



TITLE DIMENSIONAL CONTROL PROCEDURE		IDENTIFICATION DC			
		REFERENCE NO. 930212		SHT 1 OF 9	
PRODUCT LIGO BEAM TUBE MODULES CALIFORNIA INSTITUTE OF TECHNOLOGY		OFFICE PCR		REVISION 1	
		MADE BY WLR	CHKD BY SWP	MADE BY WLR	CHKD BY SWP
		DATE 4/22/94	DATE 4/22/94	DATE 5/10/95	DATE 5/10/95

1.0 SCOPE

- 1.1 This procedure describes the dimensional measurements that are required to be performed and recorded to meet the requirements of American Petroleum Institute (API) "Bulletin on Stability Design of Cylindrical Shells" (BUL 2U), the requirements of fabrication and construction, and the requirements of Caltech Specification No. 1100004.

2.0 DIMENSIONAL CONTROL EQUIPMENT

- 2.1 Calibration of specific types of equipment used for final acceptance of Code items shall meet the requirements of the LIGO QAM. A list of equipment with reference to a Calibration Certificate (CC) with traceability to the National Institute of Science and Technology (NIST), the applicable internal calibration procedure(s) or policy statement, as applicable shall be maintained by the Project Manager.

3.0 DEFINITIONS

- 3.1 Clear Aperture -- The diameter of the cross section of a right circular cylinder between beam tube termination's, whose volume is unobstructed.
- 3.2 Reference Monument -- A mark in a fixed monument system.
- 3.3 Axis for the Clear Aperture -- The axis for the clear aperture is defined by X & Y coordinates furnished by Caltech for each reference monument location.
- 3.4 Beam Tube Module -- A beam tube that is approximately 2 kilometers (km) in length and terminated with a weld joint end preparation at the following locations.
1. The ends may be at a corner station and a mid station.
 2. The ends may be at a corner station and a mid point joint.
 3. The ends may be at a mid point joint and an end station.
 4. The ends may be at a mid station and an end station.
- 3.5 Beam Tube Section -- Approximately 20 m length of fabricated beam tube with expansion joint, pumping port, and related equipment as applicable that are field assembled without intruding into the clear aperture.



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- 3.6 Beam Tube Section Dimensional Test -- A test demonstrating acceptable geometry before each beam tube section gets installed. The contractor shall provide documentation that records actual measurements and provides calculations that demonstrate acceptable geometry and traceability to each beam tube section (See Caltech Specification No. 1100004, Section 4.3.3.).
- 3.7 Alignment Acceptance Test -- A task the contractor performs to verify and document that the tube alignment complies with the clear aperture requirement (See Caltech Specification No. 1100004, Section 4.4.).
- 3.8 Cut Line -- The layout marking that shows the centerline of the circumferential weld joint. The marking is removed during the machining operation that faces the weld edge preparation.
- 3.9 Cardinal reference point -- (Clocking reference point) -- 0°, 90°, 180°, & 360° centerline punch mark at beam tube ends used during fabrication and installation for alignment control points.
- 3.10 Random Measurements -- A set of measurements taken for information only. The number and location are at the discretion of the inspector.
- 4.0 MEASUREMENT METHODS
- 4.1 Accuracy -- The methods used to obtain and record the dimensions should be at least two times more accurate than the specified tolerance.
- 4.2 Temperature Correction -- The temperature of the environment surrounding the beam tube component shall be recorded and if necessary used to correct "as-measured" dimensions. The temperature of the steel shall be recorded and if necessary used with its Coefficient of Thermal Expansion to correct "as-measured" dimensions. Standard 68° Fahrenheit shall be used, when dimensions are corrected for temperature.
- 4.3 Method to establish 0°, 90°, 180°, & 360° cardinal reference points using a pipe center head, a wrap around template, a 1/8" graduated steel tape, and a 1/64" graduated scale.
1. Set the beam tube section on set of horizontal rollers.
 2. Rotate the beam tube such that 0° is at top.
 3. Check final position with a pipe center head with level and mark each end.
 4. Measure the beam tube finished length using a steel tape and a graduated scale.
 5. Measure diameter of the beam tube ends using a pie tape.



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6. Calculate the arc distance to the 90°, 180°, & 270° cardinal points.
7. Install a wrap around template at one end.
8. Strap a steel tape clockwise around the end and mark the cardinal points using the calculated arc distances and a graduated scale.
9. Strap a steel tape counterclockwise around the end and mark the cardinal points using the calculated arc distances a graduated scale.
10. Split the difference between the two marks and mark the final cardinal point at each location.
11. Repeat steps 7 through 10 at the opposite end.
12. Clamp an extension support at the 90° & 270° cardinal points and check with a straight level.
13. Check the beam tube cardinal reference marks such that the 90° & 270° cardinal points are level at each end and the pipe center level is acceptable at the 0° centerlines.
14. Punch mark the final cardinal reference points using an offset (4") from the finished cut lines.

5.0 COMPONENT INSPECTION

- 5.1 Components -- The following list describes the beam tube component and a brief outline of the dimensional control or measurement method used.
- A. Beam Tube Coils -- Supplier documentation review for width and thickness per material specification.
 - B. Welded Expansion Joints -- Inspection by supplier, documentation review, assembly fabrication, and final installation per procurement specification with measurement record (see Attachment 1 for typical Measurement Record & Check List Form DC.1) for design outside diameter, length, thickness, deviation from the true circular form, cylindrical straightness, and end parallelism.
 - C. Spiral Welded Beam Tubes -- Inspection by supplier, documentation review, receiving inspection with measurement record for design outside diameter, thickness, and nominal length.
 - D. Welded Beam Tube Assemblies -- Assembly fabrication and final installation with measurement record for design outside diameter, length, thickness, deviation from the true circular form, cylindrical straightness and end parallelism.
 - E. Beam Tube Support Rings -- Inspection by supplier, documentation review, receiving inspection with random checks for general dimensions shown on vendor shop drawings.
 - F. Pump Ports -- Inspection by supplier, documentation review, receiving inspection with measurement record for design cylinder radius and random checks for general dimensions shown on vendor shop drawings.



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- G. Support Welded Attachment Members -- Inspection by supplier, documentation review, receiving inspection with random checks for general dimensions shown on vendor shop drawings.
Beam Tube Stiffener Rings -- Inspection by supplier, documentation review, receiving inspection with random checks for general dimensions shown on vendor shop drawings.
- H. Beam Tube Supports including related items -- Inspection by supplier, documentation review, receiving inspection with random checks for general dimensions shown on vendor shop drawings, including horizontal & vertical adjustment, and final installation. Documentation for conformance verification uses records that describe reference points located on beam tube support rings (see alignment performance test procedure).

5.2 Inspection by Supplier -- The CBI Material Specification and Product Procurement Specification specify the dimensional measurements, inspections, and records provided by the vendor. Components with HRAP finish is acceptable without measurement. Other surfaces inside beam tube shall be measured for RMS (No smoother than 2.5 microns rms roughness).

5.3 Receiving Inspection

5.3.1 Beam Tube Coil receiving inspection performed by vendors.

5.3.2 Welded Expansion Joints shall have measurements taken and recorded during fabrication. The Purchaser will review the documentation during receiving inspection.

5.3.3 Welded Beam Tubes as delivered from the vendor, have insufficient stability for completing final acceptance measurements. Receiving inspection may be completed during fabrication. The beam tube shall be supported and temporary round out fixtures shall be installed at each end. The measurements taken at receiving inspection verify procurement requirements and provide data for fabrication and installation. The circumference at each support location is used to establish beam tube support ring selection. The following measurements shall be recorded on a measurement record.

- A. Measure and record circumference using a precision diameter tape accurate to ± 0.001 " to obtain Outside Diameter (D_o) within $\frac{1}{2}$ " to 2" from each end and at support locations.
 1. End Outside Diameter (D_o)
 2. Support Outside Diameter (D_o)
- B. Establish 0° , 90° , 180° , & 360° centerline clocking reference points at each end using a wrap around template, a $1/8$ " graduated steel tape, and a $1/64$ " graduated scale. The clocking reference marks are alignment control points used during fabrication and installation.



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- C. Measure and record ordered length using a 1/8" graduated steel tape. Measure and record temperature of the beam tube, steel tape and air. Stretch the tape to remove sag at the outside top centerline of the beam tube and take measurements. Establish reference points with (4") offset inside the cut line at weld joint center line and repeat for each clocking reference point (90°) at each end for monitoring fabrication and installation.
 - 1. Tolerance: Ordered Length -- $\pm \frac{1}{2}$ "
- D. Measure local deviation (e max, see Section 7.1.2) from the true circle using an outside segmental circular template and no-go gauge at random locations. Check gap using a no-go gauge from template to surface of beam tube. This measurement controls fabrication for clear aperture.
 - 1. No-go gauge size = 0.122"
- E. Measure and record straightness using a standoff block (5") with music wire and a 1/64" graduated scale. Attach standoff block with music wire at reference points established for clocking along length. Measure the distance from music wire to side of beam tube. Take measurements at center line and 1/4 point locations.
 - 1. Tolerance -- $\pm 1/4$ "
- F. Measure and record squareness and flatness of ends using a wrap around template and a 1/64" graduated scale. Measure the distance from the edge of a wrap around template to end of beam tube. Take measurements at clocking reference points (and at middle points for flatness).
 - 1. Tolerance: Cut Line, Reference Points & Machined End -- ± 0.005 "
 - 2. Tolerance: Rough Cut End -- $\pm 1/4$ "
- G. Measure and record pumping port centerline locations along length of beam tube assembly using a 1/8" graduated steel tape. Stretch the tape to remove sag along the outside top centerline of the beam tube assembly. Establish a reference point at the top centerline of the beam tube assembly relative to the pumping port centerline. Take measurements along the top reference points.
 - 1. Tolerance -- $\pm 1/2$ "

- 5.3.4 Beam Tube Stiffener Rings have random measurements verified during receiving inspection. The measurements taken at receiving inspection are used for verification of procurement requirements. Review documentation provided by the supplier.
- 5.3.5 Support Welded Attachment Members have random measurements verified during receiving inspection with random checks for general dimensions shown on vendor shop drawings.
- 5.3.6 Beam Tube Supports including related items have random measurements verified during receiving inspection with random checks for general dimensions shown on vendor shop drawings.



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5.4 Assemblies Fabrication

5.4.1 Welded Beam Tube Assemblies shall be supported and temporary round out fixtures shall be installed at each end. The following measurements shall be recorded on a measurement record.

- A. Use circumference measurements made during receiving inspection.
- B. Use length measurements made during receiving inspection and adjust for welding shrinkage (-0.010" per stiffener).
- C. Use measurements made during receiving inspection for local deviation from the true circle.
- D. Use measurements made during receiving inspection for cylindrical straightness.
- E. Measure and record squareness and flatness of ends using a 1/64" graduated scale, the machining head and tail stock or a flat fixture and a feeler/thickness guage.
- F. Use measurements made during receiving inspection for pumping port locations.
- G. Measure and record expansion joint nominal length using two tramel points on a bar and a 1/64" graduated scale. Take measurements along the top reference points using the two tramel points on a bar. Use the graduated scale to make the final measurement between the two tramel points.
 - 1. Tolerance -- $\pm \frac{1}{4}$ "

5.4.2 Beam Tube Support Rings have measurements verified during assembly fabrication. Continue documentation within the applicable measurement record. The measurements taken shall be recorded.

5.4.3 Beam Tube Stiffener Rings have measurements verified during assembly fabrication.

5.5 Construction Installation

5.5.1 Welded Beam Tube Assemblies shall be installed in accordance with the contract drawings. The alignment procedure is used to measure and record final installation dimensions. The following measurements shall be recorded.



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6.0 CALTECH SPECIFICATION DIMENSIONAL TOLERANCES

- 6.1 Clear Aperture -- Each beam tube module shall have a minimum clear aperture of **1.07 m** (See Caltech Specification No. 1100004, Figure 4.).
- 6.2 Beam Tube Height -- The beam tube axis nominal height is approximately 1.1 m above the slab plane. The X & Y coordinates furnished by Caltech for each reference monument location at 250 m intervals (See Caltech Specification No. 1100004, Section 3.1.5.c & Figure 4.).
- 6.3 Pumping Port Spacing -- Starting at 250 m from any corner station, mid station, mid point joint, and end station a 250 m ports spacing is required for each beam tube module (See Caltech Specification No. 1100004, Figure 2.).
- 6.4 Beam Tube Section Support Alignment Adjustment Range -- An adjustment range of ± 7.5 centimeters (cm) in both the vertical and horizontal is required (See Caltech Specification No. 1100004, Section 3.1.5.c.).

7.0 AMERICAN PERTROLEUM INSTITUTE (API) "Bulletin on Stability Design of Cylindrical Shells" (BUL 2U) DIMENSIONAL TOLERANCES

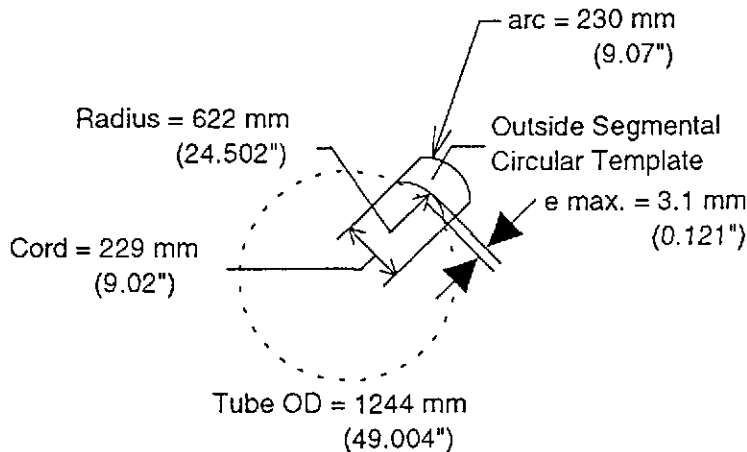
7.1 BUL 2U -- 10. TOLERANCES

- 7.1.1 Maximum Differences in Cross-Sectional Diameters -- The difference should not exceed 1% of the nominal diameter at any cross section, $D_{max} - D_{min} = 12.44 \text{ mm} (0.490")$.
- 7.1.2 Local Deviation From True Circle -- Maximum permissible deviation = 0.121" Additionally the difference between the actual radius to the shell at any point and the theoretical radius should not exceed 0.123" (0.005R).

1. Outside segmental circular template dimensions, radius = 24.502", arc length = 9.07", & cord length = 9.02"



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8.0 RECORDS

- 8.1 Measurement Record & Check List shall be initiated and completed by the Welding & QC Supervisor or a designated inspector. The forms shall show necessary calculations, theoretical dimensions, verifications, and blanks to record actual dimensions measured. The number of measurements to be taken shall be indicated on the form. The equipment identification including serial number shall be recorded on the form as necessary.
- 8.2 Taking and recording measurements is a continuous activity throughout fabrication and installation. Identify actual dimensions measured relative to the assembly fabrication and construction completion sequence. Complete verifications of location of beam tube components and establish reference marks at specified points before components become inaccessible. Minimize multiple generation reference points or temporary reference marks to avoid degradation of measurements.
- 8.3 Submit the completed measurement record & check list to the Project Manager for inclusion into the final record package.

9.0 ATTACHMENTS

- 9.1 Attachment 1 -- (Typical) Measurement Record & Check List Form DC.1



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ATTACHMENT 1



MEASUREMENT RECORD & CHECK LIST

Seq. No.	Description Operation, Inspection, or Examination to be completed	Applicable Procedure or Instruction	Int. Req'd "X"	CPI		REMARKS:
				Operation Insp. or Exam Accepted		
				Initial	Date	
1						
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3						
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Date	Date	Rev.			
		Chk'd Date			