TITLE

BEAM TUBE MODULE INSULATION

APPROVALS:		DATE	REV	DCN NO	BY	CHK	DCC	DATE
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DCC RELEASE:								

1. Purpose

This document defines the requirements for the LIGO beam tube module insulation materials and installation. Each beam tube module is to be covered with a continuous insulation blanket in accordance with this specification. The objective of the insulation is to reduce daily temperature variations of the beam tube, reduce sound (acoustic) transmission to the beam tube, and reduce heat loss during a high-temperature bakeout.

2. Applicable Documents

Beam Tube Module configuration drawings (from Chicago Bridge & Iron, Inc. (CBI), the beam tube fabrication and installation contractor):

Content	CBI Drawing No., Sheet No.
Overall layout and module configuration	Drwg. 1, sh. 1-4
Tube section (sub-assembly) configuration	Drwg. 4, sh. 1-7
Stiffener ring details	Drwgs. 15, 16
Guided support configuration, details	Drwg. 19, sh. 1-2
Fixed support configuration, details	Drwg. 6 Drwg. 7, sh. 1 Drwg. 8, sh. 1
Pump port configuration Pump port with valve, port hardware	Drwg. 13, sh. 1 Drwg. 102, sh. 2

3. Description

The LIGO beam tube modules are stainless steel vacuum vessels, approximately 49 inches (1.2 m) in diameter by approximately 6,500 feet (2 km) long. There are four such modules at each LIGO site. Each vessel consists of 50 sections of stainless steel tube with $^1/_8$ inch (3 mm) wall thickness, each 130 feet (40 m) long, separated by stainless steel expansion joints (bellows) designed to accommodate the thermal expansion of the 40 m sections during a bakeout at 300 °F (150 °C). The tube sections are supported by structures designed to accommodate the thermal expansion and to minimize heat loss through the mechanical connections. The tube sections and expansion joints are welded together to form a continuous vacuum-tight tube. The ends of the 2 km long modules are terminated by large gate valves. There are seven 10 inch (25 cm) diameter pumping ports distributed at 800 feet (250 m) intervals along the module. The beam tube is enclosed in a concrete protective cover with access doors at each pump port location. There are also smaller emergency access doors midway between the pump ports. An access road parallels the beam tube enclosure.

The beam tube module thermal insulation has been designed to reduce heat loss during the bakeout and to provide long-term thermal and acoustic insulation for the beam tube during LIGO operation. During bakeout, the beam tube is heated by passing DC current through the beam tube walls, using the electrical resistance of the wall material as the heating element. The installed insulation thickness must be highly uniform to avoid undesirable variations in the beam tube bakeout temperature.

Prevention of leaks or potential leaks into the vacuum vessel is of paramount importance. The stainless steel wall is subject to long-term stress-induced corrosion due to chemical attack. The chemicals in many glues and adhesives may promote corrosion (and could temporarily mask a small leak) and their use must therefore be carefully controlled. In addition, use of power tools which might puncture or weaken the beam tube wall (such as drills, saws, or welding equipment of any size) in the vicinity of the beam tube is prohibited.

The expansion joints compress during beam tube bakeout by nearly 4 inches (10 cm). In addition, they can expand as much as 1 inch (2.5 cm) due to ambient temperature variations (expansion amount depends on ambient temperature at the time of insulation installation). The insulation installation must provide for this motion.

There may be thermocouples and other bakeout monitoring instruments and associated wiring installed on the beam tube at the time insulation is installed. The thermocouples and wiring present minor variations in the otherwise smooth beam tube surface which are of no concern to the insulation installer. The instrument and wiring attachments are secure and may be safely ignored.

The beam tube has been manufactured on precision equipment and is highly uniform. More than 90% of the beam tube module wall area consists of tubing $48^7/_8 \pm ^1/_8$ inches (1241 ±3 mm) in outside diameter (OD) with $^3/_{16}$ inch (5 mm) thick by $1^{13}/_{16}$ inch (4.6 cm) high stiffener rings installed at $29^1/_2 \pm ^1/_2$ inches (756 ±7 mm) intervals (see CBI Drwg. 1, sheets 1-4, Drwg. 4, sheets 1-7 and Drwgs. 15 and 16 for details). This precision manufacturing with tight tolerances means that pre-cut insulation material may be efficiently used. The insulation contractor is encouraged to adopt material preparation and installation procedures to take full advantage of this highly regular geometry.

Fifteen (15 of 400) tube sections at the Hanford, WA site have extra stiffener rings installed midway between pairs of regularly spaced stiffener rings described above. The locations of these extra stiffeners are clearly marked on the beam tube enclosure floor.

3.1 Site Conditions

Laydown areas: A laydown area, near the Hanford, WA site entrance and approximately 5 acres in size, is available to the insulation contractor. Additional smaller areas nearer the beam tube entrances may be made available upon request to the LIGO Construction Manager on site.

Power: There is no electrical power available along the beam tube enclosure. The insulation contractor is responsible for providing temporary electrical power as needed to perform the insulation installation work.

Lighting: There is no lighting inside the beam tube enclosure. The insulation contractor is responsible for providing temporary lighting as needed to perform the insulation installation work.

Confined space: LIGO considers the beam tube enclosure to be a confined space. No special permit is required to work in this space. The contractor is responsible for furnishing adequate ventilation in the work area.

Coordination of activities: The contractor is required to coordinate his activities with other contractors on site and with LIGO staff. The contractor shall not block the access roads at any time.

4. Requirements

The insulation consists of two layers of thermal insulation materials. The first (inner) layer is a fiber glass blanket material rated for 650 °F (343 °C). It complies with the requirements of ASTM-C-795 for controlling stress corrosion of stainless steel. The second (outer) layer is a fiber glass material with an FSK moisture-barrier facing, rated for 250 °F (120 °C). The beam tube bellows (expansion joints) get much hotter than the beam tube wall during bakeout, and so are insulated with a thinner layer of 1000 °F (537 °C)-rated fiber glass blanket material with an FSK moisture barrier added at installation time. Special fitting of extra thickness of the inner layer material is needed at the fixed support locations.

4.1 Materials

Inner layer: Knauf KN-75 or equivalent*, 0.75 lb/cu. ft. (12 kg/m^3) density, 3 inch (7.5 cm) thickness.

Outer layer: Knauf Duct Wrap or equivalent*, with Foil-Scrim-Kraft (FSK) vapor barrier jacket, 0.75 lb/cu. ft. (12 kg/m^3) density, 3 inch (7.5 cm) thickness. The FSK jacket shall include a 2 inch (5 cm) flange

Bellows area insulation: Knauf Elevated Temperature Blanket or equivalent*, 1 inch (2.5 cm) thickness.

Bellows area facing material: FSK or other material suitable for maintaining the vapor barrier over the bellows area insulation during expansion and compression of the bellows, and rated for service at 250 F (120 C).

Attachment bands: Aluminum, 0.75 inch (2 cm) or greater width, or equivalent*.

Aluminum foil tape, pressure sensitive: Shall be rated for service at 150 °F (65 °C) or higher.

**Proposed equivalents must be preapproved by the LIGO Project. Appendix A lists important characteristics of the insulation materials.*

4.2 Installation

4.2.1 General requirements

- All materials shall be installed in accordance with best commercial workmanship standards by skilled workmen regularly engaged in this type of work.
- All materials shall be installed in accordance with manufacturers' recommendations, applicable building codes and industry standards.
- Only the inner layer insulation material shall be placed in contact with the beam tube wall and stiffener rings. No welded, adhesive or spray glue attachments to the beam tube are permitted.

4.2.1.1 Inner layer:

- The inner layer shall be fitted firmly against the beam tube wall. The inner layer is permitted to have gaps at the butt joints or between adjacent wraps where the smallest dimension of the gap is not greater than $^3/_8$ inch (1 cm).
- The inner layer shall be secured in place with bands installed on 15 inch (30 cm) centers, at the $^1/_4$ and $^3/_4$ points between stiffener ring pairs.
- After installation, the insulation material loft shall not be reduced in thickness (including local compression under the attachment bands) by more than 0.25 inch (6 mm).
- Material shall not sag at the bottom by more than 1 inch (2.5 cm).
- Installation of the inner layer shall be inspected and accepted by a LIGO representative prior to installing the outer layer.

4.2.1.2 Outer layer:

- Edges of adjacent wraps and ends of each wrap shall be firmly butted together.
- Avoid placing butt joints over the joints or gaps of the inner layer.
- Secure in place with bands installed on 12 inch (30 cm) centers.
- After installation, the insulation material shall not be reduced in thickness by more than 0.25 inch (6 mm).
- Material shall not sag at the bottom by more than 1 inch (2.5 cm).

4.2.1.3 FSK vapor barrier

- The FSK jacket flanges shall overlap the adjacent outer layer material and shall be secured with outward clinched staples and sealed with pressure sensitive foil tape.
- The FSK jacket shall not contact the beam tube wall or stiffener rings to ensure that electrical isolation of the beam tube is maintained.
- The FSK vapor barrier shall form a continuous unbroken moisture and vapor seal over the entire length of the beam tube module; the vapor seal at the ends and at the pump ports shall be finished by LIGO.
- Foil tape may be used to patch small punctures or tears (up to 12 inch, 30 cm) in the FSK layer.

4.2.2 Location-specific requirements

4.2.2.1 Tube wall between stiffener rings

This region, making up more than 90% of the beam tube length, is illustrated in Figure 1 (see CBI Drwg. 4, sheets 1-7 and Drwgs. 15 and 16 for to-scale details).

- Each wrap of the inner layer shall consist of one piece, with the butt joint located on the roadway side of the beam tube approximately 45±25 degrees below the horizontal.

- Each wrap of the outer layer shall consist of one piece, with the butt joint located on the roadway side of the beam tube approximately 45±25 degrees below the horizontal, but at least 4 inches (10 cm) from the butt joint of the inner wrap.

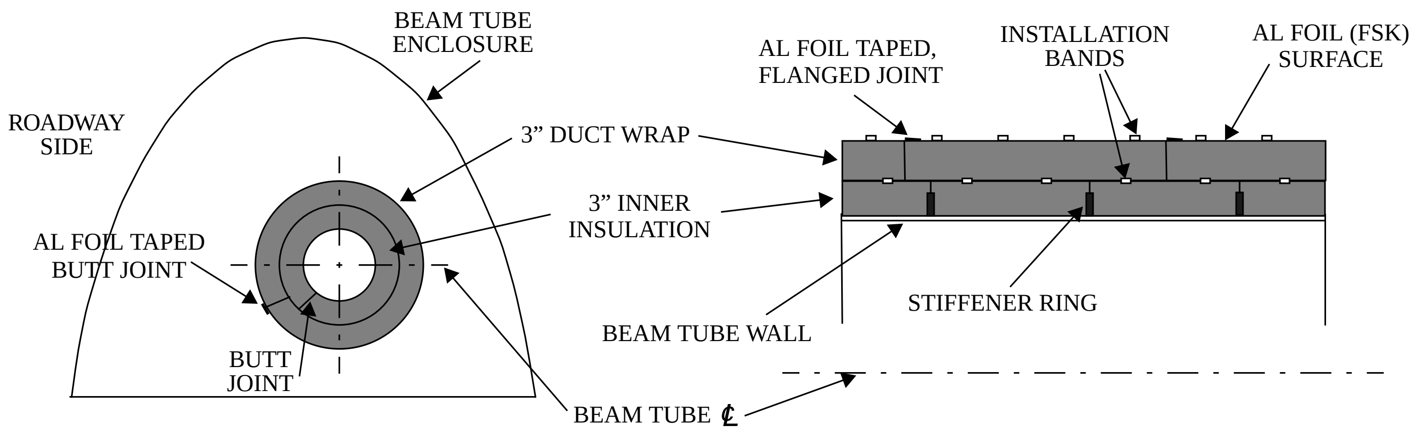

Figure 1: Beam tube wall insulation - schematic (not to scale) section views

4.2.2.2 Guided supports

Guided supports use four cable attachments to special 4 inch (10 cm) high stiffener rings on the beam tube (see CBI Drwg 19, sheets 1 and 2). Guided supports are used on each side of a bellows (expansion joint) unit, with pairs located at approximately 130 foot (40 m) intervals. There are 50 guided support pairs on each 2 km long beam tube module. Stiffener ring spacing in this area differs from the regular spacing on the main part of the beam tube.

- The inner layer shall be installed as at the tube wall between stiffener rings, but slit at the guided support attachment points (see Figure 2) and stuffed around the attachment (see CBI Drwg. 19).
- The outer layer shall be installed as at the tube wall between stiffener rings, but slit and installed around the guided support cables.

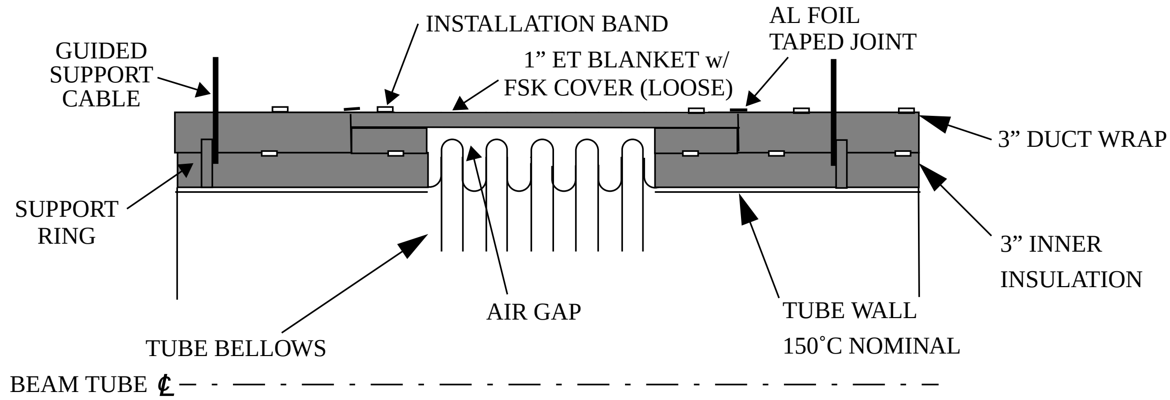

Figure 2: Schematic illustration of insulation installation at guided supports and bellows

4.2.2.3 Bellows (expansion joints) area

The bellows-area insulation forms an expansion joint for the insulation and FSK vapor barrier, to accommodate the expansion (1 inch, 2.5 cm) and compression (4 inches, 10 cm) of the bellows.

- The inner layer shall stop 2±1 inches (5 cm) from the outermost convolution of the bellows (see Figure 2), on each side of the bellows.
- The outer layer shall stop 8±4 inches (20 cm) from the outermost convolution, each side.
- A belt of 2 inch (5 cm) thick inner layer material shall be installed on each side of the bellows above the inner layer, butted against the outer layer material, to provide support for the bellows-area insulation.
- The region over the convolutions shall be covered by a single wrap of bellows-area material, installed loosely to accommodate the expansion and compression of the bellows.
- The bellows-area material shall be butted firmly to the adjacent outer layer material.
- The bellows-area material shall be completely covered with FSK vapor barrier material, installed loosely to accommodate the expansion and compression of the bellows, overlapping the adjacent outer layer FSK vapor barrier on both sides of the bellows, and sealed with pressure sensitive foil tape.
- The bellows-area material and FSK vapor barrier shall be secured at each end with bands.
- Bands over the convolution region are not permitted.

4.2.2.4 Fixed supports

The beam tube is attached to the fixed supports at special 4 inch (10 cm) high stiffener rings, with attachment flange pairs spaced apart by Micarta insulating mounts (see CBI Drwgs 6, 7 and 8).

- An additional 30 inch (0.75 m) wide wrap of the inner insulation material shall be installed on each side of the fixed support stiffener rings (see Figure 3).

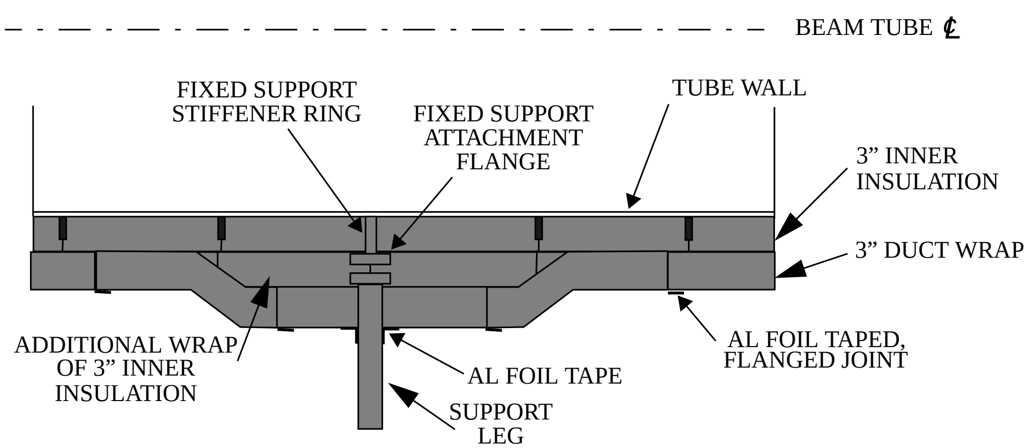

Figure 3: Schematic illustration of insulation at fixed supports

- The regions between attachment flanges at the Micarta insulators (3 places at each fixed support) shall be stuffed with inner insulation material.

- Additional inner insulation material shall be added as needed to fully embed the support attachments.
- The innermost wrap of material shall have its butt joint located at the bottom of the tube because of a gusset located there.
- Additional inner layer material may be installed as needed to simplify installation of the outer layer.
- The outer layer shall be fitted around penetrations at the support legs and brackets and secured so that air gaps between the inner and outer layers have a smallest dimension not greater than 1 inch (2.5 cm).
- The FSK layer shall be sealed to the fixed support penetrations with pressure sensitive foil tape.

4.2.2.5 Pump ports

- At seven pump ports located at the access doors along the beam tube module, the inner and outer layers shall be installed as at the tube wall between stiffener rings, but cut away to allow for the port penetration (see Figure 4; CBI Drwgs. 13 and 102 contains to-scale details).

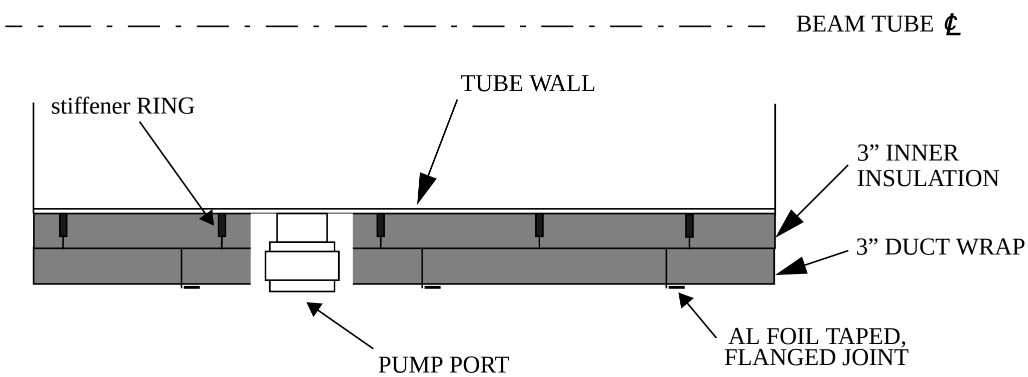

Figure 4: Schematic illustration of insulation at pump ports

- An air gap up to 3 inches (7.5 cm) around the port is acceptable.
- LIGO will be responsible for completing the FSK vapor barrier seal at the pump ports.

4.2.2.6 Module ends

- At each end of the beam tube module, the beam tube exits the concrete beam tube enclosure and penetrates the adjacent building wall.
- The insulation shall stop outside the building at the stiffener ring nearest the building wall. LIGO will be responsible for completing the vapor barrier seal at the ends of the module.

4.3 Clean up

The contractor shall remove all debris and scraps of insulation material from the beam tube enclosure, laydown and roadway areas.

5. Quality assurance

- The contractor shall furnish suppliers' certifications of compliance to specifications for all purchased materials installed on the beam tube.
- Installation of the inner layer shall be subject to inspection by a LIGO representative before the outer layer is applied.

APPENDIX A

SALIENT CHARACTERISTICS OF INSULATION MATERIAL

Characteristic	Material Selection Criteria		
	Inner layer	Outer layer	Bellows area
Temperature rating	>400 °F (200 °C)	>235 °F (112 °C)	>750 °F (400 °C)
Thermal conductivity	<0.7 BTU in/hr ft^2 °F @ 300 °F (0.1 W/m-K @ 150 °C) <0.33 BTU in/hr ft^2 °F @ 125 °F (0.05 W/m-K @ 50 °C)		
Sound absorption	Total for two layers, 6 inches: >70% @ 125 Hz >95% @ 250 Hz >99.5% @ 500 Hz >99.9% @ 1000 Hz		N/A
Density, compressive strength			N/A
Available thickness and width	Obtain 6 inches with two layers		
Water vapor transmission (ASTM-E-96)		<0.02 perm	
Puncture resistance (ASTM-D-781)		>25 Beach units	
Stress corrosion compatibility (ASTM C 795)	Complies	Complies	Complies
Moisture absorption (ASTM-C-1104)	<5% after 96 hrs at 120 °F, 95% RH		
Mold growth resistance (ASTM-C-665)	Does not promote or sustain growth		