LIGO Laboratory

California Institute of Technology
MC 18-34, 1200 E. California Blvd.
Pasadena CA 91125 USA
TEL: 617.395.2129
FAX: 617.304.9834
www.ligo.caltech.edu

LIGO Livingston Observatory
P.O. Box 940
Livingston LA 70754 USA
TEL: 225.686.3100
FAX: 225.686.7189
www.ligo-la.caltech.edu

LIGO Hanford Observatory
P.O. Box 159
Richland WA 99352 USA
TEL: 509.372.8106
FAX: 509.372.8137
www.ligo-wa.caltech.edu

Massachusetts Institute of Technology
MIT NW22 – 295, 185 Albany St.
Cambridge MA 02139 USA
TEL: 617.235.4824
FAX: 617.253.7014
www.ligo.mit.edu

Date:	3 April 2008
Refer to:	L080026-02
Subject:	Review Committee Report on the E/ITM Structural Weldments FDR & FRR documents
To:	David Shoemaker, Carol Wilkinson
From:	E/ITM Structure Weldment FDR & FRR review committee: Betsy Bland, Doug Cook, Dennis Coyne (chair), Peter Fritschel, Brian Lantz, Richard Mittleman, Norna Robertson, Janeen Romie, Brett Shapiro, Calum Torrie, Bill Tyler
cc:	SUS E/ITM Team: Justin Greenhalgh, Ian Wilmut, et. al.

Recommendation

We find that the Suspensions subsystem (SUS) has successfully completed final design of the structural weldment of the End Test Mass (ETM) and Input Test Mass (ITM) quadruple pendulum suspension. We also find that Rutherford Appleton Laboratories (RAL) is ready to proceed with production contract(s) for the E/ITM structural weldments. The review committee considered the review checklists given in the "Guidelines for Advanced LIGO Detector Construction Activities" document (M050220-07) in the process of coming to this recommendation.

Background

In June/July 2006, a Preliminary Design Review (PDR #3) was held to approve the E/ITM quad suspension, "noise prototype" design being taken forward to the pre-production stage. This was duly done and the "noise prototype" has now been fully assembled, tested in air coupled with the seismically isolated optics platform and will shortly be installed within a vacuum system for the first time at the LIGO LASTI facility. RAL is now ready to push this design forward into the final production stages. This report documents the Final Design Review (FDR) and Fabrication Readiness Review (FRR) for the Structural Weldment portion of the E/ITM quad suspension. It permits the RAL group to go forward and sign contract(s).

Scope

This review is intended to review the welded structures only. It is intended that the suspension within will be considered in only the most peripheral way, with any interfaces being the only significant items. Since the basic quad design has been reviewed in close to

its current form it is important to not repeat this work and only review changes. The specific areas addressed are:

i. Concerns outlined in PDR #3 and how we addressed them
ii. Changes to parts since the noise prototype and why
iii. Finite Element Analysis (FEA) and modal testing of the quad to explain why the modal structure should be acceptable

The documents under review are:

- E050317-03, Compliance matrix from PDR3
- E080095-00, Changes incorporated into structure design since PDR #3
- E080096-00, Critique of the Noise structure
- T070147-00, FEA Structural predictions, and test results at LASTI
- Tender 2081CT, Structure weldments RFQ specification
- E080097-A, DCN for production structures
- Drawings for E080097-A:
  - upper structures (D060492-A)
  - sleeve structures (D070552-D)
  - large parts of the implementation ring (D070538-A)
  - small parts of the implementation ring (D070539-A)
  - tablecloth interface pads (D0702471-A)
  - Removable cross members (D040499-A)

Supporting documents (not for review) include (i) a quad suspension key parameter set interpretation[1], (ii) an updated assembly and alignment procedure based on experience with the noise prototype, and (iii) and proposed drawings for the full suspension to be reviewed very soon:

- eDrawing of quad
- E050317-02, Old (PDR#3) quad overview document (out of date, but may be useful for those who are unfamiliar with quad)
- T060040-06, Updated assembly procedure based on N-Ptype work
- Quad alignment procedure based on N-Ptype work
- Additional reference drawings and DCNs
  - E060238-B-K DCN for production top stage
  - Drawings for E060238-B
  - E060239-B-K DCN for production tablecloth
  - Drawings for E060239-B
  - E060240-B-K DCN for production Pen Re and dummy masses
  - Drawings for E060240-B
  - E060247-B-K DCN for production UI mass
  - Drawings for E060247-B
  - E060248-B-K DCN for production top mass
  - Drawings for E060248-B

[1] The quadruple pendulum key parameter set document provided at the time of this review had a number of old and incorrect parameters and will be updated for the fabrication readiness review for the other mechanical elements of the E/ITM suspension. However the most critical parameters for this review, the pendulum stage lengths, were verified to be correct.

- o E060260-B-K DCN for production lower structure
- o Drawings for E060260-B
- o E060211-B-K DCN for production blades
- o Drawings for E060211-B

Findings

1) The proposed approach of relying more on machining, and less on welding (not using stock extrusions), plus the use of butt welds only, is sound, sensible and builds on the noise prototype experience.
2) The fit, finish and quality of the noise prototype weldments were adequate.
3) In addition to CMM based inspection, we suggest that RAL consider adding a limited fit check (not using helicoils, but pins) at the contractor's facility in order to minimize fit problems.
4) The RAL procurement approach calls for the contractor to deliver completed weldments to dimensioned drawings and standard weld quality specifications, with some process restrictions (e.g. limits of machining fluid properties for UHV cleanliness reasons); Processes[2] are not dictated to the contractor. This is a sensible approach.
5) The tubular sections in the welded structures can act as cable ways with the lightening/cleaning holes serving as entry & exit points. Firm attachment clamps/clips (if needed) can be devised to interface to these lightening/cleaning holes.
6) The RAL Request For Quotation (RFQ) cites a British welding standard (BS 10042:2005) which has been interpreted by the RAL group as broadly similar to US Mil-Std-2219, Class A. However, the British standard does not impose Non-Destructive Evaluation (NDE) of the welds (beyond qualification samples) except for visual inspection by the un-aided eye, whereas US Mil-Std-2219, Class A calls for 100% inspection by X-ray (dye penetrant and ultrasonic are not applicable due to contamination concerns for UHV parts). We find the proposal to qualify to a weld quality comparable to US Mil-Std-2219, Class A on the basis of sample welds (with identical geometry as the final welds) and to not require 100% NDE on the production articles acceptable (subject to LIGO Vacuum Review Board (VRB) confirmation).
7) The E/ITM noise prototype upper structure and sleeve weldments were cleaned, air baked and FTIR tested by Caltech. The sleeve weldment most closely represents the intended welding approach. The traveler, E070336-00, indicated an acceptably clean surface (by surface area sampling).
8) The note on the drawings should read "Remove all sharp edges, R .5 min" (mm) instead of "Remove all sharp edges, R .02 min"

Actions

1) B. Lantz & R. Mittleman: Provide a report on the BSC-ISI transfer function measurements taken at LASTI with the E/ITM noise prototype attached to the optics table. Include in the report a statement on the acceptability, and impact, of the influence of the E/ITM quad on the BSC-ISI. Base the assessment on design of a

[2] N.B.: The weld specification, T060113-00, is only for reference and is not an imposed specification. Moreover this document does not reflect the latest aluminum weld process information gleaned from recent LIGO prototypes.

controller for the measured transfer function. Add in a notch filter to accommodate the E/ITM resonance and design a stable controller. Calculate the change in isolation performance below the upper unity gain with this controller and the notch removed. (There is no need to consider the amplification associated the resonance, since this is harder to calculate properly and likely of less interest since it is well above the frequency range where seismic isolation should influence interferometer performance.)

2) D. Coyne: Write a specification on RGA qualification of the structural weldments (with reference to E960022-B) to be provided to the weldment contractor in the hope that they will take on the cleaning and RGA qualification for UHV service.
3) D. Coyne: Determine if the LIGO Lab is interested in sharing the cost of large vacuum chamber. This is relevant if the weldment contractor has interest and capability in providing UHV cleaned parts. The large vacuum bake oven would be a custom fabrication for this procurement.
4) D. Coyne: Seek confirmation by the LIGO VRB on the weld quality approach outlined in finding #6 above.
5) D. Coyne: No interface provision is yet defined for the Seismic Platform Interferometer (SPI). (pg. 20, ref. E050169-01, SPI). Define some locations for holes for attachment. (By the way, since the SPI is not an element of the AOS, it would not appear in ICD E050169, but rather in the SUS/UK-SYS or ISC ICD.)
6) RAL: There is some concern that warpage may occur as a result of the built-in stresses from welding after the low temperature (120C to 150C), short duration cleaning bake (48 hr. hold for each clean/bake cycle[3]). A post weld, pre-machining, stress relief heat cycle should mitigate any warpage. RAL should consider adding a requirement for a stress relief heat cycle[4] or allaying concerns that this is a plausible outcome.
7) RAL: LASTI experience is that the hole positions in the sleeve legs need tighter dimensional control and/or more clearance. RAL to reconsider the tolerancing and hole clearances.
8) RAL: While the analysis reported in T070147-00 helps to validate the FEA (or show where it overestimates the stiffness of the structure), it does not represent the boundary conditions of the in situ attachment to the ISI optics table, nor does it represent the final configuration of the completed structural assembly (with the lower structure). The FEA of the E/ITM quad structure should be revised to include the BSC-ISI stage 2 structure represented as a large rigid mass (with appropriate mass properties) attached rigidly to the base of the E/ITM structure, in the manner shown in sections 3 and 4.4 of T050014-00. If this model matches the measured dynamics results of the combined E/ITM noise prototype and BSC-ISI at LASTI[5], then this approach can be used to help design the FM & BS suspension structures.

The RFQ will serve as the basis for a contract. For that reason, we suggest the following points of clarification on “Tender 2081CT for LIGO Weldment Structures – Specification”:

[3] If a part does not initially pass cleanliness testing via RGA or FTIR testing, then it gets re-cleaned and re-baked. Typically this is only repeated once.
[4] A stress relief heat cycle should not be set at so high a temperature and time that any significant annealing occurs. Annealing may render some elements of the structure too weak and could lead to “gummy” or sticky tapped threads.
[5] See for example this 15-Feb-2008 LASTI elog entry (un: reader, pwd: readonly).

1) Section 3, weld process requirements, No. 4: only states that mineral oil is prohibited. The drawing note is complete -- states that all machining fluids shall be water soluble and free of sulfur, chlorine and silicone. The text in the table is misleading and should be expanded.
2) Section 3, filler material, No. 6: must we restrict the filler to the same material as the parent material?
3) Section 3, cleaning & contamination, No. 7: contradicts the notion of the vendor performing cleaning subsequent to welding as an option. Perhaps re-word to be clearer.
4) Section 3, weld process suggestions, 2nd bullet: extract? Perhaps exact?
5) Section 5.2, structure qualification, footnote 2: E960022-B calls for 48 hr. vacuum bake at 120C for aluminum (or an air bake in class 100, carbon filtered air).
[Also E960022-B only calls for 10 min. ultrasonic washes, but 30 min. given the size and the difficulty in cleaning welds seems a good idea. Better still would be cleaning by caustic or acid etch, as we did for HAM-SAS and for the OMC welded aluminum structure.]
6) Section 5.2, structure qualification, footnote 3: Better stated as “In short the test is looking for hydrocarbon contamination on the weldment.”
7) Section 5, Qualification: I think this section should explicitly call out the fact that all welds must be inspected per BS 15614-2:2005 (or MIL-STD-2219A, Class A) before RGA or FTIR qualification testing, i.e. pore size limit, pore density limit, full penetration, etc. must be checked for all welds. Passing the RGA test is not a means of getting a waiver from meeting the requirements of BS 15614-2:2005 (or MIL-STD-2219A, Class A).
8) Section 8, weld testing standards: This section appears to let the vendor produce all 14 production units without minimal weld process checks after qualification (just unaided eye visual examination). I think it would be prudent to ask for weld test samples by the welder performing the work every so often so that there is a check that they are not losing their edge or their control.
9) There should be a stipulation added that only certified welders (does one certify against standard BS 15614-2:2005?) be used for the work and that only the welders whose work has been specifically qualified for this job be permitted to perform the work.
10) Section 10: need to define “n”.
11) Section 11: Should probably define in a few words what suitable packaging entails, i.e. protection from damage, but also protection from exposure to hydrocarbon fumes and particulates.
12) Packaging: Even though the UK parts may not UHV clean when shipped, they are expected to be relatively clean and should be wrapped to prevent unnecessary contamination during transport. If the contractor does clean the parts for UHV service, then wrapping, packaging and tagging per E960022 is important. (See also E050317-03, Compliance matrix for Quad suspension noise prototype design, pg. 7, ref. E010613-01, 6.16.2 &3)