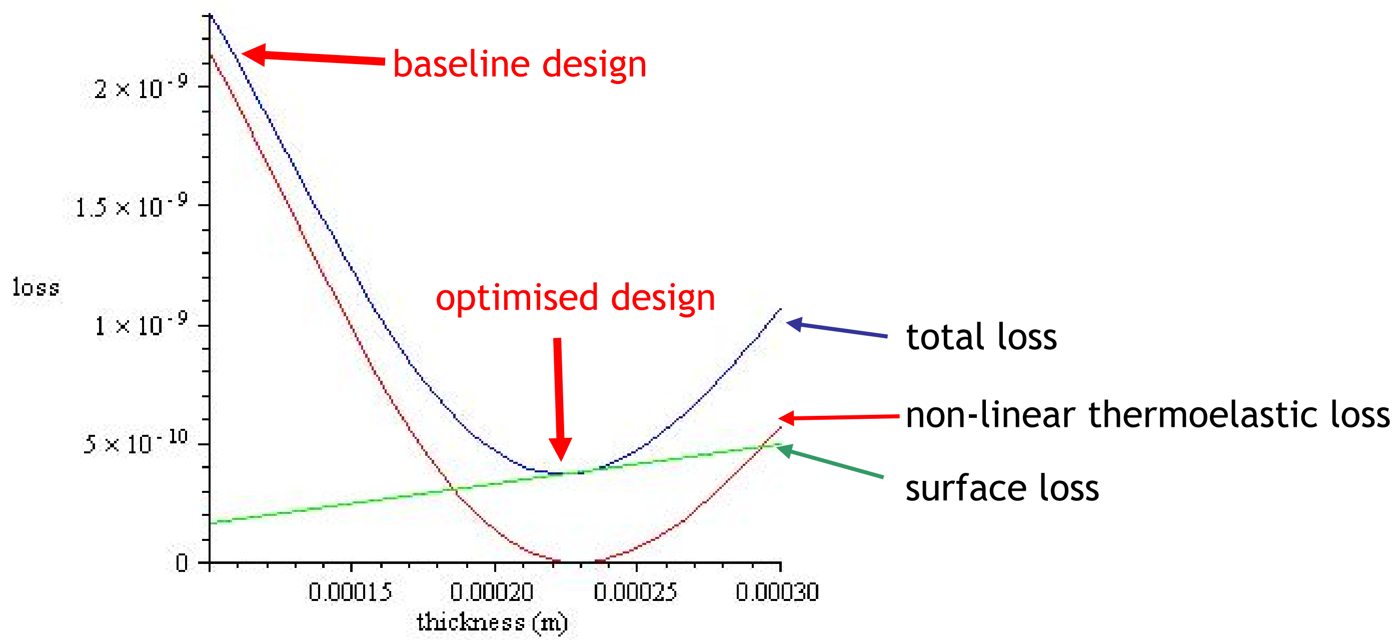
Optimisation of Fibre Shape

- Below we plot the loss at 20Hz for a ribbon fibre
- The optimum thickness for the flexure region is 0.221mm
- The total loss for this thickness is 3.76x10-10
- This is an improvement of a factor of 5 compared to the baseline design



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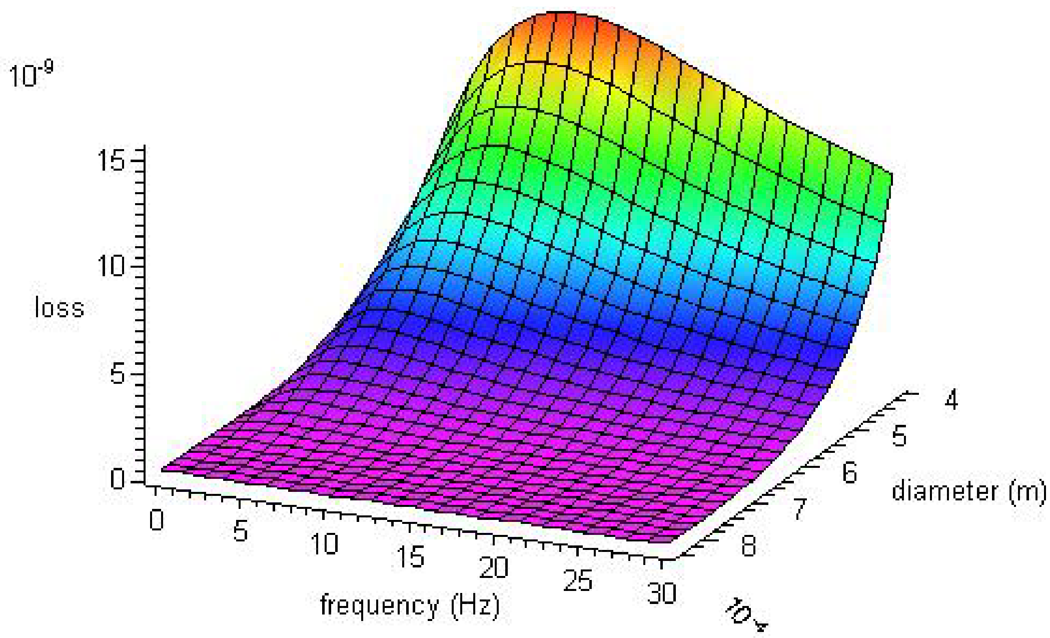
Optimisation of Fibre Shape

- This optimisation model was repeated for cylindrical fibres.
- Again a significant improvement in performance is possible by moving to thicker flexure regions



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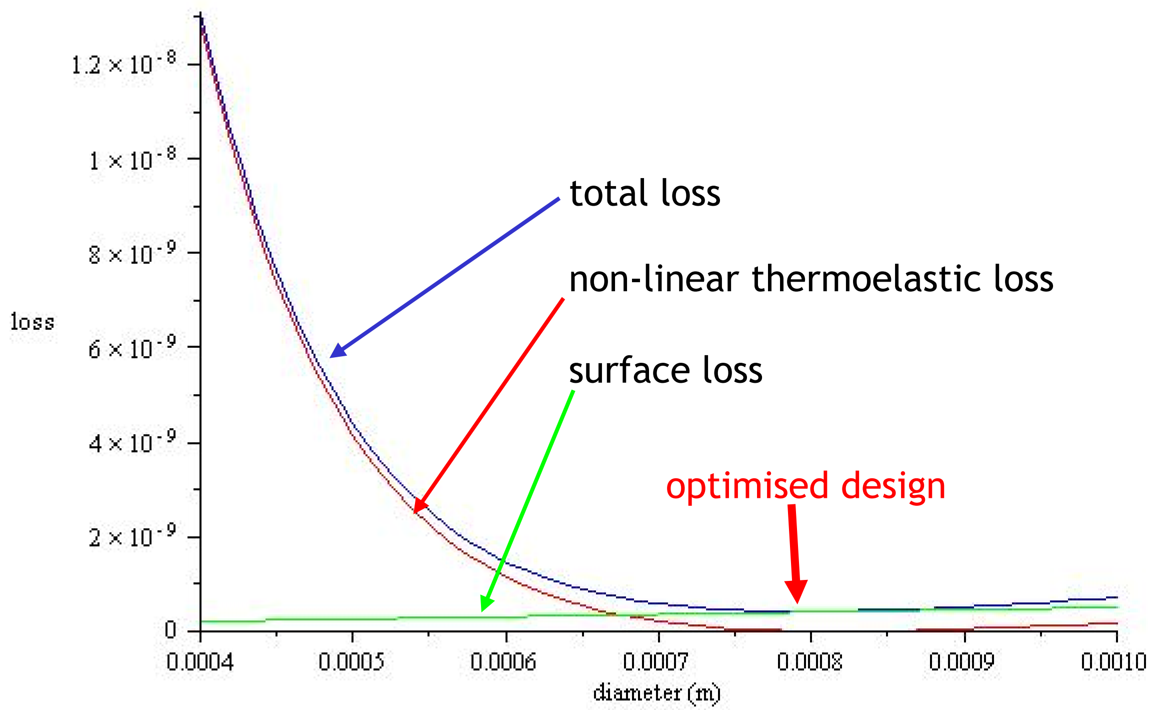
Optimisation of Fibre Shape

- At 20Hz the optimum diameter for cylindrical fibres is 794um.
- The total loss for this thickness is 4.25×10^{-10}
- The vertical stiffness of the fibre can be brought down by reducing the diameter of the central section by 8um.



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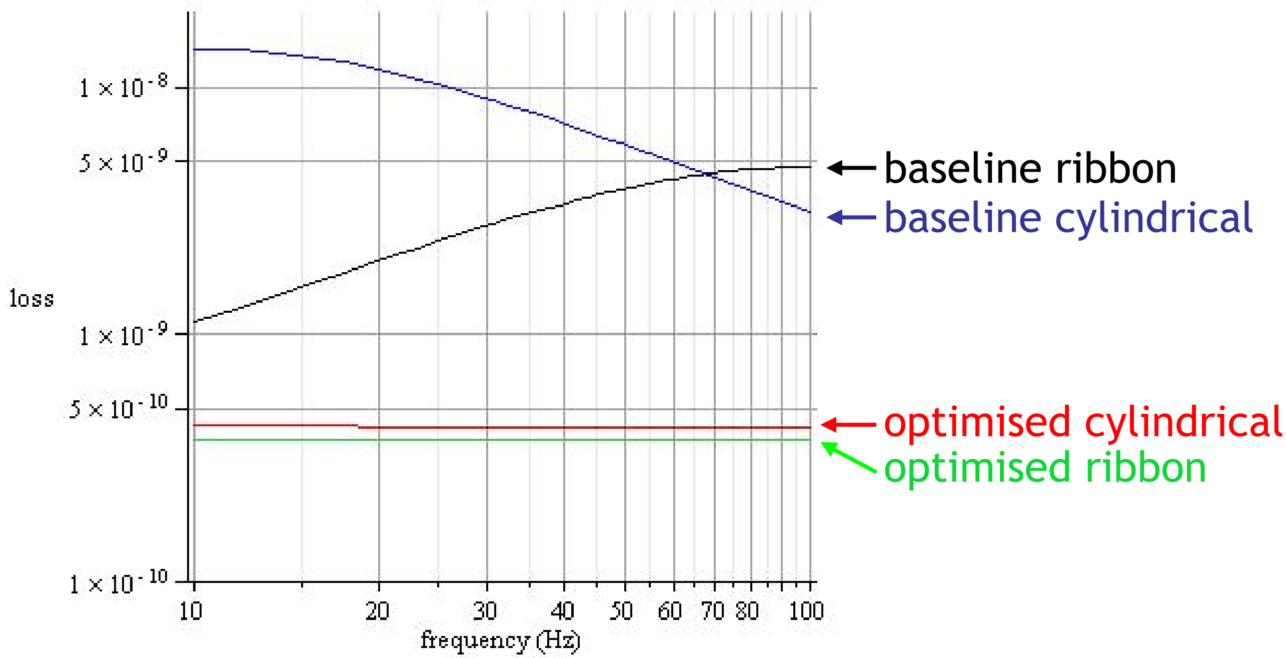
Comparison of Fibre Designs

- The plot below shows a comparison between cylindrical and ribbon fibres
- In optimum configuration there is 15% difference between ribbon and cylindrical fibre performance
- Both give significant decrease in loss compared to the baseline ribbon design
- The optimised fibre performance has a lower frequency dependence



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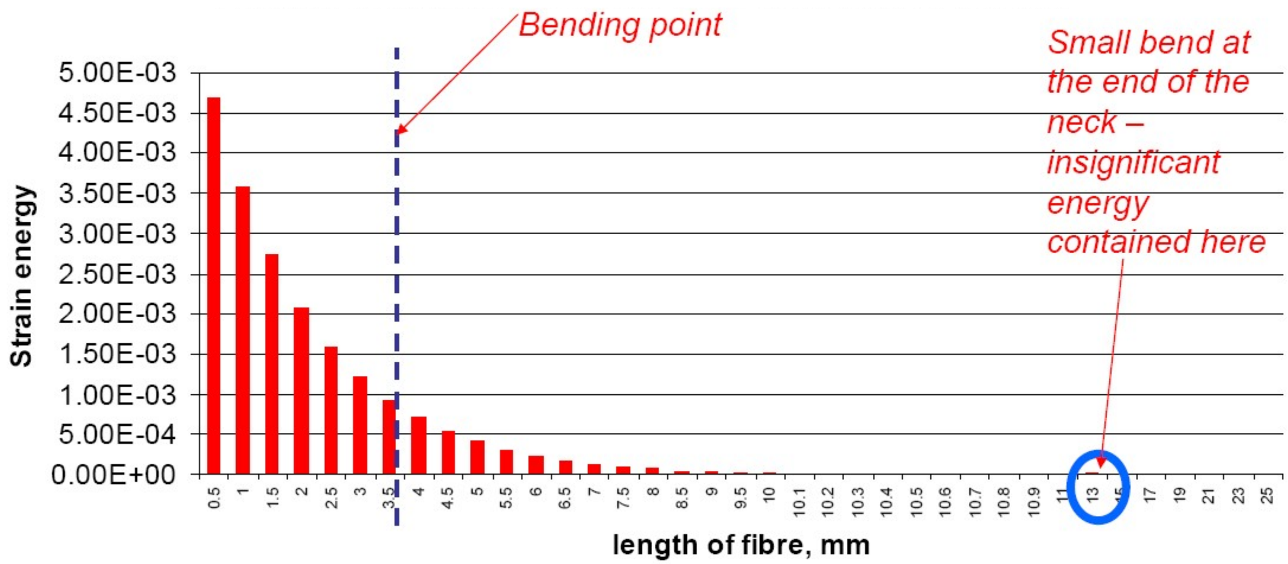
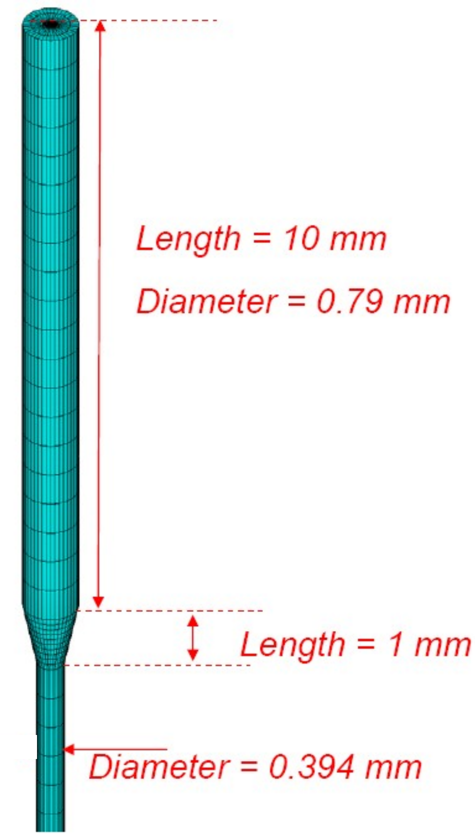
FEA Modelling of Optimised Fibre

- An Ansys model was made for an optimised fibre design.
- The fibre has 1cm long thicker ends, with a short taper down to the thinner central section
- Dilution found using FEA matches theoretical to within 3%





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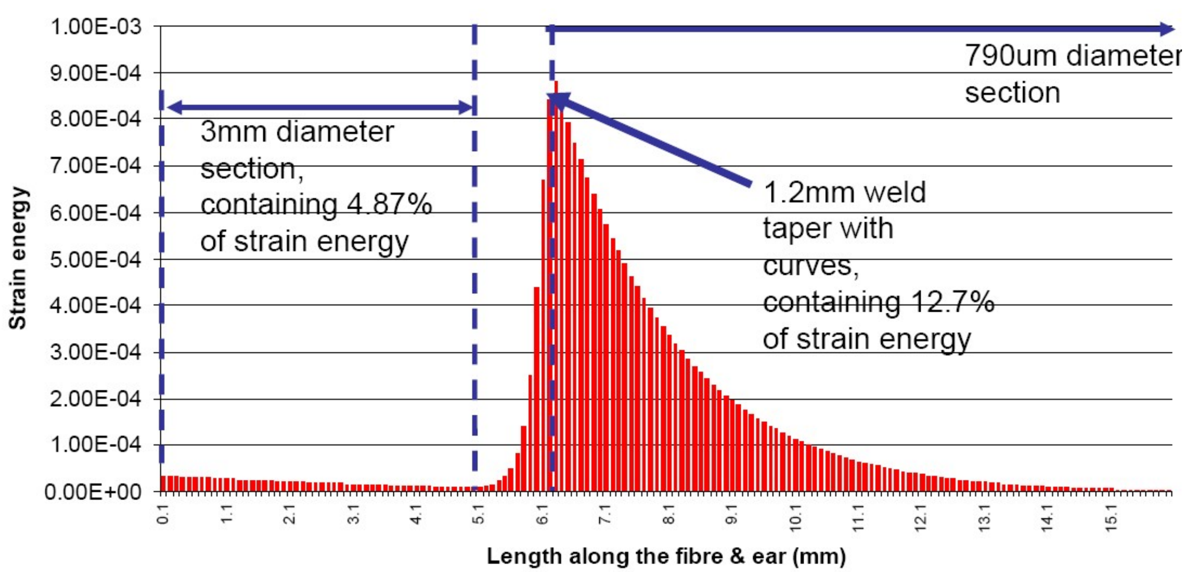
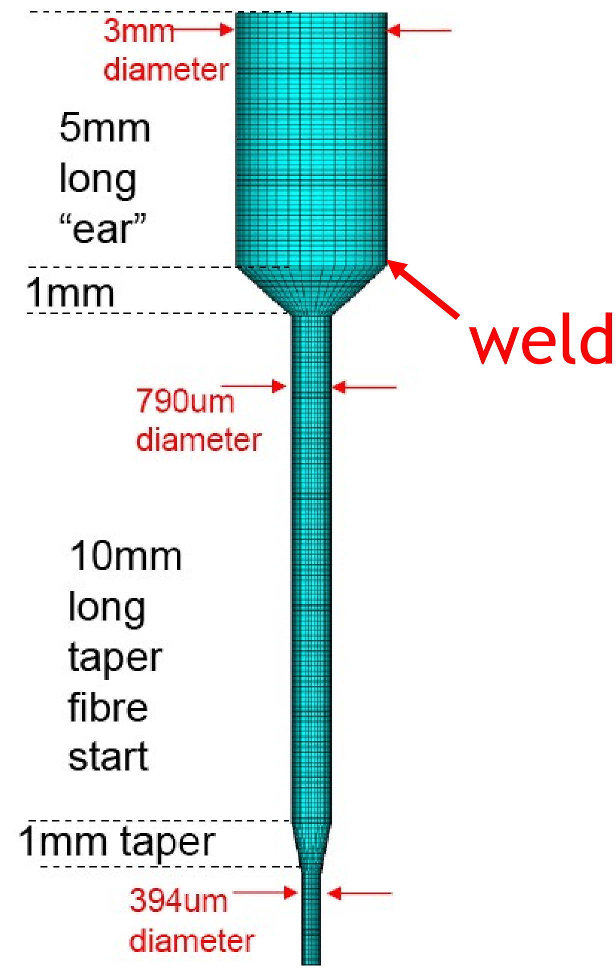
FEA Modelling of Ear Stiffness

- A further model was constructed to add in the effects of ears
- Since a real ear cannot be infinitely stiff some small amount of flexing must occur
- Using FEA we can quantify the amount of energy stored in the ear and tapered fibre end





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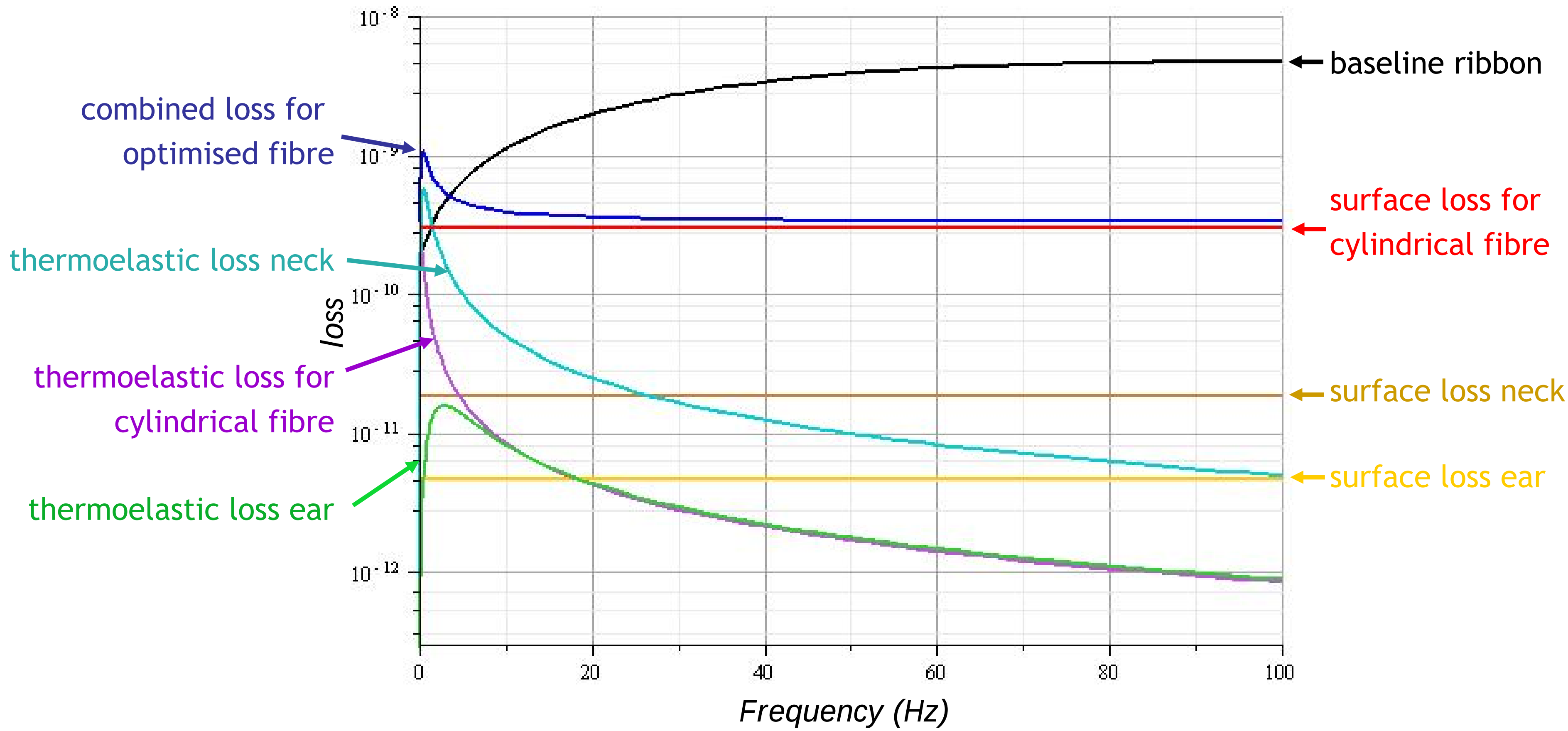
FEA Modelling of Ear Stiffness

- Using the energy ratios found from FEA it is then possible to calculate the loss contributions from each section of the fibre and ear assembly



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Conclusions

- Optimising of the thickness of the fibre ends can result in reduced loss compared to the baseline design
- There is a 15% difference between the optimised cylindrical and optimised ribbon fibres
- Cylindrical fibres have been proven in use in GEO600 suspensions, with a large quantity of literature relating to them
- They are simple to produce and tapered versions have already been demonstrated using the LASTI pulling machine
- We would suggest that use of the optimised cylindrical fibre design presented here is advantageous compared to the current baseline ribbon design in terms of superior performance and reduced risk

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