P&I	IDENTIFICATION ALI-1 LIGO-E950073-05-B			
TITLE INITIAL & FINAL ALIGNMENT DURING INSTALLATION OF LIGO BEAM TUBE MODULES USING GPS SYSTEM PRODUCT LIGO BEAM TUBE MODULES CALIFORNIA INSTITUTE OF TECHNOLOGY	REFERENCE NO. 930212		SHT 1 OF 12	
	OFFICE RSE		REVISION 5	
	MADE BY SDH	CHKD BY SWP	MADE BY SDH	CHKD BY SWP
	DATE 12/28/93	DATE 12/29/93	DATE 11/10/95/	DATE 11/10/95

1.0 SCOPE:

This procedure defines the method of establishing the LIGO Beam Tube alignment during construction activities and final alignment. This procedure uses Global Positioning System(GPS) techniques with jigs and fixtures unique to LIGO requirements. Detailed are procedures for Beam Tube Layout, Initial Alignment and Final Inspection of Beam Tube Support positions.

2.0 REFERENCES:

The alignment maintenance procedures for the Beam Tube Module are based on the following references:

1) Summary of concepts and Reference Design for a Laser Gravitational-Wave Observatory, CAL TECH; Feb-92.
2) LIGO Project Safety Manual.
3) Manufacturer's Procedures for Global Positioning System(GPS) Equipment and Computer Software.
4) Customer Site Plans and Drawings provided.

3.0 EQUIPMENT:

The following is a listing of alignment equipment selected for use in establishing and maintaining the LIGO beam tube clear aperture.

1) Global Positioning System Package consisting of the following:

   a. Base Station Receiver.
   b. Radio link system, Tribracs, Stands, Etc.
   c. Antenna Accessories and fixtures.
   d. Personal Computer workstation formatted for DOS and MS Windows®. The computer must have a math co-processor as a minimum with RAM and storage capability required based on the manufacturer's recommendations.
   e. Data Collector
   f. Real Time and Static Software.
   g. Satellite Positioning Almanac and Forecasting Software with modem.
   h. Target Reference Rod and antenna positioner

APPROVED
LIGO 11/10/95
M. Zellaui 11/10/95

2) Equipment Required for Positioning and Adjustments:

   i. Beam Tube Reference Point Layout and Antenna Support Fixture (**ALI-1, Figure 5.2a**)
   j. Tools including flashlights, shop lights, wrenches, impact drivers, equipment carts and personel transportation.
   k. Jacking equipment consisting of Pumps, Cylinders, Valves, Manifold and High Pressure Hose (see Figure 5.3a).

4.0 DOCUMENTATION:

The receiving, recording, calculation and use of data is controlled by data logging forms that will be documented in both hard copy and on 3.5" diskettes formatted to DOS.

1) Forms shall be standardized and used to record all data including dimensional and atmospheric measurements, and will include instrument information including calibration dates, instrument serial numbers and field calibration anomalies.
2) Data used to process coordinate points, atmospheric conditions, and instrument information shall be in-put to a spread sheet computer program having capabilities to sort for ranges and specific text references.
3) Standardized Documents are indexed below:
   a. Daily GPS Field Report(Figure 4.3a)
   b. Data Record(Figure 4.3b)
   c. GPS Inventory/Calibration Log(Figure 4.3c)
4) All project documentation shall include the name of the responsible technician and the date the inspection/calculations were completed.
5) A plotting format shall be used to provide a graphic representation of layout and alignment conditions when advantageous in determining relationships in visual observations. Graphing formats will be developed on a point by point situation.

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	OFFICE RSE		REVISION 5
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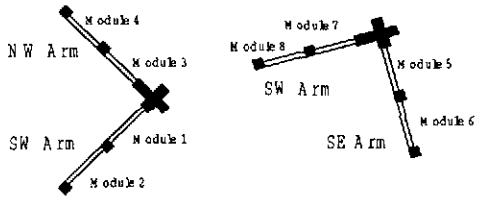
DAILY GPS FIELD REPORT

LIGO

Customer: CALTECH
Customer Contract Number: _____
CBI Contract Number: _____
CBI File Reference: _____



HANFORD SITE LIVINGSTON SITE

1. WORK SCOPE

Originator of Report: _____ Date: _____

ACTIVITY: Layout ☐ Pre-Alignment ☐ Alignment ☐

LOCATION (Circle One) HANFORD LIVINGSTON
Module Identification: _____
Breif Description of Work: _____

2. GPS MISSION PRE-PLANNING

Required PDOP (Precise Dilution of Precision): _____
Threshold Elevation Available (Degrees from Horizon) _____
Satellite Quantity and Available PDOP Review (Attach Chart): _____
Record Time When PDOP is Below Acceptble Limits: _____ AM /PM
_____ AM /PM
_____ AM /PM

3. GPS EQUIPMENT LISTING

BASE STATION SET-UP
Reveiver- _____
Antenna- _____
Antenna Support _____
Radio Repeater- _____
Misc Equipment (describe): _____

ROVER SET-UP
Reveiver- _____
Antenna- _____
Antenna Support _____
Radio Repeater- _____
Misc Equipment (describe): _____

4. WEATHER CONDITIONS

Maximum Temperature: _____F Minimum Temperature: _____F Maximum Wind Speed (mph) _____
Clear Skies ☐ Partly Cloudy ☐ Steady State Wind Speed (mph) _____
Cloudy Skies ☐ Preciption (inches) ☐
Comments _____

5. GPS POST-MISSION DOCUMENTATION

Listing of Point Locations Inspected: _____

Data Collector Down Load to Floppy: ☐ YES ☐ NO Explain: _____

Floppy Type _____ Down Load to GPS PC HARD DRIVE: ☐ YES ☐ NO
Floppy Name _____ Hard Drive File Name: _____

PERSON PERFORMING DATA TRANSFER _____ Date _____

Figure 4.3a

IDENTIFICATION			
ALI-1			
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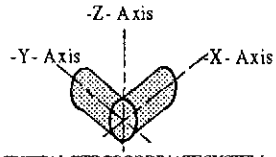
DATA RECORD

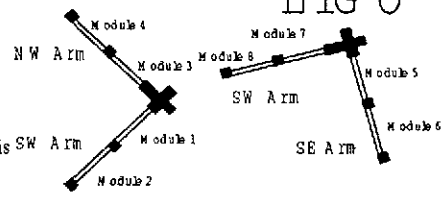
LIGO

Customer: CALTECH
Customer Contract Number: _____
CBI Contract Number: _____
CBI File Reference: _____

X -X X -X X X
FACILITY LOCATION: H = Hanford, L = Livingston
BEAM TUBE SUPPORT LOCATION: Even = Fixed Support, Odd = Guided Support
BEAM TUBE ARM DESIGNATION: NW = Northwest, SW = Southwest, SE = Southeast, LIGO = Central Point
BEAM TUBE MODULE IDENTIFICATION: 1 Thru 8



TYPICAL SITE COORDINATE SYSTEM



HANFORD SITE LIVINGSTON SITE

	SUPPORT LOCATION IDENTIFICATION	FINAL COORDINATE POSITION (ADJUSTED CENTERLINE)						ORIGINAL COORDINATE (Theoretical or Last Adjusted)			FIELD MEASURED COORDINATE (CIRCLE ONE: REAL TIME / POST-PROCESSED)			-Z' Compensation (Assembly Height)	COMMENTS
		-X-	ΔX+/-	-Y-	ΔY+/-	-Z-	ΔZ+/-	-X-	-Y-	-Z-	-X-	-Y-	-Z-	-Z'-	
01	H-LIGO-001														
02	H-LIGO-002														
03	H-LIGO-003														
04	H-LIGO-004														
05	H-LIGO-005														
06	H-NW-101														
07	H-NW-102														
08	H-NW-103														
09	H-NW-104														
10	H-NW-105														
11	H-NW-106														
12	H-NW-107														
13	H-NW-108														
14	H-NW-109														
15	H-NW-110														
16	H-NW-111														
17	H-NW-112														
18	H-NW-113														

Figure 4.3b

GPS EQUIPMENT
INVENTORY/CALIBRATION
LOG

LIGO

Customer: CALTECH
Customer Contract Number:_____
CBI Contract Number: _____
CBI File Reference: _____

LIGO
PROJECT I.D.: LIGO Example
For Information Contact:
CALTECH (818)555-1234

EQUIPMENT Identification Lable

Project Identification Number	COMPONENT NAME	MANUFACTURER	MODEL/SERIAL NUMBER	PURCHASE ORDER REFERENCE	LATEST CALIBRATION DATE
LIGO - R01	GPS Multi-Channel Receiver	XYZ Technical, Inc	TCB/Z-12/LB012596002	L-11029703	12/24/96

EXAMPLE

Figure 4.3c

5.0 EXECUTION:

The Alignment Process begins when the LIGO slab is in place and in a "cured" condition. The Layout of Beam Tube Supports, rail track systems and general reference points is detailed below.

5.1 Layout of Beam Tube Reference Points shall be performed per the following steps:

1) Perform GPS pre-planning activities by first analyzing the satellite conditions and PDOP quality. Assess the the daily accuracy level and schedule layout activities. Begin the **"Daily GPS Field Report"** by completing the applicable sections of the report as noted in **Figure 4.3a.**

2) Establish a rectangular coordinate system to identify layout points by referencing the LIGO control points defined on customer site plans. These control points are defined in three dimensions to a tracable state plane datum provided by the customer. The rectangular coordinate system shall have a vertex common with the beam tube intersection and be formated in a metric system.
3) Set-up the reference receiver at a selected LIGO Control Point and log in for satellite communication. Follow the GPS Equipment Manufacturers' guide for performing this activity. Locate the site control points and verify positon to assure set-up is correct and repeatable.
4) Locate construction reference points at predetermined locations using the Roving GPS antenna, antenna support, and Data Collector. Key the designated point identification for the specific LIGO location on the data collector. Store the GPS data with the point identification by saving the information in the data collector for reprocessing at a later date.
5) Adequately mark the location "point" on the concrete slab using scribed points identified by a painted Identification number as shown in **Figure 4.3b.**
6) Continue steps for all reference points.
7) After each day of layout activity, down-load the field measurement data from the data collector to a floppy disk and/or PC hard drive. Post-process the data using as-build satellite positions and clock corrections received via modem from the NOAA. Print out a final **"Data Record"** (**Figure 4.3b**) with point corrections for use during beam tube and support installations.

5.2 Installation of Beam Tubes Supports shall be performed per the following steps:

****

NOTE: Assure the support is in the MID position of adjustment before bolting to the foundation.

1) Pull a string line from two Beam Tube Support Reference Points. Measure the distance from the Beam Tube Reference Point along the string line and mark the open tube end distance calculated per the data record. The first Beam Tube Assembly and Support shall be positioned by locating the forward end of the tube to the layout reference and centering the weld end to the beam tube support punch mark. This mark may be extended in the same string line fashion as noted previously. When additional punchmarks are placed with GPS equipment and verified using post-processing techniques, these marks may be used in lieu of transfering points with stringlines. Check the elevation from the beam tube support ring to the concrete surface and make adjustments with the temporary jacking supports.
2) While the beam tube is still supported by the temporay jack or stand, mount the Beam Tube Reference Fixture ALI-1(Figure 5.2a)to the support ring and level with the fixture

coincedence bubble. Mark with a punch a 1mm diameter point on the O.D. of the machined stiffener.

3) Install the Beam Tube Reference Fixture with the punch sight attachment and set-up on the punchmark made in step 5.2(2). Record the difference on the rotation column of **Data Record**(Figure 4.3b).
4) Secure the Beam Tube Support to the foundation mat per the engineering detail.
5) Repeat steps 1 thru 4 for installation for each support.

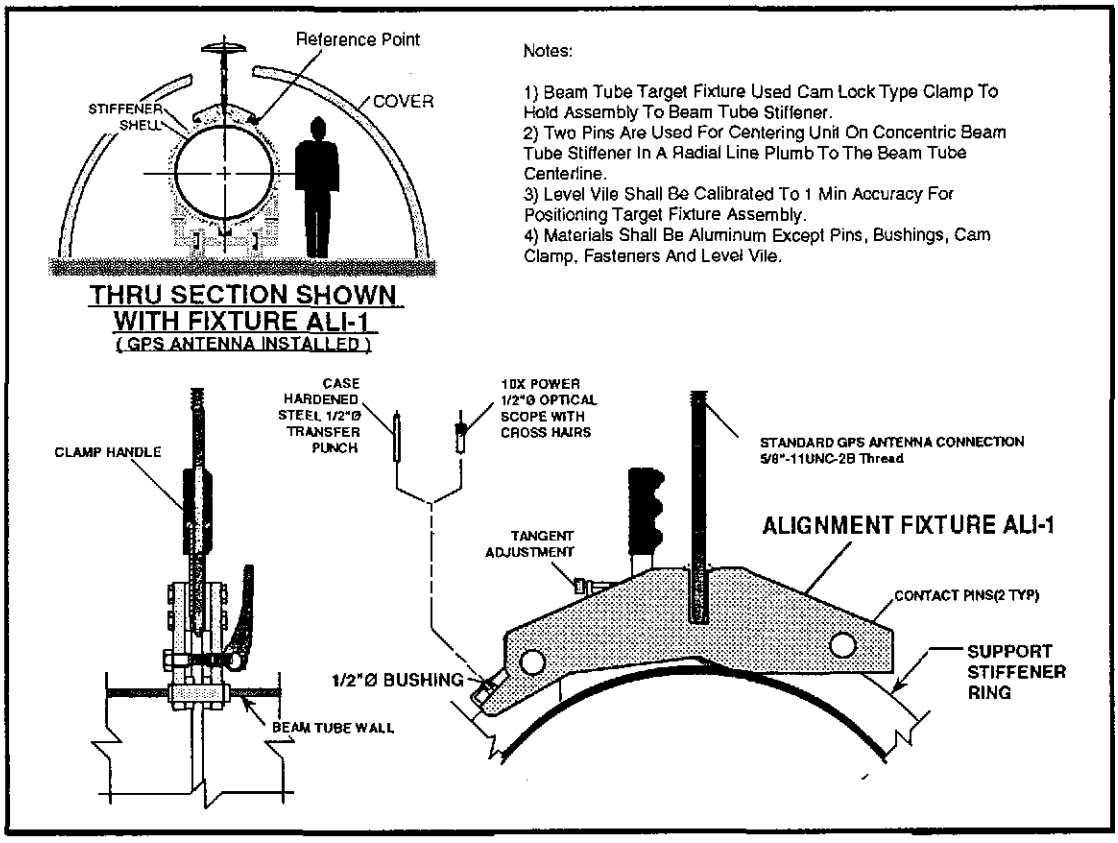


Figure 5.2a

5.3 Initial Beam Tube Support Alignment shall be performed per the following steps:

****

PRECAUTION
WHEN JACKING BEAM TUBE SUPPORT POINTS:

***GUIDED* SUPPORT LOAD LIMITS**
DO NOT EXCEED 6750 lbs TOTAL LOAD AT ANY TIME
Actual Jacking Pressure Reading = TBD .

FIXED SUPPORT LOAD LIMITS
DO NOT EXCEED 6750 lbs TOTAL LOAD AT ANY TIME
Actual Jacking Pressure Reading = TBD .

OVERSTRESSING OF THE EXPANSION JOINT WILL RESULT IF THE TUBE IS ROTATED IN EXCESS OF ± 3mm (Radial @ Support Ring O.D.).
Elevation Movement

****

1) Level the fixture(ALI-1) on the tube stiffener to within 0.001 in/ft. Record the position serial number and location on the data collector. The data collector shall provide position correction factors(off-sets) for adjusting beam tube centerlines.
2) Attach dial indicators, at all jack locations, to monitor the movements between the beam tube and the fixed support brackets. Set the dial indicators to monitor vertical and horizontal movements.
3) Set-up the jacking system for either fixed support or guided support adjustments. The fixed support system requires two(2) jacking cylinders. The guided supports require four(4) cylinders. A detail is shown in **Figure 5.3a**. Install jacks between the concrete slab and support frame, and or between the support brackets and the support frame at the designated jacking points. The jacks are to be placed at equal distances from the tube centerline and the hydraulic lines manifold together so that the jacks will apply equal forces on the supports when raising or lowering. This is done so the jacks will not apply an off center loading to the support and twist the beam tube while raising or lowering the support. Before jacking, assure the jack isolation valves for the operating cylinders are operating in the "open" position. When adjusting a fixed support, disconnect the two unused jack cylinders.
4) Extend the jacks until they contact the beam tube and pressurize to 100 P.S.I. This will apply a nominal force to the jacks.
5) Loosen "U" Bolts slowly to allow support movement.

6) Raise or lower the support frame to the specified movement. Use the dial indicators to measure the amount of movement made during the jacking operation.
7) Use a light prying effort between the horizontal support and the base to move the support when friction is encountered at the support.

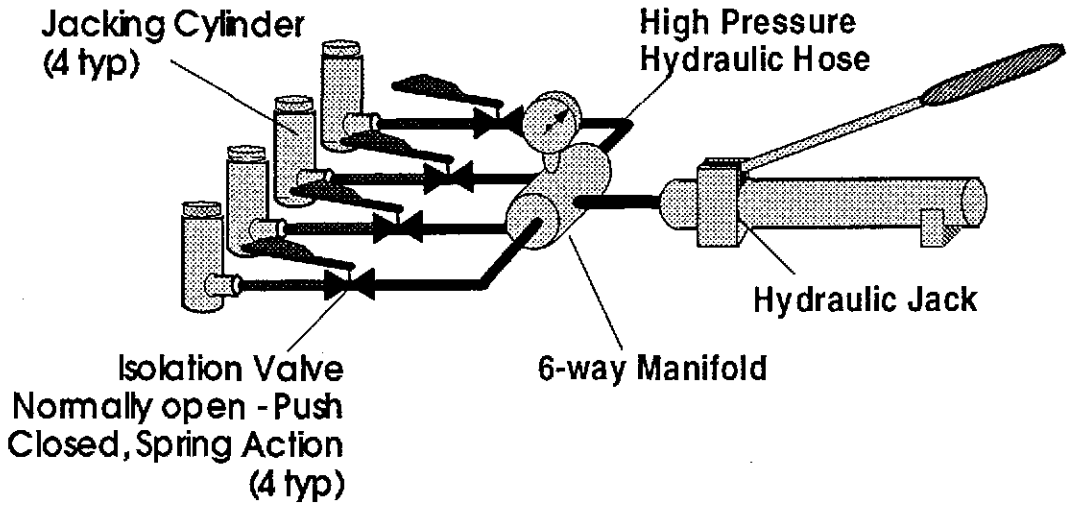


Figure 5.3a

****

DO NOT REMOVE THE "U" CLAMPS.
ONLY LOOSEN NUTS ENOUGH
TO REMOVE CLAMPING FORCES
TO PERMIT MOVEMENT OF THE SUPPORT BEAM.

****

Lateral Movement

8) Install the lateral jacking cylinder between the support frame and the fixed support brackets.
9) Move the support frame laterally with the hydraulic cylinder to the specified movement. Use the dial indicators to measure the amount of movement made during the jacking operation.

****

PRECAUTION
OVERSTRESSING OF THE EXPANSION JOINT WILL RESULT
IF THE TUBE IS ROTATED IN EXCESS OF ± 3mm
(Radial @ Support Ring O.D.).

****

ROTATION MOVEMENT

9) Re-check the beam tube rotation by setting the alignment fixture on the stiffener and locking it to the reference punch mark. Note the level of the fixture and rotate the beam tube first by loosening the "U" bolts and allowing the tube to relax back into its non-stressed condition. If this does not re-align the beam tube then rotate using the leveling jacks. Each of the leveling jacks has a normally open valve that has to be held down to permit differential leveling and twist the beam tube. Use dial indicators to measure rotation. **DO NOT ROTATE THE TUBE IN EXCESS OF +/- 3 milimeters radial at the support ring O.D.**
10) Re-clamp the support frames to the fixed support brackets and confirm that the support has been moved as specified.

5.4 Installation of "Through the Cover" Access Ports after Beam Tube Covers are installed:

1) Locate and cut, drill &/or bore each designated access penetration above the support and install the weather cover. Apply gasketing as required.

5.5 Final Inspection of Beam Tube Support Positions shall be performed per the following steps:

5.5.1 Set-up for GPS alignment activities by following the steps noted below:

1) Perform pre-planning by analyzing the satellite conditions and PDOP quality. Assess the daily accuracy level and schedule layout activities. Begin the **"Daily GPS Field Report"** by completing the applicable sections of the report as noted in Figure 4.3a.
2) Set-up the reference receiver at the base monument and log in for satellite communication. Follow the GPS Equipment Manufacturers' guide for performing this activity. Locate the site control points and verify position to assure set-up is correct and repeatable.

5.5.2 Verification of Beam Tube Support Stiffener centerline positions is performed in the following steps:

1) Locate the first support point and verify location and I.D. number. Input data in to the Data Collector.
2) Attach the Beam Tube Reference antenna fixture ALI-1 to the beam tube stiffener and level (**Figure 5.2a**). Inspect layout mark on beam tube stiffener for location to the fixture cross hair. Record the off-set in the data collector.
3) Mount the GPS antenna to the fixture connection and fine adjust level.
4) Input antenna height data into the data collector and record location.
5) Take GPS reading. Maintain the antenna location on the point for a time required to obtain static data for post processing. Real time positions should be recorded on the field copy of the **"Data Record"** (Figure 4.3b) for a quick reference, however no beam tube support adjustments should be made until the static data is post-processed.
6) Post-processing shall be performed by first obtaining the corrected satellite positions and clock corrections via modem from the NOAA. Data will be down loaded to the hard drive of the GPS work station computer.
7) Position data obtained shall be post-processed using actual satellite position and clock corrections. GPS Manufacturer provided software shall be used to post process data and determine actual corrected positions.
8) A spreadsheet program shall be used to calculate a "corrected" beam tube centerline condition and compare the line with each beam tube support ring position. Off-sets shall be calculated and those outside of the corrected centerline tolerance zone shall be highlighted for adjustments.
9) Beam Tube support adjustments shall be input into the data collector for real time inspections at each out-of-tolerance support. This will aid the field personnel during beam tube centerline maintenance activities.

5.5.3 Adjustment of Beam Tube Supports shall be performed per steps detailed in paragraph 5.3.

5.5.4 Final Alignment Measurements of Beam Tube Supports shall be performed per steps detailed in paragraph 5.5.1 and 5.5.2 as necessary.

6.0 CALIBRATION:

GPS equipment under goes a calibration during each use and the formal documents recording the calibrations are recorded on each "Daily GPS Inspection Report"(Figure 4.3a). The equipment shall be handled, calibrated and stored per manufacturer's requirements. All calibration shall be traceable to national and international standards. All equipment maintenance and calibrations shall be documented in the "GPS EQUIPMENT INVENTORY/CALIBRATION LOG"(Figure 4.3c).