Suspension Design Requirements for Advanced LIGO

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LSC Meeting, LLO
March 20-23, 2002

Administrivia

- Design Requirements Review held September 20, 2001
- Requirements are available in two LIGO documents:
  - » Cavity Optics Suspension Subsystem Design Requirements Document (LIGO-T010007-01)

    contains noise and control requirements
  - » Universal Suspension Subsystem Design Requirements Document (LIGO)

    contains duller stuff like vacuum and safety requirements

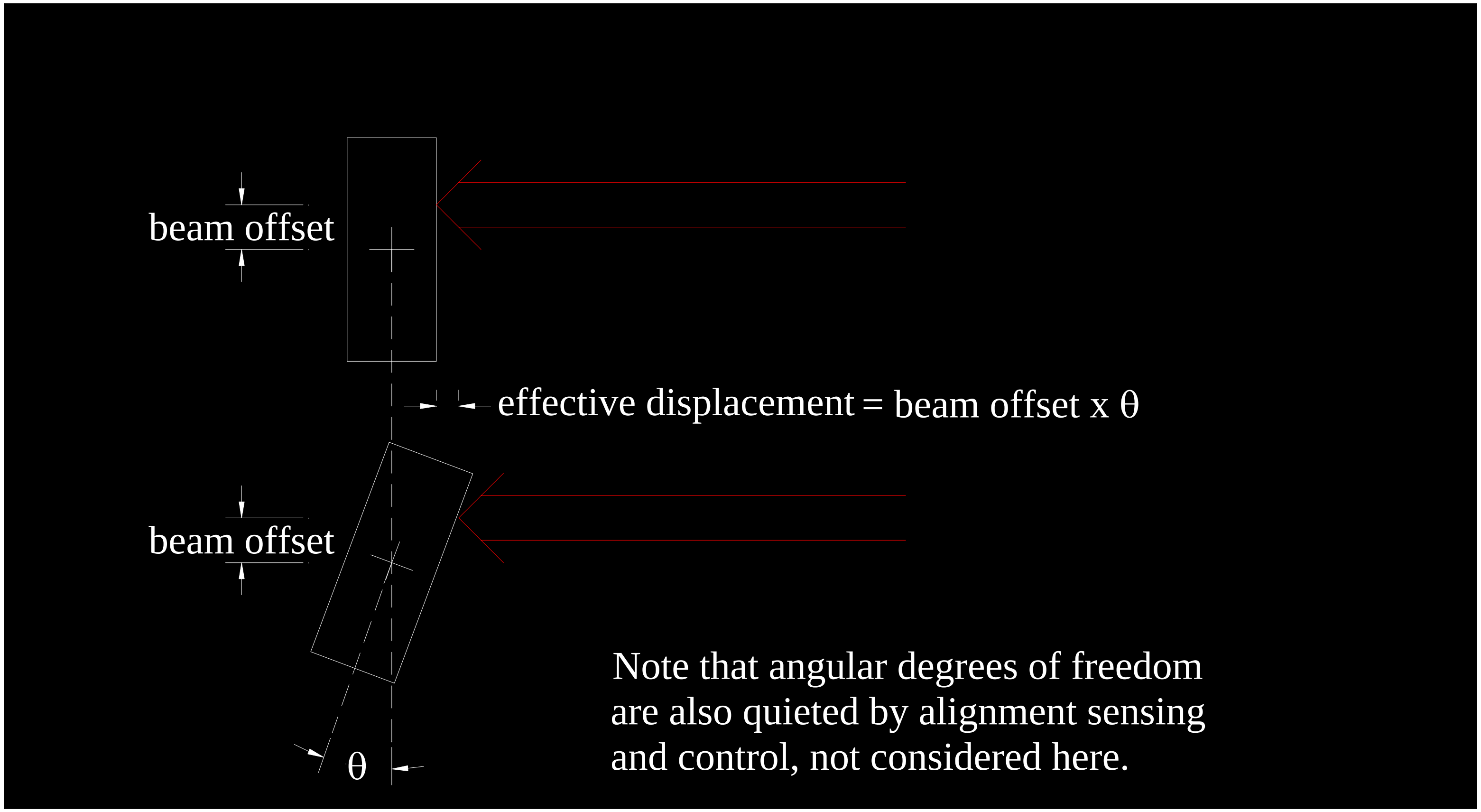
How Test Mass Requirements Were Set

- The test mass performance is <u>most critical</u> to the detector and relies most on the state of available art.
- Basic test mass noise spectrum requirement is a sum of expected internal thermal noise (with sapphire, with <u>lossless coatings</u>) and expected achievable suspension thermal noise
- All subsequent noise and isolation requirements derived from this spectrum
- For all other suspensions required performance is less, and expected to be ‘simply’ achievable with known technology.

Test Mass Suspension Requirements: Thermal Noise

Parameter	Value	Discussion
Longitudinal thermal noise due to test mass internal modes	5×10^{-20} m/√Hz at 10 Hz, falling roughly as 1/f	Figure 1; see section 3.2.1.2.1.
Longitudinal thermal noise due to pendulum motion	10^{-19} m/√Hz at 10 Hz, falling roughly as $(1/f)^2$	See section 3.2.1.2.2.
Pitch noise	5×10^{-18} rad/√Hz at 10 Hz, falling roughly as (1/f)	Requirement driven by offset of beam from center of mirror, alignment servo gain
Yaw noise	5×10^{-18} rad/√Hz at 10 Hz, falling roughly as (1/f)	Requirement driven by offset of beam from center of mirror, alignment servo gain
Vertical transverse thermal noise	1×10^{-16} m/√Hz at 10 Hz, falling roughly as $(1/f)^2$	Assumes vertical to longitudinal motion coupling of 10^{-3}
Horizontal transverse thermal noise	1×10^{-16} m/√Hz at 10 Hz, falling roughly as $(1/f)^2$	Based on .001 coupling to longitudinal motion

How Test Mass Angular Requirements Are Set



Test Mass Suspension Requirements: Seismic Isolation

Longitudinal	10^{-19} m/√Hz at 10 Hz, falling faster than $(1/f)^4$	
Horizontal transverse	3.3×10^{-17} m/√Hz at 10 Hz, falling faster than $(1/f)^4$	Assumes horizontal transverse to longitudinal motion coupling of 10^{-3}
Vertical transverse	3.3×10^{-17} m/√Hz at 10 Hz, falling faster than $(1/f)^4$	Assumes vertical to longitudinal motion coupling of 10^{-3}

No requirements currently set for angular isolation.

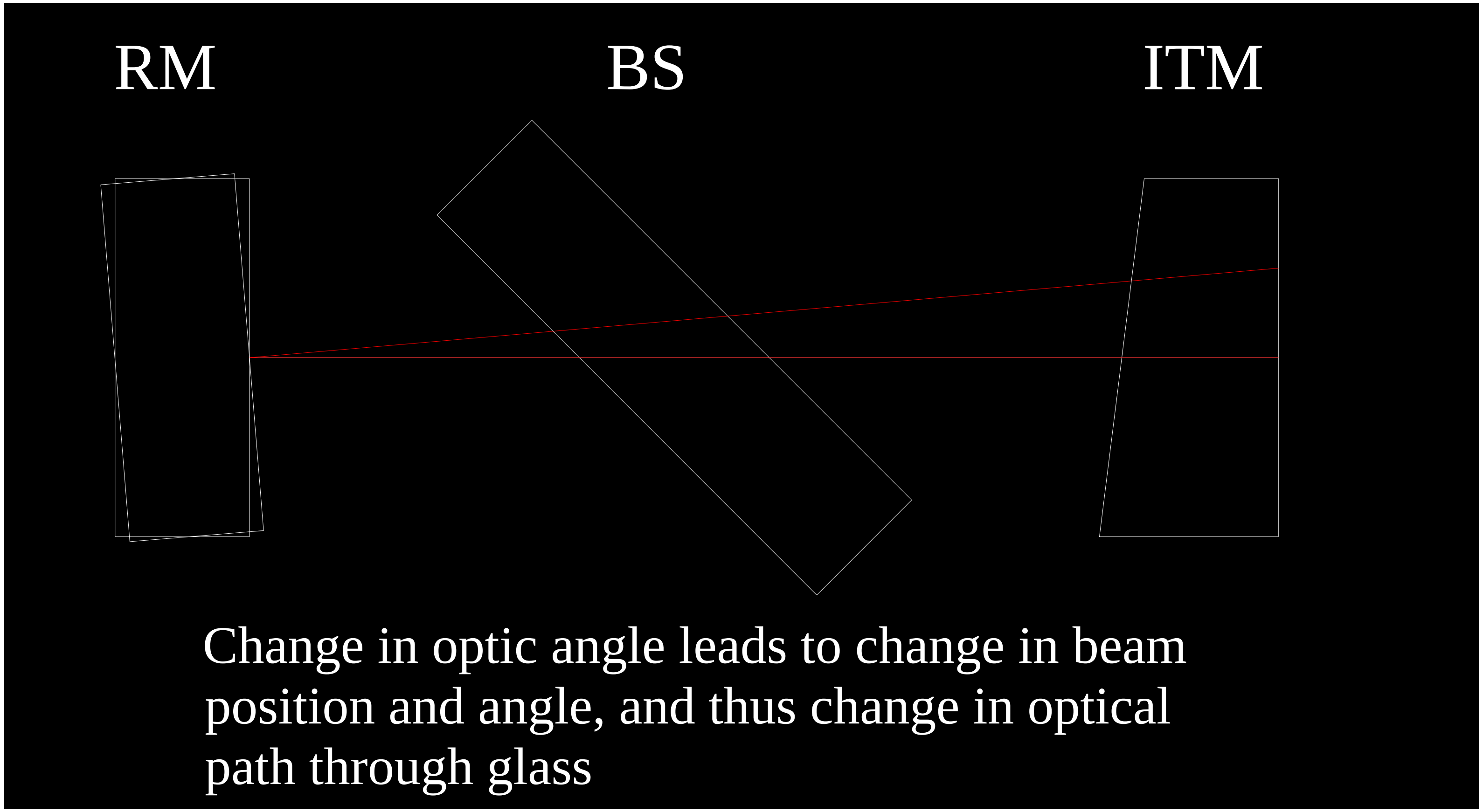
Cavity Optics other than Test Masses

Longitudinal motion requirements are derived by calculating couplings to GW signal port and comparing to test mass noise requirements (see "Auxiliary Suspended Optics Displacement Noise" by P. Fritschel*)

Noise from all sources (seismic, thermal, technical) are collectively required to sum to below the given longitudinal noise requirement

*LIGO-T010097-0-D

How Non-Test Mass Angular Requirements Are Set



Power and Signal Recycling Mirrors

Parameter	Value	Discussion
Longitudinal displacement noise due to all sources	4×10^{-16} m/√Hz at 10 Hz, falling to 1.5×10^{-17} m/√Hz at 100 Hz	See section 3.2.2.2.1 and the seismic isolation requirements
Pitch noise	4.4×10^{-14} rad/√Hz at 10 Hz, falling to 1.7×10^{-15} rad/√Hz at 100 Hz	Requirement driven by optical path length through wedged ITM
Yaw noise	2.7×10^{-14} rad/√Hz at 10 Hz, falling to 1×10^{-15} rad/√Hz at 100 Hz	Requirement driven by optical path length through beamsplitter
Vertical transverse displacement noise	2.2×10^{-13} m/√Hz at 10 Hz, falling to 8.3×10^{-15} m/√Hz at 100 Hz	Assumes coupling of vertical to longitudinal motion of .0018; see section 3.2.2.2.4
Horizontal transverse noise	4×10^{-13} m/√Hz at 10 Hz, falling to 1.5×10^{-14} m/√Hz at 100 Hz	See section 3.2.2.2.5

More About Recycling Mirrors

Predominant noise couplings:

PRM- laser frequency stability

SRM- noise sideband generation (RF readout, worst case)

By luck, these requirements are identical!

Since the signal and recycling mirrors also have the same materials and dimensions, we adopt a common design for both

Beamsplitter Suspensions

Parameter	Value	Discussion
Longitudinal displacement noise due to all sources	$2x10^{-17}$ m/√Hz at 10 Hz, falling to $6x10^{-19}$ m/√Hz at 100 Hz	See section 3.2.3.2.1
Pitch noise	$2.9x10^{-15}$ rad/√Hz at 10 Hz, falling to $8.6x10^{-17}$ m/√Hz at 100 Hz	Requirement driven by offset of beam from center of mirror and ITM vertical wedge; See section 3.2.3.2.2
Yaw noise	$1.3x10^{-15}$ rad/√Hz at 10 Hz, falling to $4x10^{-17}$ rad/√Hz at 100 Hz	Requirement driven by optical path length through beamsplitter; See section 3.2.3.2.3
Vertical transverse displacement noise	$2.2x10^{-15}$ m/√Hz at 10 Hz, falling to $6.7x10^{-17}$ m/√Hz at 100 Hz	Assumes vertical to longitudinal motion coupling of .009; see section 3.2.3.2.4
Horizontal transverse noise	$2x10^{-14}$ m/√Hz at 10 Hz, falling roughly as 1/f	See sections 3.2.3.2.5

Predominant coupling: direct coupling to dark fringe output

Folding Mirror Suspensions

Parameter	Value	Discussion
Longitudinal displacement noise due to all sources	$2x10^{-17}$ m/√Hz at 10 Hz, falling to $6x10^{-19}$ m/√Hz at 100 Hz	See section 3.2.4.2.1 and the seismic isolation requirements
Pitch noise	$4x10^{-15}$ rad/√Hz at 10 Hz, falling to $1.2x10^{-16}$ rad/√Hz at 100 Hz	Requirement driven by offset of beam from center of mirror
Yaw noise	$1.3x10^{-15}$ rad/√Hz at 10 Hz, falling to $4x10^{-17}$ rad/√Hz at 100 Hz	Requirement driven by optical path length through beamsplitter
Vertical transverse displacement noise	TBD	Vertical to longitudinal motion coupling TBD; see sections 3.2.4.2.4-5
Horizontal transverse noise	$2x10^{-14}$ m/√Hz at 10 Hz, falling to $6x10^{-16}$ m/√Hz at 100 Hz	See sections 3.2.4.2.4-5

Predominant coupling: direct coupling to dark fringe output

(same as beamsplitter)

Mode Cleaner Mirrors

Parameter	Value	Discussion
Longitudinal displacement noise due to all sources	$3x10^{-17}$ m/√Hz at 10 Hz, falling to $3x10^{-19}$ m/√Hz at 100 Hz	See section 3.2.5.2.1
Pitch noise	$3x10^{-14}$ rad/√Hz at 10 Hz, falling to $3x10^{-16}$ rad/√Hz at 100 Hz	Requirement driven by offset of beam from center of mirror
Yaw noise	$3x10^{-14}$ rad/√Hz at 10 Hz, falling to $3x10^{-16}$ rad/√Hz at 100 Hz	Requirement driven by offset of beam from center of mirror
Vertical transverse displacement noise	$3x10^{-14}$ m/√Hz at 10 Hz, falling to $3x10^{-15}$ m/√Hz at 100 Hz	Assumes vertical to longitudinal motion coupling of .001; see sections 3.2.5.2.4
Horizontal transverse noise	$3x10^{-14}$ m/√Hz at 10 Hz, falling to $3x10^{-15}$ m/√Hz at 100 Hz	See sections 3.2.5.2.5

Predominant coupling: laser frequency noise

Local Damping

- All modes are required to have a settling time less than 10 seconds (save vertical bounce and roll of the bottom mass).
- Damping must have strength tunable down to zero, or at least to a level where it does not exceed displacement noise requirements.

General Requirements

The usual important yet unexciting things… the suspensions must:

- be LIGO vacuum compatible
- not be too heavy (may be tough for FM and ITM in shared BSC)
- fit in the chamber
- not block or scatter light
- have well-documented assembly and test procedures
- not break every ten days
- etc.

Work to be Done (on Requirements)

- The vertical bounce frequency of the test mass is now required to be less than 10Hz. This may change (see low-frequency cutoff white paper).
- Electric charge noise requirements not yet known.
- Excess noise requirements difficult to quantify.
- Requirements must be revised if fused silica test masses are chosen.
- Angular noise requirements need to be evaluated further.
- All advice will be gratefully considered!