LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Advanced LIGO Suspension Ribbon/Fiber/Ear/Bonding Preliminary Design Review Report

Review Committee: Garilynn Billingsley, Doug Cook, Riccardo DeSalvo, Gregory Harry (chair), Roger Route, Phil Willems

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Report on the Preliminary Design Review of the Advanced LIGO Suspensions Ribbon/Fiber/Ear/Bonding

Participants

Presenters:

- Caroline Cantley, Gianpetro Cagnoli, Norna Robertson, Janeen Romie, Helena Armandula, Sheila Rowan

Review Committee:

- Garilynn Billingsley, Doug Cook, Riccardo DeSalvo, Gregory Harry, Roger Route, Phil Willems

Documents Presented and Discussed

Reviewed Documents:

- ETM/ITM Monolithic Stage Conceptual Design for Advanced LIGO ETM/ITM (T050215-00-K)
- ETM/ITM Monolithic Stage Fabrication and Assembly (T050213-00-K)
- Silica Bonding, Ears, Ribbon/Fibre Status/Research and Development Plan (T040170-01-D)

Presentation Viewgraphs:

- Bonding, Ear, Ribbon/Fibre PDR Summary Slides with Response to Questions (G050558-00-K)

Charge:

1) Review the requirements for Silicate Bonding, Ear Design, and Fiber/Ribbon Manufacturing and Welding. Determine whether the derived requirements are complete, correct, traceable to fundamental science/performance requirements and documented. Advise whether proposed requirement values are appropriate. If needed, recommend additional requirements to be specified (e.g. design or functional features), and recommend other appropriate actions. Some specific points to consider are:

- *definition of the scope and objectives*
- *delineation of interfaces (particularly with COC)*
- *performance requirements*
- *functional or feature requirements*
- *physical and environmental requirements*
- *documentation*
- *testing criteria*

The committee finds the requirements, both scientific and engineering, are adequate and realistic. The interface with COC does present possible effects on mirror thermal noise, which will benefit from further investigation, but adequate plans are in place to do so. The requirements on placement

of the core optics can benefit from further review by the suspension team in collaboration with the ISC team. The committee would also like to comment that suspension thermal noise will be a limiting noise source for advanced LIGO in a low frequency/low laser power operational mode, which will be an important mode for pulsar and stochastic background detection. As such, lower suspension thermal noise is always advantageous, even beyond stated requirements and goals.

2) Review the preliminary designs for consistency with the requirements and determine if they have been sufficiently advanced/tested in order to proceed with a final design. In particular, determine whether the designs are ready to proceed to the planned noise prototype of the quadruple pendulum test mass suspension. Verify that the final design plan acknowledges and adequately addresses areas of concern.

The committee finds the preliminary design is sufficiently advanced to merit proceeding with the quadruple pendulum noise prototype. There are areas of performance that are not fully understood at present, but only further research and testing, of which the quad noise prototype is the cornerstone, will be able to address them. The planned research effort should be adequate to address all important outstanding questions. Specific suggestions for research concentration are below.

Detailed Report

The preliminary design review of Advanced LIGO Suspension subsystem Ribbon/Fiber/Ear/Bonding issues was held October 31, 2005, following a preliminary meeting of the review team where they discussed the documents and compiled questions. These questions were addressed by the suspension team at the review.

It is clear to the review committee that much thought and effort has gone into the overall suspension design and that work on suspension filaments and connections is progressing well along a carefully chosen path. The committee brought up a number of issues after reading the provided support material, primarily in the categories of thermal noise, welding, fallback plans, and strength/stability. All issues were addressed by the suspension team to the satisfaction of the committee. In many cases, the practical experience using similar suspensions in GEO 600 lay to rest many concerns that might otherwise be troubling. Particular issues that were brought up by the committee and addressed included:

- Concerns about the art and practice of flame welding. The GEO 600 experience here is directly transferable to the advanced LIGO case and gives no cause for concern. Prior consultation and continuing work with professional glass blowers also makes this a non-issue.
- Effects of thermal diffusion differences between laser and flame welding.
- The ability to fallback to either flame welding as a connection method and/or dumbbell ribbons should problems arising with tapering
- Strength of silicate bonds and ears connections and the ability of these connections to survive a single wire breaking or other catastrophic events.
- The ability to achieve required geometrical tolerances on ribbons with laser drawing.

The committee felt that in many cases further research and planning was necessary to address some issues, but that the suspension team had adequate (and typically detailed) plans to do so. Particular areas that need further research and have plans in place are:

- Develop requirements (in collaboration with ISC team) on positioning of the optics.
- Effects of violent impacts (including likely installation effects) on stability of silica suspensions. Evaluation of requirements of earthquake stops spring constant in light of impact effects.
- Thermal noise effects of silicate bonding. In particular, directly measuring the mirror thermal noise effects of a silicate bond using an existing prototype interferometer, possibly the TNI or Glasgow interferometer, should be explored.
- Thermal noise effects of tapering of filaments, flame welding, and laser welding. The recent paper on suspension thermal noise from laser welded fibers addresses many inadequacies in our knowledge. It would also be desirable to explore the direct measurement of suspension thermal noise in a prototype interferometer, to allow for more direct research on effects from bonding, welding, tapering, etc, although this may not be feasible. Analysis of data from existing gravitational wave interferometers, particularly GEO, for thermal noise information should be pursued.
- Possible non-Gaussian noise from silicate bonding, welding, and/or silica hood connections. This is another area where work with an existing prototype and GEO data can be potentially useful.
- Research on the effect of long term loading in both vacuum and air on microcracking in silica. Examine existing plans and procedures for transport and storage of silica suspensions in light of any insights to determine if additional planning is necessary
- Continuing work with laser welding, including the planned development and assembly of the noise prototype for LASTI. This includes the need for further testing on lap welding, rather than the butt welding which GEO used.
- The material to be used in penultimate mass. This may require studies of effects of silicate bonding on other types of (cheaper) glass. Needs to be done along with planning for the suspension method for the penultimate mass, whether silica hooks or wires.
- Details of the necessity and method for violin mode damping. The ongoing plan involving modeling and integrating the GEO experience should be encouraged.
- Keeping the spread in violin mode frequencies down below 5% is desirable for filter design. The GEO experience may not be directly relevant here as Teflon coating was used in GEO, which is only being considered for Advanced LIGO, so some additional research may be required.
- The necessity for annealing ribbons after welding to equalize stress across the weld.
- Further development of the optical profiler to be used to characterize ribbons after being drawn.