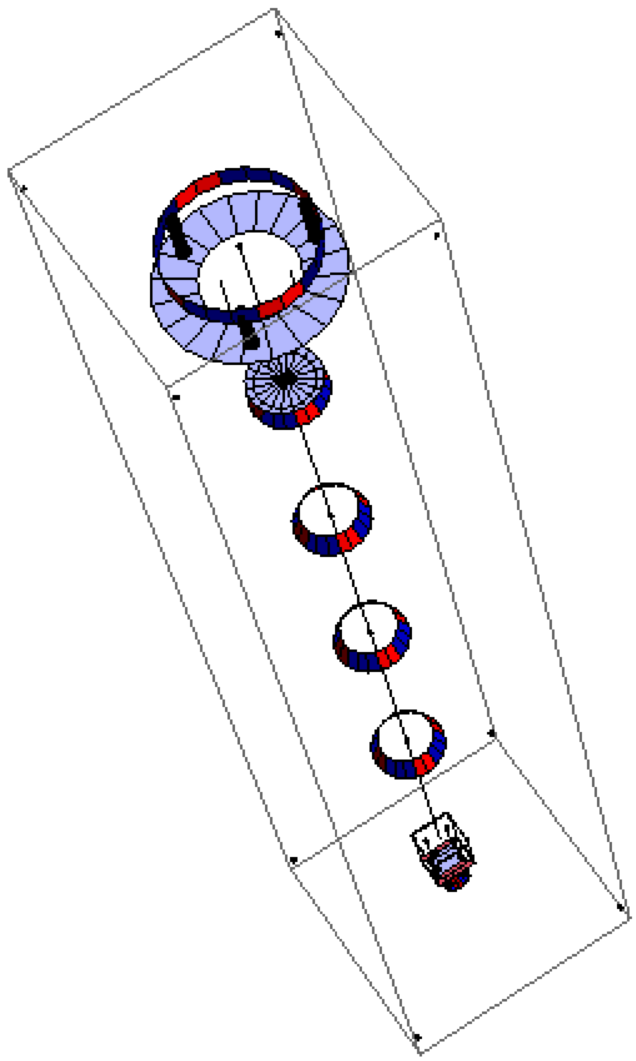
JGW-G1100549

Rigid-Body Models of the Vibration Isolation Systems in Mathematica



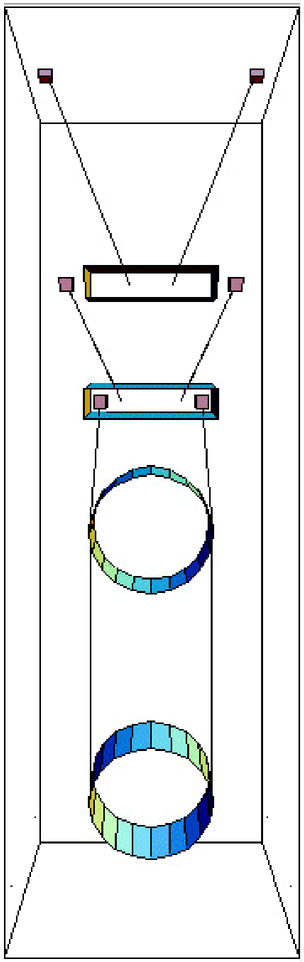
F2F Meeting, Aug. 4th, 2011

ICRR M2, Takanori Sekiguchi

Rigid-Body Models in Mathematica

- Inspired by Mark Barton's suspension models
  http://www.ligo.caltech.edu/~e2e/SUSmodels/

- In the model,
  - A wire works as a mass-less spring.
  - Bodies are connected by elastic elements (wires and springs) with each other.
  - It does not take into account the elasticity inside the body.
  - It is possible to introduce different kinds of loss factors (structure damping, viscous damping).



Calculation Sequence

- Calculate the potential energy, kinetic energy, and damping energy of the system. $E_{\mathrm{Pot}}(x), E_{\mathrm{Kin}}(x, \dot{x}), E_{\mathrm{Damp}}(\dot{x})$

- Find the local minimum of the potential to know the equilibrium point of the system.
$$\left.\frac{\partial E_{\mathrm{Pot}}}{\partial x}\right|_{x=x_{\mathrm{eq}}} = 0$$

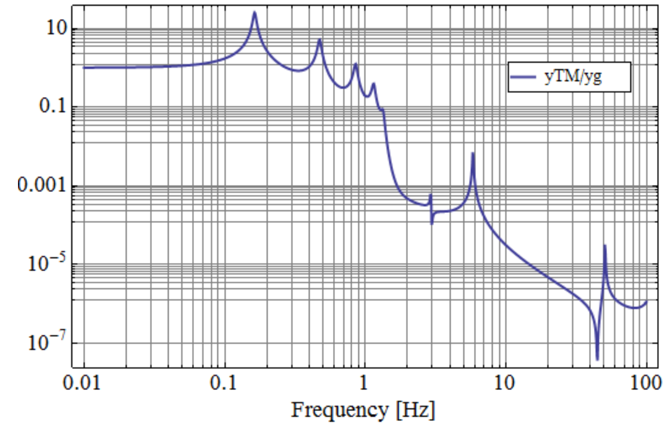
- Linearize the system to obtain the mass matrix, the stiffness matrix and damping coefficient matrix
$$\left.\frac{\partial E_{\mathrm{Kin}}}{\partial \dot{x}_i \partial \dot{x}_j}\right|_{x=x_{\mathrm{eq}}} = M_{ij} \qquad \left.\frac{\partial E_{\mathrm{Pot}}}{\partial x_i \partial x_j}\right|_{x=x_{\mathrm{eq}}} = K_{ij} \qquad \left.\frac{\partial E_{\mathrm{Damp}}}{\partial \dot{x}_i \partial \dot{x}_j}\right|_{x=x_{\mathrm{eq}}} = G_{ij}$$

- From the linearized EoMs, calculate various transfer functions in a frequency domain.
$$\mathbf{M}\ddot{\mathbf{x}} + \mathbf{G}\dot{\mathbf{x}} + \mathbf{K}\mathbf{x} = 0$$

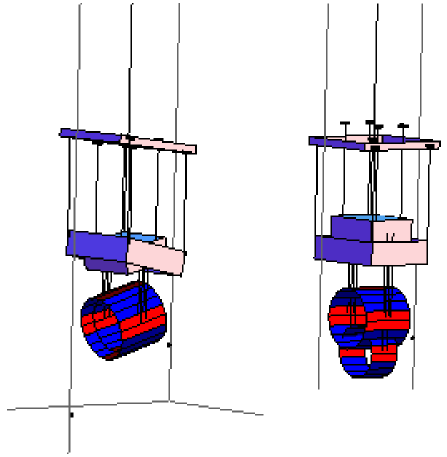
More Detail: **JGW-T1100416**

Output

- Transfer functions of the system (Frequency response of the system)

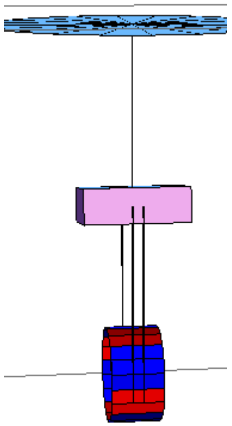


- Eigen modes of the system (Graphic tells us which sort of motion we expect and how to counteract it)



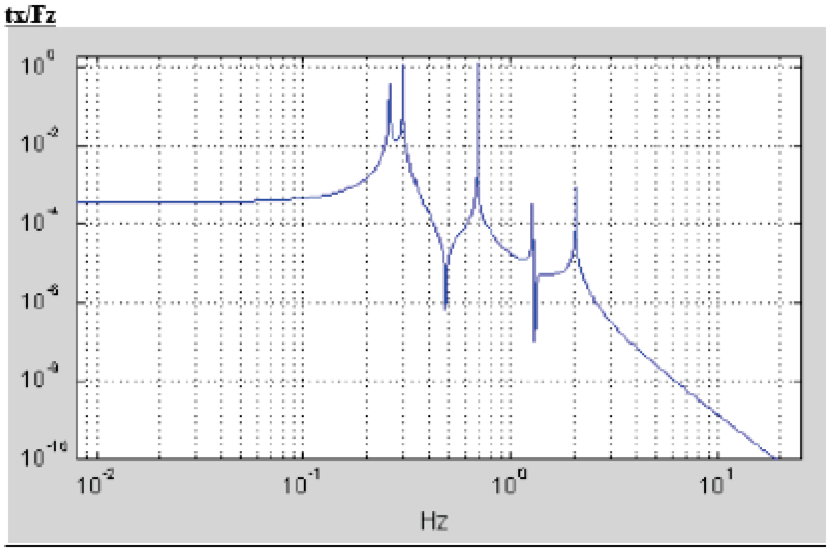
- State-space matrices for time-domain simulation

Validation of the Models

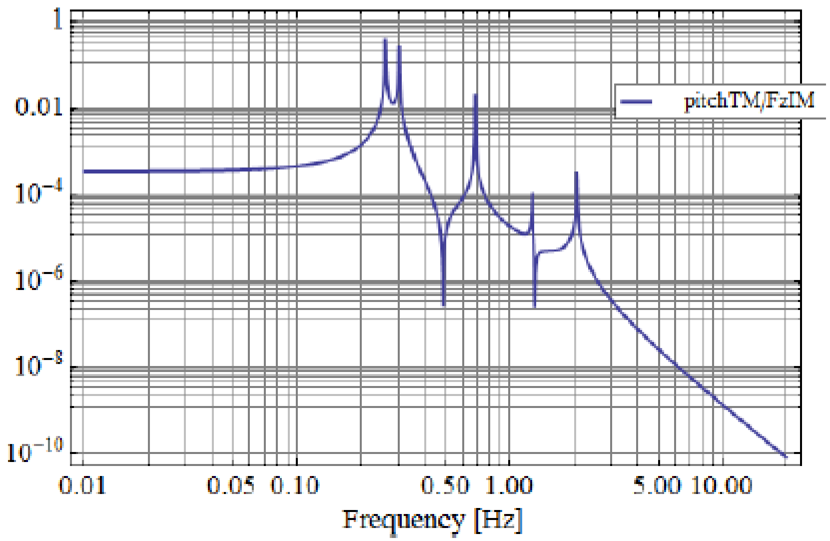


- Comparison with other models:
  MATLAB-base models by E. Majorana

MATLAB Model (Majorana)



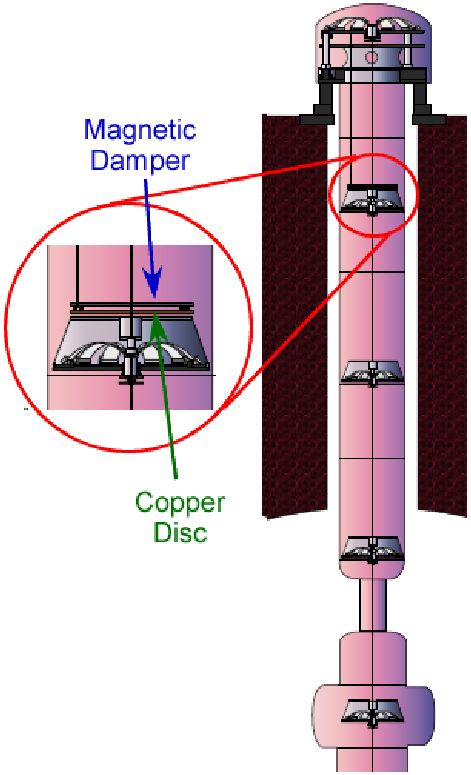
Mathematica Model (Sekiguchi)

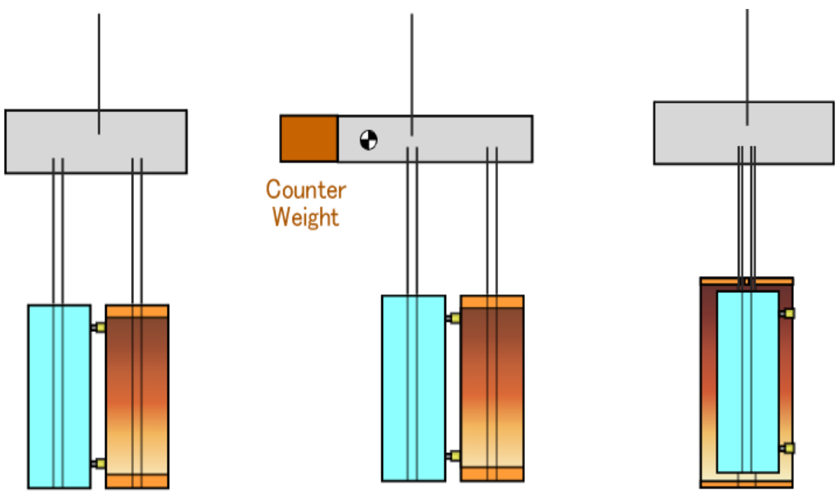


- We obtain same results (with different calculation methods).
- In future, we will check the model by prototype experiments.

Example of Simulation Results

- Eddy current damping for the type-A vibration isolation systems
- Consideration about the geometry of type-B payload





Example of Simulation Results

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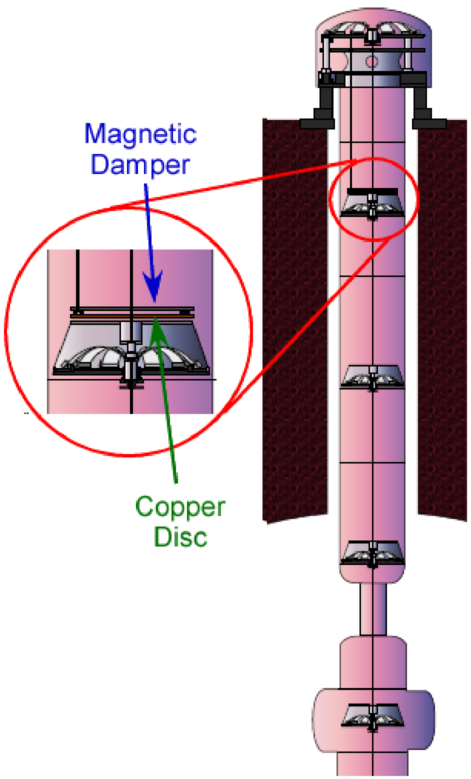
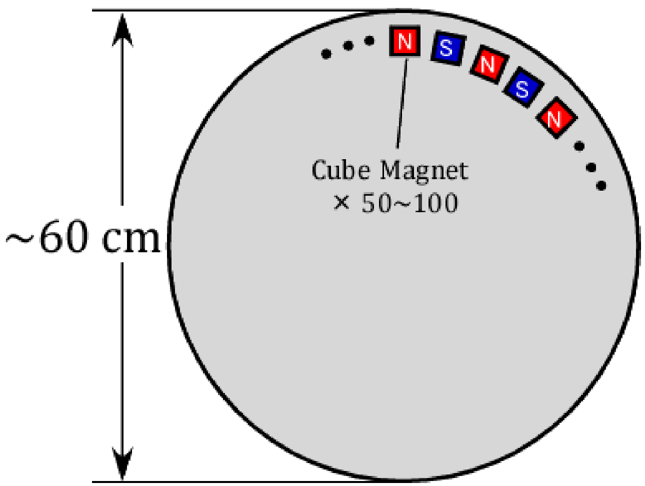
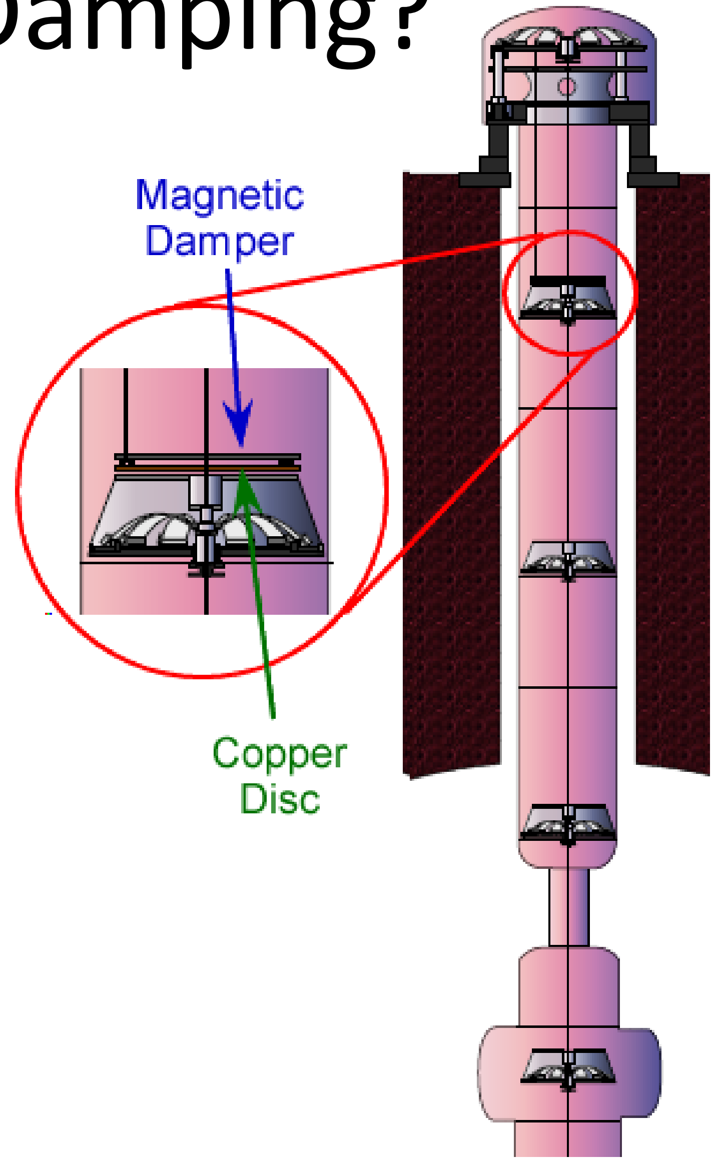


Why Eddy Current Damping?

- Torsion mode damping is indispen-sable for easy lock-acquisition.

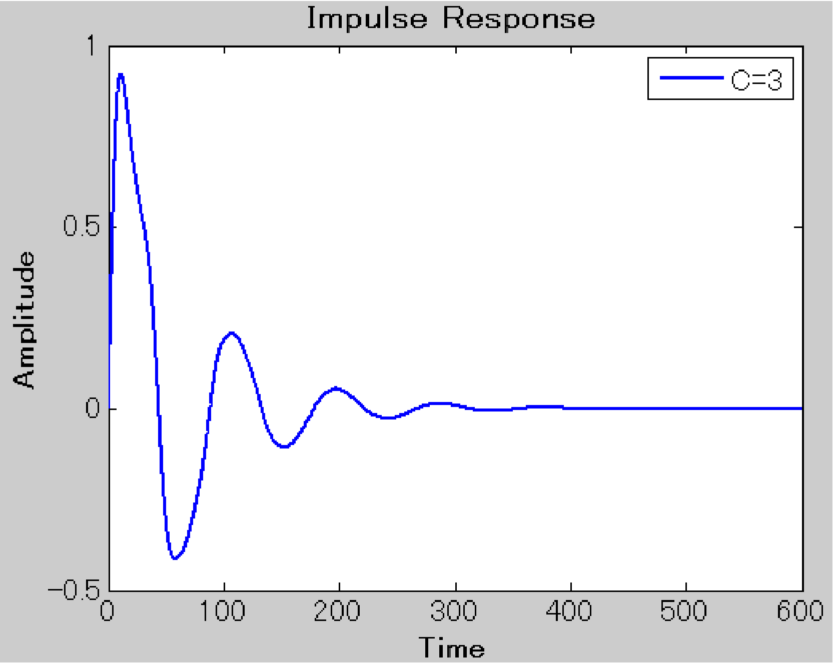
- We employ eddy current damping at the top of the chain.

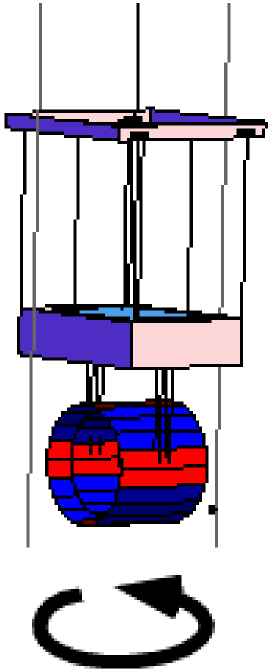




Torsion Mode Damping

- Torsion modes are damped < 5 min.

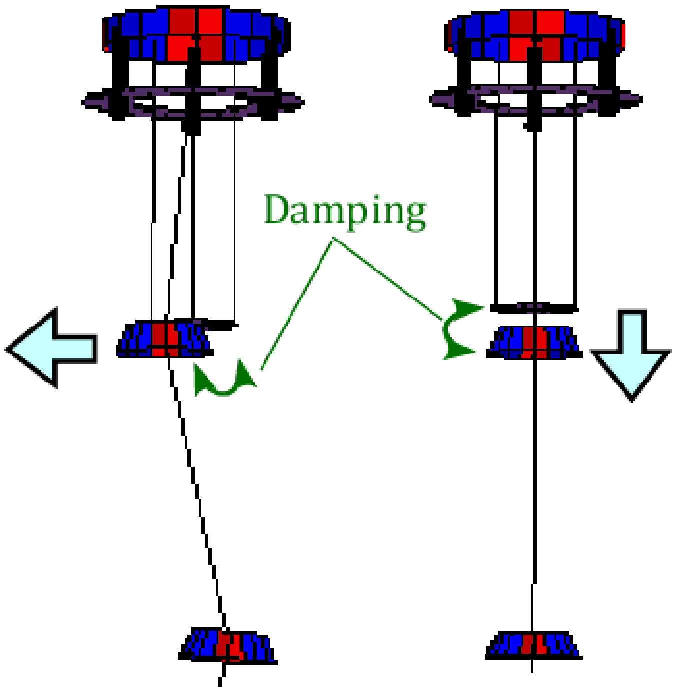




- Damping coefficient should be ~3 kgm^2/rad
- We will need ~100 magnets on the damper.
  (The number should be determined experimentally.)

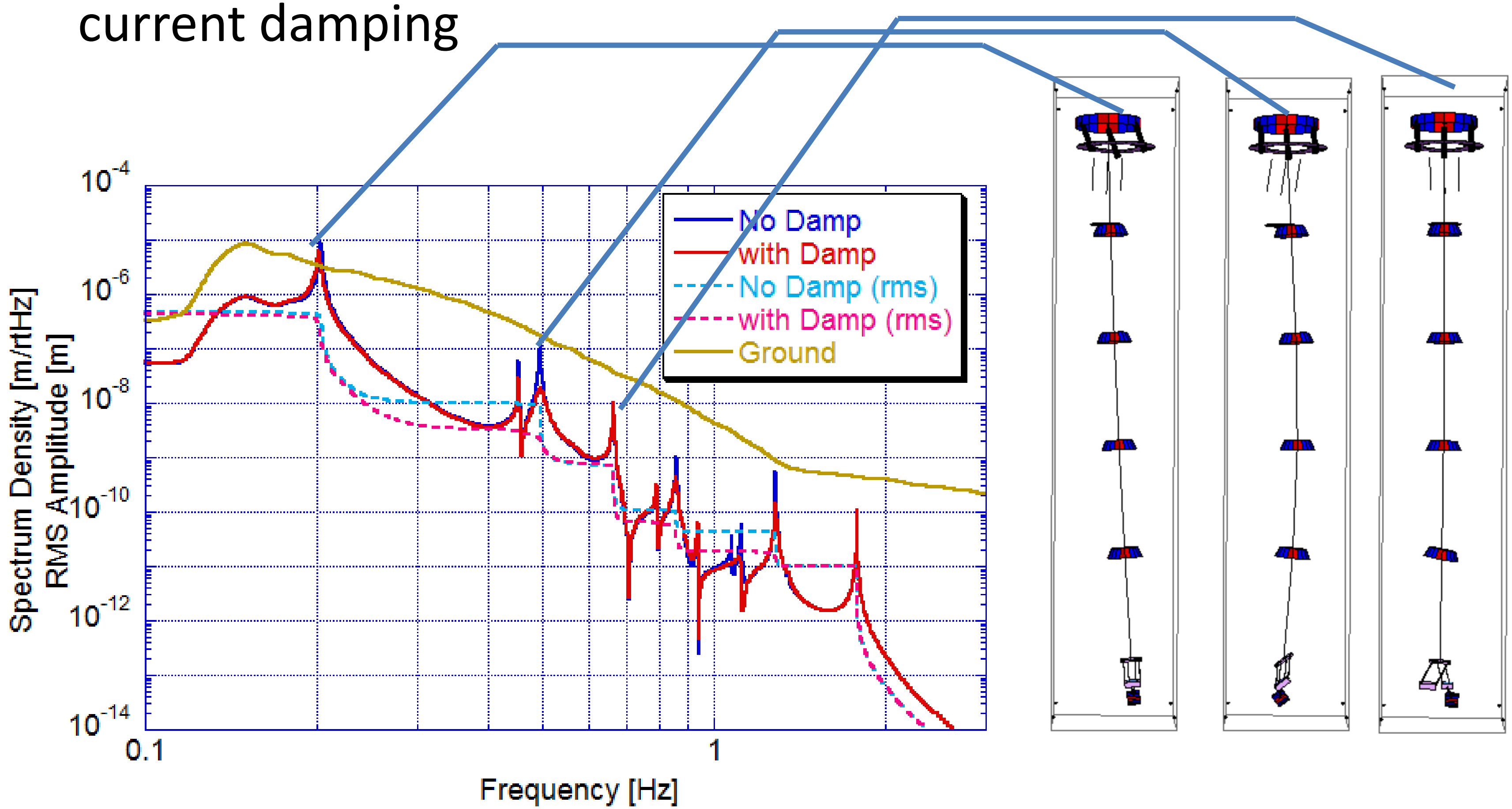
Effect of Eddy Current Damping in Other Modes

- The magnets also damp the horizontal/vertical modes of the suspension system.
- This may reduce the RMS amplitude of the seismic noise of TM.



Study of Longitudinal Modes

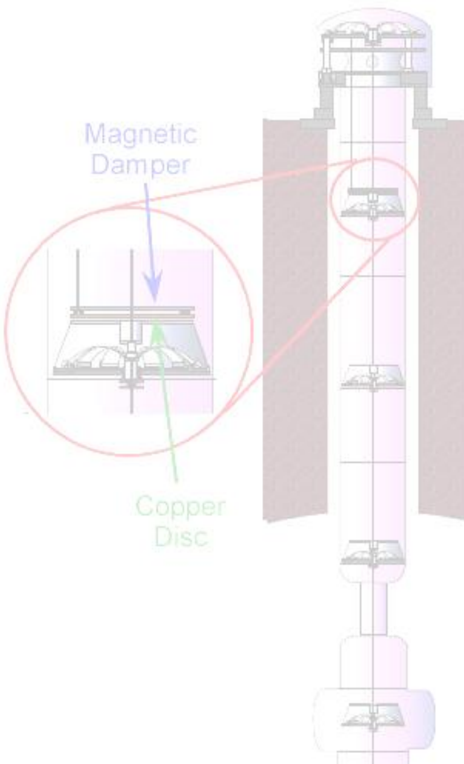
- Seismic noise induced motion of TM, with/without eddy current damping

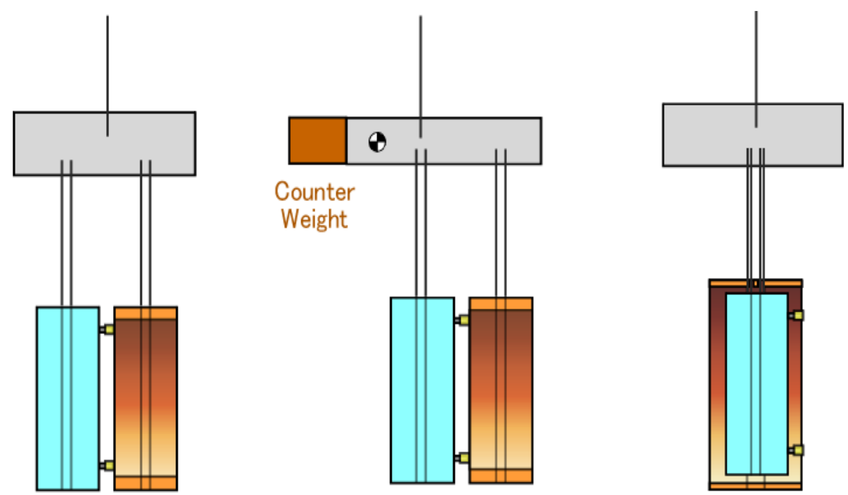


- Not so effective (we need active damping for them.)

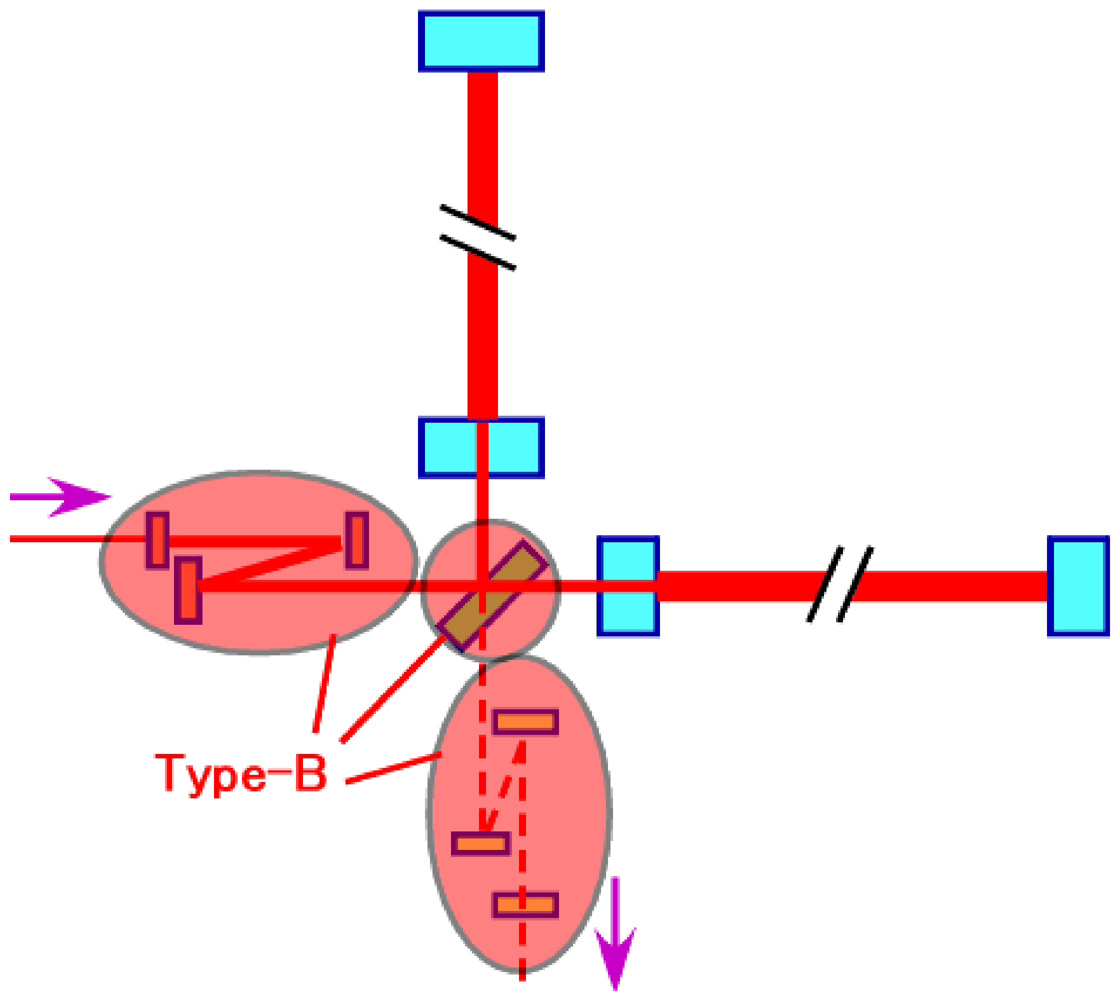
Example of Simulation Results

- Eddy current damping for the type-A vibration isolation systems
- Consideration about the geometry of type-B payload



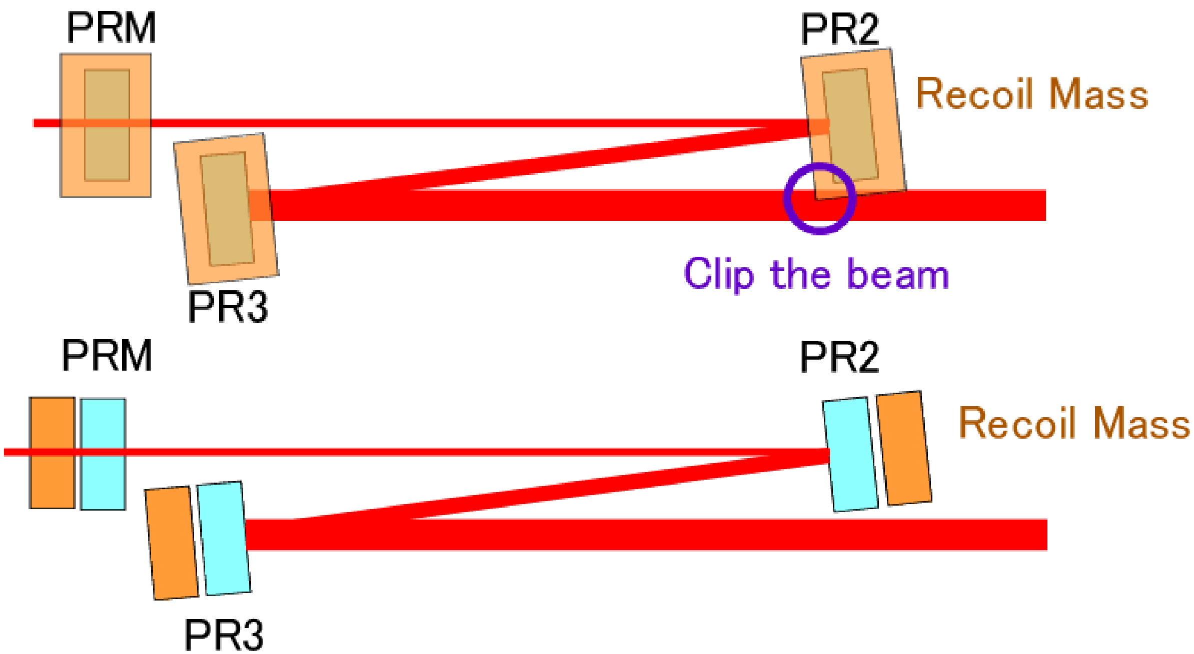


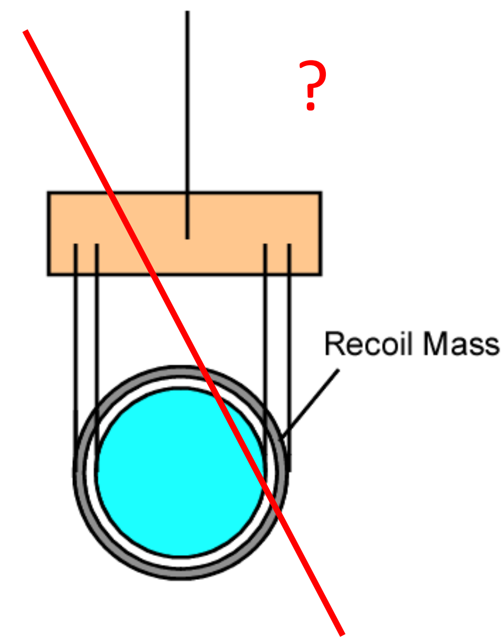
Type-B Vibration Isolation System



Payload Design for Recycling Mirrors

- The folding beam passes just next to the mirrors.
- Concentric recoil masses may disturb the beam
  → Coaxial recoil masses initially considered necessary





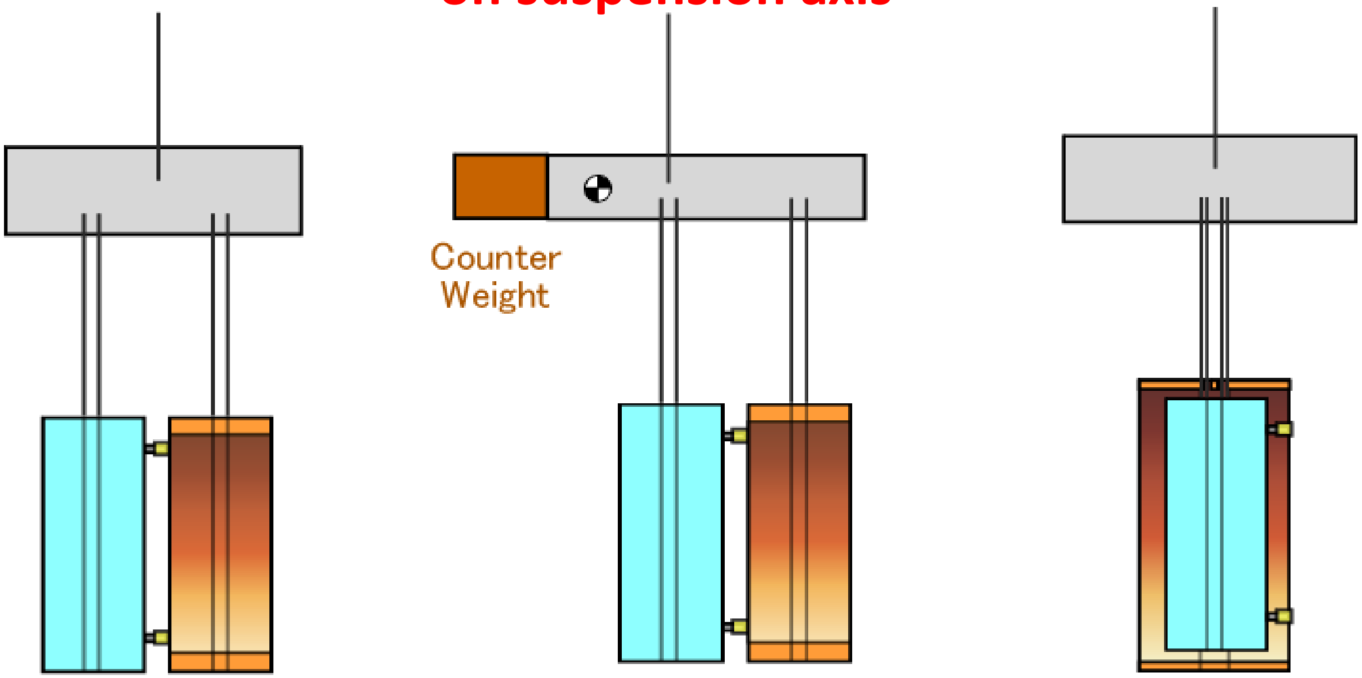
Payload Design for Recycling Mirrors

- Compare 3 kinds of designs

Ver. 1
Tandem

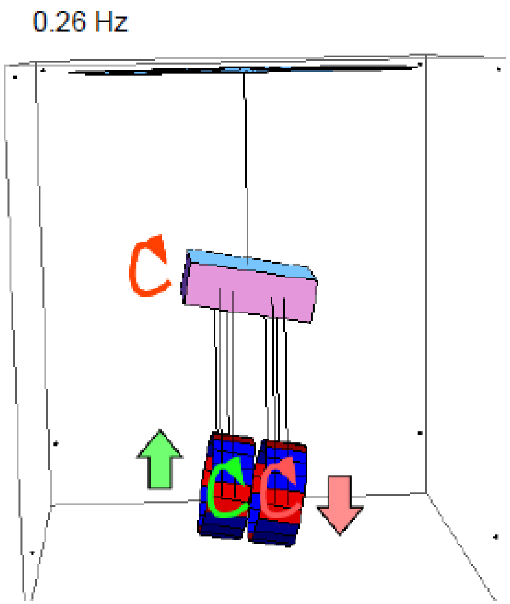
Ver. 2
Tandem mirror
on suspension axis

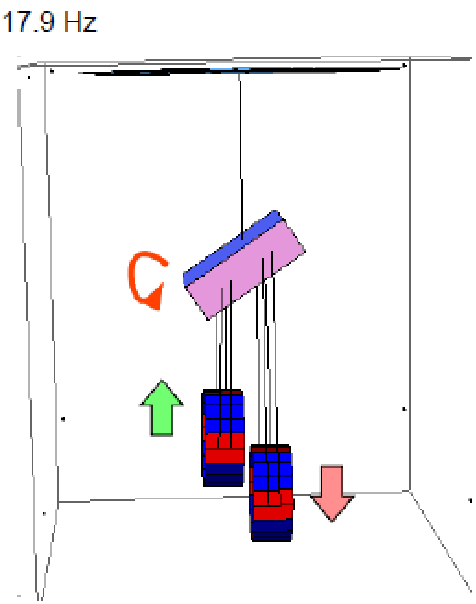
Ver. 3
concentric

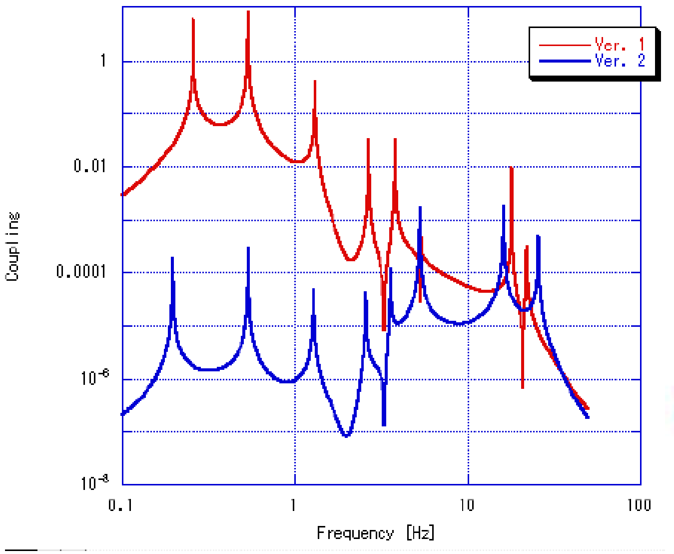


About Ver. 1

- Pitch and vertical modes are coupled.
- Horizontal → Vertical coupling is large.



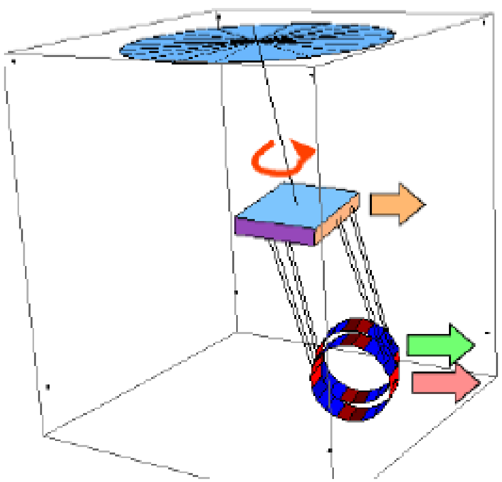




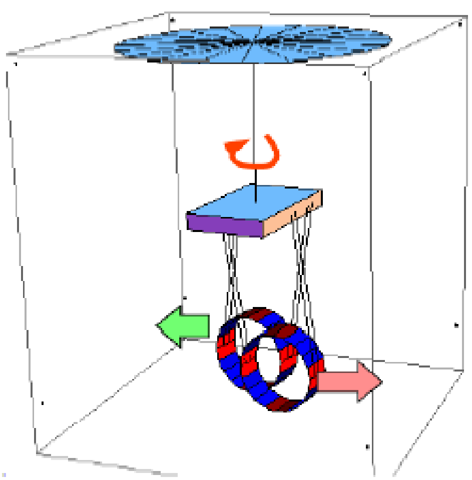
About Ver. 2

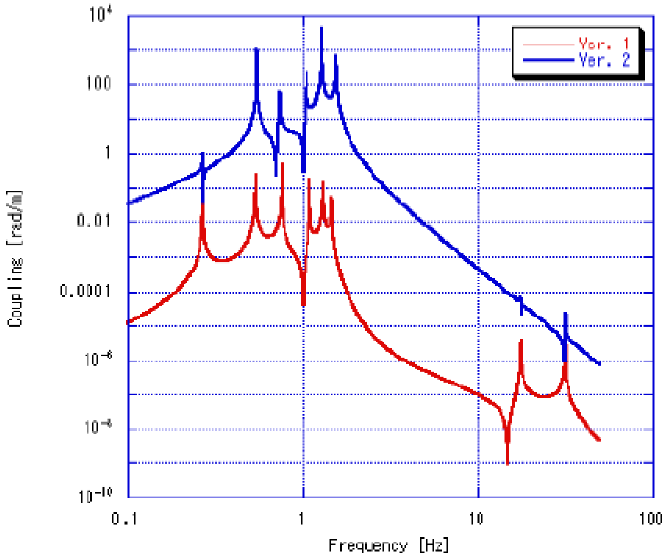
- Horizontal and yaw modes are coupled.
- Transversal → yaw coupling is large.

0.54 Hz



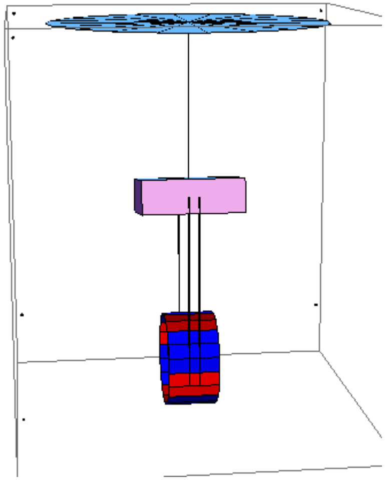
0.74 Hz





About Ver. 3

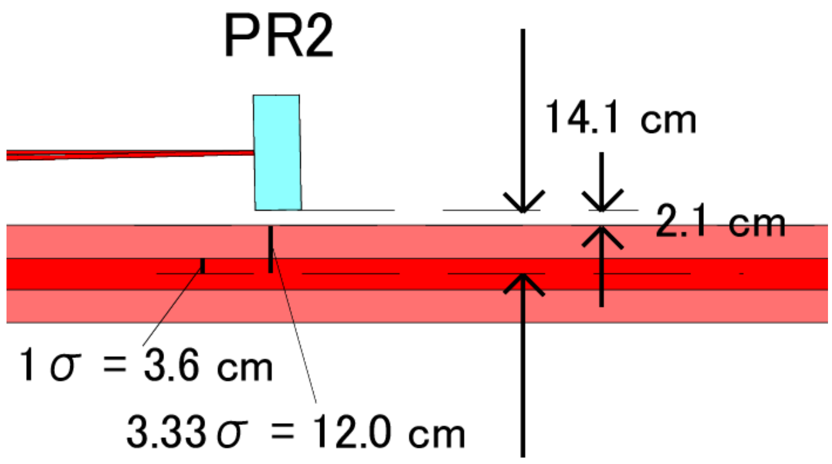
- The most symmetric design.
- Coupling between different degrees of freedom only in proportion to asymmetries



- As expected, ver. 3 (concentric) is the best solution.
- Other geometries will make the control very complicated.

Possibility of Concentric Solution

- Looking into the optical parameters more carefully, we find a small space (~2.1 cm) between PR2 and the folding beam.
- A concentric recoil mass will be allowed, if it has small thickness in its side.



- We developed tight concentric geometry, despite technical difficulties with constrained space.

Future Works

What I have done:

- Investigate the effect of eddy current damping in type-A systems
- Design about type-B payload
- Angular fluctuation of the mirrors due to seismic motions (this issue will be discussed by Y. Michimura)

Future works:

- Investigate the effect of eddy current damping in type-B systems
- Study on active controls (local damping)
- ……….