Performance test of local control for KAGRA Type-A suspension

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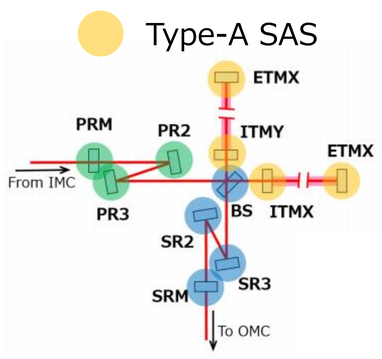
Introduction

Mirrors for a ground-based gravitational wave detector are suspended to isolate the mirror from seismic vibration. In KAGRA[1], the four test masses are suspended by so-called Type-A seismic attenuation systems (SASs). Type-A SAS consists of 9-stage pendulum and the lower 4-stages is to be operated in a cryogenic temperature. In addition, we use active control system with local sensors and actuators in order to calm down the pendulum system and to suppress the RMS of the mirror fluctuation.

In this poster, we present the status of the control system for the type-A seismic attenuation systems.

→ Performance test of local control system toward lock acquisition

Type-A Seismic Attenuation System

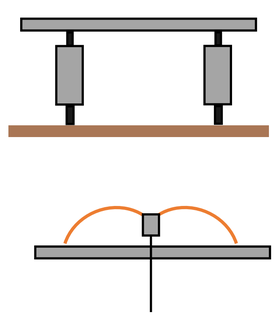


- 9-stage suspension, 13.5 m tall
- For 4 test masses for 3km-arm cavities
- Upper 5 stages in room temperature (~300K)
- Lower 4 stages in cryogenic temperature (~20K)
- Type-A SAS will attenuate displacement noise:
  horizontally < 8 *10^{-20} m/rtHz at 10 Hz
  vertically < 8 *10^{-18} m/rtHz at 10 Hz

- Type-A SAS consists of the following components:

Inverted Pendulum (IP)

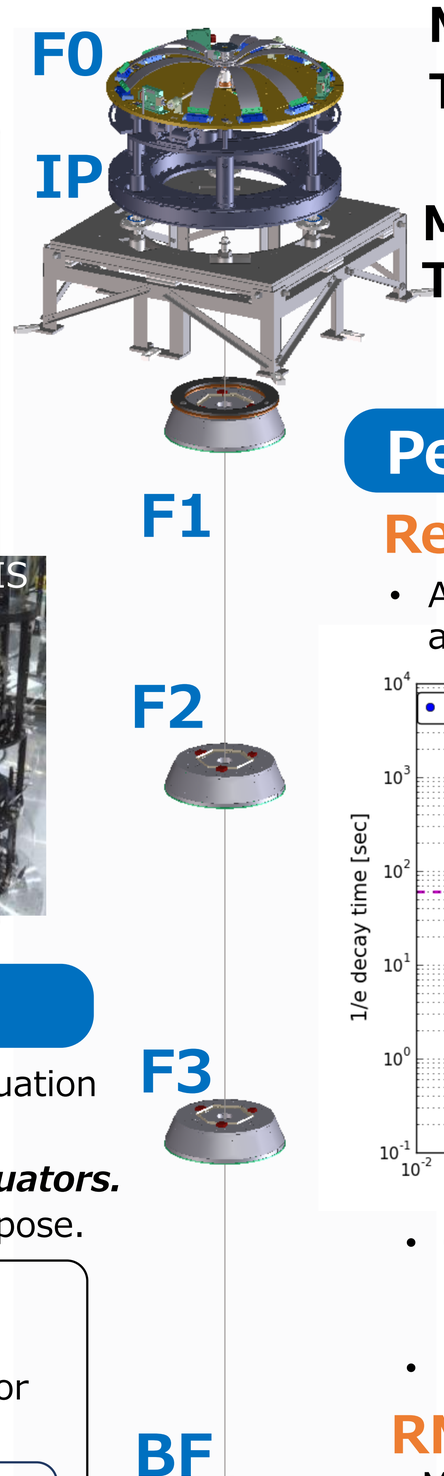
- For horizontal vibration isolation
- Tuned at ~70mHz



Geometric Anti Spring

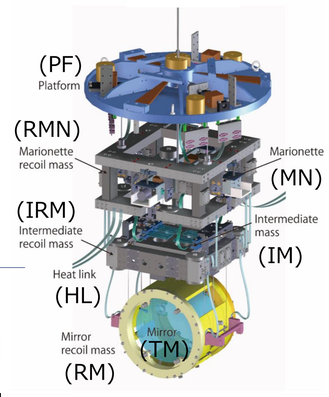
Filter Chain (F0/F1/F2/F3/BF)

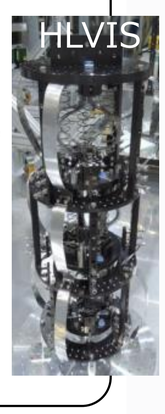
- For vertical vibration isolation
- Tuned at ~ 400mHz
- 5 stage chain



Cryogenic Payload with Heat-Link Vibration Isolation System (HLVIS)

- 4 stage pendulum system
- HL-VIS attenuates vibration from the cryo-cooler via HL.





Local control system

- In order to lock interferometer, RMS of the mirror fluctuation due to the resonances have to be suppressed.

  → Actively control the system with sensors and actuators.
- Type-A SAS following sensor and actuators for this purpose.

IP-stage
- 3 Inertial sensors & 3 displacement sensors (LVDTs)
- 3 voice-coil actuators

GAS-stage
- LVDT & voice-coil actuator

BF-stage
- LVDTs & coil magnet actuators in 3 horizontal & 3 vertical

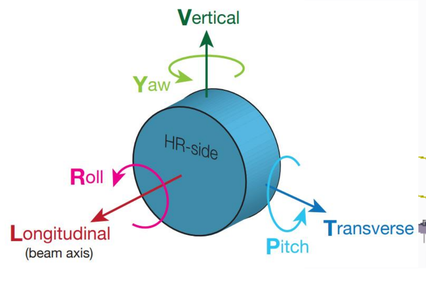
For damping pendulum modes & Torsion modes

Payload
- 3 horizontal & 3 vertical Reflective photo-sensors & coil magnet actuators in for MN / IM
- Optical lever for MN / TM
- 4 horizontal coil-magnet actuators for TM

For damping payload internal modes

Main requirements for control

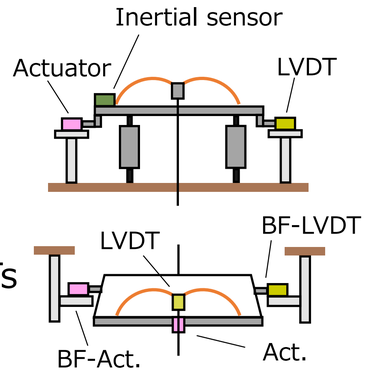
- In calm-down phase
  → 1/e decay time < 1 min.
- In lock-acquisition phase
  → RMS vel. (L) < 0.5um/s
  → RMS disp. (L) < 0.4um(*)
  → RMS angle (P, Y) < 200nrad.

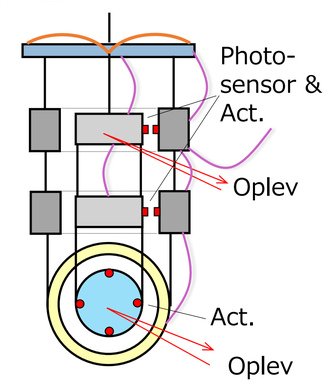


Feed-back loops

- Currently implemented servo filters:

IP	For L / T / Y	DC+Damp	with LVDTs
GAS	For each stage		
BF-damper	For Y		
MN	For L / Y	Damp	with Oplev / PS
TM	For P / Y		
MN	For some Resonant modes	Band-pass Damp	with Oplev & PS
TM to MN			

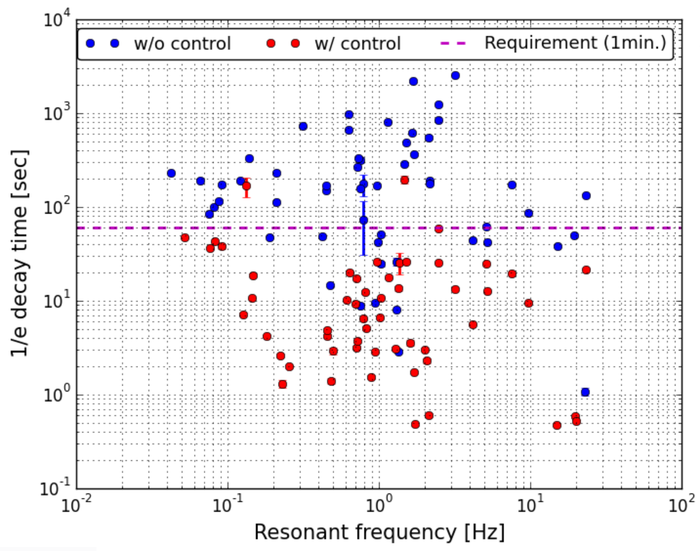




Performance test with ETMX

Resonance damping

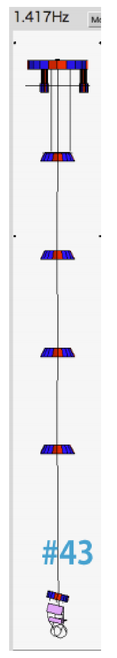
- All the mechanical resonances which disturbs the lock acquisition is damped within 1/e decay-time < 1min.



- Exception(s)

- At 1.5 Hz
  → Roll/Trans mode.
  → No problem

- At 0.14 mHz
  → Yaw mode
  → model w/o HL does not have this mode.

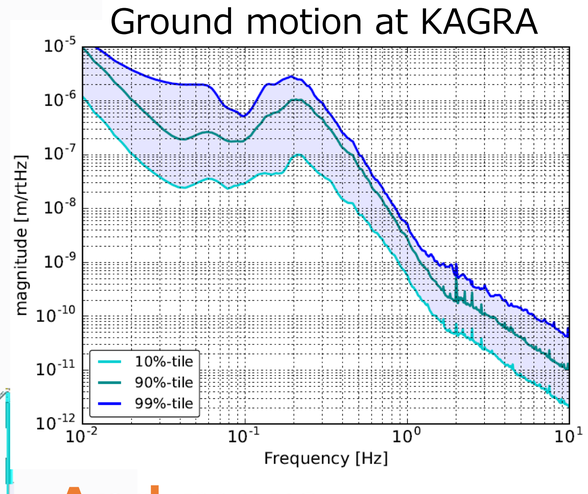


- 0.14Hz mode → not disturbs the lock acquisition in the recovery though, more naïve HL-system treatment is necessary for further steps.
- Better to utilize the Photo-sensors more effectively.

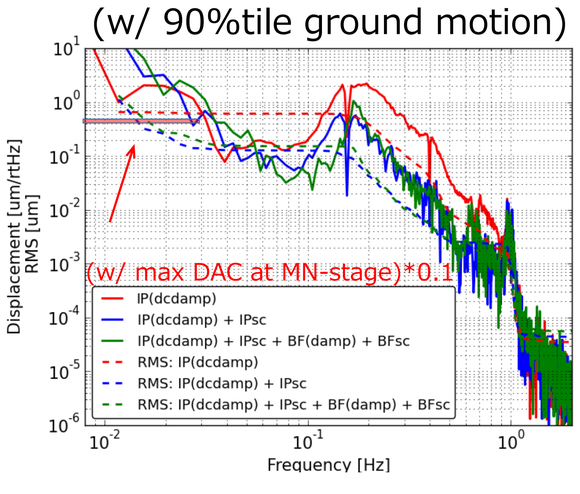
RMS suppression

- Mirror disp./vel. RMS has to be suppressed.
- Seismic signal is subtracted from LVDTs using seismometer signal on the ground.
- With IP-stage correction suppressed the RMS effectively (> ~20 mHz).

Ground motion at KAGRA



Mirror residual in L dof (w/ 90%tile ground motion)



And more..

- Vibration isolation performance measurement up to a few Hz.

Summary

1. We develop a control system for the test mass suspension for KAGRA, called Type-A SAS.
2. We have met the requirement on damping and mirror RMS in L, etc with ETMX test.
3. Further characterization including HL system would be the next, especially in the detection band (> 10Hz).

References : [1] Y. Aso et al., *Phys. Rev. D* **88**, 043007 (2013) [2] K. Okutomi, Ph.D. thesis, SOKENDAI (2019)