LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY – MASSACHUSETTS INSTITUTE OF TECHNOLOGY

To: Advanced LIGO Suspensions Group and
Design Requirements Review Committee
From: Peter Fritschel
Refer to: LIGO-L010161-00-D
Date: 8 October 2001

Subject: Advanced LIGO Suspensions Subsystem (SUS) Design Requirements Review report

The Design Requirements Review for Advanced LIGO's Suspensions (SUS) Subsystem was held on 20 September 2001. The members of the review committee were:

Ben Abbott
Gabriela Gonzalez
Brian Lantz
Warren Johnson
Virginio Sannibale

Design Requirements

1. Noise performance requirements. For the test mass suspensions, a clearer distinction between requirements and examples of noise sources is desired. It was suggested that the basic requirement be a generic longitudinal displacement level, not even split into seismic and thermal noise. While this may be a cleaner approach, it does not seem to offer any practical advantages. Angular noise does need to be specified separately, as it couples with a beam offset on the optic, which in turn must be controlled to some level. However, until a thermal noise model that includes the angular degrees-of-freedom is developed, one can not set these requirements. Regarding test mass internal thermal noise, it would be useful to separate out the part that the suspension system is responsible for – namely, the loss due to suspension attachments.

Actions:

- Keep the effective displacement requirement from thermal noise at the level of 10^{-19} m/√Hz at 10 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 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).

2. It was felt by several reviewers that requirements should be added regarding noise due to electric and magnetic fields and fluctuations. While in principle covered under the technical noise rubrique, these particular noise sources should be specifically addressed.

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.

3. Transients. The response to and generation of transients needs to be addressed.

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).

4. Global control. There were a few reviewer comments about issues pertaining to global control. The global control strategy and design is the responsibility of the Interferometer Sensing & Control subsystem. With this design will come requirements for the global actuation provided by the suspension system – force and other response characteristics of the actuators at each stage. Because the global actuation is completely independent of the local damping, detailed characteristics of the actuators do not need to be specified at this time. However, the choice of actuation type for the end test masses – photon or electrostatic drive – obviously makes a big impact on the suspension design; this choice will be driven by the force and bandwidth necessities of lock acquisition.

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.

Conceptual Design

1. Local damping. This is clearly an issue that as yet lacks a satisfying solution. Active damping suffers from sensor noise: with existing shadow sensors, the damping gain would have to be lowered so much that the Q of the low-frequency modes would be ~10^4. Eddy current damping avoids sensor noise, but it is not clear if it can practically achieve sufficient damping strength.

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.

2. Fiber vs ribbon. It was unclear in the review whether circular fibers or ribbons were the baseline design for the final stage suspension. Both are being pursued, with the obvious trade-offs of noise versus risk.

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.

3. Internal modes of blades. Concern was expressed about the internal modes of the blade springs; these are not included presently in the model, and one wonders if these modes will need to be (passively) damped.

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

4. MGASF. It was suggested that the suspension might be able to incorporate a geometric anti-spring (MGASF) for better vertical isolation. While greater vertical seismic isolation appears to have little benefit, greater isolation from vertical local sensing noise is clearly worthwhile. Though it would require a significant effort to incorporate a new mechanical element into the design, this could be traded-off to some extent by relaxed requirements for local sensor noise, and possibly avoiding R&D of better sensors.

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

5. SEI-SUS interface. It was pointed out that the SEI support structure must be designed to allow easy access to the suspensions' sensors and actuators.

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.

6. Electronics prototyping. The lack of any presented plans for electronics development and prototyping was noted. Certainly prototype electronics will be part of the LASTI suspension testing, but the electronics development path up to that point is not clear.

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

7. Assembly & installation concepts. The ideas of using dummy masses and mechanical manipulators for handling the optics were praised. It is clear that assembly and installation tooling is a key part of the whole suspension design, and there is concern that these issues be given adequate attention, beginning early in the whole suspensions design process.

Action: Tooling should be designed in concert with the design of the pendulum masses and support structure.

8. Violin mode damping. The conceptual design suggests that passive damping of the violin modes of the last suspension stage may be required to preserve clean wideband actuation of the test mass. However, the dynamics of this system were not analyzed, nor were the implications of the proposed damping technique on the vertical mode thermal noise.

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.