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LIGO Design Review Report

LIGO BEAM TUBE MODULES UPDATED DESIGN REVIEW

Title

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REPORT ON THE UPDATED DESIGN REVIEW OF THE LIGO BEAM TUBE MODULES

The LIGO Beam Tube Modules were designed by Chicago Bridge & Iron, Inc. (CBI), under contract to the LIGO Project. CBI also fabricated and tested a qualification test model of the beam tube. Both the design work and the qualification test results were reviewed by groups whose members included many of the present review board. A contract was subsequently awarded to CBI for the fabrication and installation of the beam tubes at the two LIGO sites in Livingston Parish, LA and Hanford, WA. The contract included requirements to update the design in certain areas (some due to recommendations from the qualification test review). These later efforts are the subject of the present review.

The Updated Design Review for the LIGO Beam Tube Modules was conducted on March 27, 1996, at CBI's facility in Plainfield, Illinois. This report documents the observations and recommendations made by the review board. The review board membership and charter are provided in LIGO-L960176 (Attachment I). The agenda for the review are provided in Attachment II.

The review consisted of presentations by CBI on their fabrication and installation plans and design modifications, with questions and answers intermixed with the presentations. During the review, board members were encouraged to record their observations, concerns and recommendations by completing a "Recommendation for Action" (RFA) form and submitting to the review board chairman. At the end of the presentations, the review board met in executive session and discussed each RFA. These consensus discussions serve as the basis for this report and are summarized below.

SUMMARY RESPONSE TO THE REVIEW BOARD CHARTER

We summarize the review board charter (Attachment I) and our responses below. Please see the following section for our report on detailed observations and specific recommendations.

- **Assess CBI's fabrication and installation plans, and advise whether CBI's responses to the Qualification Test Review board report are adequate to begin construction.**

The overall fabrication and installation plans are well thought out and reflect an appropriate balance of the technical and logistical tradeoffs needed to optimize the end-to-end process. We detected very few weaknesses, which we noted below and which are judged to be minor and easily corrected. With minor exceptions (also noted below), the recommendations of the Qualification Test Review board report have been satisfactorily addressed.

- **Make an independent judgement of the risks involved in CBI's fabrication and installation approach.**

CBI has put considerable effort into planning the fabrication and installation activities, and the resulting plans present no extraordinary technical risks. The recommendations made in this report are intended to enhance the quality of beam tubes and mitigate those (in our opinion, unnecessary but minor) technical risks which remain.

- **Identify any concerns or other factors which might affect the success of the LIGO Project.**

All concerns of this review board are noted in this report. As hinted at above, all of our concerns can fairly be labelled "minor." We found a positive, productive "can-do" attitude on the part of the participants in this review and would fully expect CBI's endeavors to be successful.

OBSERVATIONS AND RECOMMENDATIONS

Fabrication:

CBI plans on fabricating the beam tube sections in a facility which they are currently setting up about 15 miles from the LIGO Hanford site (a LA fabrication facility has not yet been identified, but a similar arrangement is planned). Cylindrical tubing will be formed from coil stock on a custom-built spiral tube mill. After stiffening rings, support rings, expansion joints and pump ports are welded on, the tube section ends will be expanded to a standard diameter and machined square for field welding. The completed tube sections will be leak checked to 10^{-10} atm-cc/sec (of helium), and repaired if necessary. The sections will then be stockpiled. They will be moved to a cleaning station and cleaned about two days before needed for installation, in order to minimize the exposure of cleaned tubes.

The follow observations lead to the recommendations which immediately follow. (There are separate discussions below of welding and cleaning processes.)

- When steel coils are delivered, the truck is backed into the facility for unloading near the spiral tube mill. The truck's exhaust is allowed to freely mix with air in the fabrication facility, and presents an unnecessary source of potential contamination.

- CBI relies on positive differential air pressure in the testing and cleaning rooms, provided by local HVAC systems, to prevent shop contaminants (such as welding fumes) from reaching these areas. However, no means of verifying the differential pressure is planned.

- The make-up air to create the differential pressure is picked up from outside the facility, but CBI could not verify that the air pick-ups are away from potential contamination sources, such as loading dock vehicle exhaust fumes.
- After tube sections leave the spiral tube mill, they are placed on pairs of wheeled "bogies" (one at each end) and rolled on a ground rail system to the area where stiffening rings are attached. CBI has not evaluated the stresses experienced by the tube section during this operation. We are concerned that, without the stiffening rings installed, the tube may be exposed to excessive stresses which might lead to buckling failure.
- CBI plans an adequate organization for the field fabrication operation. Although the organization charts for fabrication and installation didn't explicitly show a safety function, CBI explained their philosophy for ensuring safety and we are satisfied that this was just an omission on the charts.

Recommended actions:

1. CBI should provide positive removal of vehicle exhaust to the outside of the facility.
2. CBI should monitor and record the differential air pressures between the facility ambient environment and pressures in the test room and the cleaning room.
3. CBI should review the locations of intake air pickups for the testing and cleaning rooms and ensure that access to the areas near these pickups is adequately controlled to prevent accidental contamination of the air supply.
4. CBI should calculate the buckling loads on the tube sections experienced during transport from the spiral tube mill storage area to the stiffener welding area and compare with the theoretical buckling load capacity; take corrective action (such as distributing the support points along the section length) if the predicted loads are excessive.
5. CBI should add safety representation to the fabrication organization chart.

Welding:

The spiral welding process is different from that used for the qualification testing, where problems in achieving full penetration were experienced. The spiral welding equipment is new and appears to be well matched to the need. The revised spiral welding procedure has not been qualified for H_2 outgassing. The current plan calls for LIGO to test the H_2 outgassing of samples taken directly from the new spiral mill with the new welding equipment. CBI plans to characterize the variable parameters of this new equipment to find the optimum operating conditions and tolerance to variations in the parameters, but this has not yet been done. CBI recognizes that each time the spiral tube mill is stopped and restarted, the weld parameters may not exactly track the spiral mill motions and repairs may be required. We also note that even when the equipment is set up optimally, weld penetration may vary due to variations in the properties of individual coils of stainless steel (this variation applies to all weld processes, not just spiral welding).

The laser trackers used to control the new spiral welding equipment provide a video image for real-time monitoring. Recording these images may provide an inexpensive QA resource later to help establish a time-tagged record of welder performance, and possibly to locate and characterize local anomalies which are subsequently detected during leak testing.

CBI apparently has an established procedure for the weld process used to splice coil ends together, however this procedure has not been reviewed and approved by LIGO.

Finally, We note that a recommendation from the Qualification Test Review regarding a repair procedure for welds with copper inclusion has not yet been implemented.

Recommended actions:

6. Before LIGO approves the spiral welding procedure, CBI should establish the acceptable range of each controlled weld parameter for the spiral weld equipment.
7. CBI should consider amending the spiral weld procedure to specify that an integral number of tube sections are completed between planned stops and starts of the spiral tube mill, and removing and discarding the short stub containing any start-up flaws.
8. CBI should perform test(s) on a sample of each stainless steel coil that establishes that acceptable penetration will be achieved within the controlled range of each weld process (spiral, coil splice, girth, port installation, etc.).
9. CBI should document and submit to the LIGO project for review/approval the welding procedure for splices between coil ends.
10. CBI should consider video tape recording the laser tracker image for future QA reference. Time-of-day/date labelling, commonly provided automatically with most commercial VTRs, would be sufficient to provide later traceability, provided that date and time-of-day information for each tube section serial number was recorded in the fabrication QA log.
11. CBI should include a paragraph in all weld procedures to declare copper contamination of welds as unacceptable.

Cleaning:

Like the spiral weld process, the cleaning process is also different from that used for the qualification testing. The revised procedure replaces a room temperature bath in a diluted detergent (Mirachem) tank (used during qualification testing) with a high temperature/high pressure sprayed application of Mirachem mixed with steam, a method tested by CBI on oil-soiled coupons during preparations for the qualification test, and similar to the method used to apply an acid/steam mixture in the earlier "Beam Tube Demonstration" test performed by LIGO before CBI's involvement. CBI has modified the spray apparatus (used for steam rinsing during the qualification testing) to improve its reach over the expansion joint and to add two more nozzles to increase the flow rate. These are both positive improvements, but we doubt CBI's conclusion that doubling the flow rate will permit cutting the cleaning and rinse times in half. The permissible cleaning rate can be judged from the FTIR results obtained from the first few tube sections.

The follow observations lead to the recommendations which immediately follow.

- Prior experience with the spray apparatus failing to rotate might recur during the cleaning process.
- Cleaning will take place in a cleaning room within the fabrication facility which has its own air supply (see comments above under "Fabrication"). However, the careful design of this separate area may be compromised by contaminants brought into the area when tube sections are moved in and out through 10 ft. doors.
- The deionized water system will be leased, but specifications for the deionized water quality were not available for review.
- The effluent from the cleaning process collects on the lower side and end of the tube, and the possibility for residue contamination is greatest here. CBI's plans for removing the effluent are adequate, but nonetheless it may be useful to note the tube orientation for future reference.
- The cleaning operation is quantitatively verified by pouring a solvent through the cleaned tube section, collecting the solvent run-off at the lower end, and sending the sample to an independent laboratory for FTIR testing. During the qualification testing, some test results were suspected to be in error due to prior contamination of the sample collection bottles.
- After the first ten tube sections are cleaned and installed, FTIR samples are taken for each 10th tube section. The FTIR test results may not be available until after several tube sections have been installed. CBI has no specific obligations other than to collect the samples and send them for testing. The LIGO Project needs to develop a strategy for dealing with an FTIR result

which exceeds the established criteria.

- LIGO is to furnish completed and cleaned optical baffles to CBI for installation in the beam tube. During this review, we discovered that a protective "safety guard" which is furnished with the baffle and removed by CBI after installation is not yet subject to cleanliness controls, and represents a potential conduit for contamination to the inside of the beam tube.

Recommended actions:

12. CBI should add a feature to provide a positive indication of proper rotation of the steam spray apparatus.
13. CBI should add a provision to protect the cleaning area from unnecessary contamination introduced during ingress and egress through the doors, for example by segregating the entry/exit area with a heavy plastic curtain acting as a temporary partition. Remove gross or loose contamination from the tube sections before moving them to the cleaning station.
14. CBI should prepare a specification to control the quality of deionized water for LIGO review and approval. The specification should include limits on impurity content, not just a resistivity measurement.
15. CBI should identify and record the tube orientation during cleaning.
16. CBI should establish a procedure to verify that sample bottles are clean before use. Apply permanent ID markings to each sample bottle, and record this ID in the tube cleaning log when samples are taken for evaluation.
17. The LIGO Project should develop a contingency plan for use in the event that data from cleanliness samples show unacceptable contamination.
18. All baffle-related processes should be reviewed to ensure cleanliness, including cleanliness of auxiliary parts such as the baffle "safety guard" and cleanliness assurance during baffle installation.

Installation:

The installation process includes three-stage graded clean room entries to control the introduction of contaminants into the portable clean rooms. These graded entries look like they will be very effective. A CBI worker, garbed in clean room clothing, will enter the free end of the tube to place the interior purge dam used during girth seam welding and weld leak checking, and later to remove the purge dam, inspect the weld and install the optical baffles. There are no plans to equip this worker with any communication aids, and the worker, 65 feet deep into the beam tube module, might have difficulty maintaining synchronization with the operations on the outside. In addition, we are concerned that the working environment inside the tube may be quite uncomfortable (hot and cramped), making it difficult to control contamination from perspiration or through abrasion of the clothing. CBI indicates that they have considerable experience in this area, and prefer to work out the details in response to the specific conditions encountered in the field. Consequently we make no recommendations regarding this concern, other than suggesting that all parties remain vigilant during the operation.

CBI plans to use (hydrocarbon) lubricated bolts and nuts for installing pump port components. Silver-plated stainless steel bolt and nuts (or any other lubricant-free approach) should be used to avoid the possibility of hydrocarbon contamination inside the vacuum system.

CBI is building a new semi-cylindrical vacuum box for leak testing the girth seams. The new design appears to solve many of the problems experienced with the test box used during the qualification testing. The new test box should be tried out at the earliest opportunity to verify that these problems have indeed been solved. None of the review board members had any experience with the particular sealing putty (Nashua #102) planned for sealing the leak test box, and it may migrate on the surface and inadvertently plug a real leak.

Recommended actions:

19. CBI should provide adequate lighting and communications capability to persons working inside tube.
20. CBI should use a lubricant-free alternative to lubricated bolts for installing items at the pump port locations.
21. LIGO should perform a migration test of the "Nashua #102" sealing putty to ensure that it doesn't creep along the surface and contaminate potential leaks
22. CBI should add safety representation to the installation organization chart.

Design:

The details of the ground connection to the beam tube are lacking. A ground stake driven under the beam tube will not be serviceable after years of corrosion. Locating the stake outside the beam tube enclosure should be considered.

At LIGO's request, CBI has updated some details of design in the areas of module terminations and length, and pump port hardware. In addition, CBI has proposed additional detailed changes in the beam tube supports (both "guided" and fixed). We reviewed these modifications for functional compatibility with the stated objectives of the beam tubes (L. Jones, Beam Tube Technical Manager, certified the technical accuracy and fit compatibility). All of CBI's design modifications appear to meet the mark. However, some interface details between the vacuum equipment and beam tube, as currently planned, seem incomplete and may lead to problems. According to CBI, the beam tube termination anchors were not designed to facilitate easy adjustment while carrying a vacuum load on the end. The alignment details need to be revisited to ensure that problems which can be anticipated do not interfere with the field mating of the vacuum equipment and the beam tube, noting that either system may be installed first.

Recommended actions:

23. LIGO should define and document the procedure for adjusting the termination supports while the beam tube is under vacuum load.
24. LIGO should review the accumulation of tolerances at the beam tube/vacuum equipment interface in order to minimize alignment matching and fit-up problems. For example, a common set of local (inside the building) fiducials might be used for installing the vacuum equipment and the beam tube terminations.
25. The details of the beam tube grounding should be clarified, including grounding stake location and connection details.

Acceptance testing:

CBI's plan appears to up to the job of demonstrating performance in accordance with their contractual obligations, although the allocated schedule time of only a few days for acceptance testing seems optimistic. However, LIGO needs to develop an extended acceptance test plan which covers not only CBI's obligations (leak-free, adequate clear aperture, verification that all steel preparation and cleaning processes have been followed) but also establishes the initial pre-bake outgassing condition of the beam tube module. Several weeks may be required to carry out the full testing.

No recommended actions.

BATCH START

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SUMMARY RESPONSE TO THE REVIEW BOARD CHARTER

We summarize the review board charter (Attachment I) and our responses below. Please see the following sections for our report on detailed observations and specific recommendations.

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