LIGO LABORATORY
CALTECH, MS 18-34
PASADENA, CA 91125

TEL: 626/395-2129
FAX: 626/304-9834

Date: July 8, 2002
Refer to: LIGO-T020077-00-D

Report of the Seismic Retrofit Review Panel

A panel met on April 12 to assess the plans and progress of the seismic retrofit effort. The review panel consisted of Rana Adhikari, Mark Coles, Jonathan Kern, Joe Kovalik, Nergis Mavavala, Fred Raab, Rai Weiss, Stan Whitcomb and Mike Zucker.

The following summarizes the main findings and recommendations that resulted from this review.

Requirements / EPI Overview:

Findings:

The majority of the committee felt that the requirements for LLO are on reasonably good footing; however, a significant number felt that the current statements don't make a clear enough distinction between the requirements for a noise level during "normal" times and the requirements for peak motion reduction during exceptional times. Both are likely to be important drivers, and linking them into a coherent requirement is important. The alternative formulation of the requirements alluded to in the requirements document may address this issue.

The need for active control in six degrees of freedom was asserted without any real analysis to back it up. The two main modes at issue are the BSC modes at 1.2 and 2.1 Hz. These are beamline/pitch modes which can be damped by only doing beamline reduction. An argument for needing six DOF to suppress higher order modes doesn't really hold since there's no gain out there in any of the EPI systems anyway. The increase in complexity, cost and commissioning effort moving from a one or two DOF system to a six DOF system is substantial, and should not be taken lightly.

There is a consensus on the committee that the requirements for a seismic isolation system at LHO are not adequately understood. Data similar to that obtained for LLO (histograms of noise levels, spectra identifying the troublesome frequency regions) are needed before any significant effort goes into planning seismic remediation at LHO.

Recommendations:

Clarify the isolation requirements for the system giving both the intrinsic noise level achievable and the actuation range and suppression factors.

A requirement for noise level near 0.3 Hz at LLO combined with a study of the duty cycle of storm-enhanced noise would make the requirements more complete.

Reconsider whether the requirements for a coarse actuation system have been adequately addressed and whether a different approach is needed.

Define the data needed from LHO to set requirements for an external seismic system, and assign the job of getting those data to a specific individual.

Hydraulic actuator:

Findings:

Of the possible systems discussed, HEPI seems most mature in terms of development, has the most available resources, and that alone gives it the highest chance of success. The group has made impressive progress with the enabling technology -- the pumps, the ability to achieve quiet fluid flow, dimensional stability. The issues now have turned to practical ones. We clearly should continue with it to the tests on LASTI.

The hydraulic system appears complex, more complex, for example, than the MEPI (or a notional piezoelectric) actuator system. The team's successes at developing a viable pump system (hydraulic equivalent of a regulated power supply) and restrictor/accumulator dampers (equivalent to resistors and capacitors) are gratifying, but we still have to build and maintain it all. A complete failure mode analysis is probably not possible, but some thought to possible failure modes might anticipate and mitigate problems.

The issue of hydraulic fluid leakage is a serious one. It is probably amenable to engineering, but the Lab has minimal in-house experience in this area. For this reason it is important that an installation of comparable scale having some extended track record of hydraulics coexisting with cleanroom conditions be identified so that we have an example of engineering practices from which to draw guidance or security.
This is especially a concern in the context of this particular program, where there is neither time nor a fault-tolerant test facility to get us through a "learning curve".

The dynamics modeling is not mature enough to form a reliable performance projection. These should be expanded to include multiple degree of freedom, multiple sensor/actuator servo models for both HEPI and MEPI. The Feedback+Feedforward+SensorCorrect scheme has non-trivial crossovers that must be carefully tuned, and more complete modeling is essential to validate the design.

Recommendations:

The committee is concerned that the current design, with a bandwidth limited by the bellows dilation, effectively rules out attenuation at the suspension bounce mode frequencies. Anticipating success with the primary stack modes (even as modest as the preliminary PEPI test results), it's likely that bounce modes will soon dominate the remaining RMS velocity. Looking at the substantial investment we'll make for installation, we should consider carefully whether any available actuator solution can also afford gain (even narrowband) at 14-16 Hz. SysID might be one approach to achieving higher bandwidth.

Figure out how to insure zero leakage in hydraulic system, if possible by finding and observing example plants or facilities with comparable cleanliness concerns. Seek outside consultations on low-leakage best engineering practices.

Electromagnetic actuator:

Findings:

The work on this actuator is in a more primitive state than the hydraulic one, but for many in the Lab, it is a more conventional approach to the external active isolation system. It seems to have many "TBD"s, "probably"s and "maybe"s. There are probably no showstoppers, but the effort is marginally staffed and that reduces its viability considerably.

As stated, prototype development was started only very recently on the MEPI approach. However, elements of the HEPI which have taken longest to develop (pump source, proportional valve, resonance damper, accumulators, flow resistors, etc.) don't need development in the magnetic approach. Therefore it's probably not appropriate to expect a comparably long and convoluted development cycle for the MEPI. Viable prototypes of the main hardware elements (actuator and power amp) already exist.

Recommendations:

Initial results on induction to the geophones are promising. The degree of field containment with respect to the interferometer test masses should be evaluated more carefully. In particular, the AC field due to audio-frequency current noise coming from the MEPI coil driver should be estimated to see if it presents insurmountable shielding or electronic design constraints. Estimate fringing magnetic field interaction between MEPI actuators and interferometer test masses.

Concentrate on dynamical modeling of MEPI. If the intent is to maintain the MEPI as a real technical option, we must devote additional resources to the modeling effort; otherwise the decision for HEPI will be made by default.

Active Internal Damping

Findings:

The AID was a "best effort" shot at doing something helpful in a difficult situation, but with extremely challenging requirements to meet. The noise requirements for a system with unity transfer to the suspension point are enormously stringent, and the “cost” associated with a significant incursion into the vacuum envelope, with stack rebalancing and realignment followed by waiting for the Flourel to outgas, is high. These negatives make the AID system viable only if the EPI approach encounters problems or fails to achieve its initially projected performance.

Recommendations:

Based on the progress implementing resonant damping in EPI as a means of reducing the effects of resonances, the difficulties in achieving sufficient gain without introducing added noise at high frequencies, and the disruptions that the required vent would cause, we recommend that no further effort be directed at the AID system.

Electronics

Findings:

The electronics design presented was for the test bed, not the final system, and therefore some incompleteness is acceptable. A separate review of the electronics should take place when it reaches a suitable level of completeness.

Recommendations:

Complete visibility into the operation of the EPI system via EPICS is essential.

Estimates of the number of channels should be undertaken at the earliest possible time and the results communicated to DAQ and LDAS to ensure that the additional channels can be accommodated.

Schedule, Plan

Findings:

The schedule through this summer looks aggressive, but possible. However, the final design, fabrication and installation phases (even eliminating the IAD) seem unrealistically optimistic. The danger is that attempting to meet an unrealistic schedule could drive us toward shortsighted design decisions and insufficient pre-integration testing.

The schedule slip to date supports the voiced opinions that both the HEPI and MEPI efforts are subcritically staffed. As a result the current strategy of HEPI development with MEPI as a fallback may be an illusion; results available by decision time may be predetermined more by staffing and resource constraints rather than technical merits. This naturally leads to the question of whether an earlier HEPI/MEPI decision might be desirable to enable a concentration of resources on a single approach. The committee did not reach a consensus on this question, with some feeling that we did not have adequate information for a decision and others feeling that we did not have adequate staff to pursue even one approach on the timescale that was put forward. Unfortunately, both groups are likely correct.

It may be possible buy time with the two dimensional PZT actuation (PEPI). Applying the PZT actuator/sensor system to all 4 cavity test mass chambers has a reasonable chance to increase the Livingston duty cycle enough to give sufficient time to adequately develop and test the final solution.

Another hard question is what level of testing and performance would satisfy us to initiate production/installation. The standard in this case should be rather high, since we will be taking down a nominally operating interferometer for the retrofit.

Recommendations:

Do the PEPI at LLO ASAP. The prospect of extending available locking hours for commissioning in the near term (even if this isn't totally assured) has high value; if it works, it substantially leverages available commissioning effort. Installation of the PEPI also has very little impact on ongoing commissioning. If a study of the noise at LHO (as recommended in the requirements section) shows that such a system would be useful there, then procure parts and apply there as well.

See if there is anything comparable and "low impact" that can be done for the HAMs. Investigate whether a "quick and dirt" PEPI-like solution might exist for narrowband suppression of the HAM stack modes. For example, PEM shakers mounted on the gull wings might cool a few dominant HAM stack modes.

Rebaseline the forward EPI schedule bottom-up, taking account of reliably available manpower, observed rates of progress to date, and future economies from elimination of options and resource consolidation. Reexamine feasible installation dates and opportunities in light of more robust development schedule. Consider earlier decision regarding MEPI (pre-LASTI integration) based on intensified modeling.

We will need significant care and tooling during the installation. For these reasons the LASTI installation experience will be critical and it would not be excessive to consider a special "training installation" at LASTI for the individuals who will work on the LLO installation. The training installation should use the actual re-tooled installation rigging.