Bonding, Ear, Ribbon/Fibre PDR – Summary Slides with Response to Questions

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Comments on overall design requirements

- Overview given in T050215 'Monolithic Stage Conceptual Design'
- Details in T010075 'Systems Design', T020034 'Low-Frequency Cut-Off' and T010103 'Suspension Conceptual Design'
- Thermal noise requirements
  - SUS team heavily involved and fully in agreement with targets
- Seismic isolation requirements
  - Monolithic stage does not control overall isolation – controlled by blade performance (vertical to horizontal coupling). Little effect on isolation at 10 Hz except as given in LF cut-off document
  - Blade size/performance optimised for space envelope
- Stress levels
  - Adv LIGO has higher stress levels than GEO (~ x 2) since thermal noise targets more stringent
  - Integrity tests to date raise no cause for concern regarding achievement of x 3 safety factors

(a) How is suspension used to position optic in space? Where do requirements come from?

- Optic is positioned relative to lower structure/upper structure which in turn is positioned relative to seismic isolation platform
  - Preliminary design details of assembly are given in T050213 'Monolithic Stage Fabrication and Assembly'
  - Positioning of overall suspension structure relative to platform outwith scope of this review
- Optic alignment requirements during assembly of monolithic stage currently based on Initial LIGO T040151 'Quad Installation & Alignment Fixtures Product Design' (Section V)
- Requirements derived from overall optical layout/ISC. Should be reviewed by ISC Group.

(b) Effect of violent events like earthquake/installation on strength/stability of ribbons. Are ribbon twists required?

- Welding alignment errors can be very large with no danger of buckling (several mm) (T030252)
- During construction alignment will easily be controlled sufficiently to avoid buckling using a suitable jig
- During earthquake or assembly the largest possible dynamic bending stress on the ribbon will be at least a factor of 100 smaller than the typical breaking stress (T050236)
- Longitudinal (vertical) stress during earthquake will only be ~ 15% of operating stress
- Impact forces due to earthquake stops will be kept to 'low frequency' if compliant material used (only first few violin modes will be excited)

(c) What research would still be required to realize tapered ribbon suspensions?

- Three possible ribbon shapes can be considered
  - Straight
    - Welding difficult (ribbon can melt away)
    - Dynamic stress levels would be (unacceptably) high
  - (short) tapered neck
    - Current proposal – optimum shape to be determined (possibly exponential (TBD))
  - Dumbbell ribbons or fibres
    - Potential fall-back (T040223 'Ribbons/Dumbbell Fibres (Moving from Parallel to Serial Effort))
- Planned research
  - Optimisation of tapered neck shape - stress / thermal noise
    - Theoretical evaluation of thermal noise
    - Experimental/theoretical work on flexure points/strength

(d) Comments on long term loading with regard to stress corrosion and micro-cracking

- Currently can't quantify effects of micro-cracking on the long-term stability of silica ribbons/fibres
- GEO suspensions installed June 2001
- Adv LIGO stresses approx. x 2 those in GEO
- As back-up aim to conduct experiment in Glasgow to investigate fibre/ribbon micro-cracks after long term loading both in vacuum and in air – potentially use AFM for investigation

(e) Material for penultimate mass? Justification for use of silica "nose" (hook)

- Material for penultimate and reaction masses are both TBDs.
- Currently investigating cost of silica/quartz versus homogeneity/surface finish properties
- Will use the cheapest material meeting bonding requirements (e.g. HOQ 310)
- Silica hooks with break-off prisms
  - Aids simpler and lower risk installation of penultimate mass wires
  - Potential for creak noise should be lower due to removal of wire sling under mass
  - Potential application will be further investigated

(f) Is ±15mm ear separation adequate for flame welding? Is this an acceptable backup technology? Safety and vacuum issues with flame welding

- Based on GEO 600 experience
  - Proposed separation acceptable for both flame and laser welding
  - Flame welding acceptable as backup technology
    - Main disadvantages – more water - cannot be automated - human interface – repeatability would be more challenging but not insurmountable
  - Safety issues with flame welding no different from GEO 600
  - Vacuum issues
    - Protective covering of optic
    - Extractor system close to weld point to prevent silicon monoxide contamination
    - Vacuum issues for laser welding considered lower risk than flame welding

(g) Is there a card carrying glass blower involved at any stage of the research? Should there be?

- Glass blowers were consulted in early development of GEO
- Italian glass blowers were consulted more recently by G. Cagnoli
- Future consultation with glass blowers for general advice and in case of need would be considered beneficial to the project

(h) How much experience do we have of laser welding? Plans to improve experience? Has a monolithic suspension been constructed using laser welding?

- Glasgow already have reasonably good experience in laser welding and this will increase significantly prior to the noise prototype installation as the CO_2 laser welding and pulling machine development programme proceeds.
- Preliminary measurements of laser lap welds encouraging
  - Initial test at 12.5 kg has been running for a few days
- Plans for monolithic stage construction at various levels
  - Continuing bench tests on individual welds
  - Mock-up construction using sapphire sized lower structure from Caltech at end of year
  - Pre-assembly in Glasgow of monolithic stage for noise prototype in second quarter of 2006
  - Assembly of monolithic stage for noise prototype

(i) How much uncertainty is there in the expected mirror thermal noise from the silicate bond? How conservative is the estimate of the 7.1cm^2 area?

- Calculation based on measured loss factors and measured thickness from the literature (Sneddon et al CQG 20 5025-37 (2003)).
- Uncertainty less than 20% and estimate considered to be conservative
- Currently investigating effect on bond thickness of reduced volume of bonding fluid. A thinner bond would lead to further reduction in thermal noise level
- Note that safety factor is not required on 10% technical noise limit

(j) Alignment advantage of lap welding over butt welding? Why did GEO use butt welding? How much can we claim this is a demonstrated technology? Is laser welding more problematic with respect to heat diffusion from surface deposition of laser energy?

- Lap welding allows greater flexibility during welding with less stringent length control required on the ribbons
- GEO used butt welding since lap welding considered more difficult with flame
- Initial investigation of laser lap welding and strengths encouraging
  - Initial test of lap weld loaded with 12.5 kg running for a few days
- Absorption depth in silica only a few tens of microns hence little difference in heat transfer method using flame or laser (conduction dominates). Higher energy flux can be achieved with laser but this can be precisely controlled
- Laser welding much cleaner than flame plus problem of flame blowing removed

(k) How much do the violin modes need to be damped? Is GEO experience adequate? How does Teflon affect strength of filaments? What about vacuum compatibility? How will decision between Teflon and active damping be made?

- Mathematica/Matlab models currently being used to determine how much damping required
- Both active and passive techniques being considered
  - Sense at/feed back to penultimate mass
  - Sense and/or feedback at mixture of penultimate mass and fibres
  - Passive damping with Teflon
  - Passive damping using tuned dampers on penultimate mass – preliminary results indicate unlikely to be viable option
- Vacuum compatibility of Teflon AF tested at JPL (T050028). Extractable fluoride – Teflon AF 0.67 ppm, Fluorinert solvent 0.025 ppm.
- Effect of Teflon on strength of filaments can be further investigated if required
- Current design approach for noise prototype is to allow accommodation for active damping
- Decision for optimum damping system will be subject of future suspension review

(I) Is the surface loss/strength of a laser drawn filament the same as a flame drawn? What plans are there to investigate this? Are there plans to study the loss from the weld in more detail?

- Initial loss measurements on laser drawn fibres suggest same loss as flame drawn fibres
- Measured loss from Suprasil 300 same as Suprasil 312 with no obvious excess loss from the weld
- Plans to continue fibre/ribbon and weld loss measurements as CO_2 laser pulling & welding machine development enters its final phase

(m) Have tests been made of bond/weld strength at 3 x design load since a single filament failure would induce this on others?

- The 3 x factor for the dynamic load is considered to be very conservative
- Experiment currently being set up in Glasgow to simulate wire failure and measure actual dynamic loads induced on four wire suspension
- The bond strengths will be greater than x 3 static load. One of the test ears has already been tested up to x 3.8 without bond failure
- Welds will be developed to achieve at least x 3 static load. Work to date suggests this will be achievable.

(n) Can we get more details on the drawing of the filaments, especially with regards to the block left on each end?

- Precise shape of tapered neck to be determined to optimise thermal noise performance, stability and strength
- Block on end of pulled ribbon will be rectangular e.g. 1.5 mm x 2 mm (precise dimensions TBD)
- Precise horn dimension on ear also TBD
- Further laser pulling and welding investigations to be performed to determine parameters

(o) How much annealing does each weld need? How carefully can the annealing be controlled? How necessary is the annealing step? What can go wrong if annealing isn't done right? Does the surface deposition of heat from the laser make laser welding more challenging?

- Annealing of the full ribbons is not necessary
  - Annealing was considered previously for stress relief of the weld between the H-piece and the ribbon – H-pieces are no longer being considered
- Gentle laser heating of the welds between the ribbons and the ears may be performed during assembly to equalise the tensions (TBD)
- The heat deposition from laser and flame are similar since conduction dominates. Deposition of laser energy on surface can be precisely controlled to avoid surface damage. Laser welding in many ways considered to be less challenging and problematic than flame welding
  - Less contamination
  - Greater precision and control
  - No flame blowing

(p) What are the tolerances on the ribbon dimensions? How accurate is the optical profiler that is to be used?

- Required dimensional tolerances calculated to be ± 1.9% (T050212 'Ribbon Tolerances and Alignment Requirements')
  - Note GEO flame technique achieved ± 2.1%
- Optical profiler still being developed (T050207). Currently repeatability with ~ 5%. Absolute calibration will be carried out in near future.
- Characterisation of ribbons/fibres involves 3 steps to match suitable sets
  - Dimensional profiling
  - Bounce frequency tests
  - Violin mode frequency tests