LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Universal Suspension Subsystem
Design Requirements Document

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1 Introduction

1.1 Purpose and Scope

The Requirements and Interface Specification common to all the Advanced LIGO Suspension systems are given.

The scope of this document is limited to the requirements of the suspension subsystem (SUS) that are general to all types of suspensions. These requirements generally relate less to performance issues relating to displacement noise and more to issues regarding installation, repair, documentation, safety, and the like.

1.2 Applicable Documents

- LSC White Paper baseline design description (T990080-01-D)
- LIGO II Suspension Reference Design, The GEO Suspension Team, Jan 31 2000, T000012-00-D)
- LIGO II Suspension Conceptual Design Document (in progress).
- Cavity Optics Suspension Subsystem Design Requirements Document (T010007-01-D).

2 Requirements

2.1 Physical Characteristics

All Advanced LIGO suspensions must fit within the LIGO vacuum chambers as presently built with the advanced SEI isolation systems. For the ITM, ETM, BSC, and FM suspensions this will be the BSC chambers. For the other suspensions this will be the HAM chambers.

2.2 Interfaces External to LIGO Detector Subsystems

The final assembly and installation procedures must be compatible with LIGO site constraints and sequencing.

2.3 Reliability

The Mean Time Between Failures (MTBF) for all in-vacuum components in all suspensions collectively shall be at least two years per interferometer. The MTBF for all extra-vacuum components collectively shall be at least six months. The SEI and SUS must together deliver dynamic range sufficient to allow continuous operation over month time scales in the absence of large seismic disturbances.

2.4 Maintainability

2.4.1 In-air components

The Mean Time To Repair (MTTR) in-air components shall be less than one day. Spares for all in-air components will be kept at the sites.

2.4.2 In-vacuum components

Any repairs requiring removal of the suspension from a BSC will be performed by removing the SEI and SUS together in the 'cartridge' procedure. This will make any such repairs very time-consuming and so the SUS design should minimize their necessity. The suspensions in HAM's are expected to be individually removable, unless surrounded by other suspensions and equipment. If the time to acquire a replacement component will prevent the following repair-time requirements from being achieved, then sufficient spares of that component shall be kept at the sites.

2.4.2.1 Suspension fibers and attachments

It will probably not be possible to perform repairs on the fused silica suspension fibers in-situ. Broken fibers and attachment 'ears' will require that the suspension be removed. The time to make such repairs should not exceed fifty days, not including chamber pump-down.

2.4.2.2 Sensors and actuators

Sensor and actuator parts other than those on the test or penultimate masses (or their reaction masses) shall be replaceable with the suspension system in-situ. The time to make such repairs shall not exceed one week, not including chamber pump-down.

2.5 Environmental Conditions

The suspension system will be assembled at the Observatories from easily transportable parts (by commercial handlers in provided shipping containers).

2.5.1 Natural Environment

2.5.1.1 Temperature and Humidity

The fused silica fibers will be prepared at the observatories and stored in a carefully controlled low-humidity low-dust atmosphere. The (partially or fully) assembled suspension will be caged and housed in a hermetic/overpressured volume with a controlled environment once the fused silica fibers are incorporated.

Table 1 Environmental Performance Characteristics

Operating	Non-operating (storage of non-fused silica parts)	In assembly (with fused silica parts)	Transport
+15 C to +25 C, LIGO-quality vacuum	10 C to +70 C, 0–90 % RH; standard LIGO-class-1 procedures	15-25 C, 0-5% RH; class 10 clean room; standard LIGO-class-1 procedures	40 C to +70 C, 0–90 % RH

2.5.1.2 Seismic Disturbance

Restraint against seismically induced large motion is required once the system is assembled. Clamps will be used to restrain the system, but handling systems resembling those used in initial LIGO will be required.

2.5.2 Induced Environment

2.5.2.1 Electromagnetic Radiation

Electrical equipment associated with the subsystem shall meet the EMI and EMC requirements of VDE 0871 Class A or equivalent. The subsystem shall also comply with the LIGO EMI Control Plan and Procedures (LIGO-E960036).

2.5.2.2 Acoustic

Equipment shall be designed to produce the lowest levels of acoustic noise as possible and practical. As a minimum, equipment shall not produce acoustic noise levels greater than specified in Derivation of CDS Rack Acoustic Noise Specifications, LIGO-T960083.

2.5.2.3 Mechanical Vibration

Mechanical vibration from the subsystem shall not increase the vibration amplitude of the facility floor within 1 m of any other vacuum chambers and equipment tables by more than 1 dB at any frequency between 0.1 Hz and 10 kHz. Limited narrowband exemptions may be permitted subject to LIGO review and approval.

2.6 Transportability

All items shall be transportable by commercial carrier without degradation in performance. As necessary, provisions shall be made for measuring and controlling environmental conditions (temperature and accelerations) during transport and handling. Special shipping containers, shipping and handling mechanical restraints, and shock isolation shall be utilized to prevent damage. All containers shall be movable by forklift. All items over 100 lbs. which must be moved into place within LIGO buildings shall have appropriate lifting eyes and mechanical strength to be lifted by cranes.

2.7 Design and Construction

2.7.1 Materials and Processes

These are requirements on the materials used in the design and the processes used in assembly.

2.7.1.1 Finishes

Surface-to-surface contact between dissimilar metals shall be controlled in accordance with the best available practices for corrosion prevention and control. External surfaces requiring protection shall be painted purple or otherwise protected in a manner to be approved. Metal components shall have quality finishes on all surfaces, suitable for vacuum finishes. All corners shall be rounded to TBD radius. All materials shall have non-shedding surfaces. Aluminum components used in the vacuum shall not have anodized surfaces.

2.7.1.2 Materials

A list of currently approved materials for use inside the LIGO vacuum envelope can be found in LIGO Vacuum Compatible Materials List (LIGO-E960022). All fabricated metal components exposed to vacuum shall be made from stainless steel, copper, or aluminum. Other metals are subject to LIGO approval. Polymers and elastomeric materials should not be exposed in the Advanced LIGO SUS system, with the exception of Kapton and PEEK for cabling. Prebaked viton (or fluorel) may be used subject to LIGO approval. All materials used inside the vacuum chamber must comply with LIGO Vacuum Compatibility, Cleaning Methods and Procedures (LIGO-E960022-00-D).

The only lubricating films permitted within the vacuum are dry platings of vacuum compatible materials such as silver and gold.

Any novel materials to be used in the suspensions, in particular heavy leaded glass for the penultimate masses, will require qualification before approval for use in the LIGO vacuum.

2.7.1.3 Processes

2.7.1.3.1 Cleaning

All materials used inside the vacuum chambers must be cleaned in accordance with Specification Guidance for Seismic Component Cleaning, Baking, and Shipping Preparation (LIGO-L970061-00-D). To facilitate final cleaning procedures, parts should be cleaned after any processes that result in visible contamination from dust, sand or hydrocarbon films.

Materials shall be joined in such a way as to facilitate cleaning and vacuum preparation procedures; i.e., internal volumes shall be provided with adequate openings to allow for wetting, agitation and draining of cleaning fluids and for subsequent drying.

2.7.1.3.2 Welding

Before welding, the surfaces should be cleaned (but baking is not necessary at this stage) according to the UHV cleaning procedure(s). All welding exposed to vacuum shall be done by the tungsten-arc-inert-gas (TIG) process. Welding techniques for components operated in vacuum shall deviate from the ASME Code in accordance with the best ultra high vacuum practice to eliminate any "virtual leaks" in welds; i. e. all vacuum welds shall be continuous wherever possible to eliminate trapped volumes. All weld procedures for components operated in vacuum (excluding fused silica parts) shall include steps to avoid contamination of the heat affected zone with air, hydrogen or water, by use of an inert purge gas that floods all sides of heated portions.

The welds should not be subsequently ground (in order to avoid embedding particles from the grinding wheel).

2.7.2 Component Naming

All components shall be identified using the LIGO Naming Convention (LIGO-E950111-A-E). This shall include identification (part or drawing number, revision number, serial number) physically stamped on all components, in all drawings and in all related documentation.

2.7.3 Interchangeability

Because the various suspensions differ substantially in optic size, material, number of pendulums, and type of reaction chains, most of their components are not expected to be interchangeable. Interchangeability is therefore not a design goal.

2.7.4 Safety

This item shall meet all applicable NSF and other Federal safety regulations, plus those applicable State, Local and LIGO safety requirements. A hazard/risk analysis shall be conducted in accordance with guidelines set forth in the LIGO Project System Safety Management Plan LIGO-M950046-F, section 3.3.2.

2.7.5 Human Engineering

The suspensions must be attached to the isolation platforms with a minimum of force and torque. The design will include fasteners that can accommodate this requirement and allow space for this to be accomplished.

The suspensions will in general consist of components that are both heavy and delicate and require precise positioning for assembly. The assembly fixtures listed in a following subsection shall account for this.

The suspensions when assembled will have delicate optics hanging separated by very small gaps. The assembly, installation, and repair procedures shall include measures to prevent errors that may damage these optics. They shall also minimize the likelihood that the fused silica suspension ribbons or fibers will be touched.

2.7.6 Assembly and Maintenance

Assembly fixtures and installation/replacement procedures shall be developed in conjunction with the SUS hardware design. These shall include (but not be limited to) fixtures and procedures for:

- assembly of the in vacuo components in a clean room (class 100) environment
- initial alignment of the SUS components
- installation/removal/replacement of the actuator components

- installation/removal/replacement of the SUS stage elements in general
- installation/removal/replacement of the fused silica suspension fibers

All assembly and alignment procedures must be written by the SUS working group and tested by 'third parties', with appropriate feedback to design and procedure.

The BSC suspensions shall be assembled outside the vacuum chambers and attached to the seismic isolation platform there, and the whole shall be installed into the chamber by the 'cartridge' installation procedure. The assembly/installation procedures for BSC SUS's must be consistent with those for the SEI. The HAM SUS's shall be installed into the chamber from the side and attached to the already installed SEI.

2.8 Documentation

2.8.1 Specifications

List any additional specifications to be provided during the course of design and development, such as Interface Control Documents (ICD) and any lower level specifications to be developed.

2.8.2 Design Documents

- LIGO SUS System Preliminary Design Documents (including supporting technical design and analysis documentation)
- LIGO SUS System Final Design Documents (including supporting technical design and analysis documentation)
- LIGO SUS Prototype/Test Plans
- LIGO SUS Installation and Commissioning Plans

2.8.3 Engineering Drawings and Associated Lists

A complete set of drawings suitable for fabrication must be provided along with Bill of Material (BOM) and drawing tree lists. The drawings must comply with LIGO standard formats and must be provided in electronic format. All documents shall use the LIGO drawing numbering system, be drawn using LIGO Drawing Preparation Standards, etc.

2.8.4 Procedures

Procedures shall be provided for, at minimum,

- Initial installation and setup of equipment
- Normal operation of equipment
- Normal and/or preventative maintenance
- Installation of new equipment
- Troubleshooting guide for any anticipated potential malfunctions

2.8.5 Manuals

Manuals shall be provided for, at minimum,

- Assembly
- Alignment of mechanical system
- Alignment of electronic and electromechanical systems
- Debugging/test

2.8.6 Documentation Numbering

All documents shall be numbered and identified in accordance with the LIGO documentation control numbering system.

2.9 Test Plans and Procedures

All test plans and procedures shall be developed in accordance with the LIGO Test Plan Guidelines.

2.10 Logistics

The design shall include a list of all recommended spare parts and special test equipment required.

3 Quality Assurance Provisions

This section includes all of the examinations and tests to be performed in order to ascertain the product, material or process to be developed or offered for acceptance conforms to the requirements.

3.1 Responsibility for Tests

Testing of suspensions components shall be the responsibility of the suspensions working group and of LASTI.

3.2 Reliability Testing

Reliability evaluation/development tests shall be conducted on items with limited reliability history that will have a significant impact upon the operational availability of the system. This includes in particular the fused silica ribbons or fibers and bonded attachments, which shall be individually strength-tested before installation in the suspensions

3.3 Configuration Management

Configuration control of specifications and designs shall be in accordance with the LIGO Detector Implementation Plan.

3.4 Quality Conformance Inspections

Design and performance requirements identified in this specification and referenced specifications shall be verified by inspection, analysis, demonstration, similarity, test or a combination thereof per the Verification Matrix (TBD). Verification method selection shall be specified by individual specifications, and documented by appropriate test and evaluation plans and procedures. Verification of compliance to the requirements of this and subsequent specifications may be accomplished by the following methods or combination of methods:

3.4.1 Inspections

Inspection shall be used to determine conformity with requirements that are neither functional nor qualitative; for example, identification marks.

3.4.2 Analysis

Analysis may be used for determination of qualitative and quantitative properties and performance of an item by study, calculation and modeling.

3.4.3 Demonstration

Demonstration may be used for determination of qualitative properties and performance of an item and is accomplished by observation. Verification of an item by this method would be accomplished by using the item for the designated design purpose and would require no special test for final proof of performance.

3.4.4 Similarity

Similarity analysis may be used in lieu of tests when a determination can be made that an item is similar or identical in design to another item that has been previously certified to equivalent or more stringent criteria. Qualification by similarity is subject to Detector management approval.

3.4.5 Test

Test may be used for the determination of quantitative properties and performance of an item by technical means, such as, the use of external resources, such as voltmeters, recorders, and any test equipment necessary for measuring performance. Test equipment used shall be calibrated to the manufacturer's specifications and shall have a calibration sticker showing the current calibration status.

4 Preparation for Delivery

Packaging and marking of equipment for delivery shall be in accordance with the Packaging and Marking procedures specified herein.

4.1 Preparation

Vacuum preparation procedures as outlined in LIGO Vacuum Compatibility, Cleaning Methods and Procedures (LIGO-E960022-00-D) shall be followed for all components intended for use in vacuum. After wrapping vacuum parts as specified in this document, an additional, protective outer wrapping and provisions for lifting shall be provided.

Electronic components shall be wrapped according to standard procedures for such parts.

4.2 Packaging

Procedures for packaging shall ensure deaning, drying, and preservation methods adequate to prevent deterioration, appropriate protective wrapping, adequate package cushioning, and proper containers. Proper protection shall be provided for shipping loads and environmental stress during transportation, hauling and storage. The shipping crates used for large items should use for guidance military specification MIL-C-104B, Crates, Wood; Lumber and Plywood Sheathed, Nailed and Bolted. Passive shock witness gauges should accompany the crates during all transits.

For all components which are intended for exposure in the vacuum system, the shipping preparation shall include double bagging with Ameristat 1.5TM plastic film (heat sealed seams as practical, with the exception of the inner bag, or tied off, or taped with care taken to insure that the tape does not touch the cleaned part). The bag shall be purged with dry nitrogen before sealing.

4.3 Marking

Appropriate identification of the product, both on packages and shipping containers; all markings necessary for delivery and for storage, if applicable; all markings required by regulations, statutes, and common carriers; and all markings necessary for safety and safe delivery shall be provided.

Identification of the material shall be maintained through all manufacturing processes. Each component shall be uniquely identified. The identification shall enable the complete history of each component to be maintained (in association with Documentation “travelers”). A record for each component shall indicate all weld repairs and fabrication abnormalities.

For components and parts which are exposed to the vacuum environment, marking the finished materials with marking fluids, die stamps and/or electro-etching is not permitted. A vibratory tool with a minimum tip radius of 0.005" is acceptable for marking on surfaces which are not hidden from view. Engraving and stamping are also permitted.

Appendix A Quality Conformance Inspections

TBD

Table 2 Quality Conformance Inspections

Paragraph	Title	I	A	D	S	T
3.2.1	Performance Characteristics					X
3.2.1.1	Controls Performance		X			
3.2.1.2	Timing Performance‘		X			X
