

LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
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Beam Tube Bakeout Design Requirements Document
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Abstract

This document specifies the design requirements for the Beam Tube Bakeout to be used at the LIGO sites. It covers the heating power and control, thermal insulation, pumping and instrumentation, data acquisition, and electrical requirements to execute the beam tube bake.

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1 INTRODUCTION

1.1. Purpose

The purpose of this document is to define the requirements for the bakeout of the LIGO Beam Tube Modules. These requirements will be used to guide the design and testing of bakeout equipment and procedures.

1.2. Scope

This document provides requirements for the bakeout equipment (heating power and controls, thermal insulation, pumping, instrumentation, data acquisition and logging), processes (equipment setup and conduct of the bakeout, and post-bakeout data analysis) and electrical requirements to be used for the beam tube bakeout.

1.3. Definitions

1.4. Acronyms

AMU	Atomic Mass Unit
BT	Beam Tube
BTD	Beam Tube Demonstration
BTE	Beam Tube Enclosure
CH ₄	Methane
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
DAS	Data Acquisition System
DC	Direct Current
DRD	Design Requirements Document
LIGO	Laser Interferometer Gravitational Wave Observatory
LN ₂	Liquid Nitrogen
PLC	Programmable Logic Controller
QT	Qualification Test
RGA	Residual Gas Analyzer

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1.5. Applicable Documents

1.5.1. LIGO Documents

M950001	Project Management Plan, latest revision
E950018	Science Requirements Document, latest revision
E950020	Beam Tube Module Requirements-Fabrication & Installation Contract, latest revision
E940002	Vacuum Equipment Specification, latest revision
E94xxxx	Beam Tube Module Specification (formerly Specification No. 1100004)
E94xxxx	Process Specification for Low Hydrogen, Type 304L Stainless Steel Vacuum Products (formerly Specification No. 1100007)
M96xxxx	Configuration Management Plan, latest revision
M950046	Project System Safety Plan, latest revision
D950027	Beam Tube Pump Port Hardware, latest revision
E950089	Interface Control Document (ICD): Beam Tube (BT) - Civil Construction (CC), latest revision

1.5.2. Non-LIGO Documents

2 GENERAL DESCRIPTION

2.1. Product Perspective

The LIGO Beam Tube Modules will be fabricated and installed by a contractor, CBI, Inc. Current plans call for conducting a bakeout (the subject of this document) of each beam tube module before integration with the rest of the LIGO vacuum system.

2.2. Product Functions

The beam tube modules will be unbaked when accepted from the contractor. At that point, partial pressures for H₂O and hydrocarbon gas species will exceed LIGO partial pressure goals. The beam tube bakeout is intended to reduce these partial pressures to the goal levels.

2.3. General Constraints

The beam tube is already designed and is under construction. The bakeout must meet its objectives without modification to the beam tube design, and must not subject the beam tube, attached

components (such as gate valves), foundations or enclosure to stresses beyond the capabilities of the existing design.

Some beam tube bakeout requirements are derived from empirical results obtained during earlier test programs.

To reduce significant capital costs, the equipment required for the bakeout will be used sequentially on each 2 km beam tube module, first at the Hanford, Washington site and then at the Livingston, Louisiana site.

2.4. Assumptions and Dependencies

The following factors affect the scope of the bakeout task and, if these change, then the scope may have to be changed accordingly:

- The beam tube will be baked out in increments of 2 kilometer modules.
- Adequate AC power (13.8 kV, 1300 kVA) will be available along the beam tubes.
- Safe access to beam tube enclosures during installation and bake (if needed) will be allowed.
- The beam tube will have been accepted from the beam tube fabrication and installation contractor and will meet its performance requirements (E950020).
- The beam tube is left under rough vacuum up to the time of the bakeout.
- Leaks larger than the LIGO specification which are present after the bakeout will be identified and localized, but repair/recovery procedures are not within the scope of this document.
- Insulation and thermal sensors will be left in place after each beam tube module is baked.

3 REQUIREMENTS

The allowable residual gas pressure in the beam tubes is set by the anticipated sensitivity of the detectors in the LIGO. The LIGO Science Requirements Document (referenced in 1.5.1 above) sets the goal for residual gas pressure “...at a level at or below an equivalent strain noise of $2 \times 10^{-25} \text{ Hz}^{-1/2}$ ”. The beam tube bakeout is intended to reduce the rate of outgassing of adsorbed gases (principally H_2O , but also CO , CO_2 , CH_4 and heavier hydrocarbons) to a level which meets the residual gas pressure goal when the beam tube modules are pumped from their ends only (2 km points).

The bakeout requirements are derived from the above primary consideration and the empirical results achieved during the successful Qualification Test (QT) and earlier Beam Tube Demonstration (BTD) bakeouts.

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3.1. Characteristics

3.1.1. Performance Characteristics

3.1.1.1 Components to be Baked

All vacuum surfaces of the bake volume, including beam tube wall material, expansion joints, pump ports, pump port hardware, 122 cm gate valves, and terminations shall be maintained within temperature limits specified below during the module bake.

3.1.1.2 Partial Pressures During the Bakeout

Partial pressures during the bake shall be controlled (by suitable choice of pumping speeds and control of temperature rate-of-rise) to maintain attached RGA(s) in their linear range to ensure proper operation throughout the bake.

Partial pressures of condensible gases shall be sufficiently low at the end of the bakeout and during cool down to avoid re-adsorption. The partial pressure for water vapor at an average bake temperature of 150°C at the end of the bakeout interval shall be $P(\text{H}_2\text{O}) < 2 \times 10^{-8}$ torr.

3.1.1.3 Bake Temperature

3.1.1.3.1 Minimum Temperature

The temperature of any point along the surface of beam tube bakeout volume shall be greater than 130°C.

3.1.1.3.2 Maximum Temperature of Beam Tube Wall

In order to avoid mechanical overstress of the beam tube wall structure, the maximum temperature at any point on the spiral welded beam tube wall shall be less than 190°C.

3.1.1.3.3 Maximum Temperature of Beam Tube Bellows

The temperature at any point on any beam tube bellows shall be less than TBD (presently assumed to be quite high -- looking for the limiting driver).

3.1.1.3.4 Maximum Difference in Temperatures of the Beam Tube Wall

In order to avoid mechanical overstress (axial) of the beam tube support structures, the average temperature of any individual 20 m-long section of the beam tube wall shall not differ from the average temperature of any other section by more than 25°C.

In order to avoid mechanical overstress (transverse) of the beam tube support structures due to thermally-induced “banana mode” distortions, the average temperature of any semicylindrical half of any individual 20 m-long section shall not differ from the average temperature of its other semicylindrical half by more than 10°C.

3.1.1.3.5 Maximum Temperature of 122 cm Gate Valves

In order to avoid over heating of the 122 cm gate valve O-rings, the maximum temperature at any point on the gate or gate valve body shall not exceed TBD °C.

3.1.1.3.6 Maximum Temperature of Other (TBD) Components

TBD.

3.1.1.4 Beam Tube Insulation

Beam tube walls shall be insulated as required to achieve the above temperature limits.

3.1.1.5 Bake Duration

The coldest spot of the beam tube module under bakeout shall be maintained above the minimum temperature (3.1.1.3.1) for the earlier of either an elapsed time of 30 days, or until the water (H_2O) outgassing rate has decreased to $J(\text{H}_2\text{O}) < 1 \times 10^{-11}$ torr l/s cm^2 at 150°C . If the temperature of any sensor monitoring the vacuum wall surfaces falls below the minimum bake temperature, the bake time shall be extended as needed to ensure that the minimum time requirement is met.

3.1.1.6 Data Acquisition, Display, Monitoring and Recording

The beam tube module shall be instrumented to measure the wall temperatures at representative positions, including anticipated hot or cold spots, interfaces with pump port hardware, 122 cm gate valves and terminations. The beam tube module shall also be instrumented with at least one RGA to measure partial pressures of H_2 and H_2O during the bakeout (10^{-9} torr instrument sensitivity), and partial pressures through AMU 100 during post-bake (10^{-15} torr sensitivity) measurements. Instrumentation shall also be provided to measure of DC power supply currents and voltages, operating status of equipment (such as vacuum pumps), and such other engineering data, including ambient environmental conditions (temperature, humidity, wind speed and direction), which determine the state of bakeout equipment.

During the initial bakeout, the equipment shall include provisions for measuring representative strains on the beam tube structure. During post-bake measurements, the equipment shall include provisions for measuring pumping speeds and outgassing rates.

All needed data shall be available at a single location for the purposes of display, monitoring and recording.

All acquired data shall be time stamped and recorded as needed (at approximately 15 minute intervals during bake) and the accumulated data file shall be archived periodically.

3.1.1.7 Vacuum Components

All vacuum components attached to the beam tube module shall comply with the requirements given in the LIGO Vacuum Equipment Specification, section 5, for similar components.

3.1.2. Physical Characteristics

The bakeout equipment, excluding beam tube insulation and temperature sensors, shall be installed and de-installed from module to module during the bake of subsequent modules. In addition, this equipment shall be transportable from site to site.

3.1.3. Interface Definitions

3.1.3.1 Interfaces to other LIGO systems

3.1.3.1.1 Mechanical Interfaces

The vacuum hardware shall be compatible with the BT module pump ports hardware, Type H, as called out in drawing D950027.

Electrical connections for delivering DC heating power to the beam tube module shall use bolted attachments via holes drilled through beam tube Support Rings near each pump port.

Temperature sensors shall be attached to the beam tube wall using TBD technique.

3.1.3.1.2 Electrical Interfaces

Step-down transformers shall be used to provide needed AC power (480VAC, 120VAC) from the site power (13.8 kV, WA; 13.2 kV, LA). Up to 1300 kVA is required.

The beam tube module shall be grounded at the ends only during the bake.

The beam tube modules shall have electrical connections to DC power supplies for heating.

Monitoring and recording devices shall use AC power (110-120VAC), also derived from site utilities power.

The bakeout equipment shall have adequate protection from lightning.

3.1.3.1.3 Optical Interfaces

There are no optical interfaces.

3.1.3.1.4 Thermal Interfaces

No special provisions other than insulation and heating of the beam tube walls will be made to influence the thermal behavior of the beam tube or Beam Tube Enclosure during the bakeout.

3.1.3.1.5 Stay Clear Zones

Access to beam tube enclosure shall be restricted during bake. Access to all service and emergency entrances to module under bake shall be kept clear during the duration of the bake activities.

3.1.4. Reliability/Maintainability

As a minimum, system design shall be such to provide a 30 day bake period with 90% confidence that the bakeout performance requirements are met (reference 3.1.1).

The insulation blanket shall have a minimum usable lifetime of 1 bake cycle. As a goal, a 10 year lifetime is desired.

The thermal sensors shall have a minimum usable life of 20 years installed.

The insulation blanket shall be constructed of materials which do not pose a threat to long-term corrosion of the stainless steel tube wall or reinforcing rings.

3.1.5. Environmental Conditions

The beam tube bakeout equipment shall be able to achieve and maintain design bake temperatures under anticipated temperature extremes at either site. The equipment must be safe to other equipment and personnel during exceptional circumstances such as a power failure, earthquake, lightning, etc.

3.1.5.1 Natural Environment

3.1.5.1.1 Temperature and Humidity

Table 1: Environmental Performance Characteristics

	<i>Operating</i>	<i>Non-operating (storage)</i>	<i>Transport</i>
Equipment in contact with beam tube wall	0°C to +200°C, 0-90%RH	-40°C to +70°C, 0-100% RH	-40°C to +70°C, 0-90% RH
Equipment located inside the BTE	0°C to +70°C, 0-90%RH	-40°C to +70°C, 0-100% RH	-40°C to +70°C, 0-90% RH
Equipment located outside the BTE	-30°C to +40°C, 0-100%RH	-40°C to +70°C, 0-100% RH	-40°C to +70°C, 0-90% RH
Equipment located inside buildings	20°C to 30°C, 20-70%RH	-40°C to +70°C, 0-100% RH	-40°C to +70°C, 0-90% RH

3.1.5.1.2 Atmospheric Pressure

TBD

3.1.5.1.3 Seismic Disturbance

TBD

3.1.5.2 Induced Environment

3.1.5.2.1 Electromagnetic Radiation

TBD

3.1.5.2.2 Acoustic

TBD

3.1.5.2.3 Mechanical Vibration

TBD

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3.1.6. Transportability

All removable bakeout equipment shall be packaged to be transported between beam tube modules with minimum labor required for transportation and setup. All equipment shall be transportable across the country by commercial carrier without degradation in performance. If 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.

3.2. Design and Construction

3.2.1. Materials and Processes

3.2.1.1 Finishes

TBD

3.2.1.2 Materials

Surface-to-surface contact between dissimilar metals shall be controlled in accordance with the best available practices for corrosion prevention and control.

Insulation shall be constructed of materials which do not pose a threat to long-term corrosion of the stainless steel tube wall or reinforcing rings.

Insulation shall not emit toxic gasses when the beam tube is heated to bake temperature.

3.2.1.3 Processes

TBD

3.2.2. Component Naming

TBD

3.2.3. Workmanship

TBD

3.2.4. Interchangeability

TBD

3.2.5. Safety

Equipment and procedures associated with executing bakeout task shall meet all applicable Federal safety regulations, plus 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 Plan. Special issues expected to be addressed includes:

- working in confined space (controlled access to beam tube enclosure)
- high power (up to 1.3 MW)
- high current (2000 A)
- high voltage (13.8 kV)
- high temperature (150°C)
- lightning protection

3.2.6. Human Engineering

TBD

3.3. Documentation

3.3.1. Specifications

TBD

3.3.2. Design Documents

T960124 Issues and Consideration on the Beam Tube Bake, Nov. 30, 1995.

T96xxxx Information for the Bakeout Design, Aug. 12, 1996.

T960178 Beam Tube Bakeout Conceptual Design

3.3.3. Engineering Drawings and Associated Lists

3.3.4. Technical Manuals and Procedures

3.3.4.1 Procedures

Procedures shall be provided for, at minimum,

- Initial installation and setup of equipment
- Normal operation of equipment
- Normal and/or preventive maintenance
- Troubleshooting guide for anticipated potential malfunctions

3.3.4.2 Manuals

TBD

3.3.5. Documentation Numbering

All documents shall be numbered and identified in accordance with the LIGO documentation numbering system LIGO document TBD

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3.3.6. Test Plans and Procedures

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

3.4. Logistics

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

3.5. Precedence

TBD

3.6. Qualification

TBD

4 QUALITY ASSURANCE PROVISIONS

4.1. General

4.1.1. Responsibility for Tests

TBD

4.1.2. Special Tests

4.1.2.1 Engineering Tests

TBD

4.1.2.2 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.

4.1.3. Configuration Management

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

4.2. Quality conformance inspections

Design and performance requirements identified in this specification and referenced specifications shall be verified by analysis, demonstration, or test. 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:

4.2.1. Inspections

TBD

4.2.2. Analysis

TBD

4.2.3. Demonstration

TBD

4.2.4. Test

TBD

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APPENDIX A DETERMINATION OF MAXIMUM ALLOWABLE AXIAL AND TRANSVERSE (RADIAL) THERMAL GRADIENTS.

A model was developed to determine the maximum allowable thermal gradients during bake out. The components of the model were:

- [1] Maximum allowable forces on BT fixed supports. These included axial forces ($F < 7300$ lb) and transverse/vertical forces ($F < 1300$ lb). The values are from the Beam Tube (BT)-Civil Construction (CC) Interface Control Document (ICD) and correspond to design values provided by CB&I and Parsons for the BT design and associated slab interfaces.
- [2] Thermal expansion characteristics for the BT material (304L SS).
- [3] Axial loads at the module ends caused by atmospheric pressure on the evacuated beam tub.
- [4] Transverse force-displacement relation associated with the “banana mode” bending of the tube (in both horizontal & vertical planes) caused by the presence of thermal gradients across the BT.
- [5] The distribution function of expansion joint spring constants. The statistical representation was derived from CB&I empirical data for the first 42 joints, which have mean and standard deviations of 7800 lb/in and 232 lb/in, respectively (Figure A-1). The model incorporated the 42 data points and random samples of the distribution for the remaining expansion joints.

Using these parameters as inputs, the model was used to generate representative chains of 50 x 40 m long tube sections (length between fixed supports). The distribution of three dimensional forces at the fixed supports was determined and maximum axial and transverse thermal gradients were determined which could satisfy the maximum load limits from [1] above (see Figures A-2 and A-3).

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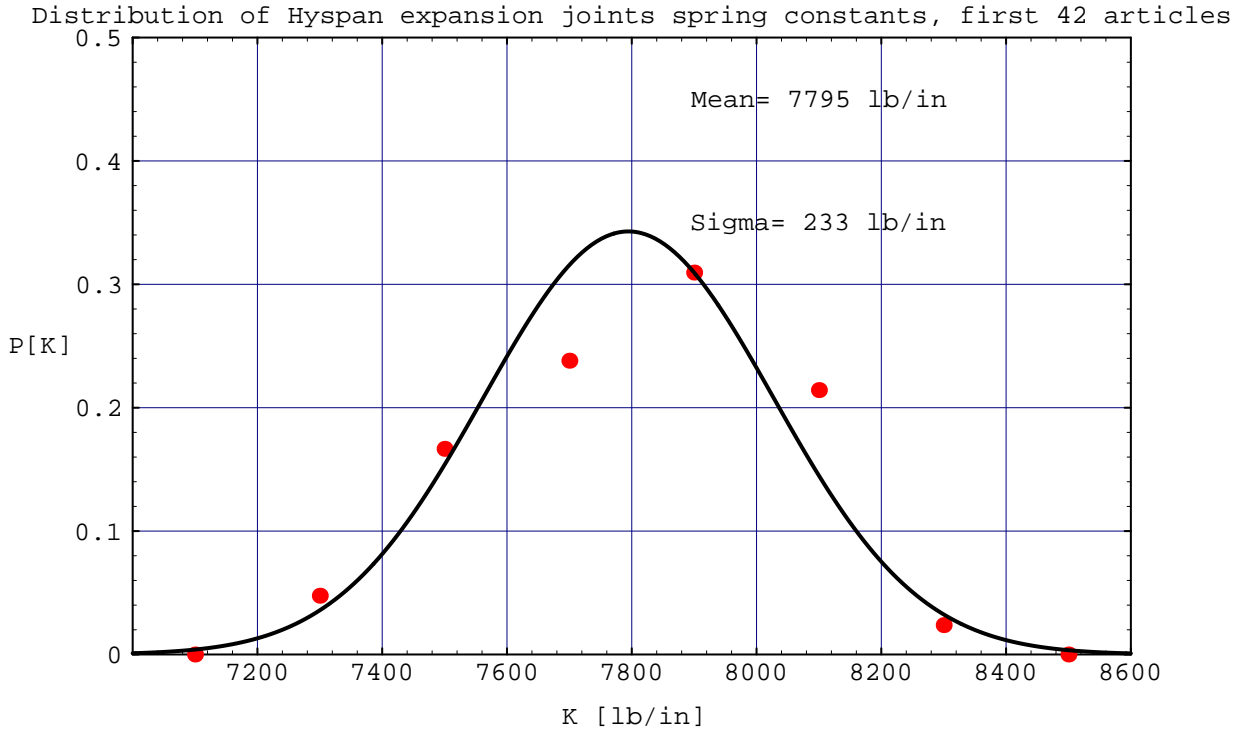


Figure A-1: Distribution of Hyspan expansion joints spring constants, first 42 articles

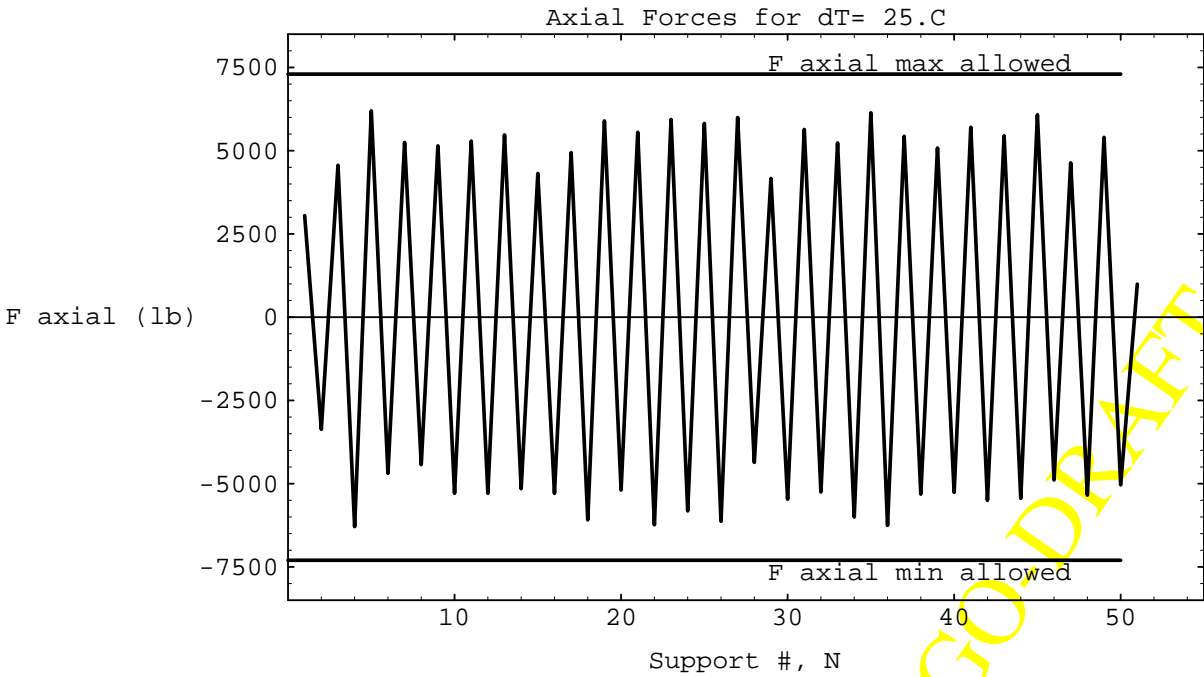


Figure A-2: Axial force at fixed supports with tube sections between adjacent pairs of supports at alternating temperatures (for temperature difference $dT=25^{\circ}C$)

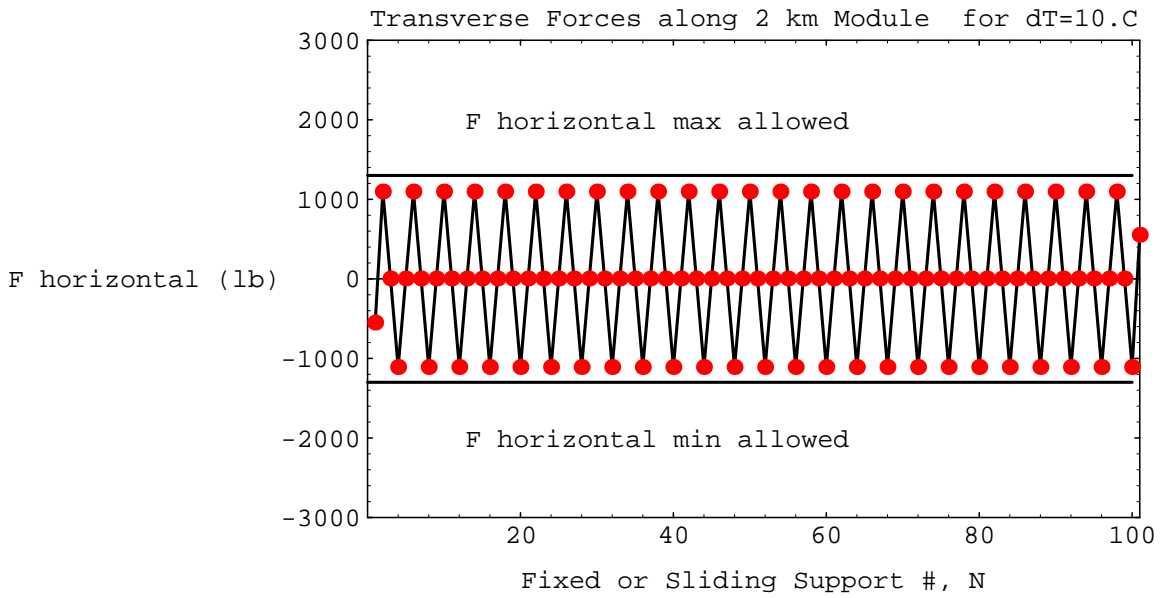


Figure A-3: Transverse forces at fixed and swinging supports for dT= 10°C

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