**Type-A Vibration Isolation System modeling**

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**0. Introduction**

**1. Seismic Noise Model**

M. Beker measured Kamioka seismic spectrum in 2010, using a Trillium 240 seismometer.

Araya measured the spectrum in 2007 with a CMG-3 seismometer on an extremely stormy day.

(Measured spectrum seems to be limited by instrumental noise above 1 Hz)



K. Yamamoto measured CLIO inner shield vibration in 2007.

Measured vibration level was 2-4 orders of magnitude larger than the ground vibration level, above 10 Hz.



Although the vibration level of actual cryostat is unknown, the following vibration level is assumed:

 \* IP base vibration: M.Beker’s mean spectrum

 \* Cryo bar vibration: CLIO inner shield spectrum

**2. Type-A SAS part parameters (COMMON IN ALL MODELS)**

**Filter 0 (F0)**

M=474 kg, Ix=60 kgm2, Iy=120 kgm2, Iz=60 kgm2

IP position from center = 600 mm

IP resonant frequency (translation) = 30 mHz, IP COP Effect: -80 dB

GAS resonant frequency = 0.2 Hz

**Magnetic Damper (MD)**

M=30kg, Ix=1.3kgm2, Iy=2.5kgm2, Iz=1.3kgm2

Suspended from F0 by 3 wires

 Wire length = 1.8 m, Material: C70 steel

Upper suspension point vertical position from C.o.M. = -120 mm

Lower suspension point vertical position from C.o.M. = +5 mm

Wire horizontal distance from center = 400 mm

Damping coefficient (between MD and F1)

Horizontal(x,z): 18 N/(m/s), vertical(y): 45 N/(m/s)

Pitch/Roll: 2.5 Nm/(rad/s), Yaw: 2 Nm/(rad/s)

**Standard Filter 1 (F1)**

M=104kg, Ix=4.4kgm2, Iy=7.3kgm2, Iz=4.4 kgm2

Suspended from F0 by a single wire

Wire length = 2.271 m, Material: Maraging steel

Upper suspension point vertical position from C.o.M. = -5 mm

Lower suspension point vertical position from C.o.M. = +5 mm

GAS resonant frequency = 0.25 Hz

**Standard Filter 2 (F2)**

M=90kg, Ix=4.0kgm2, Iy=6.4kgm2, Iz=4.0kgm2

Suspended from F1 by a single wire

Wire length = 2.271 m, Material: Maraging steel

Upper suspension point vertical position from C.o.M. = -5 mm

Lower suspension point vertical position from C.o.M. = +5 mm

GAS resonant frequency = 0.25 Hz

**Standard Filter 3 (F3)**

M=90kg, Ix=4.0kgm2, Iy=6.4kgm2, Iz=4.0kgm2

Suspended from F2 by a single wire

Wire length = 2.271 m, Material: Maraging steel

Upper suspension point vertical position from C.o.M. = -5 mm

Lower suspension point vertical position from C.o.M. = +5 mm

GAS resonant frequency = 0.25 Hz

**3. Hot Platform Type-B like model**

**3.1. Parameters**

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**Bottom Filter / Platform (PF)**

M=145.5kg, Ix=8 kgm2, Iy=12 kgm2, Iz=8 kgm2,

Suspended from F3 by a single wire

Wire length = 2.373 m, Material: CuBe

Upper suspension point vertical position from C.o.M. = -5 mm

Lower suspension point vertical position from C.o.M. = +5 mm

GAS resonant frequency = 0.25 Hz

(Room temperature)

**Intermediate Recoil Mass (IR)**

M=44.9kg, Ix=0.561kgm2, Iy=0.815 kgm2, Iz=0.899 kgm2,

Suspended from PF by 3 wires with vertical springs

Wire length = 3.630 m, Material: CuBe

Upper suspension point vertical position from C.o.M. = -75 mm

Lower suspension point vertical position from C.o.M. = +75 mm

Wire horizontal distance from center = 120 mm

Spring resonant frequency = 5 Hz

**Intermediate Mass (IM)**

M=53.2kg, Ix=0.352kgm2, Iy=0.677 kgm2, Iz=0.474 kgm2,

Suspended from PF by a single wire

Wire length = 3.785 m, Material: CuBe

Upper suspension point vertical position from C.o.M. = -5 mm

Lower suspension point vertical position from C.o.M. = -4 mm

**Recoil Mass (RM)**

M=33.7kg, Ix=0.433kgm2, Iy=0.433 kgm2, Iz=0.642 kgm2,

Suspended from PF by 4 wires

Wire length = 0.3 m, Material: CuBe

Upper suspension point vertical position from C.o.M. = 0 mm

Lower suspension point vertical position from C.o.M. = 0 mm

X-separation of wire and C.o.M. = 145 mm

Z-separation of wire and C.o.M. = 25 mm

Spring resonant frequency = 5 Hz

**Test Mass (TM)**

M=22.7kg, Ix=0.111kgm2, Iy=0.111 kgm2, Iz=0.137 kgm2,

Suspended from PF by 4 wires

Wire length = 0.3 m, Material: Sapphire

Upper suspension point vertical position from C.o.M. = 0 mm

Lower suspension point vertical position from C.o.M. = 0 mm

X-separation of wire and C.o.M. = 110 mm

Z-separation of wire and C.o.M. = 15 mm

Spring resonant frequency = 20 Hz

**Heat links Between Suspension and Cryo Bars:**

Semi-elliptic, pure aluminum (6N grade), thickness=1mm

Major radius = 400 mm (X, horizontal and perpendicular to beam axis)

Minor radius = 200 mm (Y, Vertical axis)

DC spring constant per one wire:

kx=0.387 N/m, ky=0.040 N/m, kz=0.012 N/m

First violin mode: 2 Hz, second mode: 8 Hz

Attached to IR from both sides, 4 wires for each connection

 

Vibration transmissivity of heat link (connected to a 120 kg free mass)

**Heat links Between IR and IM:**

U-shape, pure aluminum (6N grade), thickness=1mm

Straight line length (vertical axis) = 100mm, semicircle (X-Y plane) diameter = 25 mm

DC spring constant per one wire:

kx=5.04 N/m, ky=79.4 N/m, kz=2.64 N/m

First violin mode: 30 Hz, second mode: 60 Hz

Attached from both sides, 10 wires for each connection



Vibration transmissivity of heat link (connected to a 120 kg free mass)

**3.2. Model basic information**



**3.3. Vibration from heat links**

Assume 1% coupling from vertical components.



(HL\_BlikeHotPF\_default.m)

**Identification of resonant peaks:**

15 Hz: violin mode of HL from cryo bars

25 Hz: inner shield vibration

60 Hz: violin mode of HL between IR and IM

If the heat links between IR and IM are removed:



(HL\_BlikeHotPF\_redHL.m)

**3.4. Suspension Thermal Noise**

Assume 0.33% coupling from vertical components.

**Default Loss Angle:**

Sapphire fiber: 2E-7, TM Spring: 2E-7

CuBe fiber: 5E-6, RM Spring; 1E-5, Heat Link: ~1E-2

GAS filter: (Q=10)



(TN\_BlikeHotPF\_default.m)

**Identification of resonant peaks:**

5.1 Hz: TM pitch mode

5.7 Hz: RM vertical

23.7 Hz: TM vertical

60 Hz: Heat link between IM and IR

**Contribution:**

Sapphire fibers mainly contribute to the horizontal thermal noise.

Bottom GAS filter mainly contributes to the vertical thermal noise.



(TN\_BlikeHotPF \_Contribute \_H.m)



(TN\_BlikeHotPF \_Contribute \_V.m)

**Changing TM Spring Stiffness:**



(TN\_BlikeHotPF \_TMspr \_H.m)



(TN\_BlikeHotPF \_TMspr \_V.m)

In no spring case, vertical thermal noise spectrum has a huge peak at 140 Hz, which is not shown in the upper figure.

**3.5. Controllability**

**3.6. Control Noise**

**4. LIGO like Model**

**4.1. Parameters**



**Bottom Filter (F4)**

M=80.1kg, Ix=4.4 kgm2, Iy=6.0 kgm2, Iz=4.4 kgm2,

Suspended from F3 by a single wire

Wire length = 2.373 m, Material: CuBe

Upper suspension point vertical position from C.o.M. = -5 mm

Lower suspension point vertical position from C.o.M. = +5 mm

GAS resonant frequency = 0.25 Hz

(Room temperature)

**Platform Recoil Mass (PR)**

M=38.2kg, Ix=0.40 kgm2, Iy=0.63kgm2, Iz=0.80 kgm2,

Suspended from F4 by 3 wires with springs

Wire length = 3.23 m, Material: CuBe

Upper suspension point vertical position from C.o.M. = -75 mm

Lower suspension point vertical position from C.o.M. = +75 mm

Wire horizontal distance from center = 150 mm

Spring resonant frequency = 5 Hz

**Platform (PF)**

M=65.5kg, Ix=0.78 kgm2, Iy=0.91kgm2, Iz=0.35 kgm2,

Suspended from F4 by a single wire

Wire length = 3.385 m, Material: CuBe

Upper suspension point vertical position from C.o.M. = -5 mm

Lower suspension point vertical position from C.o.M. = +5 mm

**Intermediate Recoil Mass (IR)**

M=35.4kg, Ix=0.16kgm2, Iy=0.20 kgm2, Iz=0.22 kgm2,

Suspended from PF by 4 wires with vertical springs

Wire length = 0.40 m, Material: CuBe

Upper suspension point vertical position from C.o.M. =0 mm

Lower suspension point vertical position from C.o.M. =0 mm

Upper suspension point Z-translation from C.o.M. = - 80 mm

X-separation of wire and C.o.M. = 140 mm

Z-separation of wire and C.o.M. = 30 mm

Spring resonant frequency = 3 Hz

**Intermediate Recoil Mass (IM)**

M=35.4kg, Ix=0.16kgm2, Iy=0.20 kgm2, Iz=0.22 kgm2,

Suspended from PF by 4 wires with vertical springs

Wire length = 0.40 m, Material: CuBe

Upper suspension point vertical position from C.o.M. =0 mm

Lower suspension point vertical position from C.o.M. =0 mm

Upper suspension point Z-translation from C.o.M. = + 80 mm

X-separation of wire and C.o.M. = 110 mm

Z-separation of wire and C.o.M. = 30 mm

Spring resonant frequency = 3 Hz

**Recoil Mass (RM)**

M=22.7kg, Ix=0.24kgm2, Iy=0.24 kgm2, Iz=0.40 kgm2,

Suspended from IR by 4 wires

Wire length = 0.3 m, Material: CuBe

Upper suspension point vertical position from C.o.M. = 0 mm

Lower suspension point vertical position from C.o.M. = 0 mm

X-separation of wire and C.o.M. = 145 mm

Z-separation of wire and C.o.M. = 15 mm

Spring resonant frequency = 5 Hz

**Test Mass (TM)**

M=22.7kg, Ix=0.111kgm2, Iy=0.111 kgm2, Iz=0.137 kgm2,

Suspended from PF by 4 wires

Wire length = 0.3 m, Material: Sapphire

Upper suspension point vertical position from C.o.M. = 0 mm

Lower suspension point vertical position from C.o.M. = 0 mm

X-separation of wire and C.o.M. = 110 mm

Z-separation of wire and C.o.M. = 15 mm

Spring resonant frequency = 20 Hz

**Heat links Between Suspension and Cryo Bars:**

Semi-elliptic, pure aluminum (6N grade), thickness=1mm

Major radius = 400 mm (X, horizontal and perpendicular to beam axis)

Minor radius = 200 mm (Y, Vertical axis)

DC spring constant per one wire:

kx=0.387 N/m, ky=0.040 N/m, kz=0.012 N/m

First violin mode: 2 Hz, second mode: 8 Hz

Attached to IR from both sides, 4 wires for each connection

**4.2. Model basic information**



**4.3. Vibration from heat links**

Assume 1% coupling from vertical components.



**4.4. Suspension thermal noise**

Assume 0.3% coupling from vertical components.

**Default Loss Angle:**

Sapphire fiber: 2E-7, TM Spring: 2E-7

CuBe fiber: 5E-6, IM,IR,RM Spring; 1E-5, Heat Link: ~1E-2

GAS filter: 1E-1(Q=10)





(TN\_LIGOlike \_default \_cont \_H.m)



(TN\_LIGOlike \_default \_cont \_V.m)

**4.9. Concerns**

\* Is it possible to put TM 8 cm away from center line?

**5. Type-B like Model**



**5.1. Parameters**

**Filter 4 (F4)**

M=84.0kg, Ix=4 kgm2, Iy=6.4 kgm2, Iz=4 kgm2,

Suspended from F3 by a single wire

Wire length = 2.373 m, Material: CuBe

Upper suspension point vertical position from C.o.M. = -5 mm

Lower suspension point vertical position from C.o.M. = +5 mm

GAS resonant frequency = 0.25 Hz

(Room temperature)

**Platform (PF)**

M=61.5kg, Ix=2.4 kgm2, Iy=3.8 kgm2, Iz=2.4 kgm2,

Suspended from F4 by a single wire

Wire length = 3.385 m, Material: CuBe

Upper suspension point vertical position from C.o.M. = -5 mm

Lower suspension point vertical position from C.o.M. = +5 mm

GAS resonant frequency = 0.5 Hz

**Intermediate Recoil Mass (IR)**

M=44.9kg, Ix=0.561kgm2, Iy=0.815 kgm2, Iz=0.899 kgm2,

Suspended from PF by 3 wires with vertical springs

Wire length = 0.3 m, Material: CuBe

Upper suspension point vertical position from C.o.M. = -50 mm

Lower suspension point vertical position from C.o.M. = +50 mm

Wire horizontal distance from center = 120 mm

Spring resonant frequency = 5 Hz

**Intermediate Mass (IM)**

M=53.2kg, Ix=0.352kgm2, Iy=0.677 kgm2, Iz=0.474 kgm2,

Suspended from PF by a single wire

Wire length = 0.4 m, Material: CuBe

Upper suspension point vertical position from C.o.M. = -5 mm

Lower suspension point vertical position from C.o.M. = -4 mm

**Recoil Mass (RM)**

M=33.7kg, Ix=0.433kgm2, Iy=0.433 kgm2, Iz=0.642 kgm2,

Suspended from PF by 4 wires

Wire length = 0.3 m, Material: CuBe

Upper suspension point vertical position from C.o.M. = 0 mm

Lower suspension point vertical position from C.o.M. = 0 mm

X-separation of wire and C.o.M. = 145 mm

Z-separation of wire and C.o.M. = 25 mm

Spring resonant frequency = 5 Hz

**Test Mass (TM)**

M=22.7kg, Ix=0.111kgm2, Iy=0.111 kgm2, Iz=0.137 kgm2,

Suspended from PF by 4 wires

Wire length = 0.3 m, Material: Sapphire

Upper suspension point vertical position from C.o.M. = 0 mm

Lower suspension point vertical position from C.o.M. = 0 mm

X-separation of wire and C.o.M. = 110 mm

Z-separation of wire and C.o.M. = 15 mm

Spring resonant frequency = 20 Hz

**Heat links Between Suspension and Cryo Bars:**

Semi-elliptic, pure aluminum (6N grade), thickness=1mm

Major radius = 400 mm (X, horizontal and perpendicular to beam axis)

Minor radius = 200 mm (Y, Vertical axis)

DC spring constant per one wire:

kx=0.387 N/m, ky=0.040 N/m, kz=0.012 N/m

First violin mode: 2 Hz, second mode: 8 Hz

Attached to IR from both sides, 4 wires for each connection

**5.2. Model basic information**



**5.3. Seismic noise from heat links**



**5.4. Suspension thermal noise**

