LIGO document: T050277-00-R

Response to Advanced LIGO Suspensions Subsystem (SUS) Design Requirements Review report LIGO-L010161-00-D

2nd Draft incorporating comments from JR and CT
NAR, 25th May 2005

The list of actions from the report is given below, with comments.

Design Requirements

1) Noise performance requirements

Actions:
- Keep the effective displacement requirement from thermal noise at the level of 10^{-19} m/√Hz at10 Hz (falling roughly as f^{-2}); the 'effective displacement' is that due to the longitudinal motion, and the vertical motion, assuming a v-h cross-coupling of 0.001.
- Keep the effective displacement requirement from seismic noise at the level of 10^{-19} m/√Hz at 10 Hz (falling faster than f^{-4}); the 'effective displacement' is that due to the longitudinal motion, and the vertical motion, assuming a v-h cross-coupling of 0.001.
- Develop a thermal noise model for the angular motion; defer setting angular noise requirements until then.
- Horizontal transverse, and pitch and yaw thermal noise are considered technical noise sources (since they couple with some more-or-less controllable error), and should each be specified so that they are a factor of 10 below 10^{-19} m/√Hz at 10 Hz.
- Use the predicted internal thermal noise curve for sapphire (Fig 1 in the requirements document) to derive an upper limit on the mechanical loss of the test mass attachments (or attachment interfaces) associated with the suspension. Treat this as a technical noise source, so that the additional loss does not increase the intrinsic thermal noise by more than 0.5% (in amplitude) over the frequency region of 30-300 Hz (where internal thermal noise is significant).

Response to actions.

There is some inconsistency between bullet points 3 and 4. In 3, setting angular noise requirements is deferred, and in 4 pitch and yaw thermal noise requirements are defined.

Bullet points 1,2, 4 and 5.
These requirements are all incorporated in the "Cavity Optics Suspension Subsystem Design Requirement Document", T010007-02. Specifically, refer to table 2 for bullet

points 1, 2, and 4. Bullet 5 is covered in section 3.3 of the document which addresses technical noise sources. The loss associated with the suspension attachments is required to be no more than 10% of the system requirement noise level (which is dominated by the internal thermal noise around 100 Hz) such that it will not increase the overall noise level by more than 0.5% in amplitude. ($[1^2 + 0.1^2]^{1/2} = 1.005$].

Our design is aimed at satisfying all the stated requirements.

Bullet point 3. A full thermal noise model including angular motion is currently being developed by G Cagnoli. For practical purposes we have been using a simplified model of pitch thermal noise to aid in design choices. Yaw thermal noise is not likely to be so significant since there will be a dilution factor (as with longitudinal motion) reducing the losses in the yaw direction below that associated with the intrinsic losses in the fibres.

2) Electric and Magnetic fields

Actions:

- Electric fields. Estimate the maximum patch and dielectric fields or surface charge allowable on the mirror surface, and field relaxation time.
- Magnetic fields. Estimate magnetic field fluctuations due to suspension control signals; use these, and current estimate of environmental magnetic fields, to derive a value for the allowed ferritic impurity in the test masses.

Response to actions.

Bullet point 1.
Electrostatic charging is a topic of ongoing research, and has been recently discussed - for example at the LLO LSC meeting in March 2005 and at a SUS telecon on 3rd May 2005. There is research underway at the University of Moscow by V Braginsky, V Mitrofanov and colleagues on monitoring drift of surface charges on a suspended silica mass. J Hough, S Rowan and colleagues at the University of Glasgow are investigating ion implantation to raise the conductivity of sapphire and silica. G Harry at MIT is coordinating an effort to investigate surface charge effects through the use of a Kelvin probe.

Bullet point 2.
Work is underway looking at magnetic effects at the various stages in the suspension. This was a topic at the SUS summit in March 2004 where R Schofield summarised the experiences on magnetic interference from LIGO. As summarized in (reference Justin's notes) this provides a guide to maximum magnetic dipole allowable at each stage in the suspension. R Schofield has also made measurements on the Stanford ETF recording the residual magnetic field due to the SEI actuators (ref needed). One conclusion from this work was that a thin sheet of mumetal reduced the magnetic field above the SEI table by a factor of ~5. Considerations of noise due to eddy current damping at the penultimate stage for the quad suspension (the lowest stage at which magnets are present) has been

made by K Strain (T050013-01-K), and conclusions drawn for electronic design for the coil-magnet system at that stage. The force requirements for global control and limits on acceptable magnet size given by P Fritschel (G010086-00-D) are being used as a general guide in the electronic design and choice of magnet size for the quad suspensions. Regarding the specific issue of ferritic impurity in the test masses, G Billinglsey reports that the iron content of 7980 Corning fused silica is less than 20 parts per billion.

3. Transients.

Actions:

- Specify a settling/ringdown time of the suspension in response to a transient at the suspension point. Suggest: 1/*e* time constant < 10 sec. in installation and commissioning modes; possibly can be longer in the detection mode.
- Make estimates for the rate and amplitude of transients, both external and internal (creep in the suspension components).

Response to actions.

Bullet point 1. The damping requirements continue to be an active area of discussion and development, in particular by the K Strain and the ALUK team, and this topic was discussed at the OSEM reviews held in April and June 2004. A ringdown of 10 sec has been used as a guide for consideration of necessary damping for installation and commissioning modes. See also "Conceptual Design", bullet point 1 below.

Bullet point 2. Regarding creep in blades – see response under section 4 below.

4. Global control

Action: Launch a program to study lock acquisition of the Advanced LIGO interferometer, with a goal of determining the amount of force required to be applied directly to the test masses.

Response to action.
This is underway by the e2e modelling group.

Conceptual Design

1. Local damping.

Action: Eddy current damping should be further explored to determine the level of damping that can be achieved. Solutions using a combination of active and eddy current damping should be looked at. Sensors with improved noise performance should be researched.

Response to action.

Solutions with a mixture of eddy current and local control damping have been and continue to be considered. Sensors with improved noise performance have been researched. Both of these topics were covered in the OSEM design review held in April and June of 2004 (references). Eddy current damping has also been investigated experimentally at Glasgow and Caltech and this work with related modeling has been published (Plissi et al Rev Sci Instrum, **75**, 4516-4522, (2004)).

2. Fiber vs ribbon.

Action: Clearly continue R&D on ribbons, as they have a clear advantage for a low-frequency tuned interferometer. No need to identify a baseline at this point.

Response to action.
Research in ribbons is ongoing at Glasgow, and ribbons are the baseline design for the ETMs and ITMs. Fibers are the baseline for the modecleaner and beamsplitter suspensions (which have less demanding noise performance requirements).

3. Internal modes of blades.
Action: Evaluate the effect of the blade internal modes, and determine if they require damping.

Response to action.
Document on this has been written – see T050046-01-R. No definitive answer yet (see conclusions section of document for summary of situation to date)

4. MGASF.
Action: Some effort should be applied to evaluating the feasibility and benefits of incorporating a MGASF stage into the design.

Response to action.
We did consider the feasibility and held discussions with R DeSalvo and V Sannibale. As the committee pointed out, greater vertical isolation appears to have little benefit but greater isolation from sensor noise would be beneficial. However to achieve this would necessitate adding a MGASF stage at the top mass where the space available is very limited. It was not obvious how to incorporate a GAS as a straight swap for a regular blade, and extensive redesigning would have been required. In addition the overall damping method would need to be investigated, since the present design relies on good coupling of modes so that damping can be applied at the top mass alone. We therefore have not pursued their incorporation. We have however benefited from these discussions in several areas of design, and have adopted techniques used in the MGASF suspensions. These include the use of drum ended maraging steel wires, adjustable housing for such wires, and blade adjustment mechanisms. We have also adopted an improved blade processing procedure, using heat treatments to reduce creep, and collaboration on all

aspects of maraging steel is ongoing.

5. SEI-SUS interface.
Action: Add a requirement to SEI that its design must allow easy access to the suspension. Suspension design team must interact with the seismic design team to ensure this is upheld.

Response to action.
SEI are aware of this and interface issues between SEI and SUS are regularly discussed at the weekly SUS meetings, monthly SWG meetings and LSC meetings. Extensive testing at LASTI and the ETF should show up any potential problems which can then be addressed.

6. Electronics prototyping.

Action: The suspension prototype development team needs to formulate a plan on how electronics development is included in their effort.

Response to action.
Electronics development is now fully underway by the ALUK team in particular by the group in Birmingham. They are in regular contact with colleagues in LIGO through weekly SUS telecons and LSC meetings and associated visits.

7. Assembly & installation concepts.
Action: Tooling should be designed in concert with the design of the pendulum masses and support structure.

Response to action.
Assembly tooling is the responsibility of the SUS team and designs are already prototyped for the modecleaner and the ETM quad. These assembly fixtures will be optimized as we move to the final design stage.

Concerning the installation fixtures, the engineers who are working on the designs are working with experts on the Initial LIGO installations. Their expertise will assure that the lessons learned with initial LIGO will be folded into these designs. The engineers participate in the weekly SUS and design telecons and provide weekly status reports on their designs and analyses. This allows them to benefit from GEO and initial LIGO installation knowledge. It also allows them to be involved with detailed aspects of the suspension and support structure design. A requirements review for the quad installation fixtures was held on May 4th 2005.

8. Violin mode damping.

Action: An analysis needs to be made of the influence of the violin mode resonances on force applied to the final suspension mass, and also of the influence of the possible damping solutions on thermal noise.

Response to action.
This topic is underway. M Barton has a Mathematica model of the quad suspension incorporating violin modes and he is working with the e2e team to incorporate the quad model into the e2e model to investigate the effects of the violin modes on global control.