LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Suspensions Acceptance Documentation: Test Mass Quadruple Suspension (ETM/ITM)

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Introduction

The DCC tree for suspensions (SUS) documentation starts at E1200482: aLIGO, SUS. From that top-level DCC page the related documents appropriate to this type of suspension are

E1200933: aLIGO SUS General Documentation

E1100290: aLIGO SUS QUAD Assembly and Installation Documentation

E1000495: aLIGO SUS QUAD Testing and Commissioning Documentation

E1201038: aLIGO SUS QUAD Acceptance Documentation

The SUS electronics documentation tree is found by following the path

E1200482: aLIGO, SUS

> E1200933: aLIGO SUS General Documentation

> E1100337: Suspension Electronics Drawing Tree

In sections 1 to 10 below we address the 10 items as sited in the Acceptance Review template E1300457-v3 with information appropriate to all quad suspensions. Individual suspensions will have their own acceptance documentation, to be found from the filecard for this document (i.e. from E1201038) going to related documents, and then following the link to E1201044 aLIGO SUS Quad Individual Acceptance Reports.

1 Requirements documentation

The design requirements document must be brought up to date, and pointers to background material, analyses, etc. added to the Requirements document. Pointers to prototyping endeavors including testing results if they are not superseded by subsequent testing should be included here.

a. Design Requirements Document (DRD)

T010007 Cavity Optics Suspension Subsystem Design Requirements

T060067 AdL Quad Suspension UK Coil Driver Design Requirements

b. Supporting documents (models, analyses, …)

2 Design overview and detailed design documentation

a) Final Design Document (FDD): must bring the FDD up to date.

T1000286 aLIGO Quadruple Suspension (QUAD) Final Design Document

T1000337 Quadruple Suspension Monolithic Stage Final Design

b) Review reports:

- cite the final design review committee's report

- cite the design team's response to the final design review (note that any resulting changes to the design should have been incorporated into the FDD).

T1200463: Summary of Suspension Final Design Reviews, of which items 1, 2, 3, 4, 5, 6, 7, 8, 15, 16, 17, 18 and 20 are quad related. References to the reports for each of these reviews are given in this summary document.

c) Supporting design documents: models, analyses, specifications, etc. If not applicable, then state so.

E1200933: aLIGO SUS General Documentation: this DCC filecard lists references to aLIGO SUS documentation that this generic to many or all suspensions.

E1300848 aLIGO SUS QUAD ESD Documentation. This DCC filecard brings together various documents (mechanical, technical, cabling) addressing aspects of the ESD design.

T1100595 ETM/ITM Quad Suspension Control Ranges

G1300537 aLIGO QUAD "Level 2" Damping Loop Design

T1100185: Summary of technical documentation for University of Birmingham deliverables

E1100337: Suspension Electronics Drawing Tree: this leads to electronics documentation.

Also for electronics, the following link is to a wiki in which information on requirements, sensor and actuator electronics chains and wiring diagrams for all suspensions are linked:

https://awiki.ligo-wa.caltech.edu/aLIGO/SuspensionElectronics

See also links at E1100604 aLIGO SUS Quad Design Documentation

Further info on modeling is found on the SVN, see section 8.

d) Drawings: cite the top level assembly drawing for each major assembly or subsystem. In the DCC, all subsidiary drawings (sub-assemblies and part drawings) must be linked in a drawing tree manner.

D0901346 Advanced LIGO Quadruple Suspension Assembly

D1000759 Advanced LIGO SUS ETM Production Monolithic Assembly

e) Bill(s) of Materials (BOM): cite any collected BOMs. If the BOMs are only to be found on the Assembly and Sub-Assembly drawing sheets, then state so.

These are found on the relevant drawings.

f) Interface control: cite any documents (such as RODAs) with interface definition/control and/or cite the relevant sections of the DRD and FDD.

Relevant RODAs:

M040005 Record of Decision/Agreement (RODA) - CP to be the Ultimate Mass in the ITM Reaction Chain

M040020 Record of Decision/Agreement (RODA) - Sapphire/fused silica downselect date

M040099 Record of Decision/Agreement (RODA) - Decision on ETM/ITM Quad Pendulum Structure Length

M040135 Record of Decision/Agreement (RODA) - Detailed Scope of Work on Advanced LIGO

by the UK AdL Team

M050397 Record of Decision/Agreement (RODA) - Core Optic sizes, including TMs, BS, FM and RM

M050418 Record of Decision/Agreement (RODA) - Separation of chains in quad suspensions

M060305 Record of Decision/Agreement (RODA) - Compensation Plate dimensions

This is out of date. Garilynn confirmed it is on her to-do list to address.

M060043 Record of Decision/Agreement (RODA) - Determine Need for OSEM Sensors for UIM and PUM in the ETM and ITM and Determine Need for OSEM Cable Electrical Shielding

M080109 No Fibre Pulling Machine for Adv LIGO at LLO

M080134 E/ITM and BS/FM pitch frequencies and d-values

M080363 Record of Decision/Agreement (RODA) - ETM/ITM suspensions will use tapered circular cross-section silica fibres

M0900034 Use of SmCo and NdFeB Magnets in Advanced LIGO Suspensions

M0900087 All in vacuum cabling will be shielded

M0900271 Division of Responsibilities for Harnesses for Adv. LIGO Suspensions

M0900293 Delivery of Electrostatic Drivers from UK

M1000312 Use of SS 316 in AOSEMs and BOSEMs

M1100053 RODA to reserve real estate for ACD on ETM / ITM optic and associated parent assemblies

M1100256 Suspension Earthquake Stops to be Set at 0.75 mm

M1200147 RODA: Removal of eddy current damping magnets in various suspensions.

Also see technical review board decision on use of thin CP:

T1000175 Thinner Compensation Plates for reduced Squeeze film damping

g) Software: cite any software design description documentation. If not applicable, or not available, then state so.

Software is documented on the SVN, see section 8.

h) Design source data:

- Confirm that all mechanical design CAD models are in the SolidWorks/PDMWorks vault, or explain what is not and why.

Mechanical CAD models are in PDM works.

- Confirm that all electronics design CAD models (schematics and PWB layouts) are backed up and available on LIGO Lab archives, or explain what is not and why.

Electronics CAD models are available on the DCC.

3 Materials and fabrication specification

Any special materials, or treatment of materials including preparation for in-vacuum use; this may be integrated into the Design documentation.

The process used for manufacturing maraging steel blades is given in E0900023. Producing acceptable blades is a complex multi-step process which has been developed from external input and internal experience with prototypes over several years.

Particular materials and processes for monolithic parts such as ears and fibres are called out on the relevant drawings.

4 Parts and in process spares inventoried

All elements of aLIGO must be recorded in the ICS or in the DCC using the S-number scheme. As-built modifications for parts or assemblies should be found here.

Assemblies are recorded in ICS. Individual spare mechanical parts which have gone through clean and bake are in general recorded in ICS. In some cases spare sub-assemblies have been put together but not yet recorded as such. Electronics are recorded using the S-number scheme. A separate document has been prepared which summarises storing of spare parts, see T1300908.

5 Assembly procedures

All assembly procedures must be in the DCC and annotated or updated for lessons learned. Storage, if used, should be described here along with procedures to maintain the equipment in good condition (e.g., purge frequency). Transportation procedures and cautions must be noted.

E1000006 Advanced LIGO Quad Suspension Metal-Build Assembly Procedure

T1000521 Monolithic Final Design Review Documentation and Drawing Overview

E1000366 QUAD Monolithic Fiber Pulling/Welding Procedure

6 Installation procedures

All installation procedures must be in the DCC and annotated or updated for lessons learned.

T1100406: Quad cartridge installation procedure check list

Chamber installation procedures are also used. These are specific to a chamber and thus will be referenced in the acceptance documentation for specific suspensions.

7 Test documents

Test rationale, plans, and data for each unit must be documented as described in M1000211. That tree structure should be pointed to by the overall tree structure laid out in this Acceptance prescription. The top-level objective is to make clear how the measurements performed, which often will not directly measure a required performance parameter, give confidence that the subsystem will fulfill the requirements.

7.1 Suspension testing

G1100693: Ideal Order/Contents of aLIGO QUAD Testing / Commissioning

This is the top level description of testing.

A useful link for key testing procedures is the Checkout/Testing page in the Operation Manual at

https://awiki.ligo-wa.caltech.edu/aLIGO/Suspensions/OpsManual/Testing

Testing related documentation is kept on the SVN repository at

https://redoubt.ligo-wa.caltech.edu/websvn/

The "SUS" svn, linked from the above site contains:-

(a) Suspensions models (Mathematica & Matlab, Damping Filter Design)

(b) Testing tools (DTT templates & Matlab Testing Scripts)

(c) Results from all testing Phases 1-3 (i.e. Transfer Functions (TFs), Power Spectra & B&K)

The measurement list for all quads is found by following the route as shown below

"sus" -> "trunk" -> QUAD -> "Common" -> "MatlabTools" -> plotallquad_tfs.m

This gives TFs. Other types of results are found in a similar way.

Key test results for each individual suspension are linked from the DCC filecard for the acceptance documentation for that suspension.

In addition to TFs, spectra and B&K results, which are found on the SVN, the following results which are called out under phase 1 testing in G1100693 can be found on the DCC (or as noted) as follows:

a) T1000068: aLIGO Quad blade and clamp pairing and characterization data

b) Vibration Absorber Test Reports E1101122, and the testing procedure, described in E1200009.

c) OSEM inventory with open light current data, E1200343 (continually being updated as builds proceed)

d) AOSEM Pre-Bake Test Data E1000417 (includes coil resistance and inductance)

e) AOSEM Electronic Noise Test Data E1101030

f) BOSEM test data, T0900496

BOSEM and AOSEM test data are also archived on the SVN at

WebSVN link:-

https://redoubt.ligo-wa.caltech.edu/websvn/listing.php?repname=sus&path=%2Ftrunk%2Felectronicstesting%2FAOSEM%2F&#a44646e7e36d81f2cf1e45386c48e2dda

and

https://redoubt.ligo-wa.caltech.edu/websvn/listing.php?repname=sus&path=%2Ftrunk%2Felectronicstesting%2FBOSEM%2F&#aac680895873bf8fd434d4adf1cffdf72

g) Confirmation of magnet strengths within +/-5%. This requirement was developed after the purchase of the magnets to be used in the quads. Hence checks were made on the purchased magnets. See “Information on Magnets for BSC Suspensions”, T1000618, and references therein

for details of these checks and the procedures followed to choose magnets for use in the suspensions.

h) Information on as-built alignment/positioning of suspensions is captured in alog entries.

7.2 Electronics testing

The results of the reports are posted in the DCC, under the serial number of the chassis, e.g.

<https://dcc.ligo.org/LIGO-S1000254-v6>

These can be found for LLO by following through the electronics tree, an example of which is given here:

E1100337 - Suspension Electronics Drawing Tree

> S1200522 - LLO Suspension Electronics Racks

A similar structure for LHO is TBC at time of writing.

8 User interface software

User interface software, and the test routines indicating proper functioning of the software, must be described in words and have code under configuration control (SVN). Watchdog and Guardian routines must also be treated in this way.

Each suspension has a user model that is constructed referencing wiring diagrams, built and installed, which runs on a front-end computer. MEDM screens are created to present an operator with model information and enable interaction with a running model. Filter coefficients, gains and other settings can be captured using BURT snapshots, which also provide a safe state to revert to following model restarts e.g. due to power loss etc, as well as retaining alignment offsets for the suspension. All of the aforementioned items; Simulink models, MEDM screens, BURT snapshots, and filter coefficients are maintained under svn revision control. For example, the "cds_user_apps" contains:-

(a) SUS Simulink front-end models, located at

- LHO *${userapps}/sus/h1/models/*
- LLO *${userapps}/sus/l1/models/*

Guide:- https://awiki.ligo-wa.caltech.edu/aLIGO/Suspensions/OpsManual/Simulink

(b) BURT snapshots of model configurations (SAFE, ALIGNED, MISALIGNED etc), located at

- LHO *${userapps}/sus/h1/burtfiles/*
- LLO *${userapps}/sus/l1/burtfiles/*

Guide:- https://awiki.ligo-wa.caltech.edu/aLIGO/Suspensions/OpsManual/BURT

(c) FOTON filter blocks deployed in front-end models, located at

- LHO *${userapps}/sus/h1/filterfiles/*
- LLO *${userapps}/sus/l1/filterfiles /*

Guide:- https://awiki.ligo-wa.caltech.edu/aLIGO/Suspensions/OpsManual/FOTON

(d) MEDM screens for interacting visually with front-end models, located at

- LHO *${userapps}/sus/h1/medm/*

- LLO *${userapps}/sus/l1/medm /*

Guide:- https://awiki.ligo-wa.caltech.edu/aLIGO/Suspensions/OpsManual/MEDM

(e) Scripts to automating processes, interact with suspensions and saving alignments etc, located at

- *${userapps}/sus/common/scripts/*

Guide:- https://awiki.ligo-wa.caltech.edu/aLIGO/Suspensions/OpsManual/PythonTools

Other useful links,

https://awiki.ligo-wa.caltech.edu/aLIGO/Suspensions/OpsManual/Computing (overall cds guide)

https://awiki.ligo-wa.caltech.edu/aLIGO/Suspensions/OpsManual/SVN (svn guide)

https://redoubt.ligo-wa.caltech.edu/websvn/listing.php?repname=cds_user_apps (websvn GUI)

https://redoubt.ligo-wa.caltech.edu/svn/cds_user_apps/ (websvn html interface)

Links to html interfaces for snapshots of currently running Simulink models at each site,

LHO https://lhocds.ligo-wa.caltech.edu/simlink/

LLO https://llocds.ligo-la.caltech.edu/daq/simlink/

9 Operation Manual

A manual appropriate for operators, written in accordance with M1200366, covering setup/initialization, check-out, operating instructions, calibration, maintenance, storage/transport and troubleshooting. It must be accessible from standard user screens.

E1200633: aLIGO SUS Operation Manual.

Note that this covers quads and triple suspensions due to the large element of commonality between suspensions.

There is also a “rogues gallery” to aid in troubleshooting transfer functions, called “TransferFunctionColoringBook”. It is located on the aLIGO wiki at

<https://awiki.ligo-wa.caltech.edu/aLIGO/TransferFunctionColoringBook>

10 Safety

Safety documentation must be in the DCC for all phases of the subsystem development, including any needed for normal use or foreseen maintenance/repair scenarios.

E1000030 QUAD Suspension Metal Assembly Hazard Analysis

M1000334 LHO_CO2 Silica Fiber Welding Machine Operating in the LVEAs and END Station, Standard Operating Procedure

E1100814 Cartridge Assembly Hazard Analysis

E1200925 BSC Cartridge Installation (Universal) Hazard Analysis, aLIGO

E1000489 Hazard Analysis for Silica Fiber Pulling and Welding In the LHO Fiber Lab and In the LHO and LLO LVEAs and VEAs

T080231 ERGO Arm Hazard Analysis