Development of Fused Silica Suspension Fibres for Advanced Gravitational Wave Detectors

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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:
  - Strength (x3 safety margin)
  - Thermal noise performance
- To meet these criteria we require
  - Breaking stress > 2.4 GPa
  - Intrinsic loss <3 x 10^{-11}/t, where t is the thickness of the ribbon
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 CO₂ 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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Pulling fibres using the CO$_2$ laser
Virgo laser pulling machine installation

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Controlled shaping of the neck

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

\[ h\phi_{surface} = 4.7 \times 10^{-12} \text{ m} \]

From Penn et al we can calculate values:

- for suprasil 2 \[ h\phi_{surface} = 6.05 \times 10^{-12} \text{ m} \]
- for suprasil 312 \[ h\phi_{surface} = 3.25 \times 10^{-12} \text{ m} \]

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.
Where does dissipation arise in our material?

- In order to reduce thermal noise we need to reduce dissipation.
- To do this we must first understand where it arises.
- Loss in fused silica is normally split into two categories
  - **Bulk**: A very low level dissipation in the body of the material recently shown to be due to the residual effects of dissipation due to a two level system
  - **Surface**: A much higher level of dissipation in the damaged surface layer
- The dominant loss mechanism depends on surface to volume ratio.
- This can now be controlled to a level acceptable for next generation detectors
- However a better understanding of the physics of these loss mechanisms is needed to reduce thermal noise for future detectors

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Recent measurements at Glasgow (1)

- Loss measurements made on laser pulled fused silica fibres have shown a length dependence to dissipation.
- This is consistent with a source of loss close to the top of the fibre.
- This has been shown analytically and using finite element modelling.
- Source of loss thought to be due to welding.
- This is a previously unknown source of loss - highly relevant for development of detector suspensions.

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Recent measurements at Glasgow (2)

- 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 (3)

- 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.
Ribbon fibre development

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Ribbon cross-sectional shape development

- First ribbon fibres pulled had a non-rectangular cross-section due to heat loss from edges.
- Laser was run at close to maximum power due to heat loss.
- Polished aluminium heat shield was developed to reflect heat back at edges.
- Further improvements to the symmetry of the fibre neck and cross section were achieved by using slides on either side to reduce the edge effects.
- Laser stabilisation has been significantly improved
  - Fast sensor
  - Wedged Brewster window for pick-off
- Profile of pull has been investigated to create good shapes for the neck regions
Profiling of ribbon dimensions
Strength and bounce frequency testing
Welding technology

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Bonding test mass ears at LASTI (1)
Bonding test mass ears at LASTI (2)
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 CO₂ lasers.
- Laser pulled cylindrical fibres have a surface loss at a similar level to flame pulled fibres.
- Data shows evidence of length dependent loss which appears to be related to the quality of weld.
- 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.
- Further studies in progress.
- The construction of the monolithic pendulum stage for LASTI has begun, with successful bonding of the ears to both the penultimate and test masses.