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HAM Auxiliary Suspensions Design Requirements

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Contents

Introduction

1.1 Purpose

Purpose of this document is that of summarizing the design requirements for the HAM Auxiliary suspensions, and links to the applicable documents. It is intended as a reference for verification that the proposed HAM Auxiliary suspensions design is indeed compliant.

1.2 Scope

This document corrects and extends LIGO-T0900354-v2. It addresses HAM Aux requirements divided in the following groups:

- Generic mechanical requirements:
    - Optic size
    - Clear aperture
    - Safety stops
    - Mounting interfaces
    - Cable routing
    - DC pointing resolution and range without AOSEMs
- Performance requirements:
    - DC pointing range with AOSEMs
    - Resonant frequencies
    - in- and out-of-band beam pointing noise
    - in band displacement noise
    - Passive damping of non-controlled degrees of freedom

1.3 Acronyms

AOSEMS	Another Optical Sensor Electromagnetic Motor
HAM	Horizontal Access Module
HAM Aux	HAM Auxiliary Suspensions
IO	Input Optic
ISC	Instrument Sensing and Control
PMMT	Pre-Mode Matching Telescope mirror
SM	Steering Mirror

1.4 Applicable Documents

1.4.1 LIGO Documents

LIGO-T0900142-v2, “Pointing requirements for Advance LIGO”

LIGO-T0900354-v2, “aLIGO HAM Aux suspension (SOS) requirements from IO”

LIGO-T020020-v2, “Advanced LIGO Input Optics Design Requirements Document”

Assumptions

The HAM auxiliary (HAM Aux) suspensions are used for suspended mirrors located in the IO on HAM 2 (straight) and HAM 8 (folded). Mirrors suspended in HAM Aux suspensions are steering and focusing mirrors.

HAM Aux suspensions are not planned for used in any aLIGO cavities.

1.5 HAM Aux Mechanical requirements

1.5.1 Optic size

The HAM Aux must be able to accommodate optics with a diameter of 75 +1/-0 mm and an horizontal wedge of 0.5 deg. The thickness of the optics on the thickest location is 25 +0/0.5 mm.

1.5.2 Clear aperture

The maximum nominal angle of incidence on the optic is expected to be 53.2 deg on the horizontal plane, 0 on the vertical plane. The maximum beam diameter at the 10 ppm level is expected to be 10.56 mm.

The suspension must guarantee that under this circumstances none of the incident, reflected or transmitted beam is clipped.

1.5.3 Safety stops

The suspension structure should provide safety stops for the optic in all degrees of freedom (except rotation around the optical axis).

As space on some of the HAM Table is tight, these safety stops should be easily accessible from the front, back or lateral faces.

1.5.4 Mounting interfaces

The support structure should provide the following mounting interfaces:

- AOSEMs support plate, with adjusting capability for centering once the optic is suspended.
- Tapped holes on the front side (HR of the optic) for baffles installation

1.5.5 Cable routing

Due to tight space and abundance of beams nearby the suspensions, AOSEMs' cables are requested to be routed to the table along the structure to avoid the risk of clipping a beam.

Wire routing should be defined and necessary support hardware (i.e. cable clamps) provided, as well as necessary tapped holes on the suspension.

1.5.6 Mechanical alignment

The suspension arrangement should be able to compensate for variations in the center of mass of the optic due to the machining tolerances mentioned in 1.5.1.

Moreover, to reduce the DC torque required from the AOSEMs, it should be possible to align mechanically the optic in pitch and yaw at the level of 1 mrad or better.

1.6 Performance requirements

1.6.1 Pointing range

Beam pointing using the AOSEMs has to be able to correct and fine tune the alignment performed using mechanical means. Therefore, the range has to be bigger than the precision requested for the mechanical alignment, i.e. 1 mrad.

1.6.2 Resonant frequencies

Resonant frequencies of modes affecting the pitch, yaw and x degrees of freedom are requested to be below the aLIGO band, i.e. < 10 Hz.

Although the coupling with the beam jitter noise is expected to be much weaker, other degrees of freedom are recommended to comply with the same requirement

1.6.3 In band displacement noise

Displacement noise of the mirrors translates in variation of the path-length L and consequent phase noise

$$S_\phi^{1/2} = \frac{2\,\pi}{\lambda} S_L^{1/2}$$

The phase noise is in turn related to the frequency noise as:

$$\nu(t) \equiv \frac{1}{2\pi}\frac{d\phi(t)}{dt} \qquad \Rightarrow \qquad S_\nu^{\frac{1}{2}}(f) = \frac{1}{2\pi}\omega\, S_\phi^{1/2}(f) = f\, S_\phi^{1/2}(f) = f\,\frac{2\,\pi}{\lambda} S_L^{1/2}$$

The requirement for the frequency noise introduced by components after the mode cleaner is found in LIGO-T020020-v2 in terms of its value at 10 Hz and 100 Hz:

$$S_\nu^{\frac{1}{2}} \leq 5\cdot 10^{-3}\frac{Hz}{\sqrt{Hz}} \ \text{@}\ 10Hz$$
$$S_\nu^{\frac{1}{2}} \leq 1\cdot 10^{-4}\frac{Hz}{\sqrt{Hz}} \ \text{@}\ 100\,Hz$$

Between the input mode cleaner and the power recycling mirror, the aLIGO input beam is reflected on 4 mirror installed on HAM Aux suspensions (SM1, PMMT1, PMMT2 and SM2). Neglecting correction due to non-zero angle of incidence, the displacement of a single mirror by δx translates in a variation of the optical pathlength δL = 2·δx. If we consider the x displacements of these mirrors to be independent, from the above relations we can obtain the requirement for a single mirror:

$$S_{x,single}^{\frac{1}{2}} = \frac{1}{4}S_L^{\frac{1}{2}} = \frac{1}{f}\frac{\lambda}{8\,\pi}S_\nu^{\frac{1}{2}} \leq \frac{1}{10\,Hz}\frac{\lambda}{8\,\pi}5\cdot 10^{-3}\frac{Hz}{\sqrt{Hz}} \approx 2.1\cdot 10^{-11}\frac{m}{\sqrt{Hz}} \ \text{@}\ 10\,Hz$$
$$\leq \frac{1}{100\,Hz}\frac{\lambda}{8\,\pi}1\cdot 10^{-4}\frac{Hz}{\sqrt{Hz}} \approx 4.2\cdot 10^{-14}\frac{m}{\sqrt{Hz}} \ \text{@}\ 100\,Hz$$

1.6.4 In band angular noise

The overall jitter in the IO beam above 10 Hz, expressed in term of the TEM10 mode amplitude, has to satisfy the requirement (see LIGO-T0900142-v2):

$$S_{\epsilon 10}^{1/2} \leq 10^{-8} \sqrt{1+\left(\frac{100\ Hz}{f}\right)^4} \frac{1}{\sqrt{Hz}}$$

When a gaussian beam propagation direction changes by an angle 2α with respect to the propagation axis defining the TEM_{00} mode, the relative TEM_{10} component become $\varepsilon_{10} = 2\ \alpha\ \pi\ w/\ \lambda$, where λ is the wavelength and w the beam radius. If we call α the rotation of a mirror with respect the its nominal position (giving a rotation of the beam direction of 2α), the above requirement becomes:

$$S_{\alpha}^{1/2} \leq \frac{\lambda}{2\ \pi\ w}\ 10^{-8} \sqrt{1+\left(\frac{100\ Hz}{f}\right)^4} \frac{rad}{\sqrt{Hz}}.$$

Between the input mode cleaner and the power recycling mirror, the aLIGO input beam is reflected on 4 mirror installed on HAM Aux (SM1, PMMT1, PMMT2 and SM2). We can consider the pitch and yaw of these mirrors to be all independent (not exactly true, as they are on the same platform, but a good enough approximation considering that they are in different places and with completely different orientations) and assume that the beam size is almost the same on all the 4 mirrors. The total noise is given by $S_{\alpha,tot}^{1/2} = 2\ S_{\alpha,\ single}^{\ 1/2}$, and the requirement on the single mirror angular noise becomes:

$$S_{\alpha,single}^{1/2} \leq \frac{\lambda}{4\ \pi\ w}\ 10^{-8} \sqrt{1+\left(\frac{100\ Hz}{f}\right)^4} \frac{rad}{\sqrt{Hz}} = 6 \cdot 10^{-13} \sqrt{1+\left(\frac{100\ Hz}{f}\right)^4} \frac{rad}{\sqrt{Hz}}$$

Where a beam size of w = 1.5 mm has been assumed.

1.6.5 Out of band angular noise

At low frequency (about 0.1 Hz and below) ISC is planning to take care of the suppression of the IO beam jitter with a global servo loop. In the 0.1-10 Hz band, the RMS jitter has to be maintained below a safe value by a local control loop. This value has been set to an RMS of 1 µrad, based on a preliminary study by the ISC group (M. Evans, e-mail to G. Mueller and P. Fritschel, 7 June 2010).

Suspension transfer functions and AOSEMs' sensing and actuation performances have to be adequate to satisfy this requirement.

1.6.6 Passive damping

Both for easiness of alignment and to avoid too big oscillations even if below the measurement band, the degrees of freedom not directly controlled by the AOSEMs (i.e. roll, bouncing and lateral swing) have to be passively damped. ISC suggested obtaining a Q of a few tens on each of these resonances