Development of Fused Silica Suspension Fibres for Advanced Gravitational Wave Detectors

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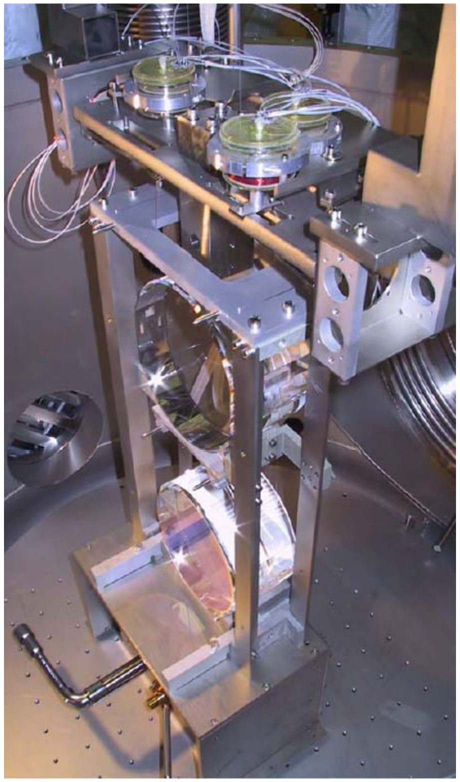
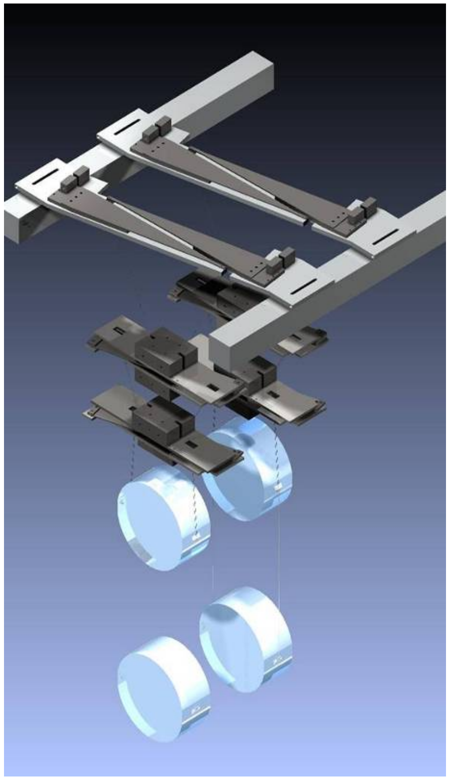
LIGO-G070730-00-Z

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 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





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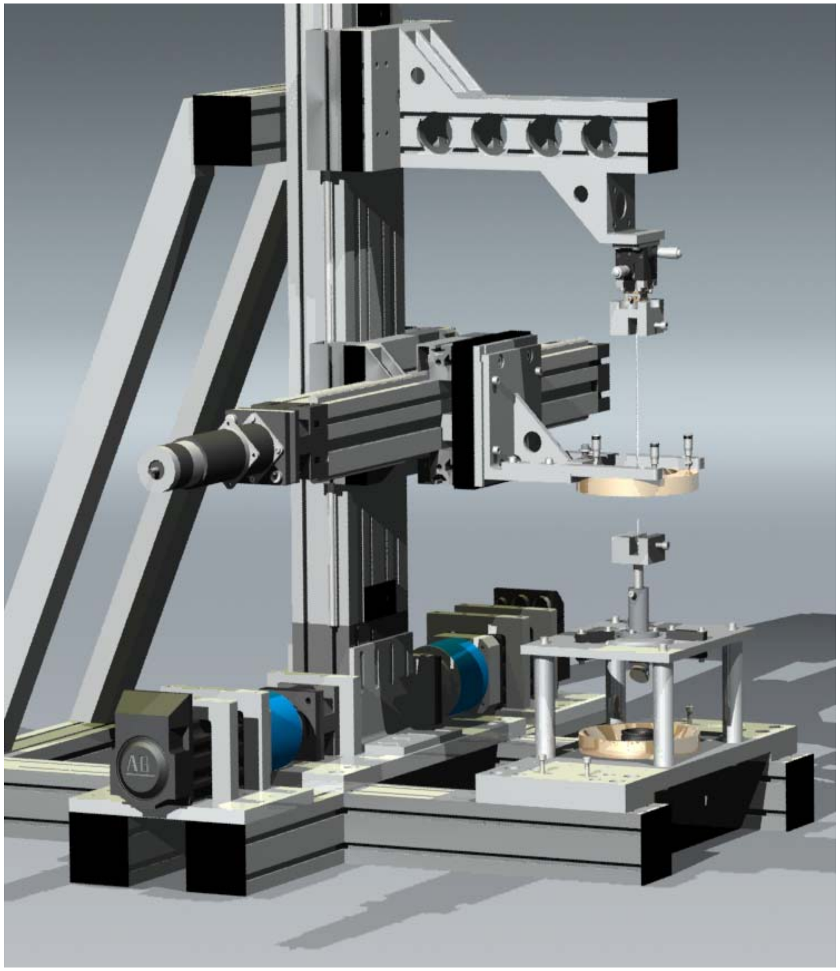
Improving fibre pulling technology

- Advanced LIGO suspensions require ±1.9% tolerance on fibre dimensions.
- This is a slight increase on the ±2.1% achieved in GEO600.
- Repeatability and tolerance in flame pulling machines is limited by gas regulation and slack in mechanical parts.
- A new machine was developed in Glasgow using a CO_2 laser and high precision drive systems
- Designed for both ribbon and cylindrical fibre production to be suitable for both LIGO and Virgo upgrades.
- The machine is also capable of welding fibres.



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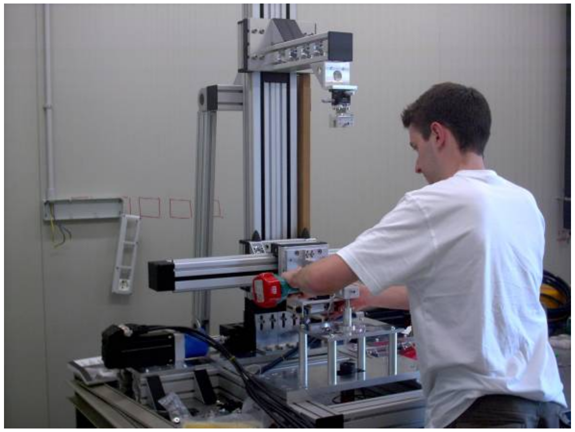
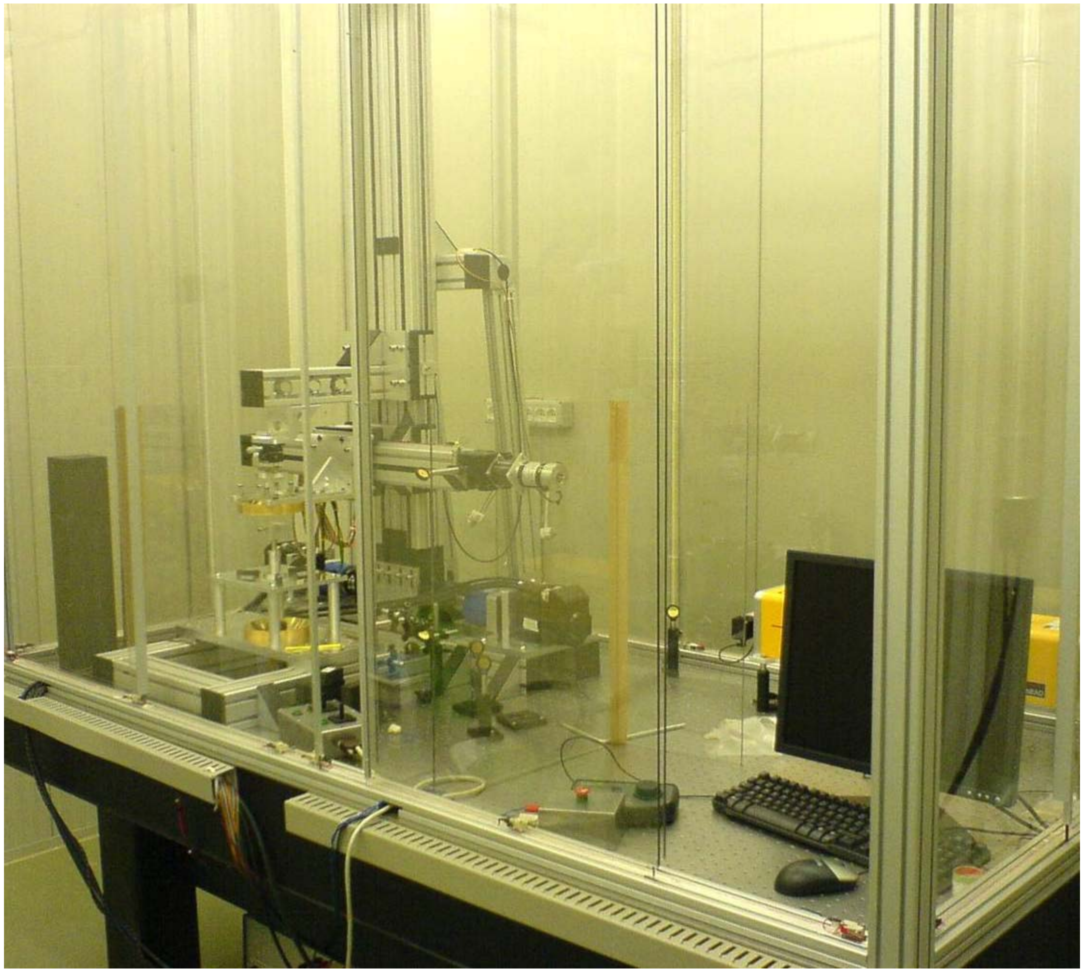
Virgo laser pulling machine installation





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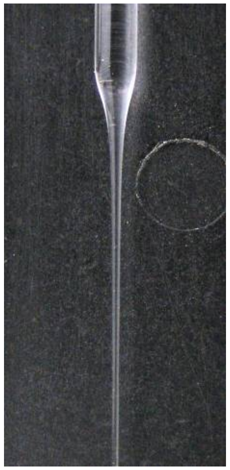
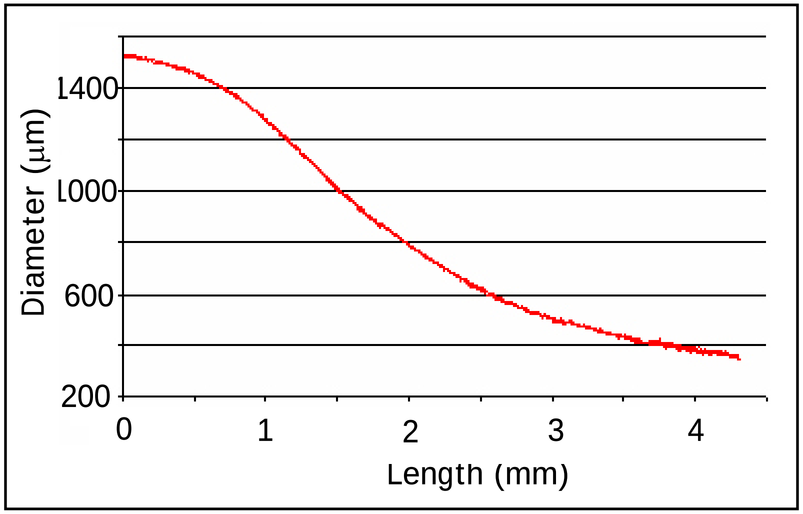
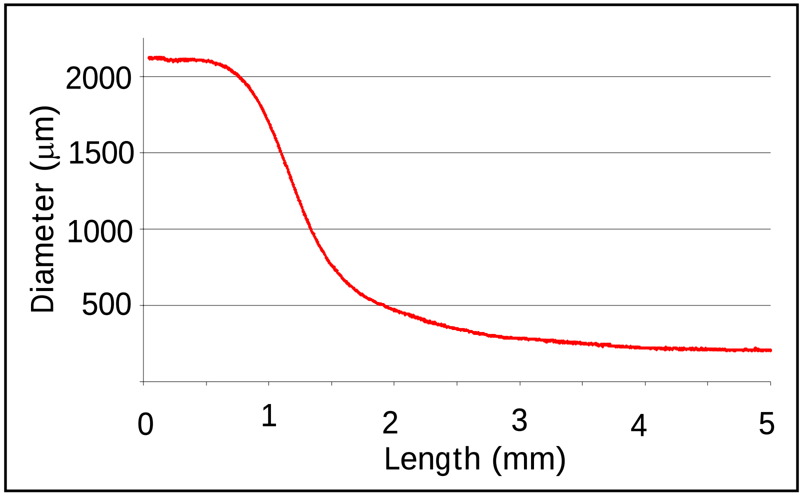
Cylindrical fibres - controlled shaping of the neck







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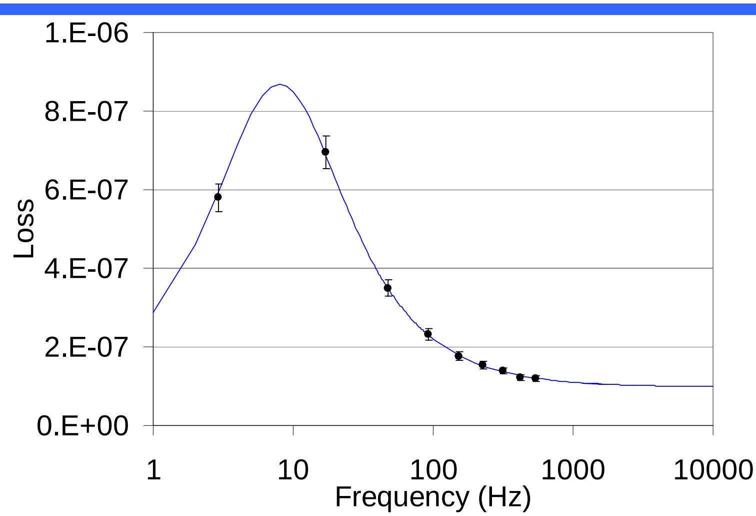
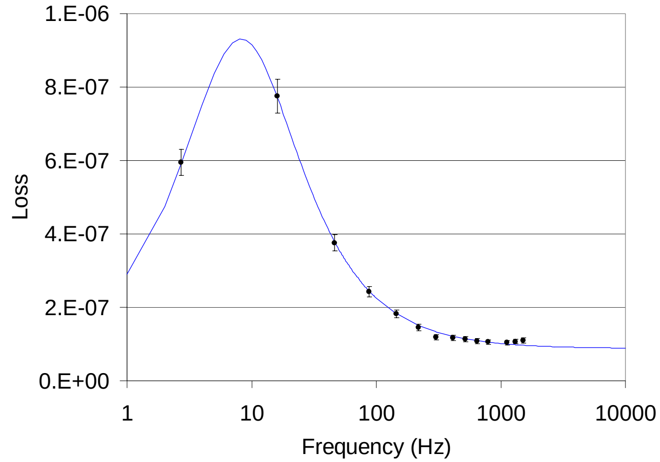
Mechanical loss in CO_2 laser pulled fibres





- Four Suprasil 300 fibres of diameter ~470μm were measured
- Initial analysis of losses shows a surface loss consistent with:

$$h\phi_{surface} = 4.7\times10^{-12}\,\mathrm{m}$$

- From Penn et al we can calculate values:

for suprasil 2 $\quad h\phi_{surface} = 6.05\times10^{-12}\,\mathrm{m}$

for suprasil 312 $\quad h\phi_{surface} = 3.25\times10^{-12}\,\mathrm{m}$

- Suprasil 300 is not necessarily expected to be similar to 312 or 311 as it has a different manufacturing process and a lower OH content

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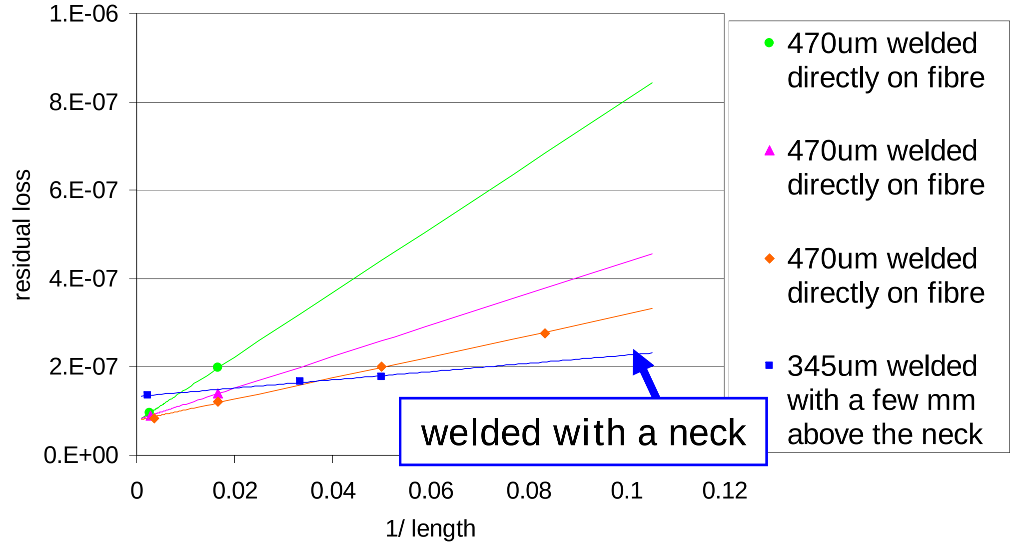
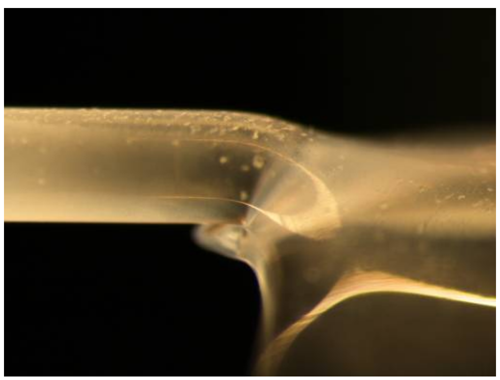
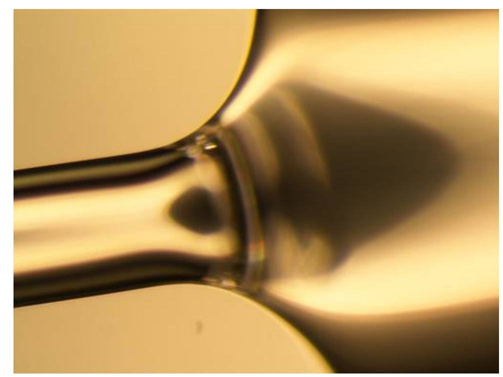
Recent measurements at Glasgow (1)

- Length dependent loss seen
- Consistent with loss at weld
- Each weld gives different value for loss
- When viewed under a microscope possible loss mechanisms can be seen
- Fibre attached using thick neck shows lowest loss as less energy stored in weld







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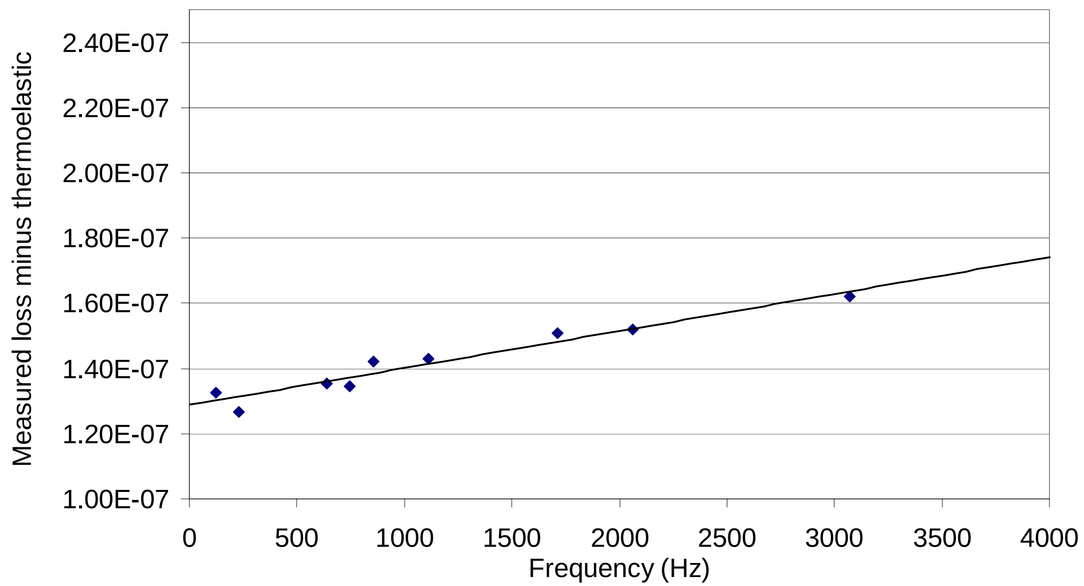
Recent measurements at Glasgow (2)

- Analysis of dissipation in fibres has shown evidence of a frequency dependent bulk loss seen at a higher than expected level
- Approximately 10 times that seen in bulk samples
- At higher frequencies this contributes as much as 25% of loss



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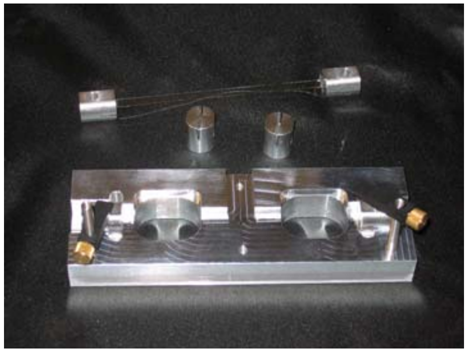
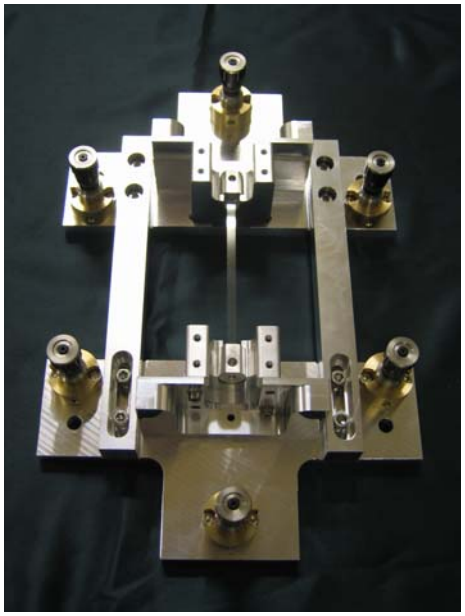
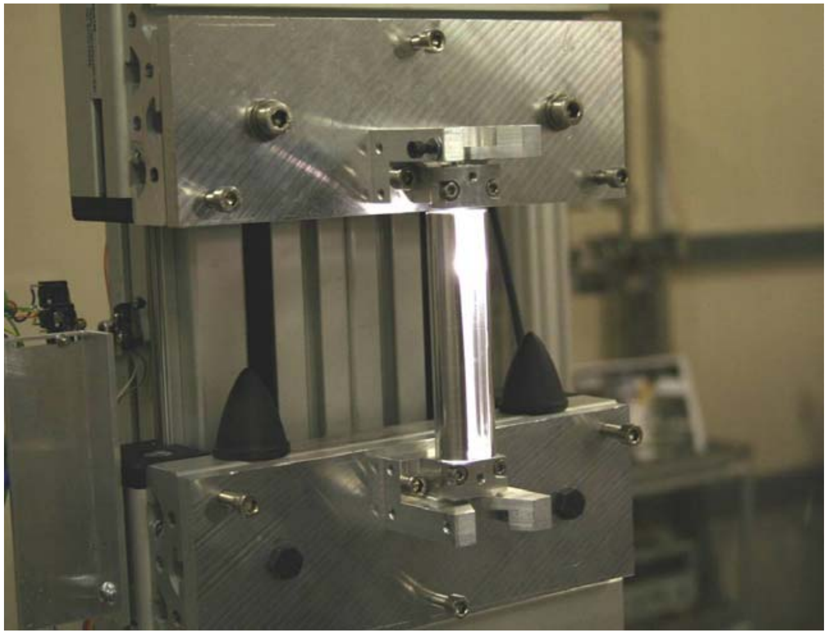
Ribbon fibre development







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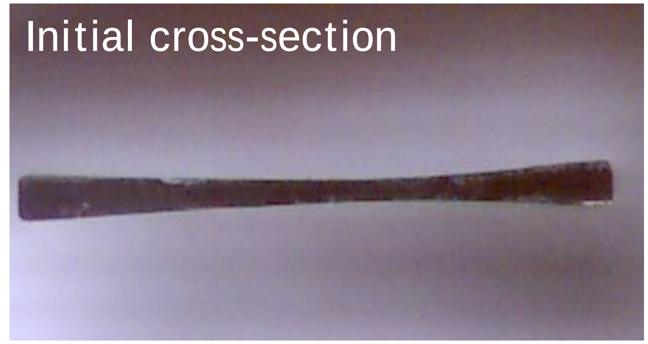
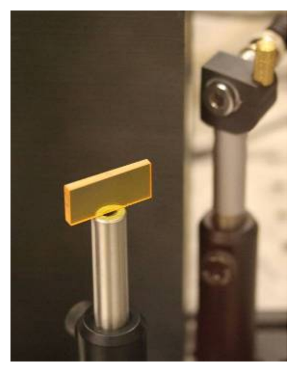
Ribbon shape development

- First ribbon fibres pulled had a non-rectangular cross-section due to heat loss from edges.
- Wave form of laser scanning investigated
- Polished aluminium heat shield developed to reflect heat back at edges.
- Laser power stabilisation has been significantly improved
  - Fast sensor
  - Wedged Brewster window for pick-off has stopped large laser fluctuations
  - Positioning of heat shield is critical
- Main section of fibre is pulled in 'steady state' condition.
- Profile of the start of pull to create a good starting neck has taken work but is now good.





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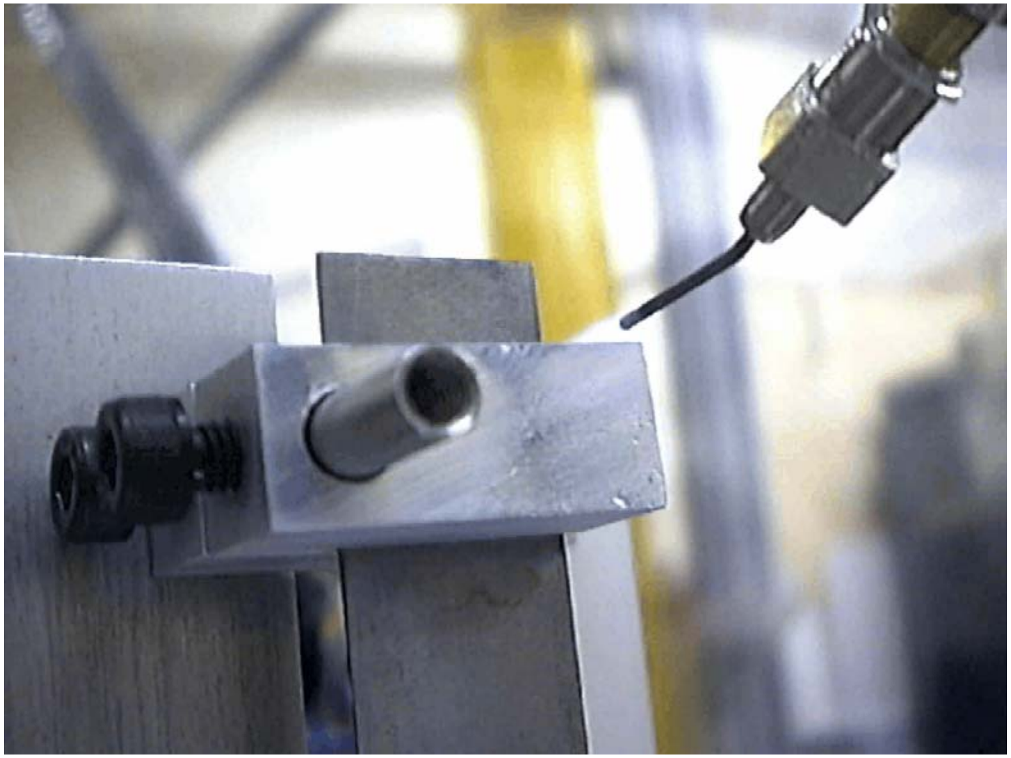
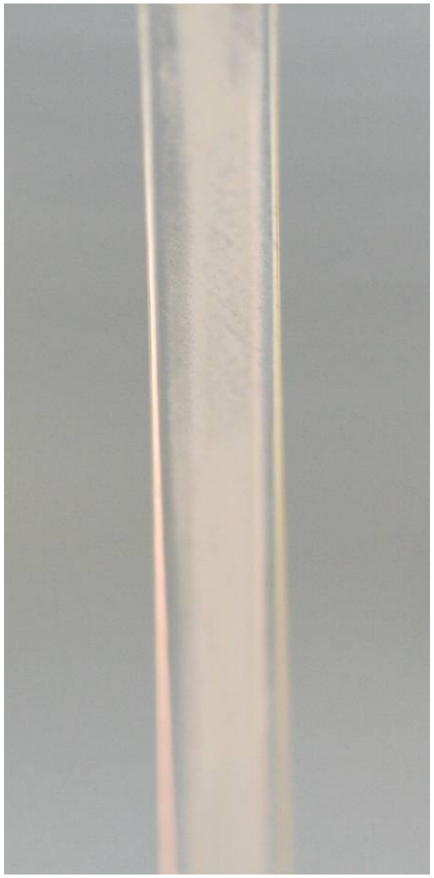
Flame treatment of silica pre-form





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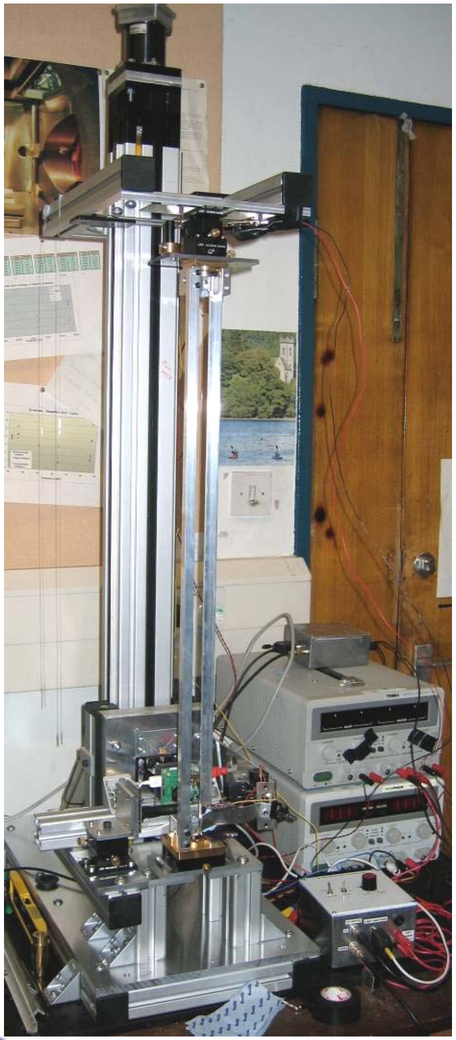
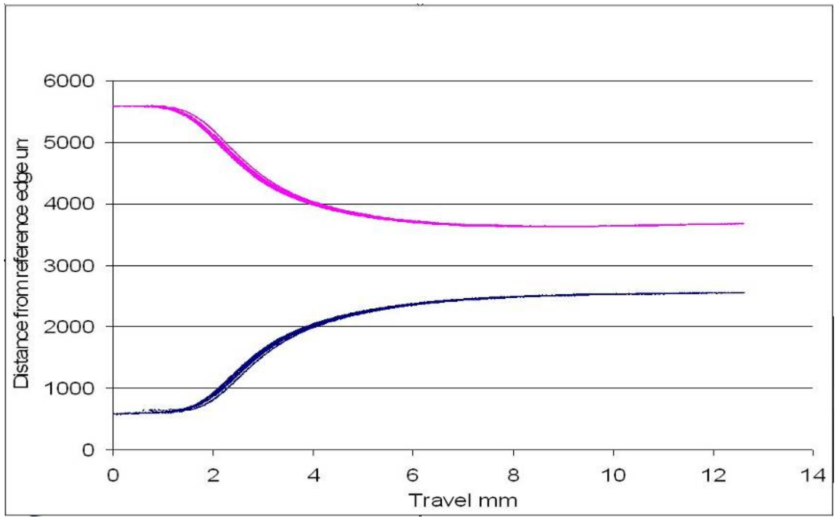
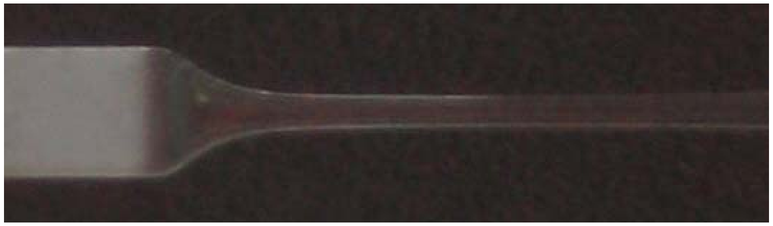
Dimensional characterisation



- Measurements can be taken every ~10um of large ribbon dimension and every ~1um of small dimension,
- Allows particular emphasis to be placed on the neck regions, giving profiles which can be used in flexure calculations and modelling





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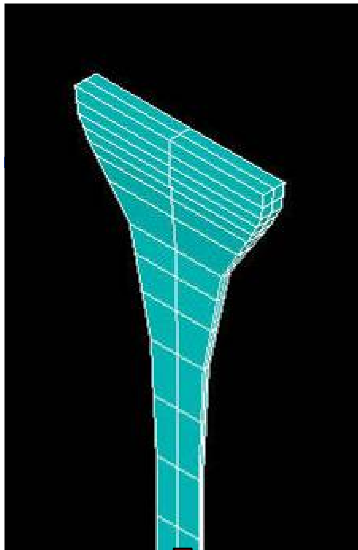
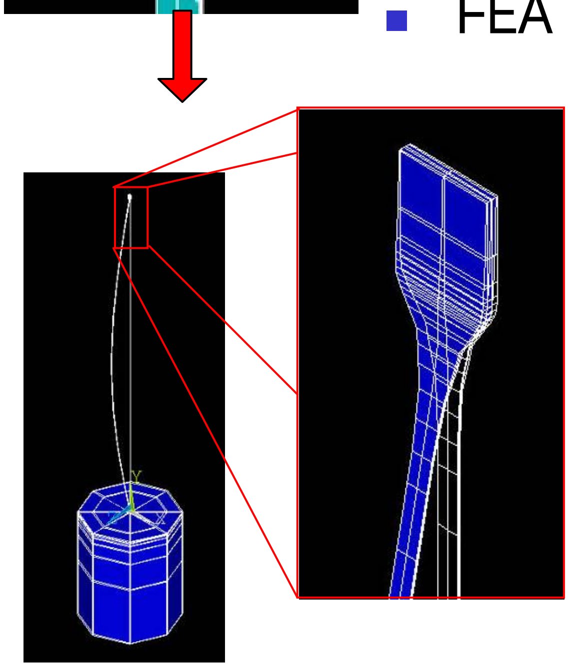
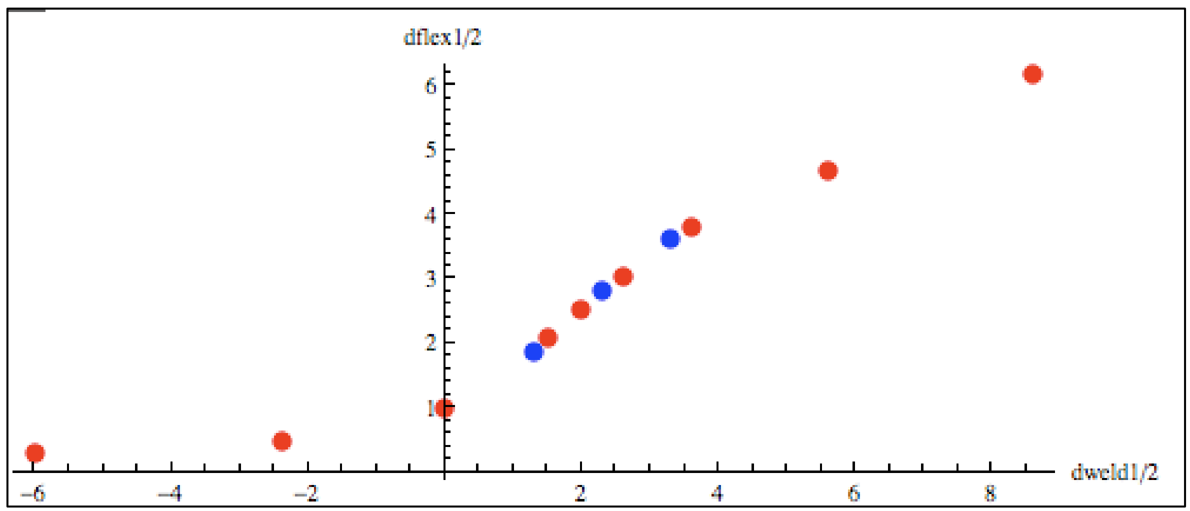
Flexure calculation



- Calculation of the flexure point is needed to understand pendulum dynamics
- Needed before bonding of the ears
- Flexure calculations by Barton and Willems are in agreement (see below)
- FEA based on profiler data shown



1st Violin 490Hz



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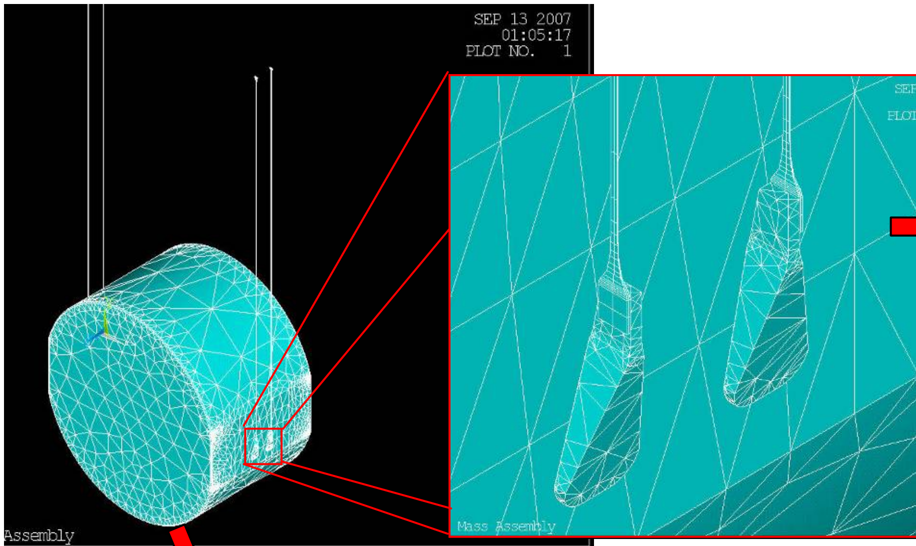
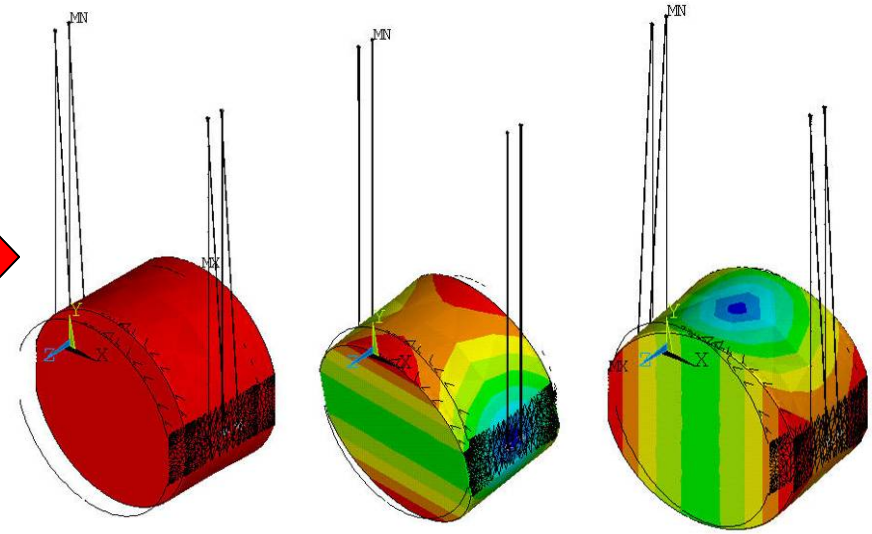
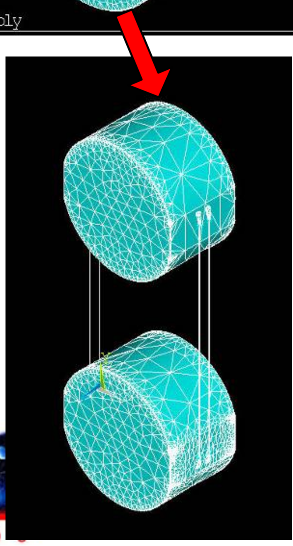
FEA model of Adv. LIGO suspension

- Technique of creating FEA model from fibre data has been applied to the monolithic stage of the Adv. LIGO suspension







- Models will permit analysis of stress distribution, and possibly pendulum dilution
- Further work required to fully refine models and ribbons

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IGR

Over-stress and bounce frequency testing

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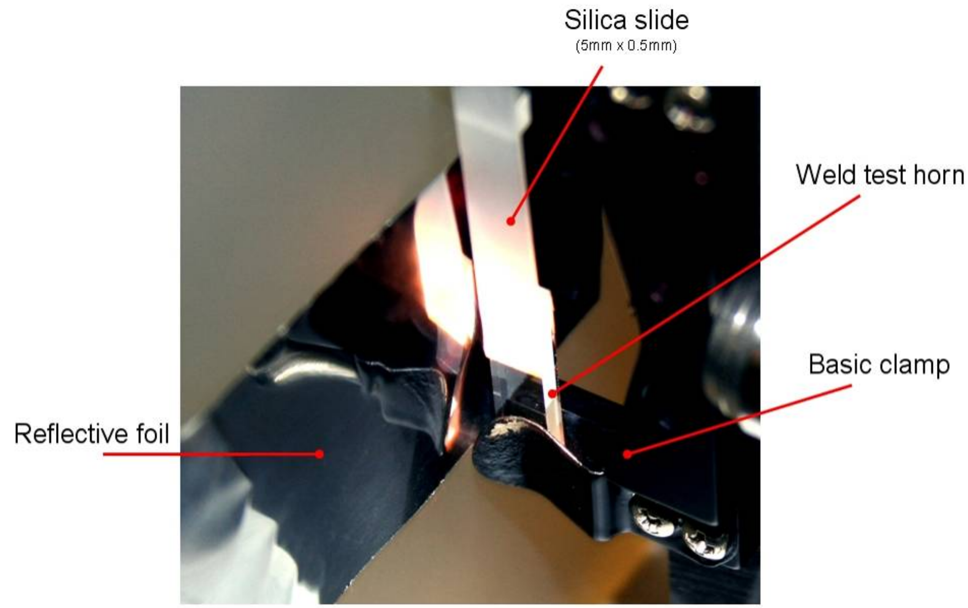
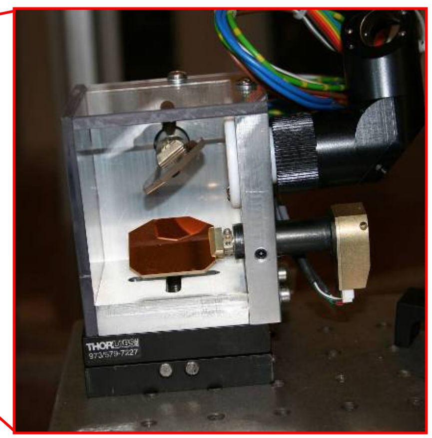
Welding technology





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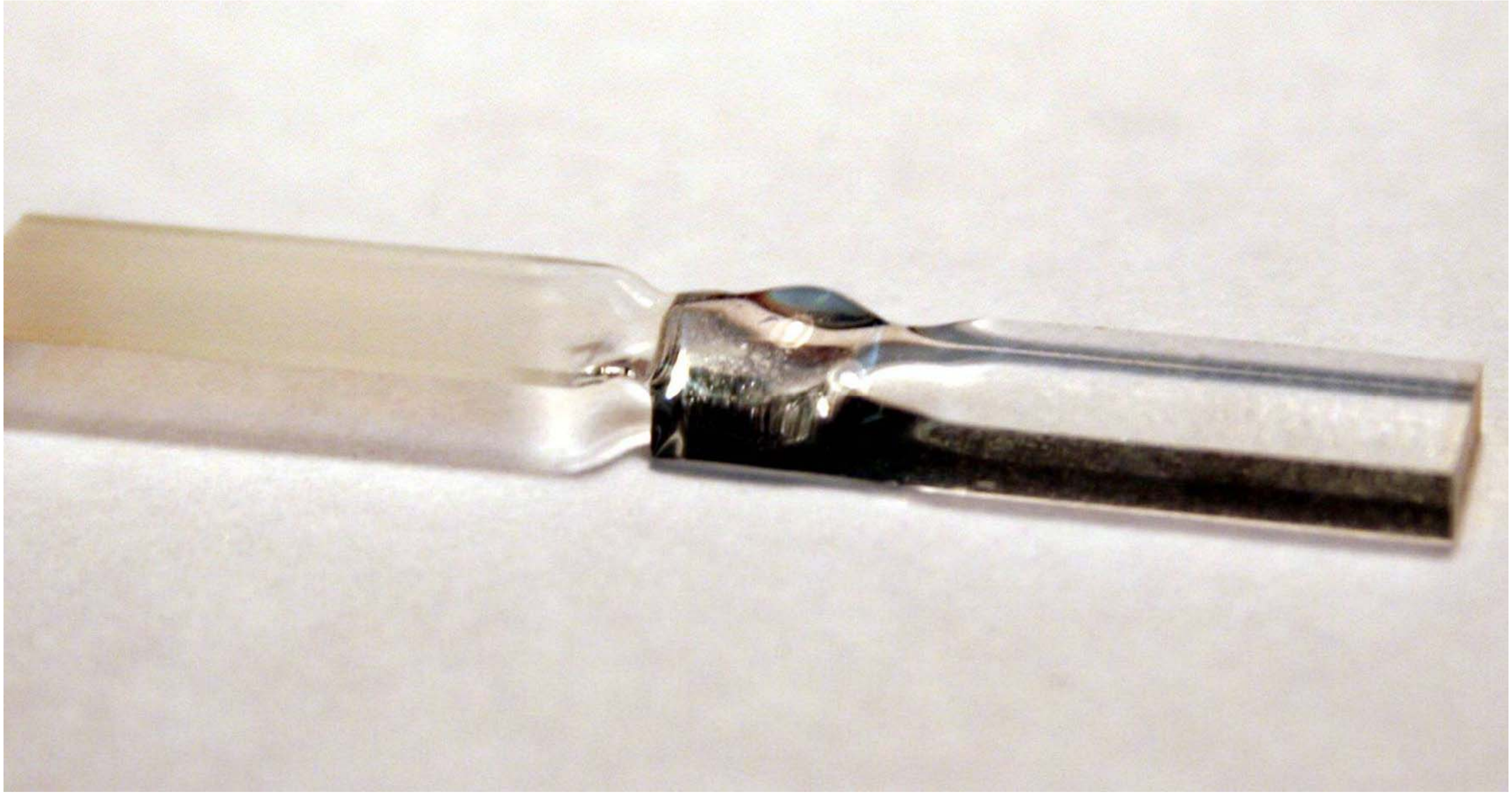
Reflection welding tests



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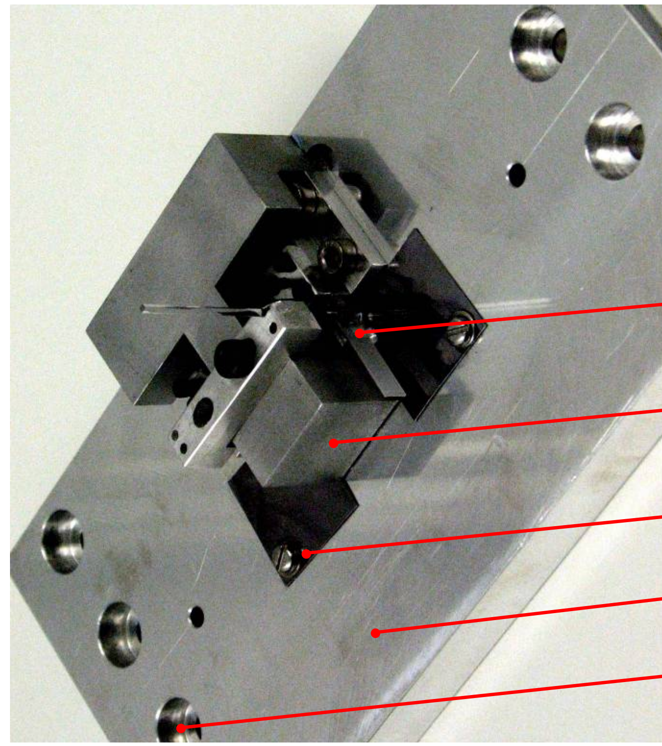
Welding in and around the structure

Main structure

Flat on side of mass



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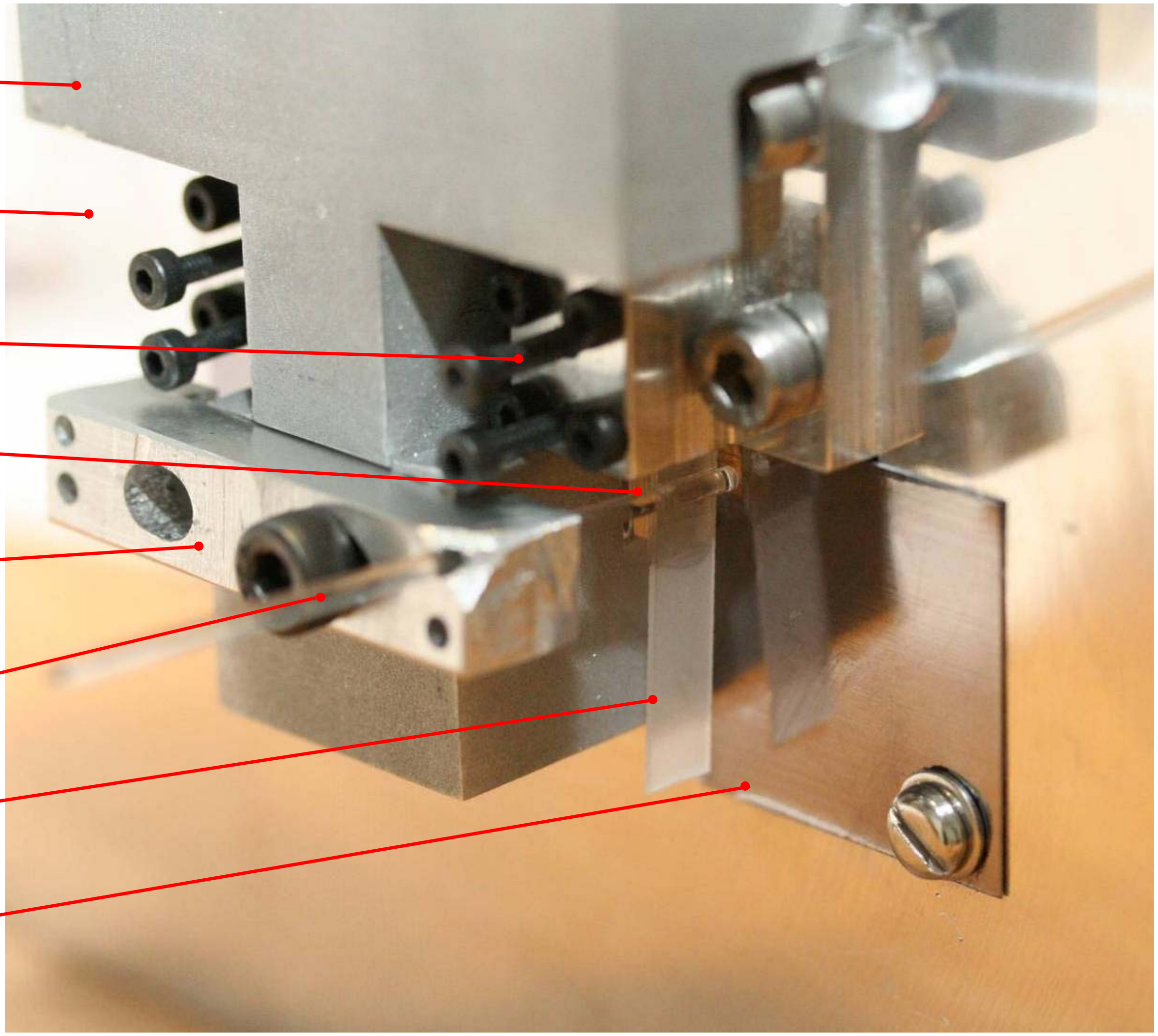
Testing of welding fibres in the structure



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Conclusions

- Based on the experience of the flame pulling machines used for the GEO600 suspensions we have designed and built new fibre pulling machines using CO_2 lasers
- Laser pulled cylindrical fibres have a surface loss at a similar level to flame pulled fibres
- Evidence seen of length dependent loss which appears to be related to weld quality
- There is strong evidence of frequency dependence in residual loss of fibres studied
- This appears to arise due to dissipation in the bulk of the fibre material but at a higher level of loss than is seen for larger 'bulk' samples
- Both the above effects need included in any model of suspension thermal noise in monolithic silica suspensions
- Significant effort has been put into improving ribbon fibre cross section and neck shape
- Welding technique planned for Adv. LIGO has been shown to work well in bench test
- We are now working on developing this for welding inside the confines of the suspension structure

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