Development of 13.5-meter-tall Vibration Isolation System for the Main Mirrors in KAGRA

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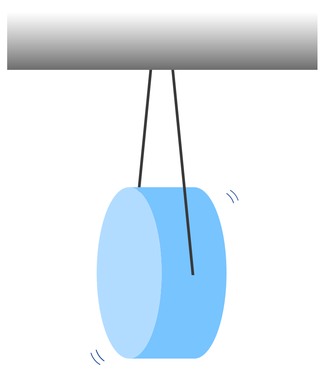
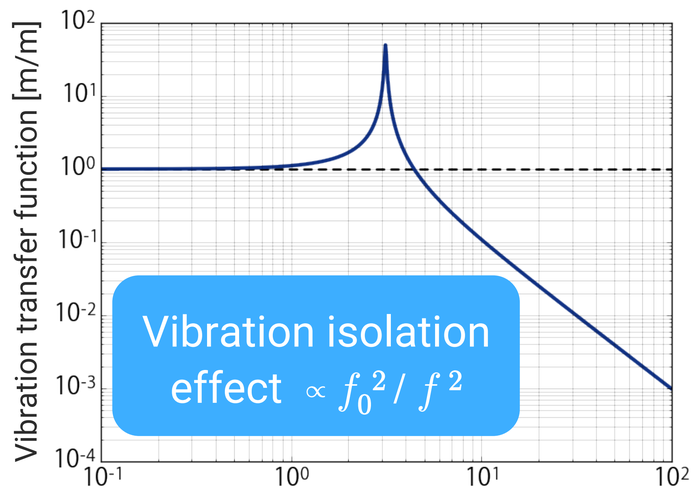
Introduction

Terrestrial gravitational wave detectors suffer from seismic disturbances which fluctuate the mirrors of the interferometer. The vibration transmits to the mirrors can be attenuated by suspending the optics like a pendulum. The vibration isolation systems used in KAGRA are multi-stage suspension systems with local sensors and actuators; the suspension systems provide not only seismic attenuation but also controllability of the mirrors. Here we present the performance test of the vibration isolation system for the main mirrors (test masses) in KAGRA, called Type-A suspension.



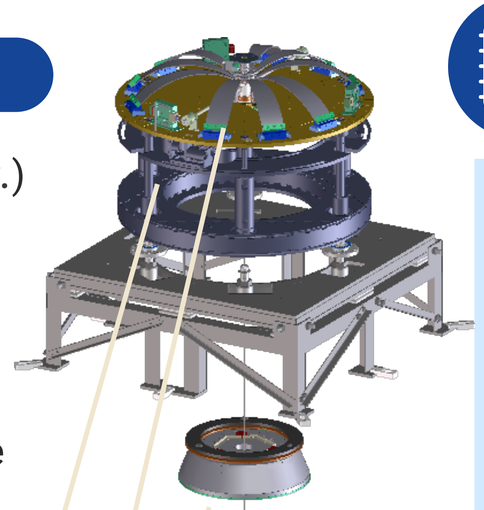


What's Type-A suspension?

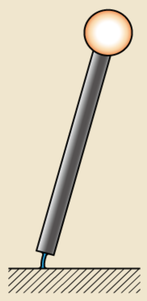
- 13.5 m tall, 9-stage multi-stage suspension (***right fig.***)
- For 4 test masses in 3 km arm cavities

Tower: upper 5 stages

- Room temperature (~ 300 K)
- Key components for vibration isolation performance implemented (listed below)
- **Main target of this study:**
  To evaluate the performance of the Type-A tower

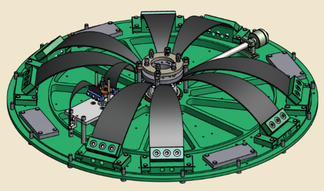


Inverted pendulum (IP)



Horizontal low-frequency oscillator
- ❖ Pre-isolation stage: f_0 ~ 70 mHz
- ❖ Static positioning of the suspension point

Geometric anti-spring (GAS) filter

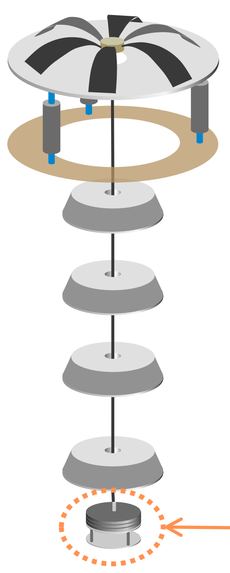


Verticall low-frequency oscillator
- ❖ 5 stage chain: f_0 ~ 300 mHz
- ❖ Vertical fluctuation couples cavity length variation

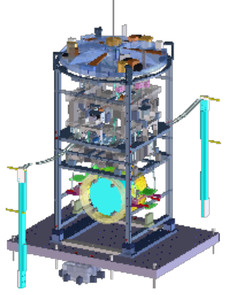
Payload: bottom 4 stages

- Cryogenic temperature (~ 20 K)
- Key components for vibration isolation performance implemented (listed below)
- Out of scope in this study

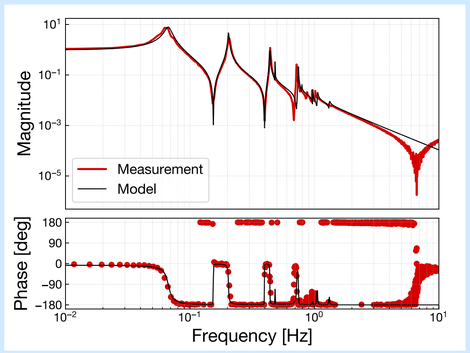
Installation & Test setup



- Type-A tower installed at the X-end is tested
- Tower and payload are separately installed into the vacuum chamber then integrated later
- Performance test of the Type-A tower is done before integration with the payload
- A dummy payload with equivalent weight is suspended during installation and the test

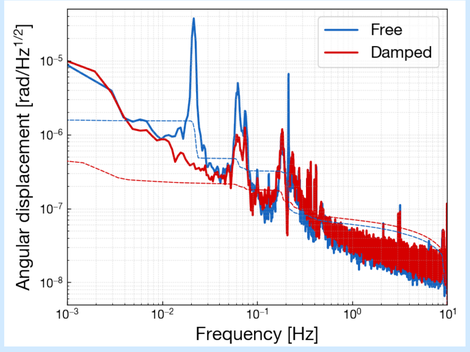


Tests & Results



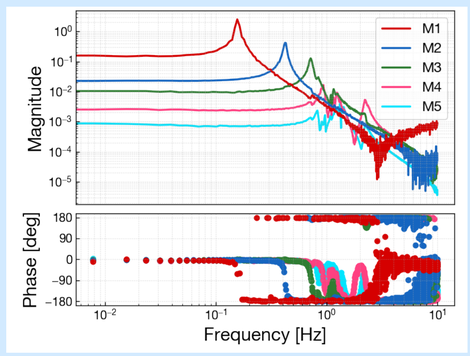
Transfer function measurement

- Frequency response
- Compared with model prediction
- Gross behavior is as expected



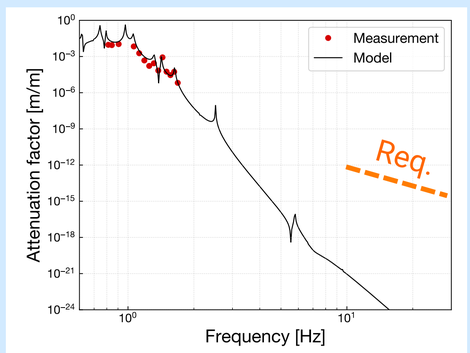
Torsion mode damping

- Yaw resonant modes are damped with bottom filter control
- RMS ~ 230 nrad ✔
- Decay time < 1 min ✔



Modal damping in GAS chain

- Coupled mode decomposition ✔
- Functionality ✔
- Independent mode damping ✔



Vibration isolation ratio measurement

- Using MICH signal in phase-1 operation
- Measured data + model extrapolation
- Estimated: 10^{-21} ✔

Conclusion

- We constructed Type-A suspension satisfying the basic requirements for vibration isolation
- Modal damping is implemented and validated
- Full Type-A suspension will be tested and commissioned