Sapphire mirror suspension control of KAGRA

Masahide Tamaki A*, Shinji Miyoki B, Takafumi Ushiba B, Takahiro Yamamoto B, Koseki Miyo B, Takayuki Tomaru C, Ryutaro Takahashi C, Satoru Ikeda C

Phys. S. U. T A, *ICRR* B, *NAOJ* C **tamaki83@icrr.u-tokyo.ac.jp*

Abstract

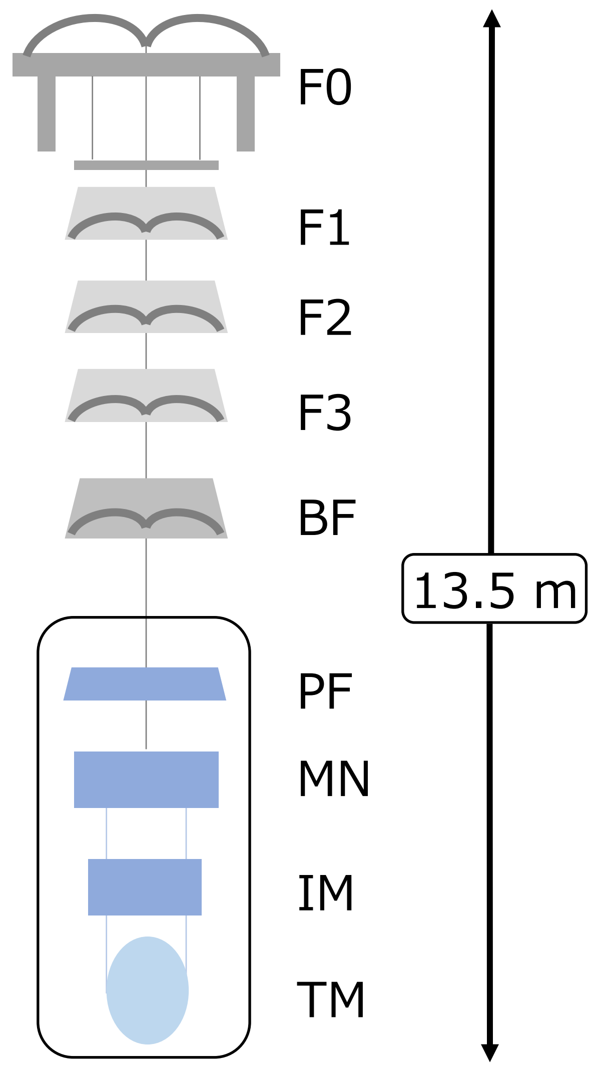
KAGRA, which is based on a Michelson interferometer and has an optical cavity in each arm, needs seismic noise isolation system for mirrors to reach the targeted sensitivity especially for the low frequency range below ~ 100 Hz. To obtain enough seismic noise isolation, a multi-stage suspension system is adopted.

However, the excess motions of the mirror at many resonance frequencies of the multi-stage suspension system are expected without damping controls. These motions should be damped below the requirement levels for the stable interferometer operation as a gravitational wave detector. Then, the requirement for the motion of sapphire mirrors, that are suspended by so called Type-A suspension and form arm Fabry-Perot cavities, is that the 1/e decay time (τ) of the major resonances must be less than 60 sec.

If τ is short, we can reduce dead times during KAGRA operation after earthquakes happen or we accidentally excite motion of any suspension stages. This means that we can quickly recover the interferometer to the observation mode and to lengthen the observation time.

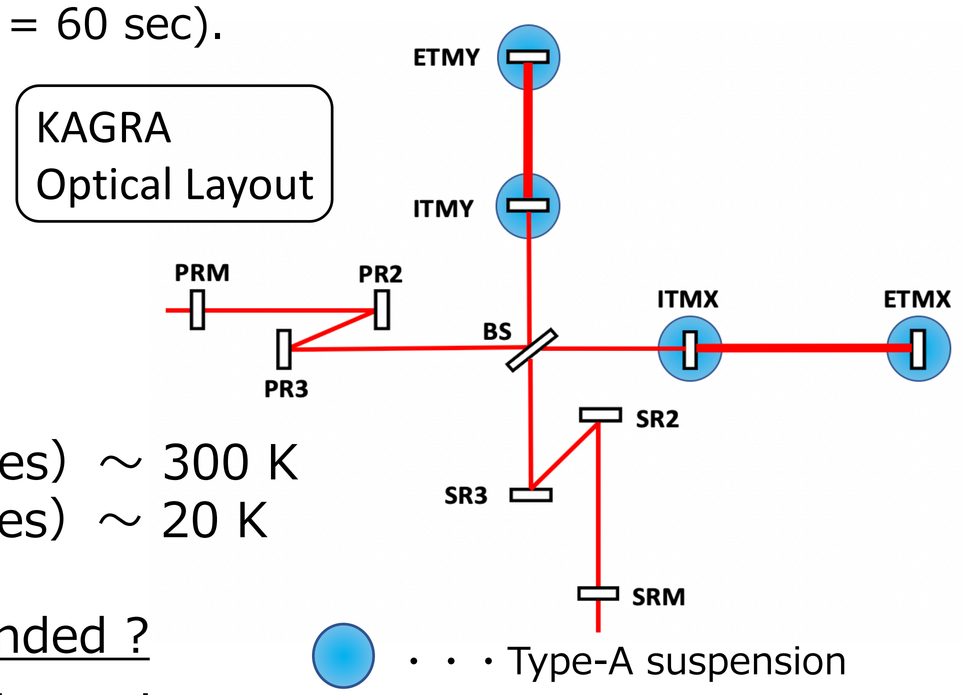
To satisfy this requirement for damping motions, we made damping control filters and applied. Then, we checked whether the resonance peaks are suppressed or not, and the 1/e decay times were within the requirement (τ = 60 sec).

Introduction



Type-A suspension

Nine Stages
・Tower (upper 5 stages) ~ 300 K
・Payload (lower 4 stages) ~ 20 K



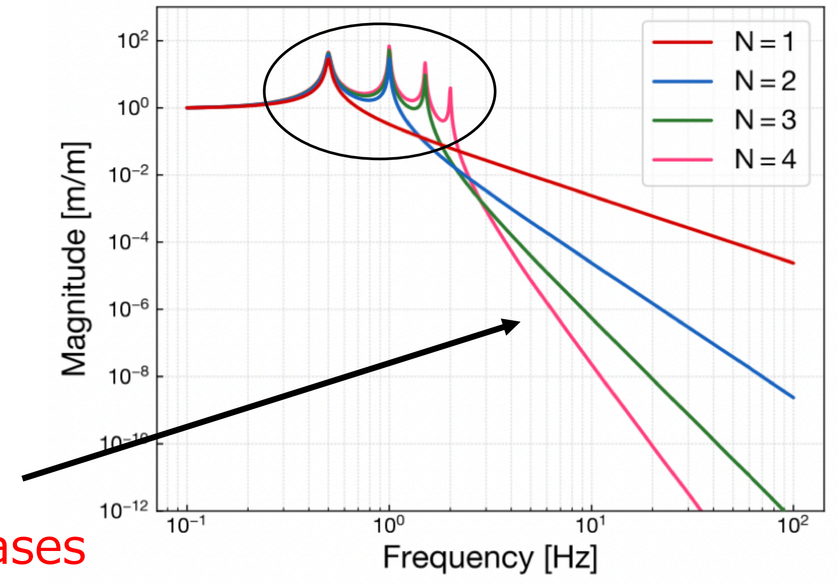
Why is the mirror suspended ?

→ isolation from seismic motion

attenuation characteristic of the multi-stage pendulum

$H(f) \sim (f_0/f)^{-2n}$

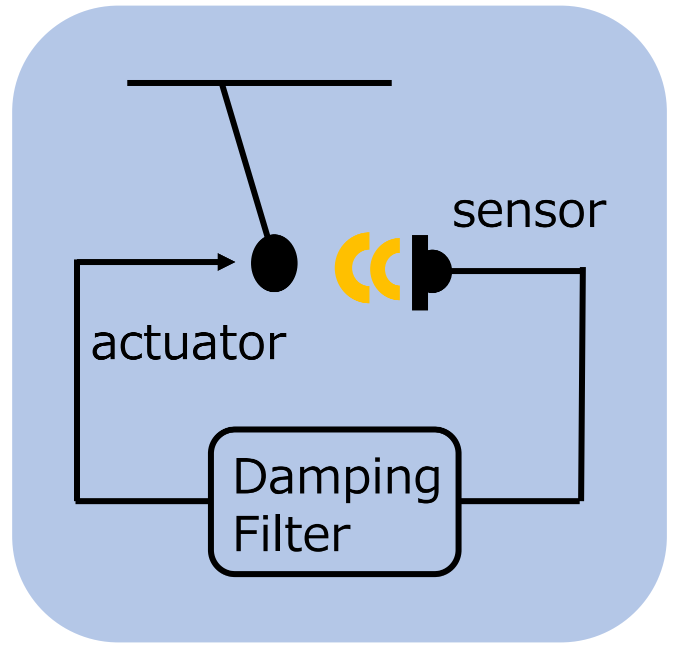
f: frequency
n: number of stages



with multi-stage suspension, vibration isolation ratio increases

Seismic motion is amplified at resonance frequency ⟶ damping control

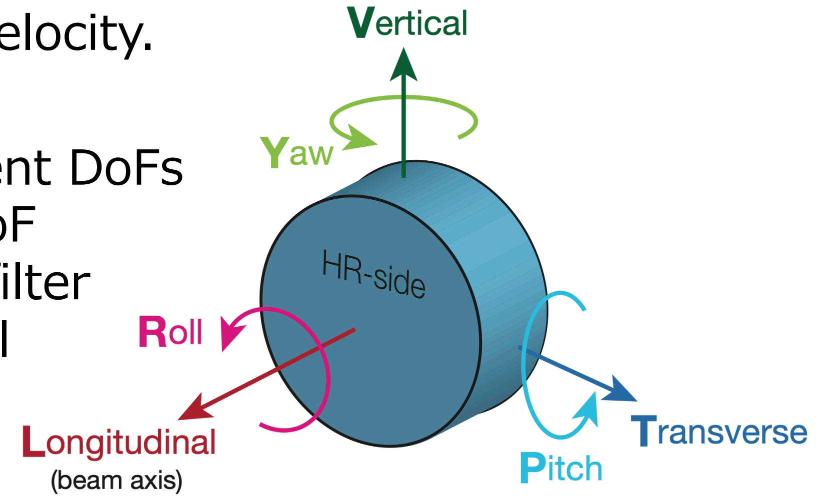
Damping control



Displacement of the mirror is detected locally by sensors which attached to each stage, and produce a feedback to the mirror actuator with a force proportional to the mirror's velocity.

∗the signal from sensor
・・・a mixture of different DoFs
→ Decompose into each DoF and apply the damping filter to create feedback signal

DoFs (of the TM) →

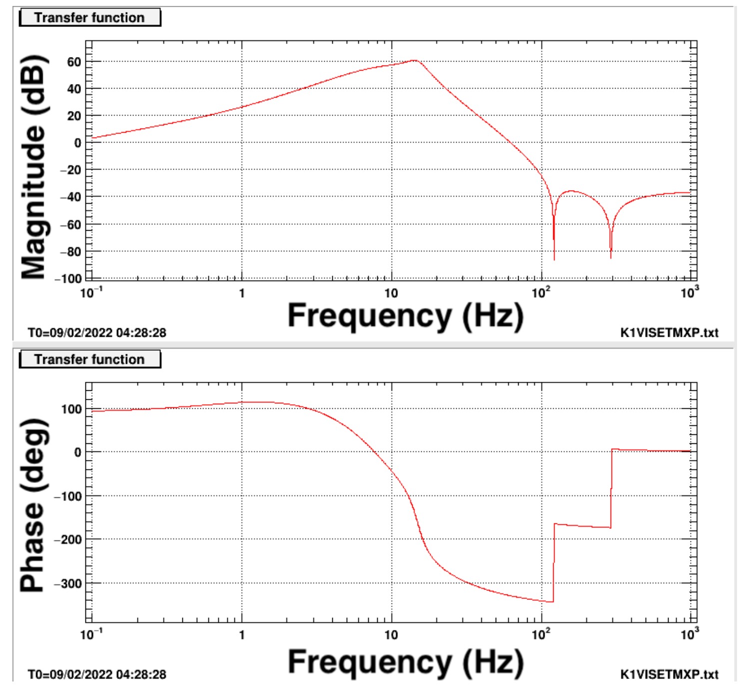


∗Damping control can reduce a shaking at high frequency, but at the same time, it produces a noise at high frequency, so we have to consider this trade-off.

What we did

We made the damping filter which suppress the main peaks at once

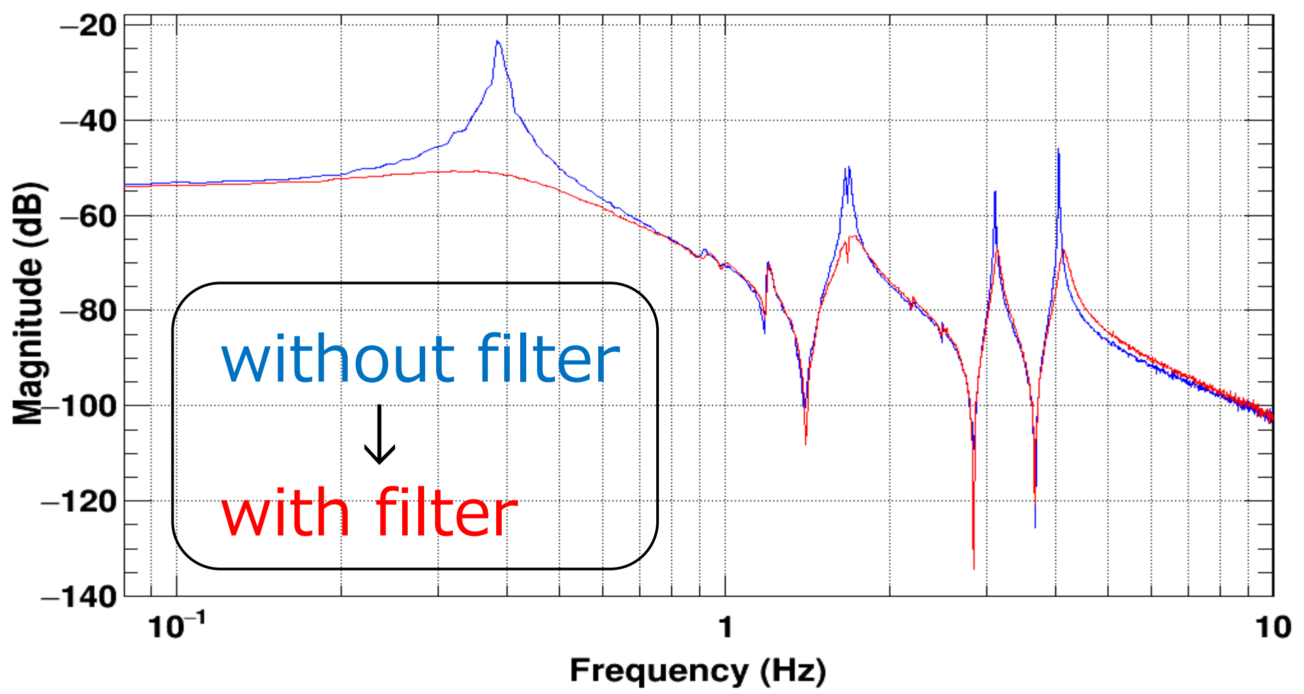
ex) ETMX TM Yaw



↑ damping filter which we made

1. Apply a filter that is proportional to frequency
2. Apply a low-pass filter from a certain frequency (to reduce the noise at high frequencies)
3. Determine the gain so that the UGF has a phase margin

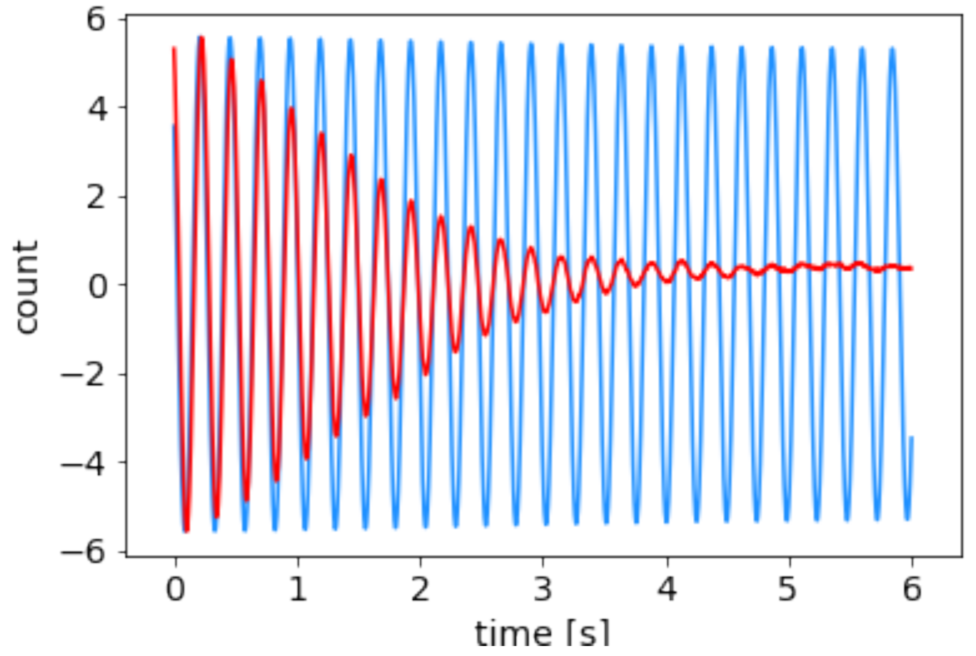
transfer function (ETMX_MN_Y) →



∗the peaks at the resonant frequencies were damped as we aimed.

Then, we measured 1/e decay time to check the performance of the damping filter

Right figure shows the difference of the decay time for 4th mode (4.08 Hz) of Yaw motion (MN in ETMX)

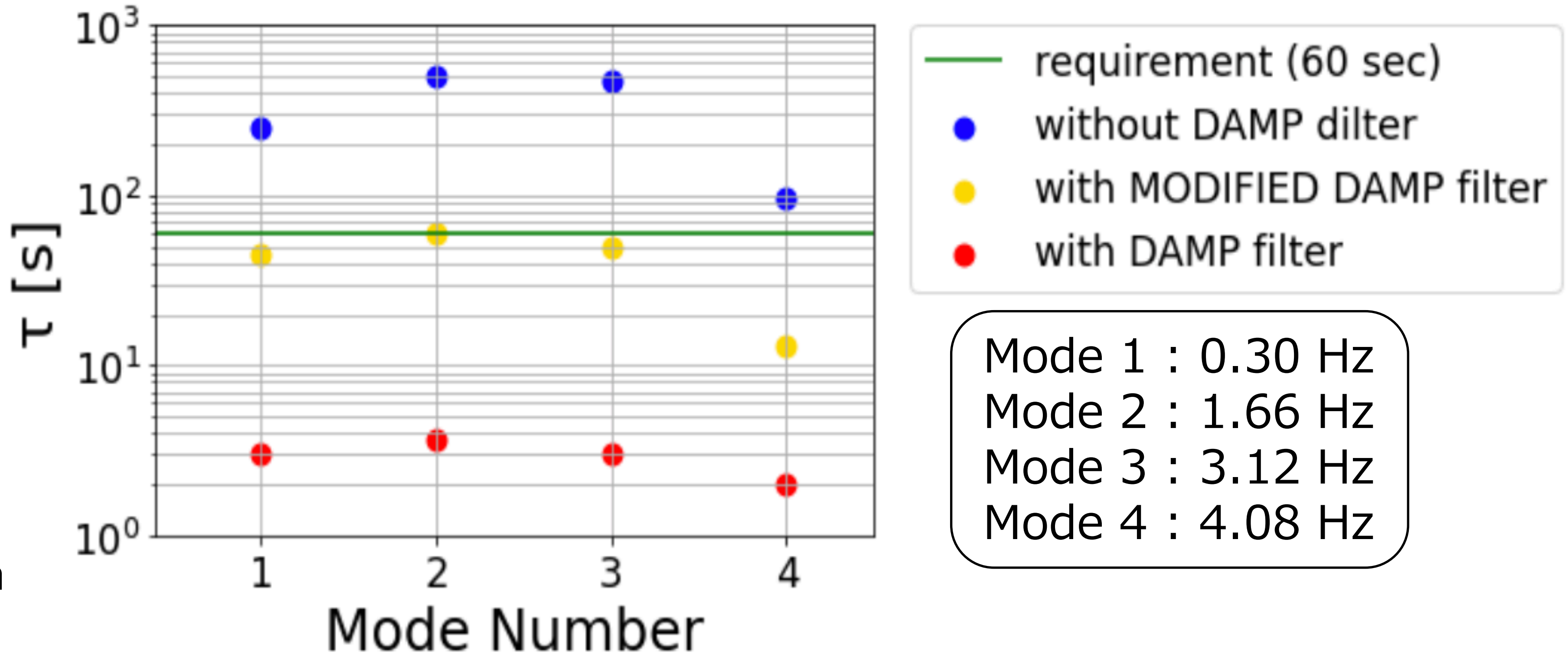


1/e decay time (requirement = 60 s)
∗calculated by fitting with $y = a\exp(-t/b) + c$

without damping filter ・・・ 97.1 ± 0.4 s
with damping filter ・・・ 2.07 ± 0.21 s

Results

1/e decay time for Yaw motion (MN in ETMX)



Mode 1 : 0.30 Hz
Mode 2 : 1.66 Hz
Mode 3 : 3.12 Hz
Mode 4 : 4.08 Hz

Without damping filter (Blue points)

⇩ damping control

Without damping filter (Red points)
The higher the gain of the damping filter, the shorter τ becomes. However, at the same time, the noise at high frequencies becomes higher.

⇩ to reduce the noise at high frequency

Final results (Yellow points)
We could design a filter that satisfies the requirement for 1/e decay time and keeps the noise as low as possible.

Summary and Future steps

- We made the damping filter for Yaw action of MN in ETMX and the requirement for the 1/e decay time was satisfied. We also could adjust the gain of the damping filter to minimize the excitation due to the control noise itself.
- This allowed us to quickly reduce the shaking when an earthquake occurred or when the suspension was accidentally shaken. This mean that the interferometer could be quickly returned to its locked state, which would lead to longer observation times.
- For the next step, we will do the same process for the other degrees of freedom (Longitudinal, Transverse, Roll, Pitch) and also for the other suspensions (ETMX, ITTMX, ITMY).
- Consider whether modal dumping is necessary.