LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

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Advanced LIGO HAM Seismic Isolation Technology: Consideration of HAM-SAS as alternative to the baseline design

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Advanced LIGO Team, LSC

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Summary

An evaluation of a 'soft' alternative to the Advanced LIGO baseline 'stiff' HAM seismic isolation was undertaken, to determine if there were net advantages for adopting the alternative. The timing of a decision now is forced by the schedules for both Advanced LIGO and enhancements to initial LIGO, and limited Lab resources.

Based on the current information, I have decided that we will continue with the baseline 'stiff' system for Advanced LIGO.

Background

There have been parallel efforts to develop systems of seismic isolation compatible with second-generation interferometers carried out in the context of the LIGO Laboratory and the LSC. The design approaches are distinguished by their choice of natural resonant frequencies and servo control philosophy. The 'stiff' approach basically uses high natural resonant frequencies in combination with inertial and position sensors in high-bandwidth control loops to 'slave' the optics table to the inertial sensors. The 'soft' approach uses low natural resonant frequencies (achieved mechanically and with electro-magnetic anti-springs assistance) to attenuate motion, complemented with positioning (quasi-DC) servo controls; de-coupling and damping is implemented via low bandwidth feedback (and possibly feed-forward) control loops.

The design approach for Advanced LIGO was established in 2000 (LIGO M000170-00-M, Selection of the Technical Approach for Upgraded LIGO Seismic Isolation, Barish and Sanders), where the principle of high natural resonant frequencies in conjunction with wide-bandwidth servo controls was selected, and this has become the baseline for Advanced LIGO (LIGO M060056-07, Advanced LIGO Reference Design, Advanced LIGO Team).

Work has continued on both approaches. In the case of the baseline 'stiff' approach, several prototypes have been characterized, a design has been prototyped for the test-mass (BSC) isolation and has so far been passively characterized (it is now in a cleaning cycle), and a design has been completed for an auxiliary optics (HAM) solution. In the case of the 'soft' approach, a design has been realized for the Japanese TAMA interferometer and is now being used and tuned, and a design has been prototyped and undergone a brief characterization as an alternative HAM solution.

Advanced LIGO is considering the 'soft' alternative to the HAM baseline at this time, for potential advantages in performance, simplicity, and/or cost, in anticipation of production of the final prototypes of the HAM isolation. The Advanced LIGO team, and the LIGO Laboratory, cannot afford the resources to continue parallel development. The Advanced LIGO schedule requires a decision on which approach to be made in April 2007, in order to maintain the overall schedule promised to the NSF for Advanced LIGO.

A prototype effort for the alternative 'soft' system was approved by the Lab CCB in February 2006, and a plan was established for the evaluation of the 'soft' system (G060025-00-M, HAM-SAS CCB Information, Coyne, Shoemaker, Wilkinson). A test plan was developed, and manpower allocated for the fabrication and testing. The prototype was bid, fabricated with LIGO Lab personnel participation, and installed in the MIT LASTI testbed. The system has been in test and characterization since roughly 15 February 07. A combination of staff from the group which has worked on the soft isolation systems, LASTI staff, Lab staff from all sites, and LSC members joined in the fabrication, installation, commissioning, and documentation. Some modeling was undertaken as well.

The HAM-SAS team has developed reports on the installation, commissioning, and characterization experience (T070079-00 and T070080-00; additional information at http://www.ligo.caltech.edu/~citsas/HAM-SAS/Docs/Docs.shtml).

As part of the normal development process for the baseline 'stiff' solution, a status report (LIGO T070088-00-R) has been developed in preparation for the letting of bids for prototyping of that design.

The HAM-SAS team, and many others in the Laboratory and LSC, have put a lot of energy into the effort to develop, fabricate, install, and characterize the system. The top-level Advanced LIGO schedule, and the inevitable irregular path of research, have led to a limited characterization of the prototype. However, a remarkable amount of progress in the limited time interval has been made, and we know much more now about the suitability of this approach for LIGO and other potential applications. The HAM-SAS team, and the support around it, deserve warm thanks.

Evaluation

An evaluation committee has been working with the HAM-SAS team as the effort has drawn to a close, and have become well informed on the status of the tests. The committee delivered a document (LIGO-M070061-01-W) with their recommendation on the scope of the charge (see below).

The Advanced LIGO Management (Coyne) has been very deeply involved in the HAM-SAS technical development and its documentation. The Advanced LIGO Leader (Shoemaker) and has participated regularly in the HAM-SAS and in the baseline seismic isolation meetings. Expert advice on both technical and management issues has been sought from individuals in the Lab and LSC.

The Advanced LIGO Management has considered the available information on critical measures of suitability: installation and commissioning ease; seismic attenuation in the GW and controls bands; pointing and control stability and margin from instabilities; ease of payload installation and dynamic interactions with the payload; controls compatibility; reliability, flexibility; cost/schedule impacts; and organizational issues.

Much of the testing of the prototype 'soft' system has not reached a clear conclusion, and very little detailed analysis of the system exists, and so in some measure this decision is based on the fact that we know significantly more about the 'stiff' system. There are several concerns about the 'soft' system which were raised in the research and review process: the coupling between multiple suspensions on a given optical table and between the suspensions and the isolation system appears to be significant, tilt-horizontal coupling probably requires additional sensors and control loops, and the integration of the controls for the isolation system into the global controls looks difficult. The system does not, at this time, meet the isolation requirements at all frequencies, in particular at frequencies below the gravitational-wave band. It is not clear experimentally at this time and models do not exist to indicate that there is a simple path to providing that isolation, and eliminating the resonant features, without compromising the performance at higher frequencies. It did not appear to be any easier to commission and 'tune' the 'soft' system than the 'stiff' systems.

Positive features of the solution remain – it appears that it would be somewhat less expensive to implement than the complete 'stiff' system along with the external HEPI pre-isolator, and the large range of internal motion could be advantageous for many moderate earthquakes. The current performance of the prototype is in large measure due to the limited time to commission it, and problems with the measurement infrastructure which have nothing to do with the HAM-SAS isolator.

However, it appears clear that the 'stiff' solution is one which is better understood (in its advantages and disadvantages, and in its resolved and remaining challenges) in experiment and models, and one which appears capable of meeting requirements within the cost and schedule we have established for Advanced LIGO.

Path from here forward

We will start with the process of fabrication of prototypes of the HAM-ISI immediately, which will be installed in the enhancements to initial LIGO.

Work on HAM-SAS will continue, principally by a student completing a thesis and paper based on the effort, until September 2007. At that time we expect activity to stop on the HAM-SAS at LASTI.

The outcome of this decision determines the seismic isolation approach for the Advanced LIGO HAM chambers, and with the use of the baseline system for the BSC/testmass chambers, fixes the seismic isolation approach for the lifetime of Advanced LIGO.

Documentation used in making the decision

M070061-01, Report of the HAM-SAS Evaluation Committee, 23 April 2007
T070088-00, Status Report for the Single Stage HAM ISI for Enhanced LIGO and Advanced LIGO, April 2007, 20 April 2007
HAM- SAS Home Page
HAM- SAS Pre-Proposal Conference web page
HAM- SAS Prototype Development web page
M060004-00, Review Report for HAM-SAS LASTI experiment prototype proposal, 1/17/2006
T060021-01 , Response to Findings from the HAM-SAS LASTI Experiment/Prototype Review, 1/27/2006
T060020-00 , HAM-SAS System Dynamics Model, 1/23/2006
T060037-00 , AdLIGO HAM-SAS Mechanical Model with Lumped Elements, 2/17/2006
T060038-00, Acoustic Coupling Through Cabling for the HAM-SAS System, 2/18/2006
T060066-00, HAM-SAS Spring Box Simulations, 3/29/2006
T060002-00, SAS Installation and Tuning Procedure
G050485-00, Inverted Pendulum Studies for Seismic Attenuation
G060025-00, HAM-SAS CCB Information, 2/22/2006
T060213-00, HAM-SAS Test Plan at LASTI, 8/2006

G060184-00, HAM SAS Test Plan at LASTI, 11/2005

M060062-00, HAM Single-Stage Isolation Baseline Option Review Report
G060190-00 , Single Stage HAM for Advanced LIGO: Performance Modeling, 4/14/2006
M050025-01, Final Report on the Seismic Isolation BSC Critical Review, 8/18/2005
M000154-A, Technical Evaluation of Alternative Design Concepts for the LIGO-II Seismic Isolation System, 5/22/2000
E990304-01 , Evaluation Criteria for the LIGO-II Seismic Isolation System, 8/1999

Charge to the Committee

To the HAM-SAS evaluation committee:
Mark Barton, Richard Mittleman, Peter Fritschel, Rana Adhikari,
Norna Robertson, Joe Giaime, Doug Cook, Fred Raab (chair)

The baseline approach employs the HAM-ISI (internal seismic isolation) system coupled with HAM-HEPI (hydraulic, external pre- isolator). HAM-SAS (seismic attenuation system) is an alternative seismic isolation concept for the AdL HAM chamber. (Note that HAM-SAS can be used with or without the HEPI system.) This committee is asked to evaluate the capability of the HAM-SAS system to meet the HAM seismic isolation system (SEI) requirements on basis on prototype test results and simulations/analyses. The HAM-SAS team will present the results of the prototype effort to the committee in a written report by April 2nd. The committee is asked to review the report (as well as previous reviews and evaluations of HAM-SAS) and provide written questions to the HAM- SAS team by April 9th. The HAM-SAS team will then meet with the HAM-SAS evaluation committee, on or about April 16th, to respond to the committee's questions.

In evaluating the HAM-SAS compliance with the HAM SEI requirements, the committee is explicitly asked to consider the following factors:
1. Vacuum compatibility of the HAM SAS system, including materials compatibility, compensation for buoyancy, and implications of floor tilt.
2. Form and fit of the HAM SAS system in a LIGO HAM chamber, including compatibility with the existing support structure (piers, scissor tables, crossbeams, support tubes and (at LLO only) the HEPI system).
3. Effectiveness and ease (duration, skills required, repeatability/predictability) of the HAM SAS installation and 'tuning', characterization, and integration/commissioning
4. Seismic attenuation factor of the HAM SAS, including total rms motion (without a HEPI system) and ground tilt sensitivity and any indication of self-generated noise (electronic/controls, and/or mechanical)
5. Long term pointing stability and long-term control stability (as a function of temperature, floor tilt, other accessible and likely variables)
6. Efficacy of optics table mechanical "locks" and limiters for safety (integrating optics table payloads) and for earthquakes
7. Margin against instability
8. DC compatibility of the HAM SAS and triple installation (mechanically locking HAM-SAS and

aligning to an optical reference)
9. Controllable or negligible coupled dynamic interaction of the HAM-SAS and a triple pendulum suspension
10. Judgement on the ease of integration into a hierarchical control system (tidal/microseism tracking, quasi-DC suspension force minimization, etc.)
11. The effect of cable compliance on the isolation performance
12. Adaptability, extensibility, reconfigurability to handle payload variations (position and range in mass properties)
13. Reliability and repairability/serviceability of the in-vacuum sensors and actuators
14. Cost and schedule
The committee is not asked to review management, staffing, or contingency. The committee is also not asked to make a comparison with the baseline.

The committee's findings should be provided in a written report to AdL management on or about April 20th. AdL management will consider the committee's HAM-SAS evaluation and an implementation plan. In addition AdL management will consider the status of the Baseline (HAM-ISI + HAM-HEPI) by getting a report from the SEI leadership, especially any news on meeting requirements, ability to fabricate, costs, reliability, technical updates/issues from the BSC and HAM variants. David Shoemaker, AdL Project Leader, will then make a decision to either continue with the baseline approach or switch to the HAM-SAS approach, by about April 23th.