LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Document Type **LIGO-T960066 - 00-D** 4/15/96

Seismic Isolation Conceptual Design

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1 INTRODUCTION

1.1. Purpose

1.2. Scope

The Seismic Isolation subsystem (SEI) provides a vibrationally quiet platform for interferometer components inside the vacuum system. There are two different seismic isolation designs, one for HAM chambers and one for BSC chambers, that are both covered in this document. The seismic isolation subsystem starts with support piers that rest on the facility floor and extends up to (and including) the optical platforms inside the vacuum chambers, to which other optical components and support equipment are attached. Seismic isolation of components external to the vacuum system (such as laser/optical tables) is outside the scope of SEI.

This document presents the conceptual design for the SEI subsystem. These follow the requirements defined in another document, *Seismic Isolation Design Requirements Document* (LIGO-T960065-0x-D). Some information is reproduced herein for completeness.

1.3. Definitions

1.3.1. Names of Components

The Seismic isolation subsystem consists of assemblies in, and surrounding, the HAM and BSC chambers that are composed of the following elements:

- The *Optics Platform* is the table-like surface that has been isolated from vibration and has provisions for mounting optical components (both fixed and suspended), stray-light shields and cabling.
- *Spring Elements* are the compliant elements of the seismic isolation system.
- *Mass Elements* are inertial elements that separate the spring elements.
- A *Stage* refers to a mass-element/spring-element pair, that comprises a tuned filter to block transmission of seismic noise and vibration.
- The *Support Platform* provides a flat surface onto which the cascaded stages are mounted.
- The *Support Beam* provides support for the support plate and transfers the weight of the isolation components and payload from within the vacuum chamber to supporting structures outside the vacuum chamber.
- The *Support-Beam Bellows* provide a flexible vacuum connection between the support beam and the vacuum chamber.
- *Actuators* allow the position and orientation of the seismic isolation and payload to be adjusted. These provide for both coarse and fine adjustment. Coarse and fine actuation may be accomodated in either a single modular unit or in separate modular units, to be decided as an

outcome of the preliminary SEI design.

- *Coarse* adjustments have a larger range and are not intended to be used while maintaining interferometer lock.
- *Fine* adjustments have a more limited range than coarse adjustments and may be used without interfering with interferometer operation.
- *Active Isolators* are modules that incorporate local sensing and feedback actuation to achieve enhanced low-frequency vibration isolation.

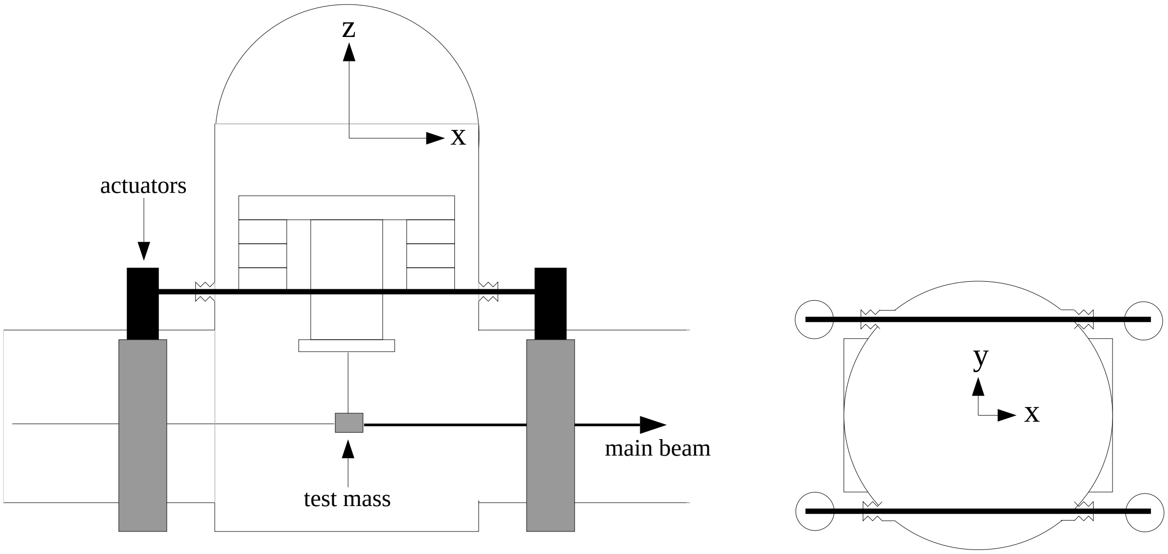
Figures 1 through 4 below illustrate the relationships among these parts.

1.3.2. Definitions of Terms

- *lock* indicates the state of the interferometer when all optical cavities are resonating satbly with the light
- *lock acquisition* indicates the process of bringing the interferometer into resonance
- *lock maintenance* indicates the process of maintaining resonance in all optical cavities of the interferometer
- *amplitude spectral density* (sometimes referred to as *amplitude spectrum*) indicates the square root of the power spectral density
- *on-line actuators* indicates actuators that operate when the interferometer is fully operational without causing disturbance as opposed to *off-line actuators* which are not used when the interferometer is operational

1.3.3. Definition of Coordinates

The x axis is defined for each chamber as the axis parallel to the line joining the ports through which the support beams penetrate the vacuum envelope. This is shown in Figure 1. The z axis is vertical (increasing upwards, and the y axis is transverse to x and z, forming a right-handed coordinate system. The x axis is along the optical axis of the Ham chambers, BSC chambers in VEAs and certain BSC chambers in the LVEA. In the other BSC chambers, the y axis is along the optical axis.



elevation view

plan view

Figure 1: Definition of coordinate system using a test-mass chamber as an example.

1.4. Acronyms

- IFO indicates Interferometer
- SEI indicates Seismic Isolation subsystem
- SUS indicates Suspension subsystem
- IOO indicates Input/Output Optics subsystem
- COC indicates Core-Optics Components subsystem
- COS indicates Core Optics Support susbsystem
- ASC indicates Alignment Sensing and Control subsystem
- LSC indicates Length Sensing and Control subsystem
- HAM indicates horizontal-access, vacuum chamber used for input/output optics
- BSC indicates vacuum chamber type used for beam splitters and test masses
- RMS indicates root-mean-square as in “RMS motion”

1.5. Applicable Documents

- *Seismic Isolation Design Requirements Document* (LIGO-T960065-01-D)
- *LIGO Science Requirements Document* (LIGO-E950018-02-E)
- *Suspension Design Requirements Document* (LIGO-T950011-06-D)
- *Measurement of Ambient Relative Test Mass Motion in the 40 M Prototype* (LIGO-T950038-00-R)
- *Response of Pendulum to Motion of Suspension Point* (LIGO-T960040-00-D)
- E. Ponslet, *Isolation Stack Modeling* (HYTEC-TN-LIGO-01), January 23, 1996.
- E. Ponslet, *Isolation Stacks Preliminary Design Methodology* (LIGO T9600026), February 21, 1996.
- E. Ponslet, *BSC Stack Design Trend Study* (LIGO-T960034), March 1, 1996

2 GENERAL DESCRIPTION

2.1. Product Perspective

The relation of the SEI subsystem to other detector subsystems and the facilities (FAC) is shown below. The seismic isolation support equipment from the COC, COS, IOO and ASC on the optical platform and supports the CDS cabling. The seismic isolation is physically supported by the Facility floor. CDS monitors the status of SEI hardware and delivers signals to SEI actuators.

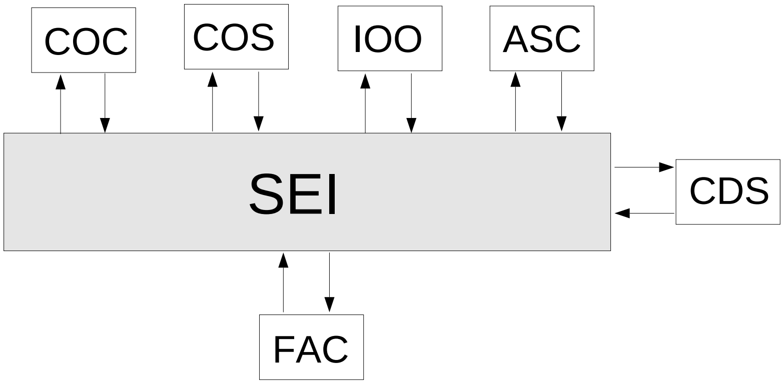


Figure 2: Relation of SEI to other subsystems.

2.2. Product Functions

The seismic isolation system must fulfill the following general requirements:

- Provide stable support for the payload.
- Maintain the total motion of the test mass within a range suitable for lock acquisition and

maintainence, using the suspension actuators.

- Minimize vibration of the optical-table surface to which optical components are mounted.
- Provide adequate space for mounting of components and adequate space for access to components.

3 DESIGN PRINCIPLES AND ASSUMPTIONS

3.1. Philosophy

The philosophy adopted for the seismic isolation design was guided by two concerns:

- Most of the critical LIGO interferometer components are supported, either directly or indirectly, by the seismic isolation. Thus the seismic isolation will be required to be installed in the earliest stages of the detector integration process. Significant departures from scheduled delivery of the seismic isolation components will place the entire detector integration activity at risk.
- The seismic isolation and suspension systems determine the background of non-gravitational strain and displacement in the detector. It is desirable to have the highest possible performance from these systems, both for signal-to-noise considerations and because a low displacement background simplifies the design of control systems.

This constrains the design to be conservative, so as to guarantee readiness at the beginning of integration, but to make the system readily upgradeable to higher performance without major replacement of equipment.

3.2. Guidelines

- Identify the likely upgrade paths and make necessary provisions in the initial design so that upgrades can be accomodated easily.
- Minimize deviations from past experience wherever possible in the initial implementation.
- Preserve options and flexibility as long as possible in the design process so that results from R&D experience can be incorporated into the mature design.
- Where feasible, identify and agressively pursue work in areas that could bring significant performance improvements.

4 BSC SEISMIC ISOLATION

4.1. Description

Following the design guidelines, the proposed initial seismic-isolation design uses a similar configuration and similar spring elements to the seismic isolation system currently employed in the 40-meter interferometer. This is currently the highest performance seismic-isolation system for which there is good data under operating conditions that resemble the LIGO conditions. The seismic isolation has been well characterized using the interferometer and has confirmed the linearity of the spring design at extremely small displacements. The upgrade path assumed for the seismic isolation and factored into the initial design includes:

- Substitution of higher-performance spring elements after these have been suitably tested, including shaker tests, vacuum qualification and characterization by substitution in the 40-meter interferometer.[1]
- Incorporation of active isolation to reduce the overall motion.[2]
- Installation of a double suspension for critical components, such as the test masses.[3]

The current design is intended to facilitate these upgrades without major hardware modifications, except for replacement of the spring elements. The design expects to accomodate spring-element replacement in the BSC chambers without removal of the payload.

Although LIGO interferometers will be similar to the 40-meter interferometer, there are some differences. The major departures in this conceptual design relative to the system used in the 40-meter interferometer are:

- The LIGO isolation will be larger and will support a larger payload.
- The configuration of the BSC chamber constrains the payload to be below the lowest stage of the stacks.[4] This necessitates the use of a down structure.
- LIGO will operate with much higher light powers and intensities on the test masses, placing more stringent constraints on vacuum compatibility of components.

Two identical sketches of the BSC seismic-isolation design are shown below as Figures 3 and 4, identifying the proper part names. In the initial installation, the parts labelled active isolators will not be present, their space occupied by similarly sized structural modules. Also not shown are special fine actuators to be used on the BSC chambers in the end-station and mid-station buildings. These fine actuators are used to remove tidal drifts from the interferometer arms under control of the LSC system.

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[1] The 40-meter interferometer test would only require changing the spring elements in the final stage of the seismic isolation on one chamber to verify linearity at small displacements and the absence of excess noise associated with the springs.

[2] Active isolation systems capable of handling the payloads used in LIGO have not yet been demonstrated.

[3] The design below would also be compatible with three or more suspension stages.

[4] The seismic-isolation configuration for the HAM chambers is similar to that used in the 40-meter interferometer in this respect.

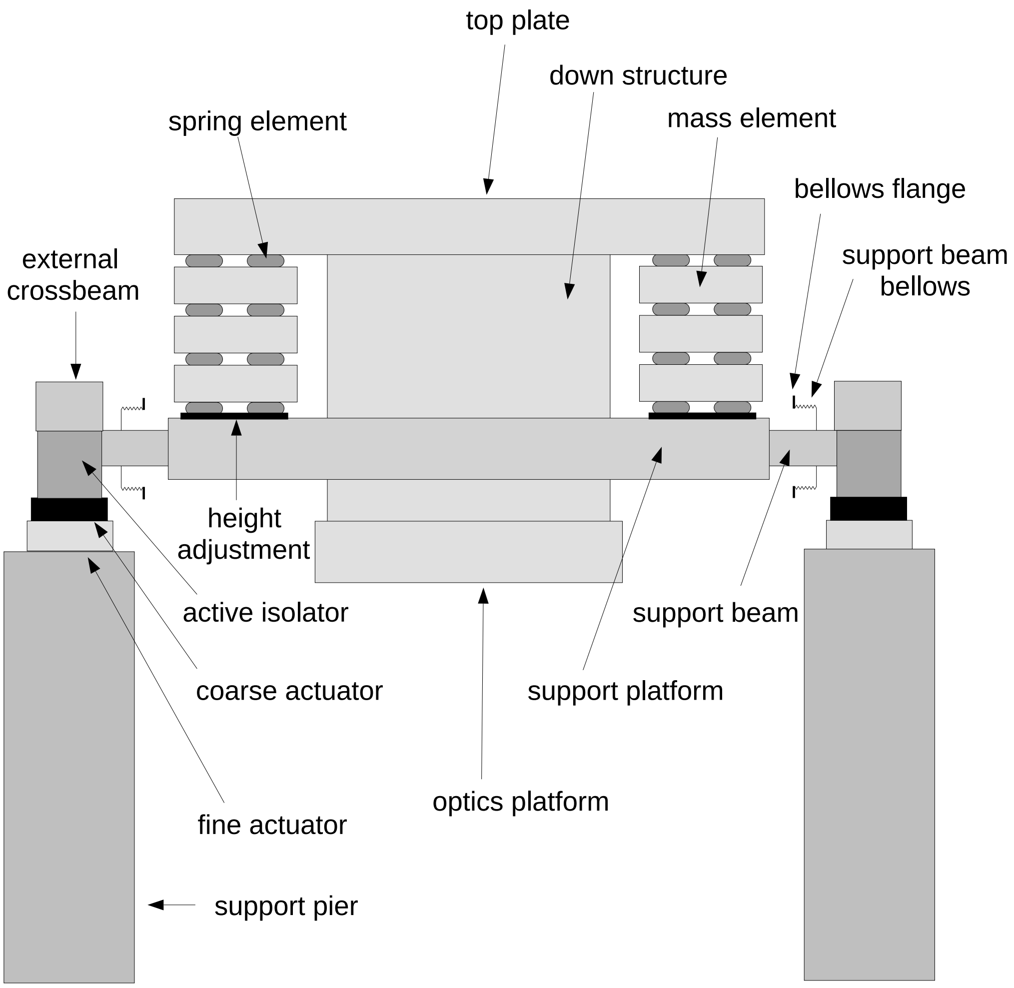

Figure 3: Naming convention for BSC-SEI parts

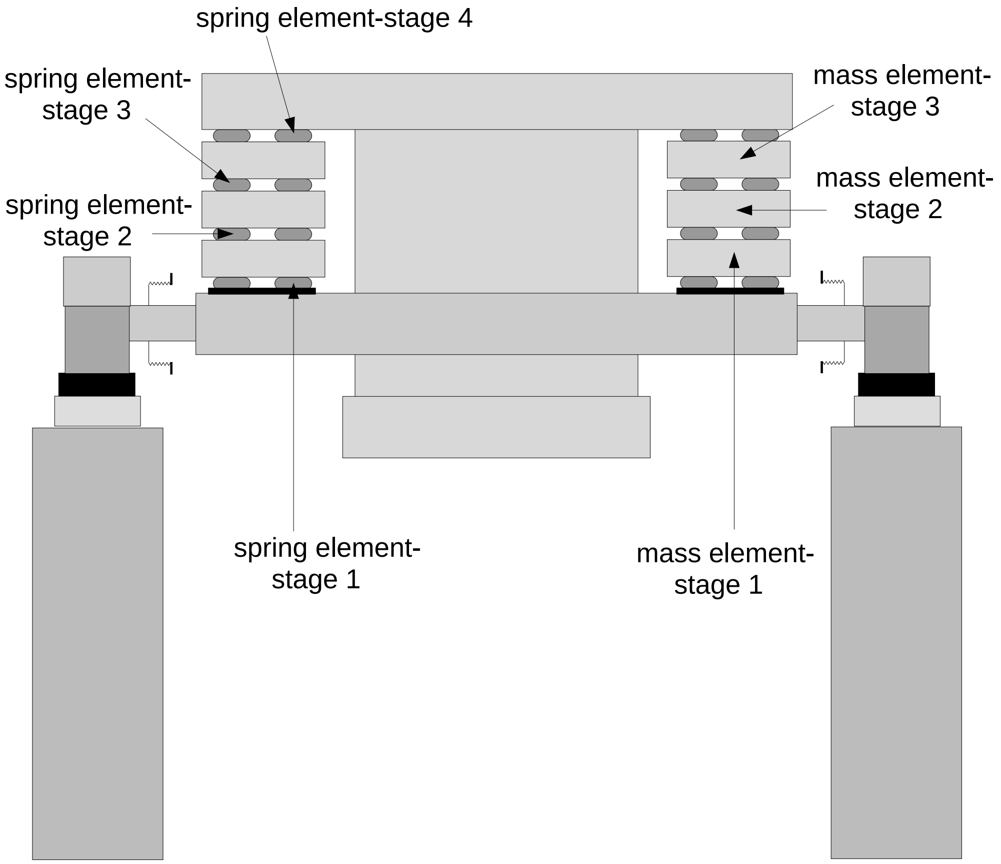

Figure 4: Naming convention for BSC-SEI parts

4.2. Estimated Seismic-Isolation Transfer Functions

A seismic isolation design that uses a four-legged, four-stage stack with viton spring elements of the same size as those used in the 40-meter interferometer and the MIT test stack has been evaluated by HYTEC as a candidate for the initial LIGO interferometer.[1] (Referred to hereafter as HYTEC1.) The 12 mass elements in stages 1 through 3 were assumed to have a mass of 350 kg each and the assumed down-structure mass was 1680 kg, including the optical platform. The payload mass was assumed to be 227 kg. The effect of the mass of the mass elements was studied and found not to be a significant factor in the stack performance[2], except for digitization affects associated with the number of springs needed for a given static displacement. The total mass above the support structure was estimated to be approxiamtely 6100 kg.

A finite-element model (FEM) of the spring elements was adjusted[3] to reproduce test data from MIT.[4] This FEM spring model was used to derive frequency-dependent real and elastic moduli for

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1. E. Ponslet, *BSC Stack Design Trend Study* (LIGO-T960034), March 1, 1996.
2. E. Ponslet, *Isolation Stacks Preliminary Design Methodology* (LIGO T9600026), February 21, 1996.
3. E. Ponslet, *Isolation Stack Modeling* (HYTEC-TN-LIGO-01), January 23, 1996.
4. J. Giaime, P. Saha, D. Shoemaker and L. Sievers, "A Passive Vibration Isolation Stack for LIGO: Design Modeling and Testing", *Rev. Sci. Instrum.* **67**, 208, (1996).

the spring elements. These spring constants were then incorporated into a fully three-dimensional MATLAB model of the stack, with the mass elements assumed to be rigid. The excitation functions were assumed to be identical in horizontal and vertical translation, with no pitch or yaw motion. The largest transfer functions are given in Figure 5 below. The transfer function from horizontal ground motion to horizontal motion of the optics platform is compared to the requirement in Figure 6. The design transfer function exceeds the requirement in the region from 20-75 Hz

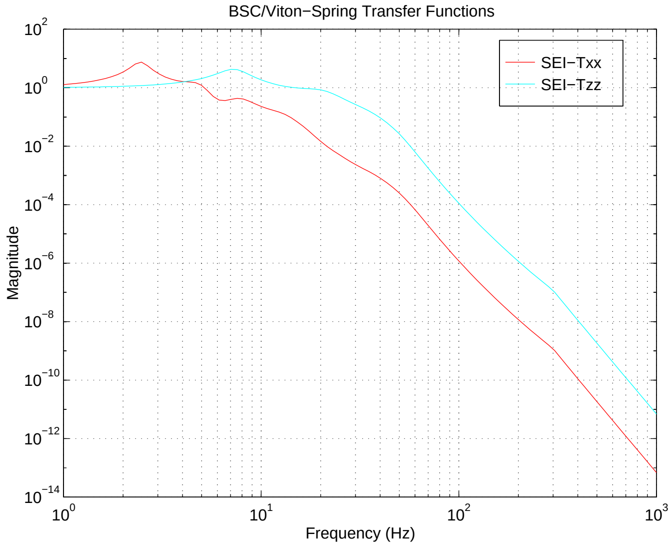

Figure 5: Transfer functions for a seismic-isolation system using viton spring elements similar to those employed in the 40-meter interferometer.

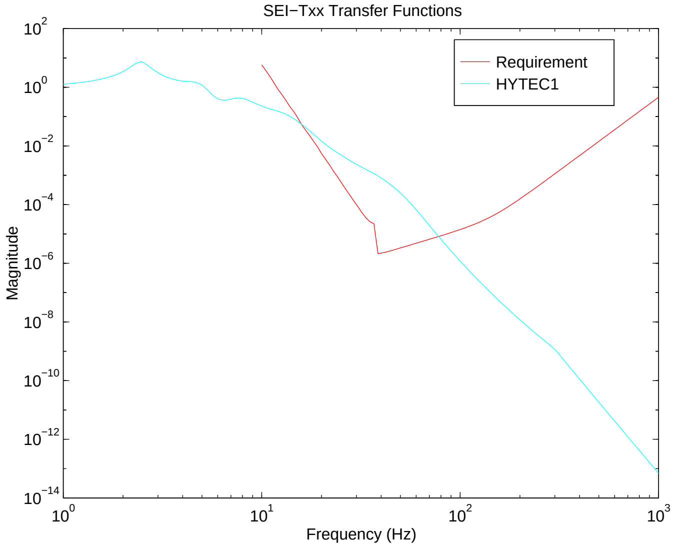

Figure 6: Comparison of SEI design horizontal transfer function with requirement.

The vertical-to-vertical transfer function also exceeds the requirement over a similar range of frequencies, as can be seen in Figure 7. The consequences of exceeding the seismic-isolation requirement can be seen more readily in Figure 8, which compares the predicted test-mass displacement for this design with the science requirement. The seismic noise transmitted to the test mass exceeds thermal noise at frequencies between 35-62 Hz.The frequency at which the total interferometer noise is a minimum, approximately 150 Hz, is not affected by the seismic noise.

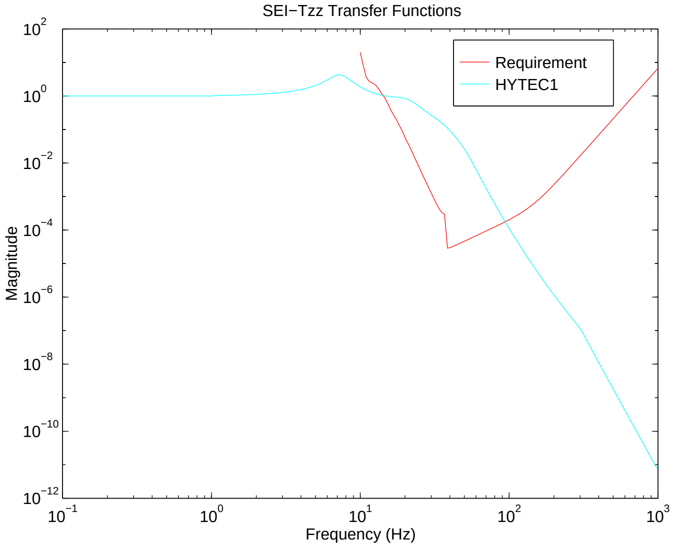

Figure 7: Comparison of SEI design vertical transfer function to requirement.

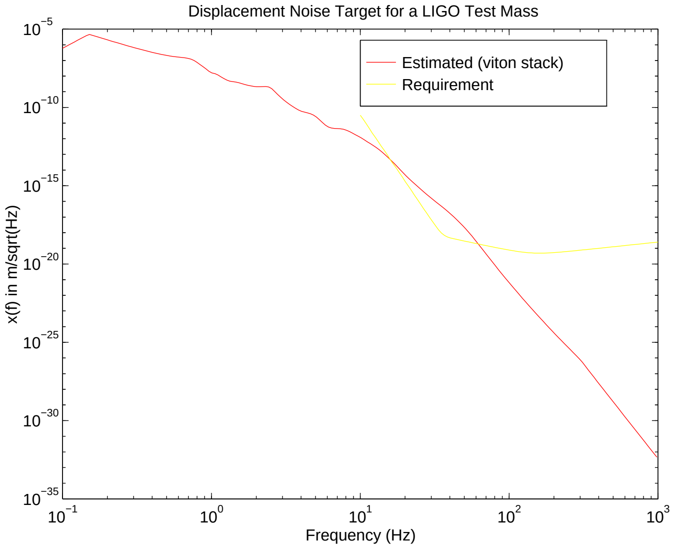

Figure 8: Comparison of LIGO test-mass displacement due to horizontal ground noise with the science requirement.

The sensitivity of searches for coalescing binaries are principally affected by the frequency at which interferometer noise is a minimum[1], whereas stochastic-background searches with LIGO

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[1] See, for example, Figure 7-1 of A. Gillespie, Thermal Noise in the Initial LIGO Interferometers (LIGO-P950006-00-I), April 1995.

will be more strongly influenced by the crossover frequency between seismic and thermal noise[1].

Figure 9: Estimated displacement of a LIGO test mass under combined effects of horizontal and vertical ground noise. The science requirement is also shown for comparison.

The influence of the vertical component of seismic noise, causing test-mass displacements along the optical axis because of nonorthogonality between local vertical and the light beam, is apparent in Figure 9. This effect raises the crossover frequency from 62 Hz to 75 Hz, but has no effect at the frequency of minimum interferometer noise.

4.3. Estimated Total Motion

The estimated total displacement and velocity along the optical axis of the cavity are the RMS values derived from the total test-mass displacement plotted in Figure 9. This gives $x_{\mathrm{RMS}} = 1.0 \mu\mathrm{m}$ and $v_{\mathrm{RMS}} = 1.2 \mu\mathrm{m/sec}$, which fulfills the lock-acquisition requirement.[2]

The lock-maintenance condition (based on the maximum force available from the SUS actuators before the output drivers saturate) requires that the RMS value of

$$\chi(s) = F^{-1}(s) T^{-1}_{\mathrm{SEI},xx}(s) \cdot [T_{\mathrm{SUS},xx}(s) T_{\mathrm{SEI},xx}(s) + T_{\mathrm{SUS},xy}(s) T_{\mathrm{SEI,yy}}(s)] \cdot G(s)$$

be less than 2.7 microns. Here *G(s)* is the composite ground-noise spectrum, $T_{\mathrm{SEI,ii}}(s)$ is the appropriate transer function of the seismic isolation (where i refers to x or y), $T_{\mathrm{SUS,ii}}(s)$ is the

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1. B. Allen, LIGO Seminar, January 1996.
2. Lock Acquisition requires that the RMS velocity be less than, or comparable to, 1 micron/sec when the test mass is damped by SUS actuators (pendulum *Q* less than 3) but not controlled by LSC.

appropriate transfer function of the suspension, and $F^{-1}(s)$ is the inverse of the saturated-force limit of the SUS actuators, normalized to unity at DC.[1]

The calculation using the above stack design yields

$$\chi(s) = 1.5\mu\mathrm{m} \leq 2.7\mu\mathrm{m}$$

which is sufficiently small to avoid saturation of the actuators once the interferometer has acquired lock.

4.4. Seismic-Isolation Support Structure

4.4.1. Support Structure

The SEI support structure provides a platform upon which the seismic isolation stages are placed. There are also provisions for height-adjustment shims, which are used to accomodate tolerances in components when the optical platform is initially leveled.[2] Details are TBD.

4.4.2. Support Beams

Two SEI support beams carry the load from the support structure, inside the vacuum chamber, through 34-cm-ID ports out to supporting structural members in the LVEA and VEA areas. These are tied together by two additional beams, external to the vacuum chamber. There are also cross beams inside the vacuum chamber that provide additional bracing and support the support structure. Bellows are used to provide a compliant vacuum connection between the penetrating beams and the vacuum chamber. The center-to-center spacing for the penetrating support beams is 1.676 m. Each beam has an overall length of approximately 3 m. Using a preliminary loaded-beam analysis, it was estimated that a 25-cm-OD, solid, SS beam would have a lowest resonance frequency above 20 Hz. This is not an efficient shape of support beam, but sets an upper bound of approximately 1200 kg on the support-beam mass. By using a more efficient I-beam or U-beam design with cross bracing, it is expected that the combined mass for support structure and support beams will be approximately 3000 kg.

4.4.3. Support-Beam Orientation

The orientation of the support structures/beams for the BSC chambers in the LVEA are illustrated in Figure 10. The beams outside of the chambers are supported on structural piers, depicted by the 75-cm-diameter circles at the four corners surrounding each chamber. These support structures are equipped with coarse actuators that are used to adjust position and angle of the optical plat-

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[1] See Appendix D of *Seismic Isolation Design Requirements Document* (LIGO-T960065-01-D) for further information.

[2] This allows the coarse adjustment mechanisms to be centered within their ranges upon initial alignment and also provides a means of compensating initial settlement of the spring elements.

forms, but only when the interferometer is not fully operational. The lines forming a square surrounding the structural piers denote the stay-clear zone for cross beams reinforcing the seismic isolation system. Two sides of the stay-clear zone (where the support structure is shown to overlap) block the region below. The other two sides are reserved for demountable structures (if needed) and are to be kept clear of other equipment.

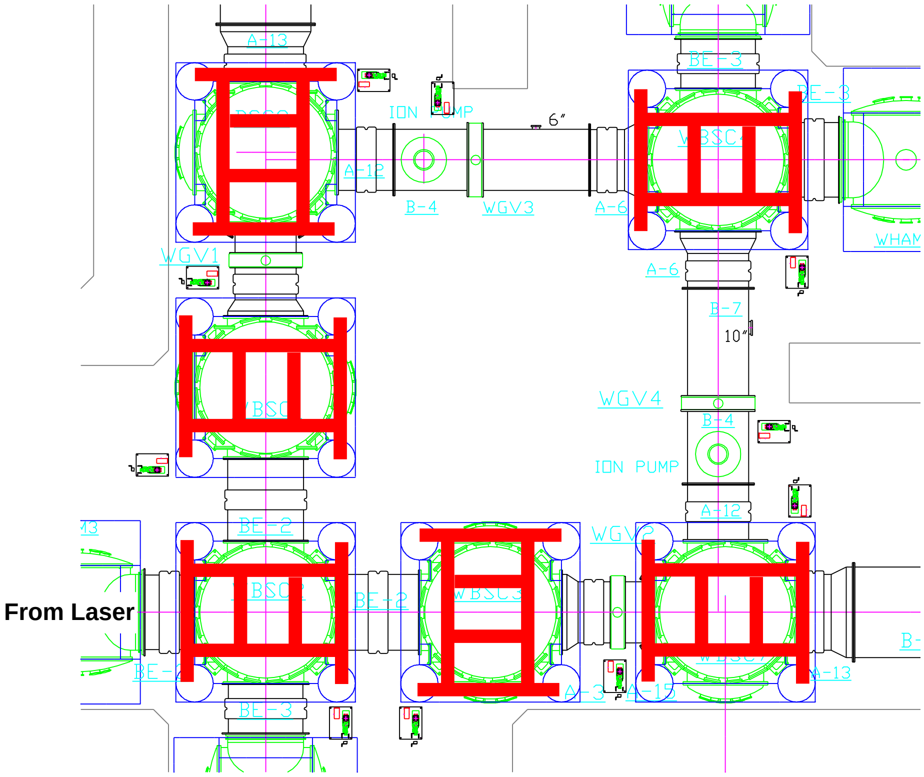

Figure 10: Support-structure layout in the LVEA at Hanford.

The layout for the mid-station VEA at Hanford is shown in Figure 11. and the layout for the end-stationVEA is illustrated in Figure 12. The support structures in these buildings can be lined up so that the the support beams are parallel to the beam-tube axis. This allows fine actuators, that are intended to operate while the interferometers are fully operational (under control of the LSC sys-

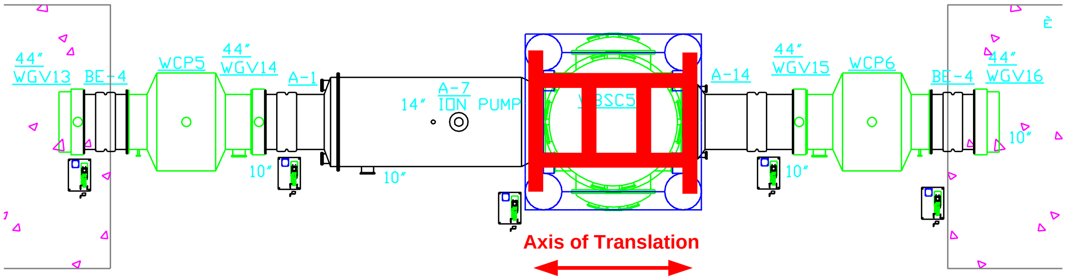

Figure 11: Support-structure layout in the mid-station VEA at Hanford.

tem) to function smoothly over a large range by using the most compliant axis of the support-beam bellows.

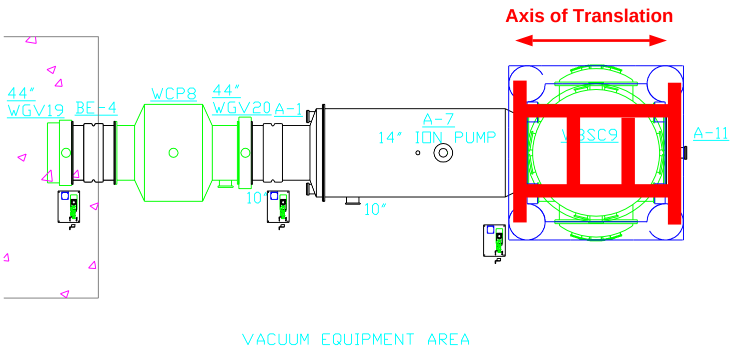

Figure 12: Support-structure layout in the Endstation-VEA.

The resonances in the support structure and beams will affect the seismic-isolation transfer functions shown in the previous section. These resonances will become better know during preliminary design, and will then be incorporated into theseismic-isolation transfer functions.

4.4.4. Support Piers

A 75-cm-OD space has been reserved for the support piers. The pier design will proceed as the loading from the seismic-isolation components becomes better defined during the preliminary design.

4.4.5. Support-Beam Bellows

4.5. Actuators

4.5.1. Coarse Actuators

Coarse actuators provide translations along x, y, and z directions and rotations about the z (vertical) axis without exceeding the constraint on rotation about the axes of the support-beam bellows. This constraint corresponds to about 90 microns of rotation at the flange, or approximately 0.8 mm of differential height adjustment between the two support beams. Such rotations are prevented in this design by mechanically constraining the z tranlations to be common mode, using ball screw jacks driven by a single geared-down stepper motor driving a common shaft. Translations in x and y directions are facilitated by geared-down stepper motors that drive x and y ball bearing slides, confined by a circular wall to which the motors are attached. Two geared stepper motors drive along the y direction. By changing the relative direction of these two motors, the user can select between y translation and rotation about the z axis. For the BSC chambers in the LVEA, which do not use fine actuators, the coarse actuators are similar to the HAM actuators sketched in Figure 17.

The BSC chambers in the mid-station and end-station VEAs require fine actuators which significantly complicates the arrangement of coarse actuators. Here the coarse actuator for vertical translation is above the fine actuator, whereas the ball-bearing plates and associated coarse actuators for x and y translational (and rotation about y) are mounted below the fine actuator.

4.5.2. Fine Actuators

Fine actuation, used to remove changes in interferometer arm lengths due to earth tides and (smaller) thermal effects while the interferometer is fully operational, is accomplished by using flexures to hang the support structure from a space-frame tower structure and driving lateral motion using a gas spring. The basic concept is roughly sketched in Figure 13.

The flexure is a 40-cm-long, 10-cm wide strip of metal, welded to blocks at both ends. The flexure is used to avoid sliding contacts and stiction. The upper block is attached through a jack screw to the tower, but is constrained not to rotate when the jack screw is used for coarse height adjustment. The bottom block attaches to the support-structure cross beam on one side, and the other side is bonded to a 10-cm-diameter, 5-cm-thick, gas piston which provides a force output proportional to temperature. The gas piston is essentially a bellows, capped on both end and filled with argon gas to a fixed pressure, near atmosphere. Heating/cooling of the gas causes expansion/contraction of the piston. The temperatures of gas pistons on opposing sides of the structure are driven in opposite directions to cause a translation in the x direction, but changes in ambient pressure cause no net movement (except for slight imbalances in the bellows). The strap-like flexures are compliant along the x direction but stiff along the y and z directions.

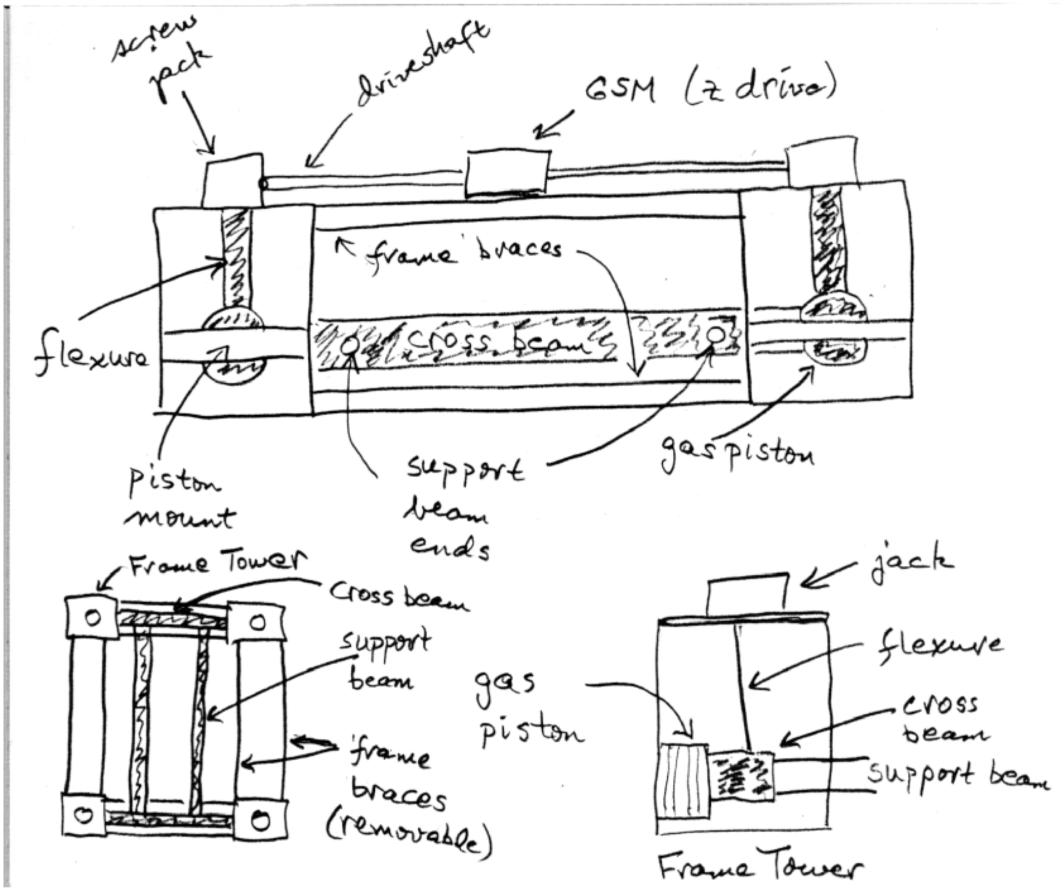

Figure 13: Rough sketch of fine actuator concept.

The flexure/gas-spring system has a resonant frequency for motion along x of approximately 1 Hz and requires a 4 K temperature at each piston (with properly opposing signs) to translate a total mass of 10,000 kg approximately 150 microns. Since the tidal effects have 12-hr and 24-hr periods, slew rate is not a problem.

4.5.3. Active Isolators

Active isolation is not planned for the initial interferometer. However a demountable structural module of TBD height will be installed to reserve space for later addition of active isolators, which may be part of future upgrades. Unlike the case with the HAM seismic isolation, the height of the isolators is not strongly constrained.

4.6. Down Structure

4.7. Optical Platform

The optical platform is a circular, disk-shaped structure, 1.5 m in diameter, whose other structural dimensions fulfill the requirements for resonant frequencies and *Q*s of internal vibrational modes. This provides a continuous, 57-cm-wide, annular, access space between the optical platform and the inner BSC wall. The upper and lower faces of the optical platform have a matrix of holes on 2.54-cm centers. Every fourth hole is a 1.25-cm-diameter hole (aligned axially on the two faces), which allows suspension fibers from a multiple suspension system to penetrate the platform without interference. The remaining holes are threaded to accept 1\4-20 screws (or metric equivalent, if required).

4.8. Mass Elements

TBD

4.9. Spring Elements

TBD

4.10. Alignment Dowels / Safety Bars

Removable alignment dowels will be used to align seismic-isolation components during installation, shimming and spring-element replacement. The dowels will mount to the support structure and will be demountable. During normal operation, safety bars (smaller in OD than the alignment dowels) will be used to constrain motion of the seismic-isolation components in the event of an earthquake or other catastrophe.

4.11. Clamps for In-Vacuo Cabling

5 HAM SEISMIC ISOLATION

5.1. Description

The HAM seismic isolation is similar in configuration to the seismic isolation installed into the 40-meter interferometer in 1992. It consists of a supporting structure, four stages of alternating mass and spring elements and a simple optical platform, without the complicated down structure used in the BSC chambers. The principal differences are the larger size, particularly the larger optical platform, and the more sophisticated actuator mechanisms. The HAM isolation only requires coarse adjustments when the interferometer is not fully operational. Figures 13 and 14 are identical sketches of the HAM seismic isolation, illustrating the standard names for components.

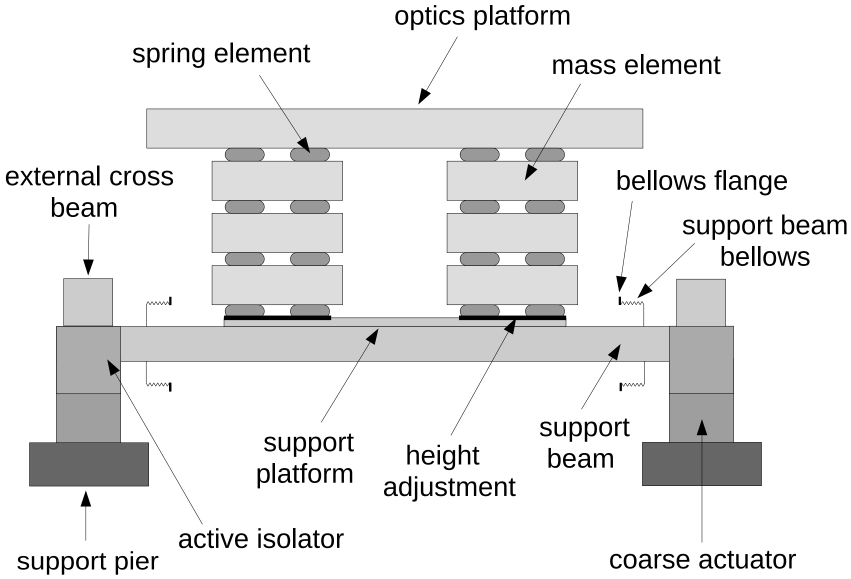

Figure 14: Naming convention for HAM-SEI parts

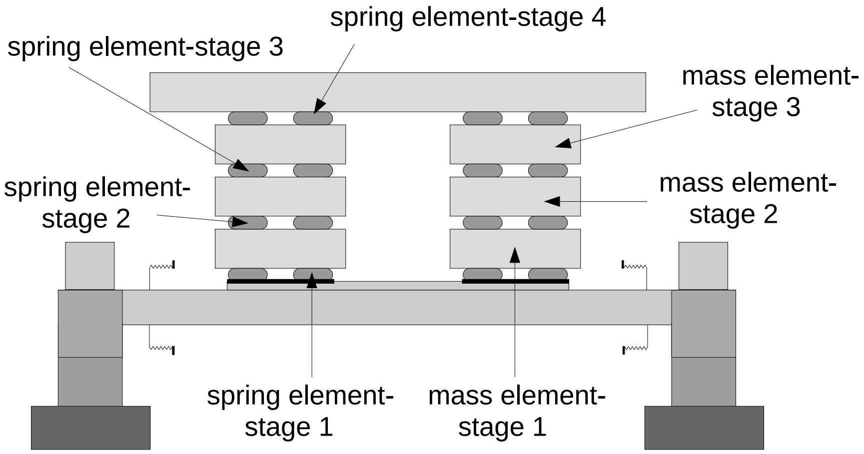

Figure 15: Naming convention for HAM-SEI parts

5.2. Seismic-Isolation Transfer Functions

Because the seismic-isolation performance does not depend critically on the masses of the optical platform or mass elements, the performance is expected to be comparable to the performance of the initial BSC seismic isolation. In Figure 15, the horizontal-to-horizontal transfer function for the HYTEC1-design seismic isolation is compared to the HAM-SEI requirement. The performance is better than required at all frequencies. Since the requirements for vertical-to-vertical isolation are much less stringent, this design will easily satisfy those criteria.

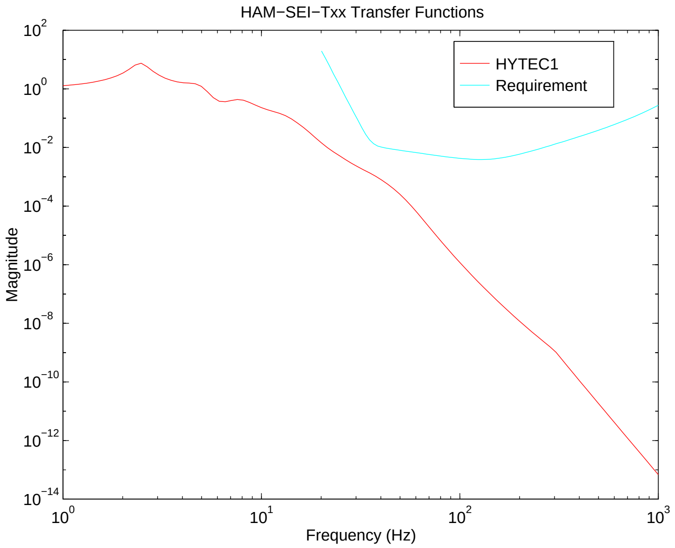

Figure 16: Comparison of SEI design horizontal-to-horizontal transfer function with requirement.

5.3. Estimated Total Motion

TBD

5.4. Seismic-Isolation Support Structure

5.4.1. Support Structure

This is similar in concept but not detail to the BSC support structure. The structures in the HAM chamber carry less mass and will be smaller in dimension. Height adjustment plates will be used here as for the BSC seismic isolation.

5.4.2. Support Beams

The support beams will be similarly configured to the BSC seismic isolation, except for size. The center-to-center spacing for the support beams that penetrate the vacuum envelope will be 1.37 m.

5.4.3. Support-Beam Orientation

The support beams that penetrate the vacuum will be parallel to the optical beam axis in all HAM chambers.

5.4.4. Support Piers

The support piers will be as small as possible, likely consisting of a cap plate and grouting. The piers accomodate variations in the height of the facility floor relative to the optical beam height.

5.4.5. Support-Beam Bellows

The support-beam bellows mate to the flanges of the 30-cm-OD nozzles on the HAM chambers and to the TBD-OD collars on the support beams. The bellows are TBD long.

5.5. Actuators

5.5.1. Coarse Actuators

A proposed coarse actuation concept for HAM-SEI is sketched roughly in Figure 16. The key requirements are that the coarse actuators provide translations along x, y, and z directions and rotations about the z (vertical) axis without exceeding the constraint on rotation about the axes of the support-beam bellows. This constraint corresponds to about 75 microns of rotation at the flange, or approximately 0.7 mm of differential height adjustment between the two support beams. Such rotations are prevented in this design by mechanically constraining the z tranlations to be common mode, using ball screw jacks driven by a single geared-down stepper motor driving a common shaft. Translations in x and y directions are facilitated by geared-down stepper motors that drive x and y ball bearing slides, confined by a circular wall to which the motors are attached. Two geared stepper motors drive along the y direction. By changing the relative direction of these two motors, the user can select between y translation and rotation about the z axis.

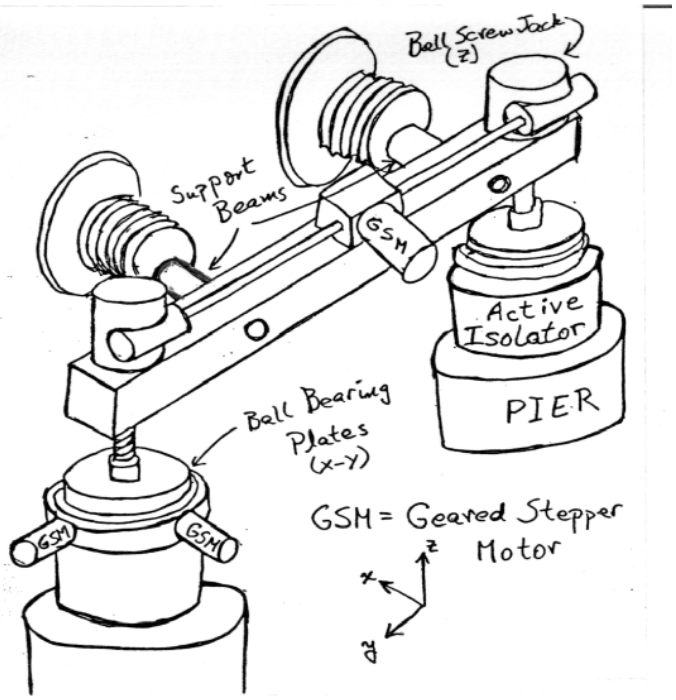

Figure 17: Sketch of coarse actuators for a HAM chamber.

The challenge in the design of this isolator will be to maximize the room available for later addition of active isolation, given the small vertical clearance between the facility floor and the 152-cm-ID nozzle along the optical axis of the chamber.

5.5.2. Active Isolators

Active isolation is not planned for the initial interferometer. However a demountable structural module of TBD height will be installed to reserve space for later addition of active isolators.

5.6. Optical Platform

The HAM optical platform will be 1.9-m long and 1.7-m wide, whose other structural dimensions fulfill the requirements for resonant frequencies and *Q*s of internal vibrational modes. This provides the largest area of mounting surface for optics, with sufficient clearance for cabling. (The HAM chamber provide adequate access through side doors and removable spool sections.) The upper faces of the optical platform have a matrix of holes on 2.54-cm centers, threaded to accept 1\4-20 screws (or metric equivalent, if required).

5.7. Mass Elements

TBD

5.8. Spring Elements

The spring elements for the HAM-SEI are identical to those used for the BSC-SEI. The number of elements will be adjusted according to the mass supported by each stage.

5.9. Alignment Dowels / Safety Bars

These serve the same function as similar units in the BSC-SEI. Details are TBD.

5.10. Clamps for In-Vacuo Cabling

TBD