LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

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LIGO Detector Subsystem Review Report

PRELIMINARY DESIGN REVIEW
Suspension System (SUS)

Title

Review Board: A. Abramovici, R. Bork, D. Coyne (Chair), G. Gonzalez, L. Jones, A. Lazzarini, M. Zucker

Authors(s)

This is an internal working note
of the LIGO Project

California Institute of Technology
LIGO Project - MS 51-33
Pasadena CA 91125
Phone (818) 395-2129
Fax (818) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project - MS 20B-145
Cambridge, MA 01239
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

REPORT ON THE DESIGN REQUIREMENTS REVIEW OF THE CDS CONTROL AND MONITORING

Review Board:

A. Abramovici
Detector Scientist

R. Bork
CDS Task Leader

D. Coyne, Chairman
Detector Chief Engineer

G. Gonzalez
Detector Scientist

L. Jones
Beam Tube Task Leader

A. Lazzarini
Integration and Systems Engineering Manager

M. Zucker
Interferometer Sensing and Control Task Leader

REPORT ON THE PRELIMINARY DESIGN REVIEW OF THE SUSPENSION SYSTEM

PARTICIPANTS

Presenters

S. Kawamura, J. Hazel and F. Raab

Review Board

A. Abramovici, R. Bork, D. Coyne (chair), G. Gonzalez (telephone), L. Jones, A. Lazzarini, M. Zucker (telephone)

Other attendees

W. Althouse, J. Camp, R. Fischer, P. Fritschel, D. Jungwirth(?), B. Kells, M. Krasich, J. Logan, G. Sanders, L. Sievers, D. Tanner (U. of Florida), S. Whitcomb, J. Worden, W. Young, R. Weiss

DOCUMENTS Delivered and Reviewed in Support of the PDR:

1) S. Kawamura, Correction of SUS DRD and PDD, LIGO-L960390-00-D, 5/28/96.
2) S. Kawamura and F. Raab, Suspension Design Requirements, LIGO-T950011-14-D, 5/23/96
3) S. Kawamura and F. Raab, Naming Convention and Interface Definition for SUS, LIGO-T960060-03-D, 5/23/96.
4) S. Kawamura, F. Raab and N. Solomonson, Suspension Test Plan, LIGO-T960086-02-D, 5/29/96.
5) S. Kawamura, J. Hazel and F. Raab, Suspension Preliminary Design, LIGO-T960074-05-D, 5/23/96.
6) S. Kawamura, Settlement of SUS (DRR) Action Items, LIGO-L960331-02-D, 5/14/96.
7) J. Hazel, Suspension Drawing Package: (a) Large Optics Suspension Assembly Drawings, (b) LOS Suspension Structure Assembly Drawings, (c) LOS Fixtures, (d) Small Optics Suspension Assembly Drawings, (e) SOS Fixtures, various LIGO-D numbers, 5/23/96.

Viewgraph Handouts

Suspension System Preliminary Design Review Presentation, G960136-00-D, 6/6/96.

REVIEW BOARD REPORT

The review was conducted on 6 June 1996, in the Caltech LIGO Science Conference Room. The presenters summarized the design requirements and preliminary design, illustrated by the viewgraph handouts. During the course of the presentation, the Board discussed the documents, the presentation, and developed Recommendations for Action (RFA). Immediately following the presentation the Review Board caucused in order to discuss significant RFAs. In the period following the presentation, the board deliberated on proposed action items and its findings. The

Review Board charge (as specified in document LIGO-L960392) and its response are as follows:

1. **Charge**: Determine if the requirements identified in the (PDR level) Design Requirements Document (DRD) are complete; advise whether proposed requirement values are appropriate; if needed recommend additional requirements to be specified, and recommend other appropriate actions. Some specific points to consider:
   a) are the performance requirements compatible & consistent with Detector system requirements and the requirements of other subsystems?
   b) are the performance and functional requirements sufficiently developed to proceed with final design (e.g. are fabrication/assembly, installation/commissioning, operations and maintenance considered)?
   c) is the delineation of the interfaces accurate?
   d) are the testing criteria for prototype testing, acceptance testing, self-test, and diagnostics for system/subsystem testing adequately defined at this point in the design?

   Response: The requirements in the DRD are substantially complete, appropriate and at a PDR level, except for questions to be resolved through the recommended action items below. In particular, the required actuation range and low noise performance appear to be unachievable. Revision of this requirement (by re-allocation of actuation range) may have impact on the design of the seismic isolation system.

2. **Charge**: Evaluate the preliminary design of the SUS to determine if:
   a) the design is consistent with the requirements
      - key performance & functional requirements are substantiated with supporting design calculations
      - all requirements are addressed
   b) the design is sufficiently developed to proceed with a Final Design
      - layout/assembly drawings are adequate
      - prototype drawings are complete
      - fabrication/assembly procedures, processes and fixtures are identified and defined (to preliminary level)
   c) final design plans/tasks and schedule are appropriate, and technical risks are identified and addressed in planning

   Response: The preliminary systems and mechanical design for the suspension system is complete and appropriate except for questions to be resolved through the recommended actions below. It is likely that the response to some of these suggested actions will result in design modifications, but the Review Board believes that the design is substantially correct.

   It would have been appropriate for the electronics design to have been reviewed simultaneously (i.e. the entire of the entire Suspension System), but the electronics design tasks have been scheduled to occur much later. The Review Board recommends that the suspension electronics design tasks be accelerated with the intent to review the final systems and mechanical design simultaneously with the preliminary electronics design. Despite this issue, the Review Board believes that it is appropriate for the Suspension System task to move into final design efforts including the fabrication and testing of prototype units.

3. **Charge**: Determine if actions from the Design Requirements Review (DRR) have been adequately addressed.

Response: The action items assigned from the DRR have been adequately addressed. A synopsis of the disposition of action items has been compiled. Some of the actions have been forwarded to a Detector Systems action item list (where they are more appropriate).

RECOMMENDED ACTION ITEMS

MANAGEMENT:

1. Concern: The mechanical and electronic design tasks for the suspension system are not as closely coupled as they ought to be, as evidenced by the fact that this review only addresses the mechanical design and not the suspension system in its entirety. This lack of close coordination is inherent in the schedule.
   Recommended Action: It is recommended that the Detector Management re-align these activities, in order to:

- perform a DRR and PDR of the on-going CDS electronics design activities in support of the suspension system as soon as possible,
- implement the suspension electronics design in prototype for testing as soon as possible, and
- define the FDR for the Suspension system to include all design activities (mechanical and electronics).

REQUIREMENTS/CONCEPTUAL DESIGN:

2. Concern: The proposed range requirement (80 microns_pp) appears to be impractical to implement in a single suspension actuator set with the low noise performance requirements.
   Recommended Action: The actuator dynamic range allocation between quasi-static seismic isolation system (displacement) actuation and suspension system actuation should be re-examined; We suggest that either PZT or hydraulic actuation on the seismic stack (external to the vacuum) can achieve the required actuation.

3. Concern: The dynamic range allocation
   Recommended Action:

4. Concern: The necessary reduction of the suspension actuator range (as a consequence of AI#2) implies that the suspension magnet size may also be reduced.
   Recommended Action: After determining the reduced range required by the suspension system actuators (as a result of AI#2), re-examine the magnet size; the magnetic moment of the magnets needs to be given a system approach to trade off between the following considerations:

   4.1 The required force dynamic range and coil heating.

   4.2 The noise from stray and fluctuating magnetic fields in the LIGO

   4.3 buildings and the rest of the detector.

   4.4 The damping of the internal modes of the mirror leading to the

   4.5 thermal noise.

However, these considerations should be made in parallel with continuation of the fabrication of the prototype as currently designed and presented at the PDR; valuable experience will result from the prototype development. If, as a consequence of the re-design activity recommended by this action, there is significant benefit to be achieved from a reduction in magnet size, then the schedule and cost impact this should be undertaken as re-work activity for the prototype.

5. Concern: Actuator unbalance (cross-coupling) requires clarification.

Recommended Action: Coordinate with the ASC group to establish the requirement.
?Is this in the DRD?

6. Concern: The initial alignment accuracy is not defined in the DRD (though discussed in the presentation as 0.1 mrad)
   Recommended Action: Verify initial alignment meets ASC requirements and include in the DRD.
7. Concern: LSC has not provided required SUS range during acquisition.
   Recommended Action: LSC to provide range requirement when simulation becomes available.
   ?Is this a worthy RFA?
8. Concern: A match of the proposed force envelope to expected actuation force (especially for f > 0.1 Hz) has not been documented. Effects which should be considered include stack resonances, pendulum vertical mode and transient seismic disturbances.
   Recommended Action: Show an analysis to verify the adequacy of the proposed suspension actuator force-frequency envelope.

INTERFACES:

9. Concern: The beam heights and wedge angles need to be established for the suspended components.
   Recommended Action: Detector Systems to establish beam locations and wedge angles based on an optical layout.
10. Concern: The operational modes need to be reconciled between LSC/ASC and SUS designs.
    Recommended Action: Reconcile the required modes.
11. Concern: The LSC/ASC/IOO signal inputs to the SUS controller are shown in actuator drive basis but should be in pitch, yaw and length basis.
    Recommended Action: Provide an output matrix function in the SUS controller in order to transform the pitch, yaw and length commands to SUS actuator drive signals.

PRELIMINARY DESIGN:

12. Concern: Crescent wire guide concept appears unlikely to provide kinematic constraint; The alternative design using clamps (as in the current prototypes) is not compatible.
    Recommended Action: Present a coherent design for wire guide/clamping and back up solution(s) with analysis and documentation.
13. Concern: Welding the crescent wire guide to the prototype limits the capability to explore modifications and alternatives to the wire boundary condition during prototype testing, e.g. different brazing techniques, change in curvature at wire "break-away" point, etc.
    Recommended Action: If crescent wire guide is pursued (see action item (X)), consider a temporarily bolted crescent design until reasonable Q performance is demonstrated.
14. Concern: The LOS sensor actuator brackets are unnecessarily large which contributes to increased eddy currents and reduced optical clear aperture.
    Recommended Action: Reduce the size of the brackets -- if possible make the top and bottom brackets as similar as possible.

15. Concern: Drainage for cleaning agents in LOS support structure legs.
    Recommended Action: Relocate holes in the LOS support structure legs to the corners at the ends.
16. Concern: Welded joints on the LOS are "welded all around" which can cause virtual leaks.
    Recommended Action: Provide a venting notch at each trapped weld joint (such as the crescent) and switch to skip welding each joint.
17. Concern: Welding deformation of LOS and adapter interfacing plates may cause "rocking". In addition, the large expanse of flat interfacing surfaces may trap air and cause virtual leaks.
    Recommended Action: Revise the interfacing surfaces to have a number of small flat pads, each machined after welding.
18. Concern: The Suspension Block (D960003) and the Tower Base (D960004) are attached to the Left (D960006) and Right Side Plates (D960005) of the Small Optics Suspension (SOS; D960001) with bolts that do not provide much stability for racking or rotation in the pitch direction.
    Recommended Action: Add through holes in the Tower Base and Suspension Block and mating threaded holes in the Left and Right Side Plates which are spaced between (and are orthogonal to) the bolts in the existing design.
19. Concern: Coil pigtail wires are not heat-sinked and may get quite hot.
    Recommended Action: Transition to a heavier gauge wire at the point where the coil leads depart from the coil.
20. Concern: Weld preparation does not call out UHV cleaning before welding.
    Recommended Action: Revise weld procedure to call out UHV cleaning prior to welding.
21. Concern: Cleaning procedure does not employ ultrasonic agitation.
    Recommended Action: Investigate the availability of ultrasonic cleaning bath equipment of sufficient size to fit the suspension structural elements. If practical, revise the cleaning procedure to incorporate ultrasonic agitation.
22. Concern: Teflon pads used in shipping/handling can possibly damage the fused silica glass by evolving fluorine which may act as an etchant.
    Recommended Action: Investigate the use of specially prepared teflon which has no dangling fluorine chemical bonds, or the use of an alternative material.
23. Concern: Frictional forces on the wire along the crescent may preclude adjustment.
    Recommended Action: Calculate the force required to adjust the mirror and the resulting stresses in the wire due to friction.
24. Concern: The groved cylindrical wire standoff may not afford the same boundary condition as previously observed in smaller diameter optics.
    Recommended Action: Examine the scaling of friction damping with wire diameter and standoff diameter in order to verify scaling from the PNI and 40m interferometer experience.

TESTING:

25. Concern: Outgassing measurements are not called out in the test plan and the sensor/actuator head stress test does not determine the thermal time constant (useful in determining the peak/rms allowed for locking transients).

Recommended Action: Measure the outgassing of the head(s) as the coil current is increased (for thermal equilibrium conditions at a number of current values which span the coil drive current range). In addition, determine the head time constant by using current pulses.

26. Concern: Pitch and yaw Qs are scaled from violin mode measurements, but preliminary results in the PNI indicate that they can be much worse.
    Recommended Action: Add the requirement (in section 1.4 of the "Suspension Test Plan", T960086-02-D) to perform measurements of angular Qs in the prototype suspensions.
27. Concern: In order to minimize the unbalance of coils in a suspension assembly, matched selection should be performed; Present plans for coil measurements and lack of sensor/actuator head marking do not permit matched selection.
    Recommended Action: The assembly requirements should call for matched selection of sensor/actuator head components. The actuator resistance and inductance should be measured to 1% (not 5% as indicated in the "Suspension Test Plan", T960086-02-D) and each head should be marked with a serial number.
28. Concern: The list of wire materials to be used in tests of intrinsic, material Q, should be expanded from elements to include alloys as well (or instead, depending upon time/funding limits).
    Recommended Action: Investigate the availability in wire form of alternative high strength alloys (with appropriate heat treatment) such as the following: Beryllium-Copper (BeCu), Phosphor Bronze (PhCuSn), Invar, and Titanium-Aluminum-Molybdenum-Vanadium (TiAlMoV).
29. Concern: The LOS are our most critical suspensions since they hold the test masses. The current plan does not include a test of the LOS in a displacement sensitive system in vacuum due to schedule constraints.
    Recommended Action: Reconsider whether there is really no time for such a test in the 40 meter schedule before the suspensions are fabricated for the initial LIGO detector. As an alternative, consider whether there is time before the suspensions are installed. Doing such a test may save time during the shake down of the initial detector by eliminating one variable of the many that will thought of when (if) we experience excess noise in the field.