A part of Status of Type B suspensions in KAGRA and Implementing the State Space Approach for Controlling a Suspension System in KAGRA

@ The University of Perugia, Italy

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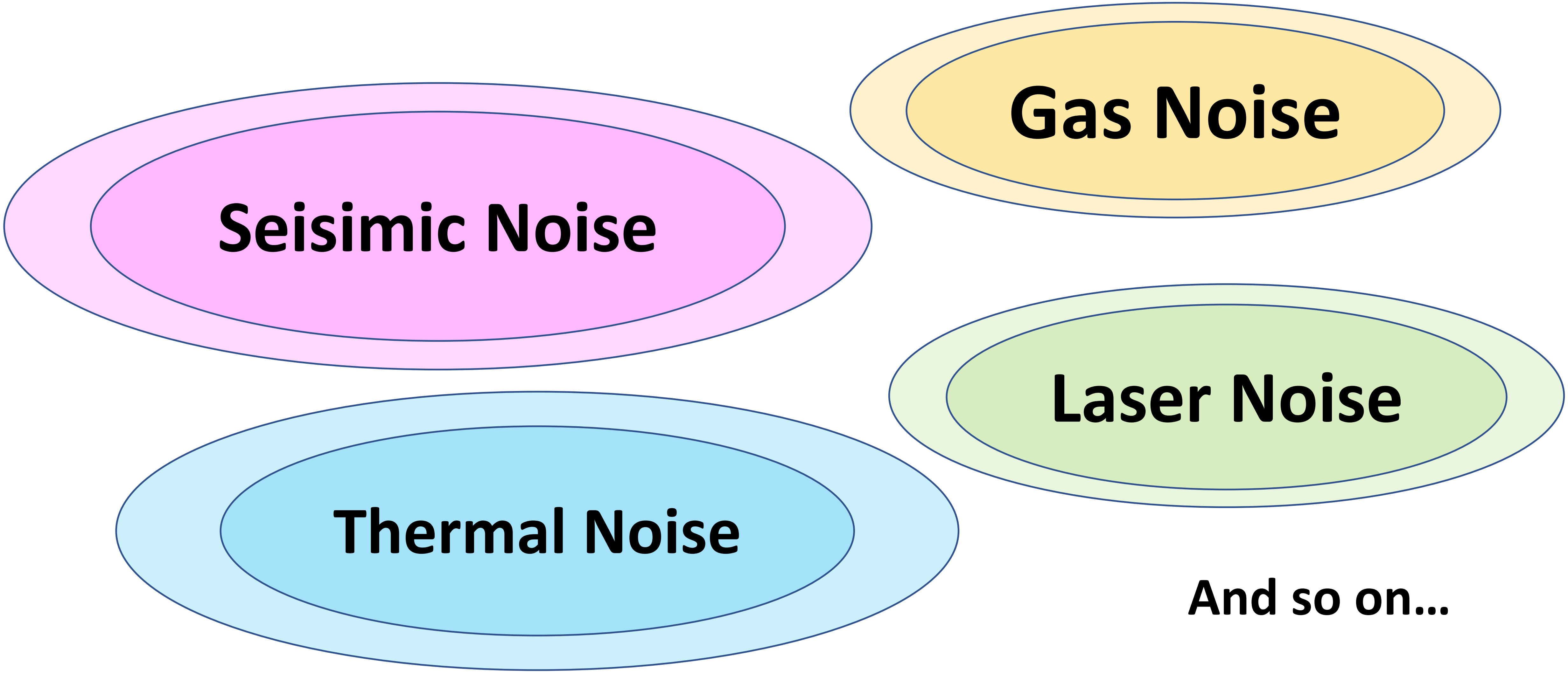
on behalf of KAGRA collaboration

Overview

- Introduction
- GAS filter tuning
- Cross coupling cancellation
- State space represent

Introduction

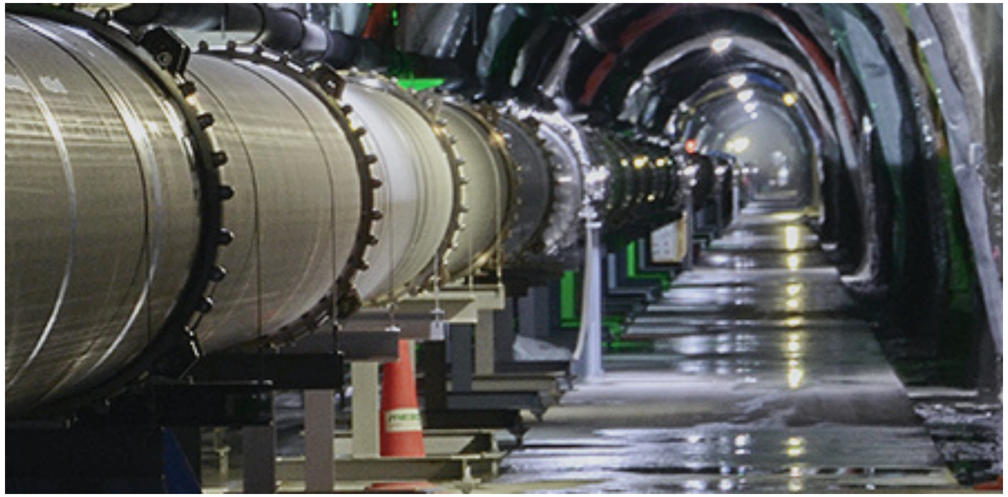
Noise Sources



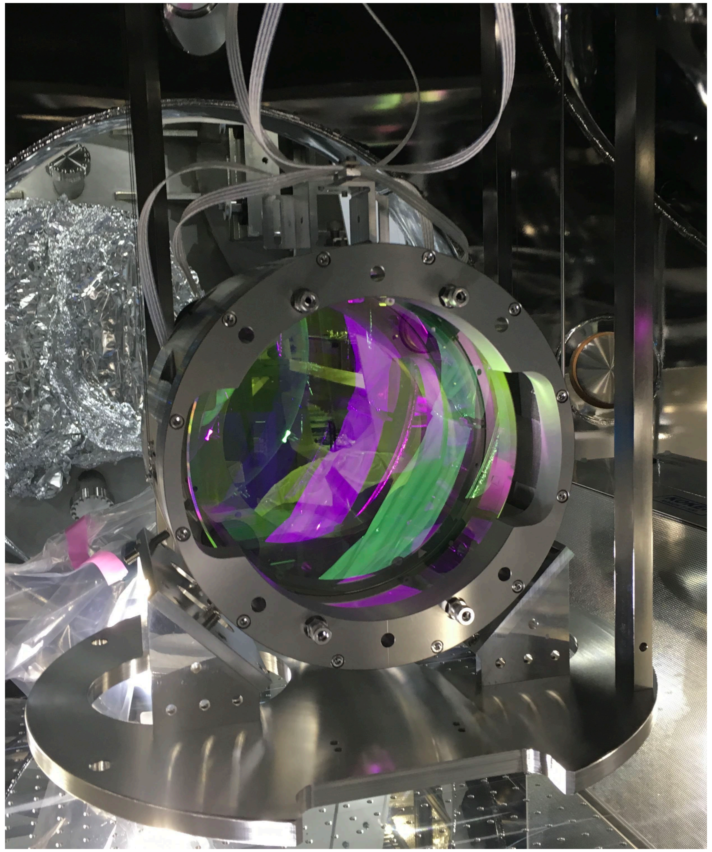
And so on…

How can we reduce Seismic noise?

1. Choosing a tranquil area

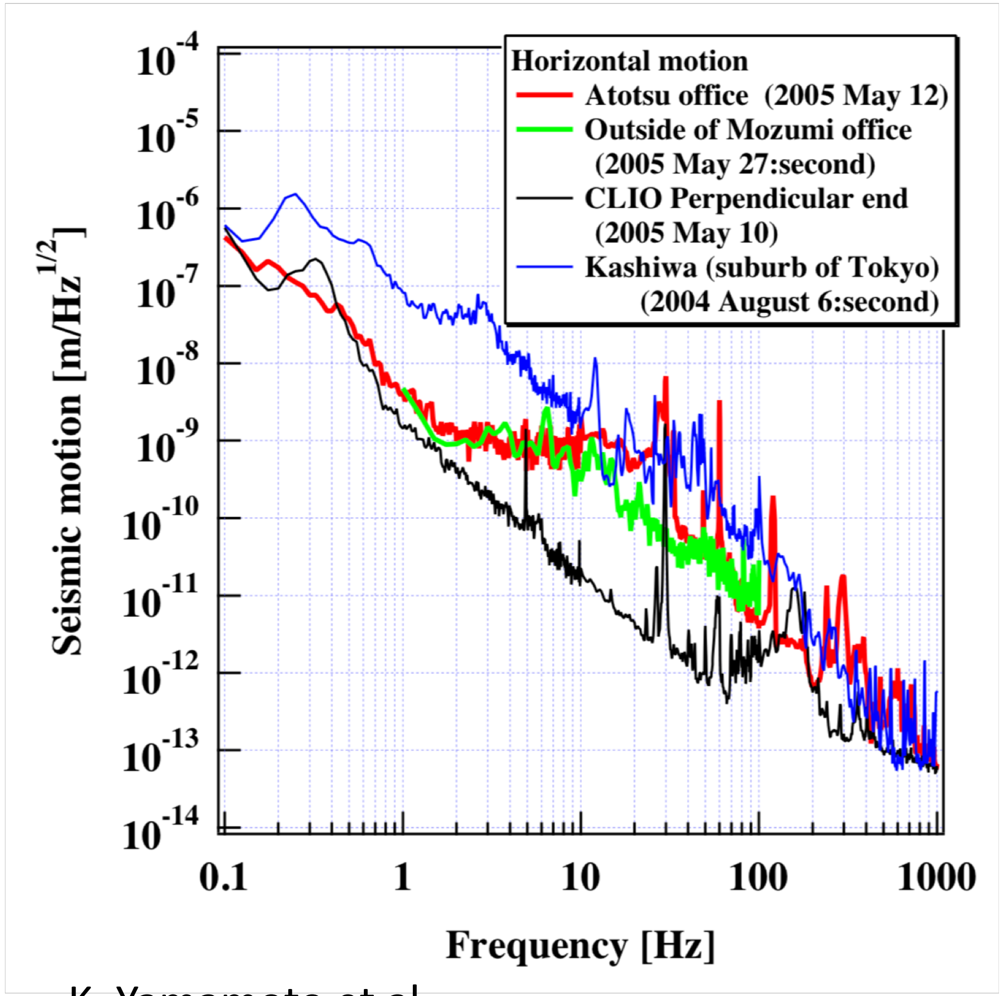


2. Hanging a mirror



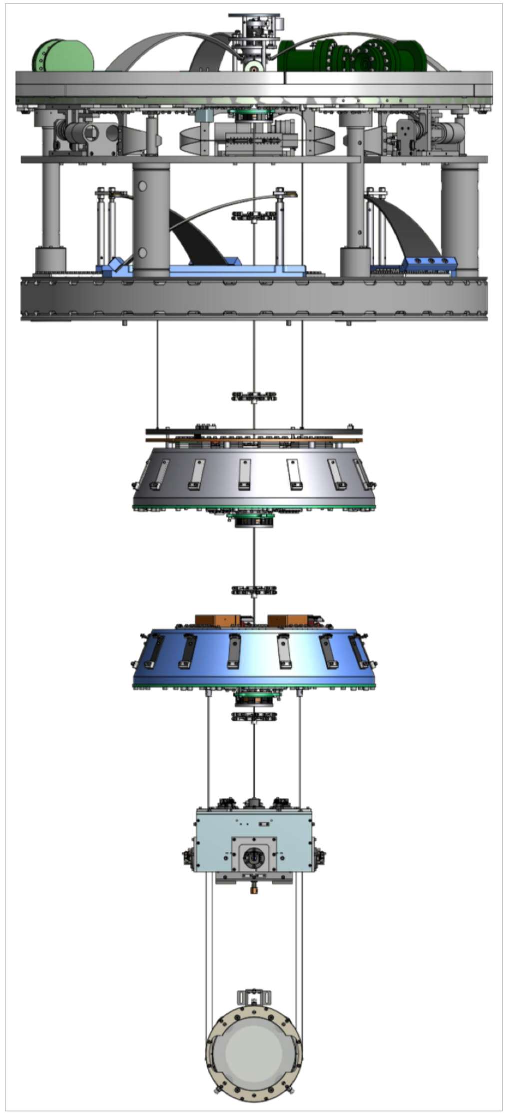
Seismic feature

- Underground reduces the motion of ground 1/100 times smaller in 1 – 100 Hz than that of ground.

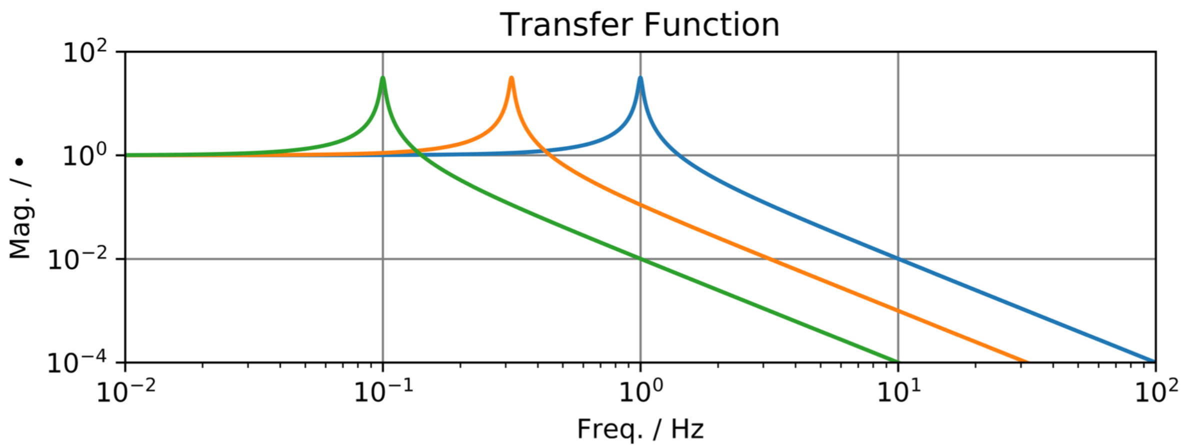


K. Yamamoto et al., "Measurement of seismic motion at Large-scale Cryogenic Gravitational wave Telescope project site"

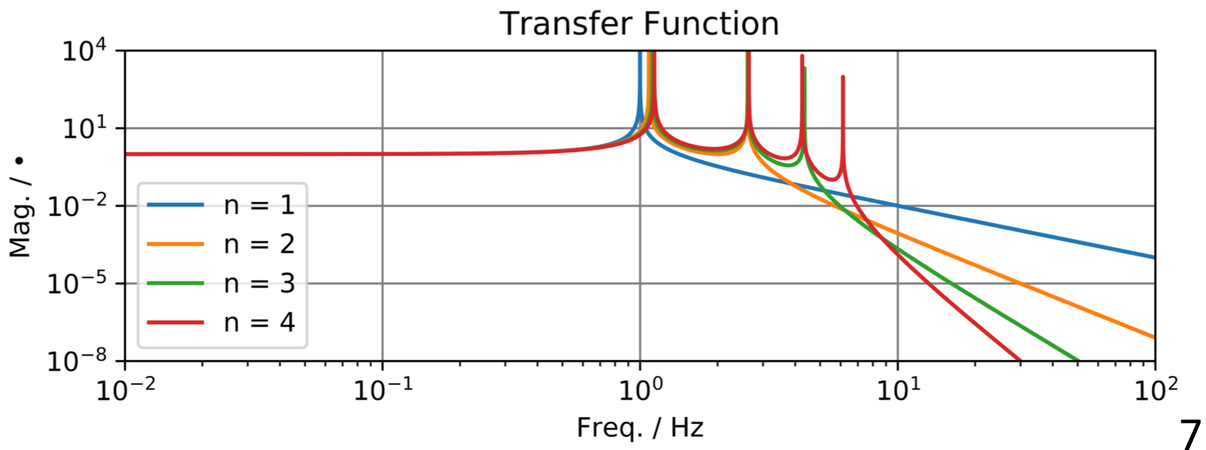
Pendulum Features

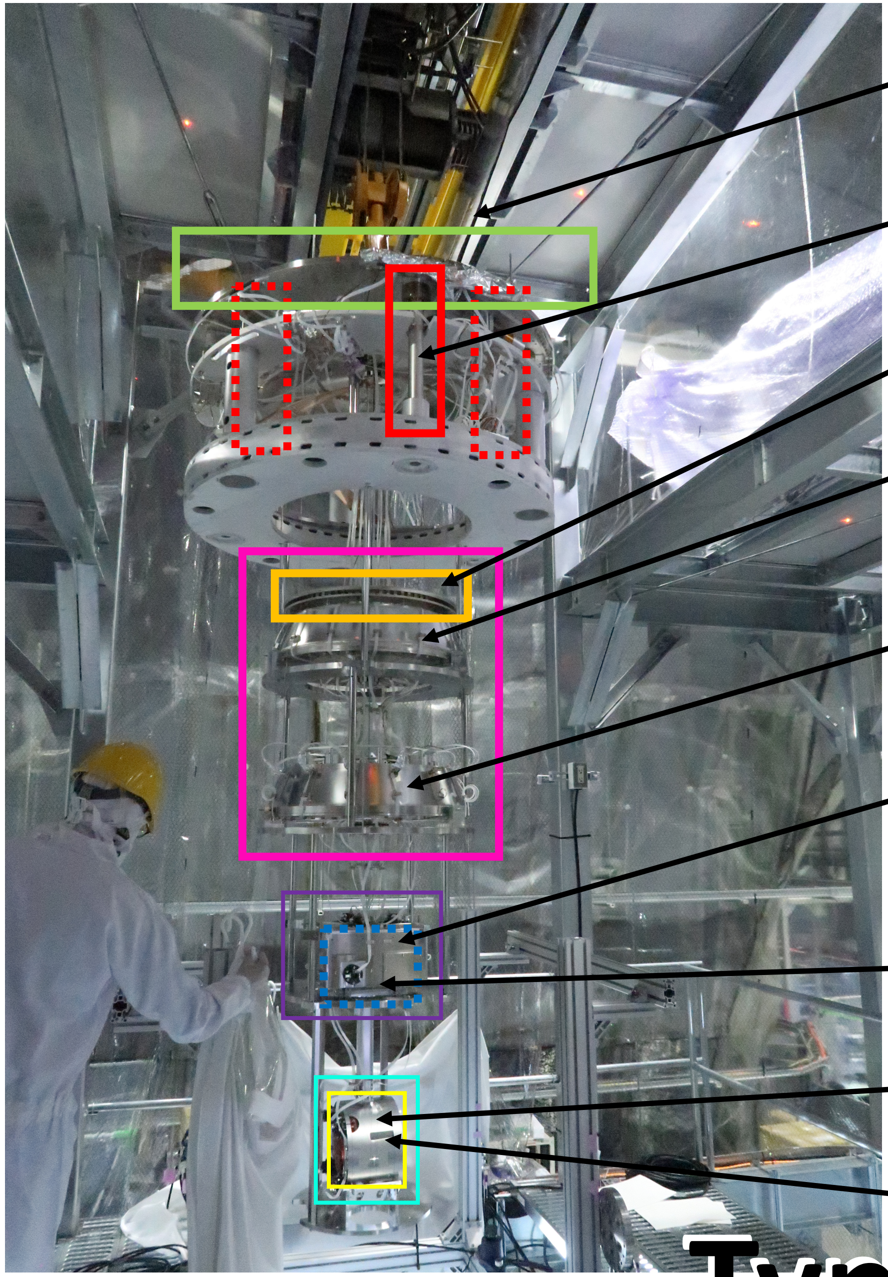


Low resonant frequency



Multiple Pendulums





Top Filter (F0)

Inverted Pendulum

magnet damper

Standard Filter (F1)

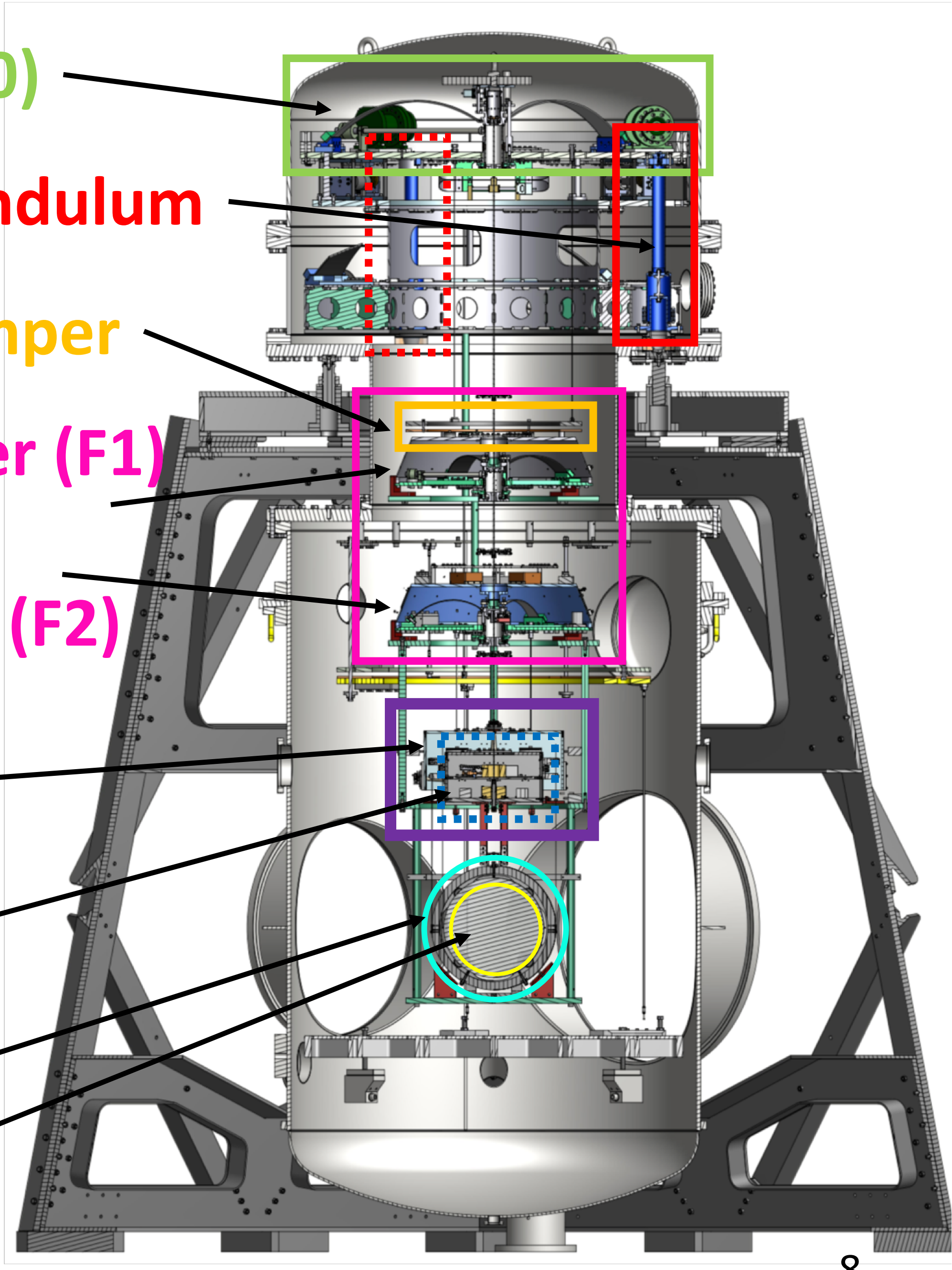
Bottom Filter (F2)

Intermediate Recoil Mass

Intermediate Mass

Recoil Mass

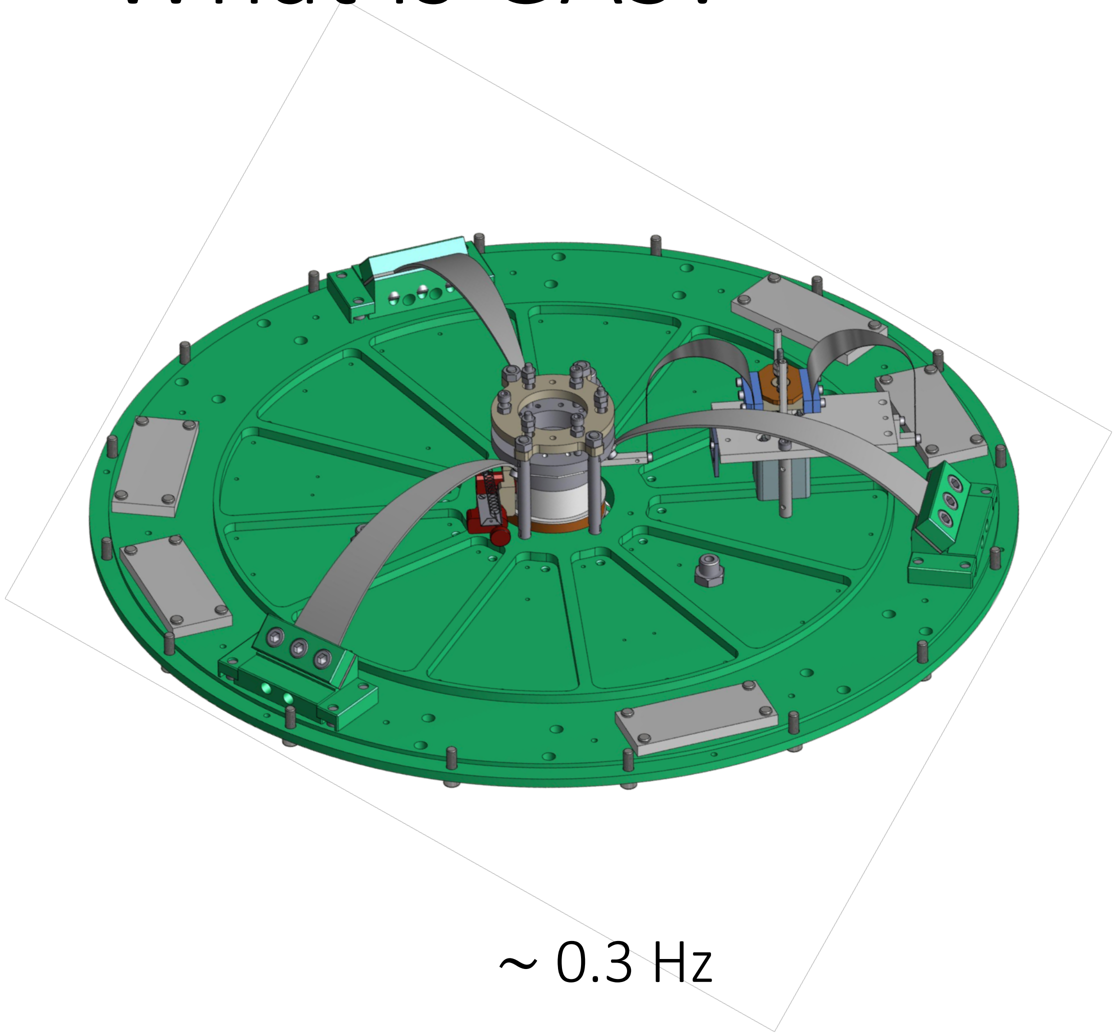
Test Mass



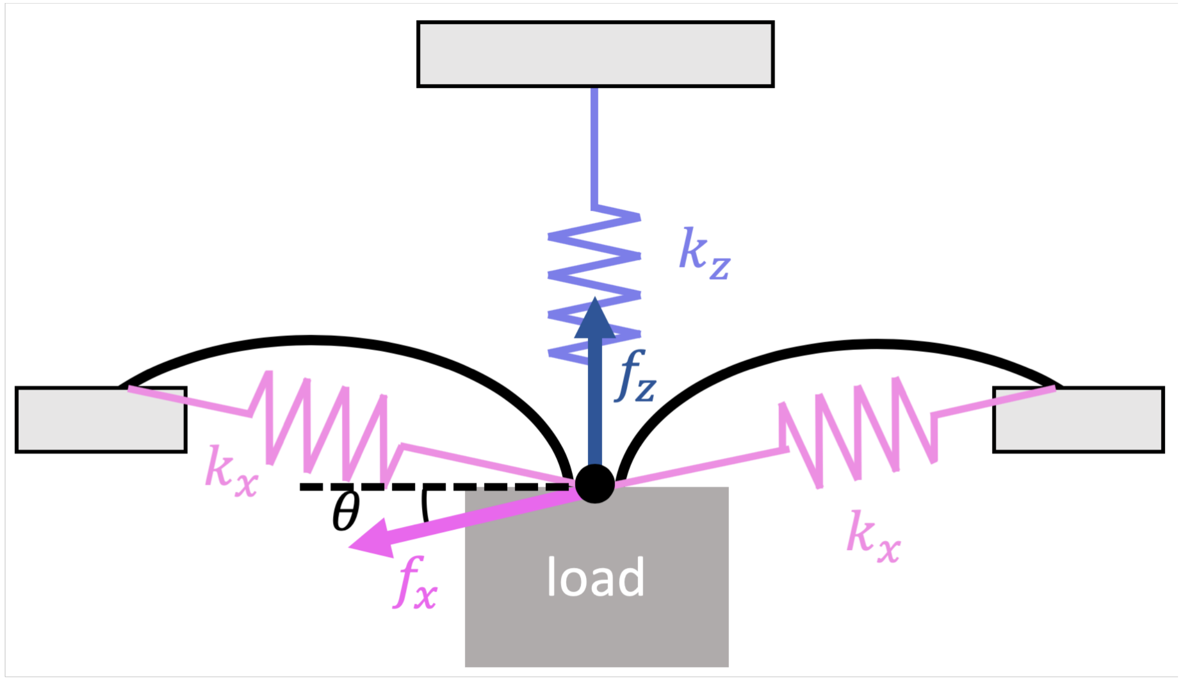
Type B SR3

GAS filter tuning

What is GAS?



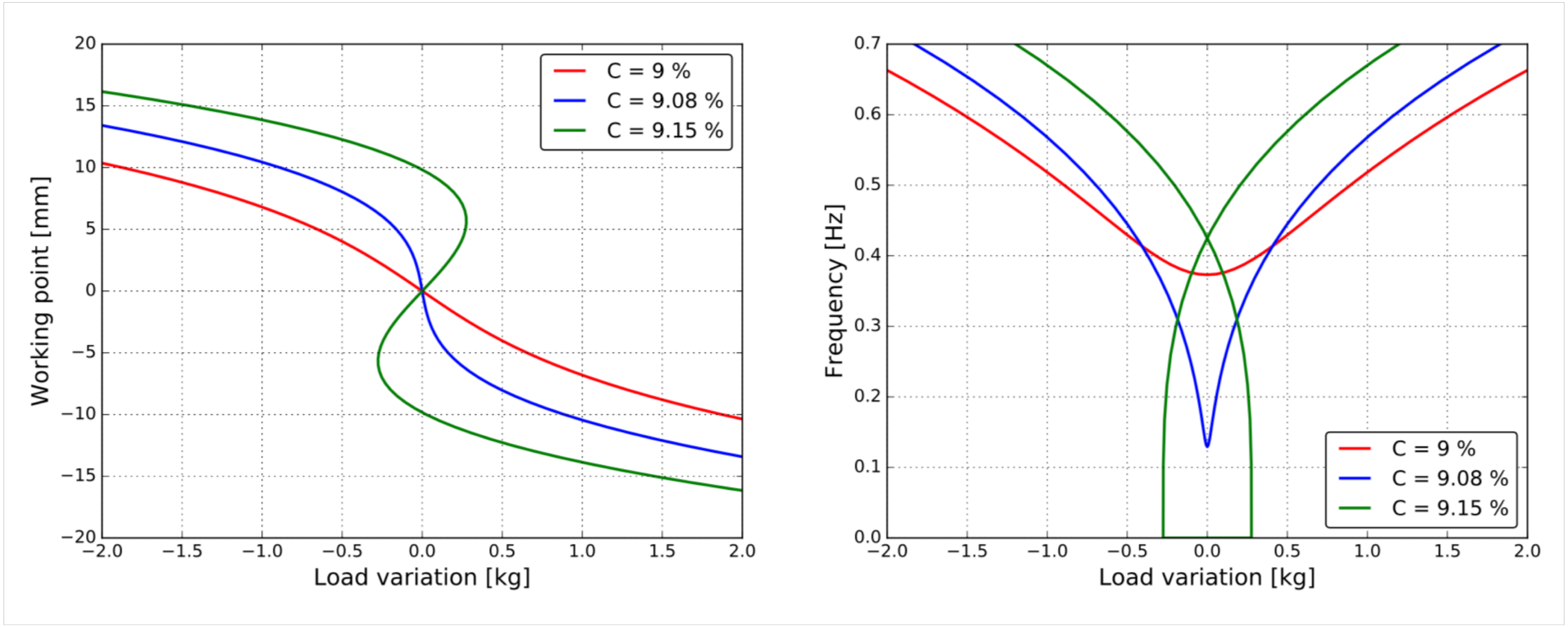
~ 0.3 Hz



$$k_{\text{eff}} = k_z - \left(\frac{l_{0x}}{x_0} - 1 \right) k_x$$

$$\omega_0 = \sqrt{\frac{k_{\text{eff}}}{M}}$$

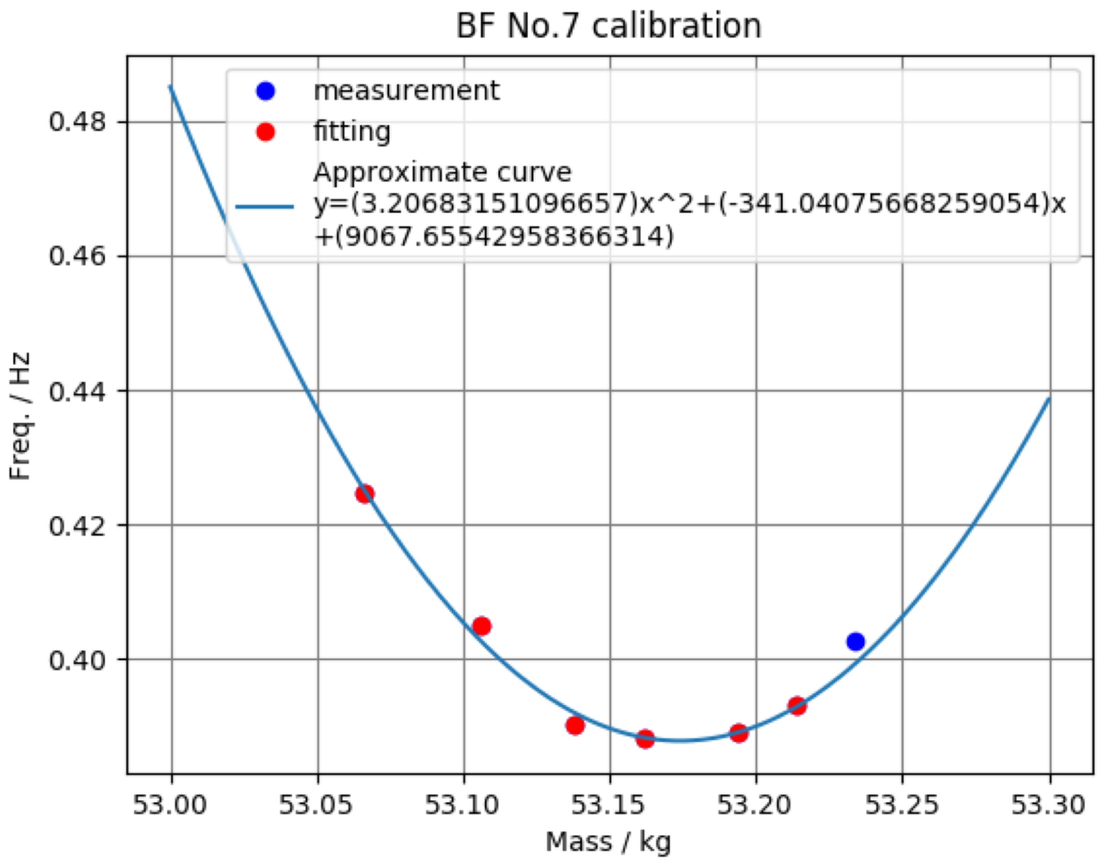
GAS blade behavior

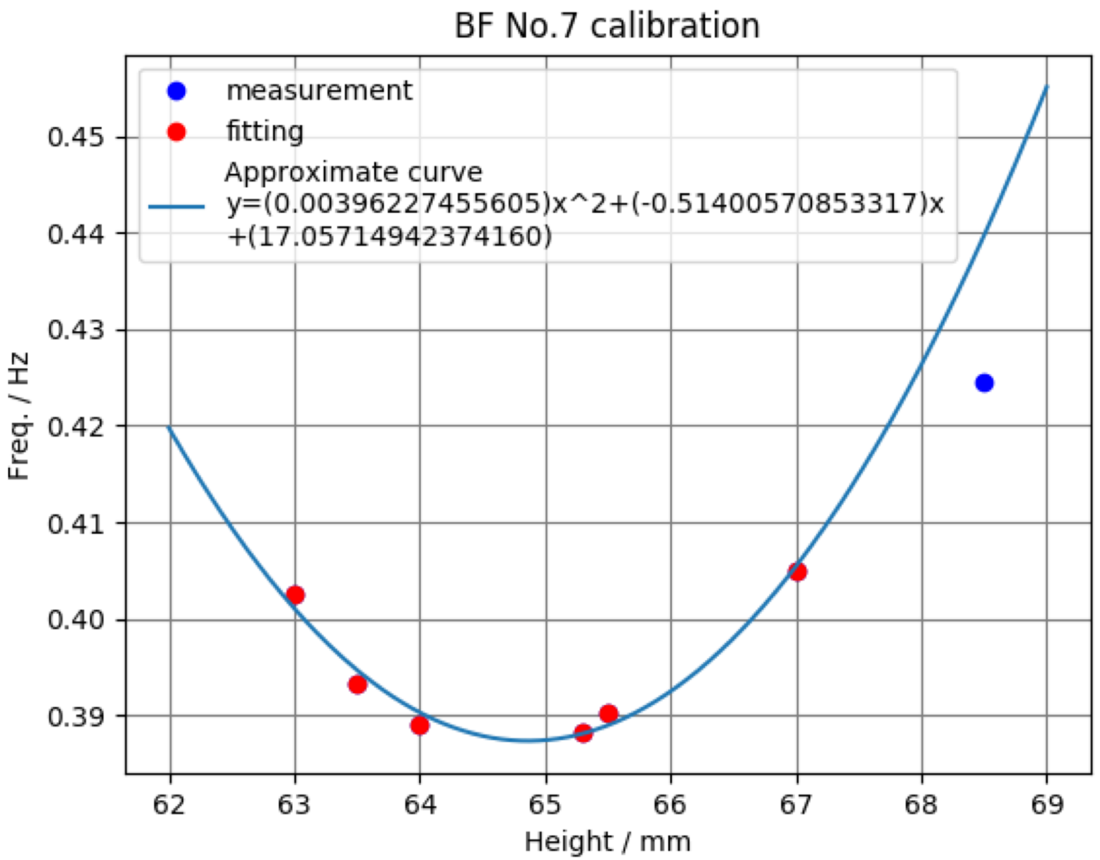


$$C = (l_{0x} - x_0)/l_{0x} \quad m = 200 \text{ kg}$$

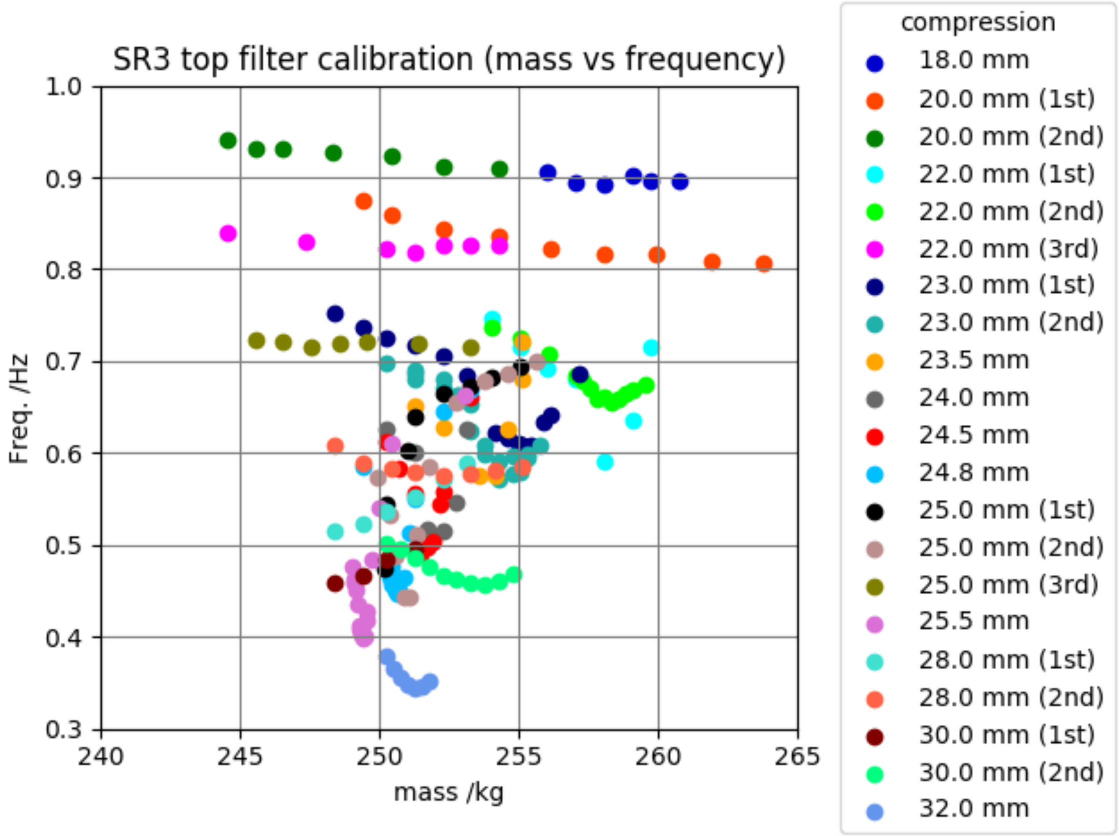
[Y. Fuji master thesis]

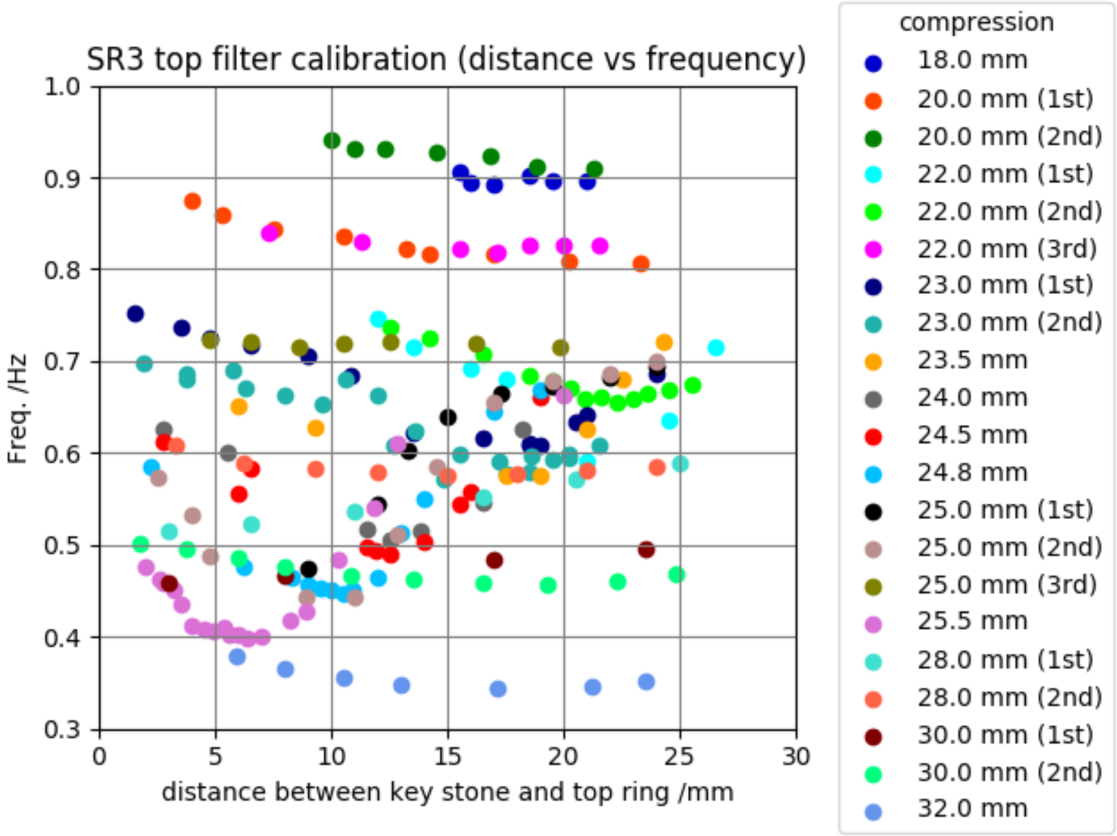
Calibration result: SR2 bottom filter





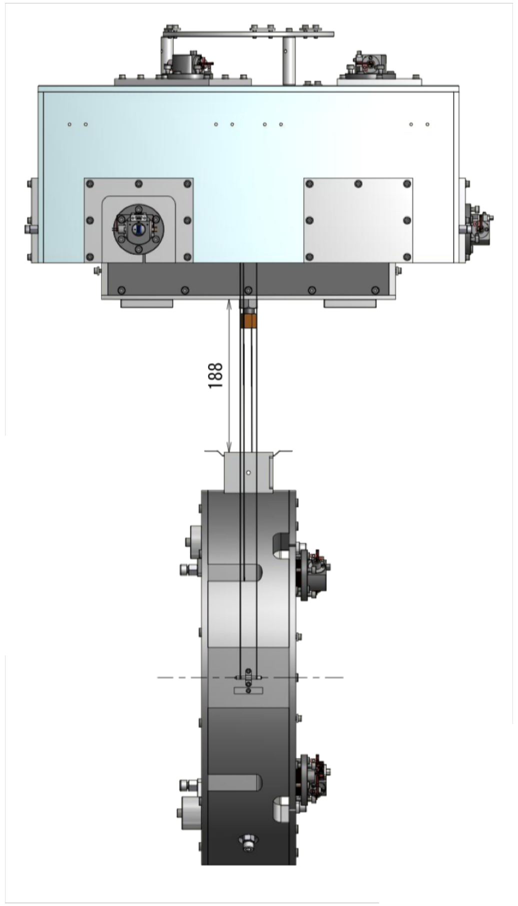
Calibration result: SR3 Top filter

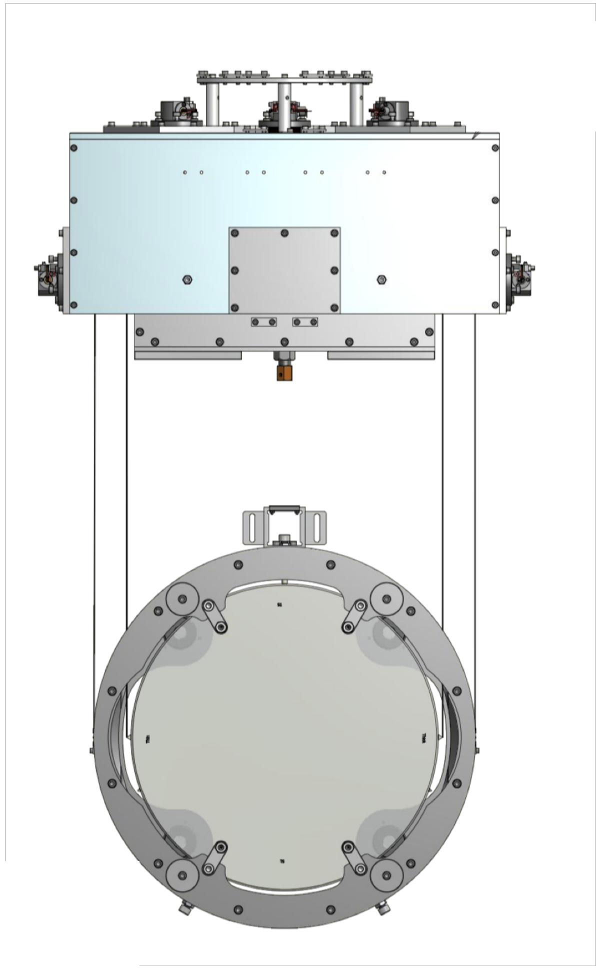


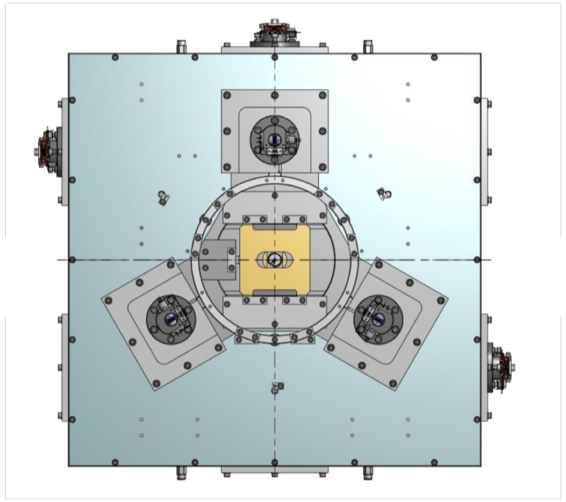


Cross Coupling Cancellation

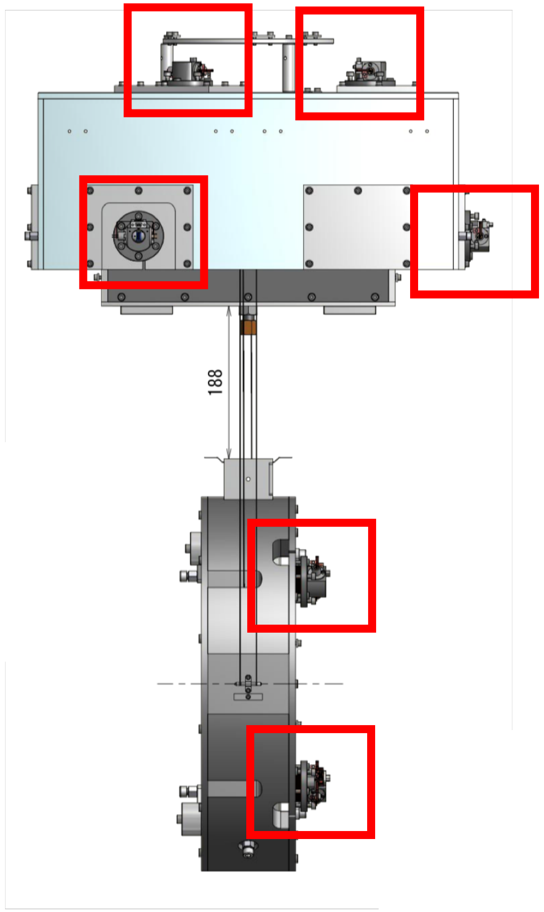
Payload

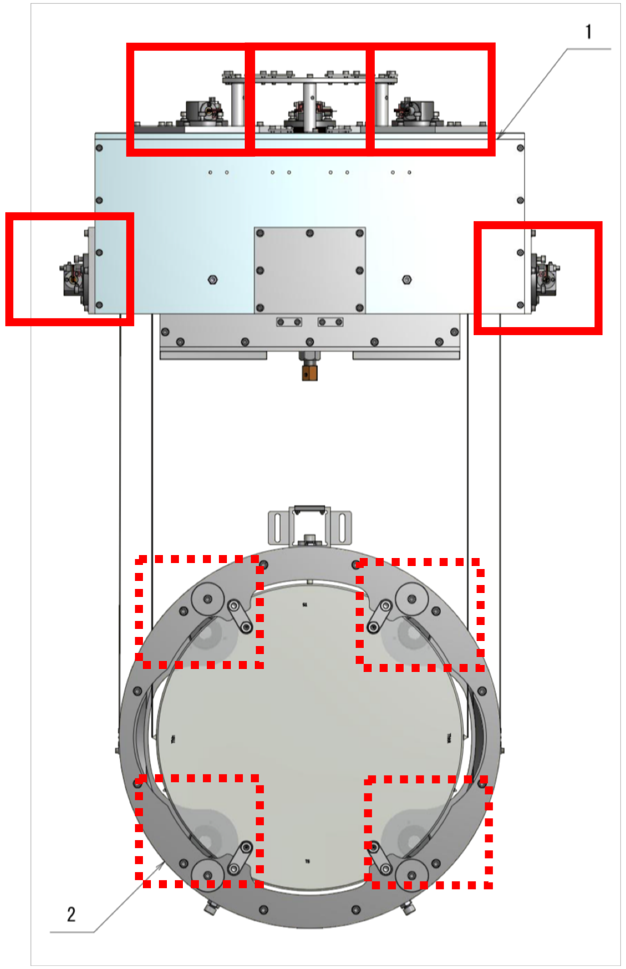


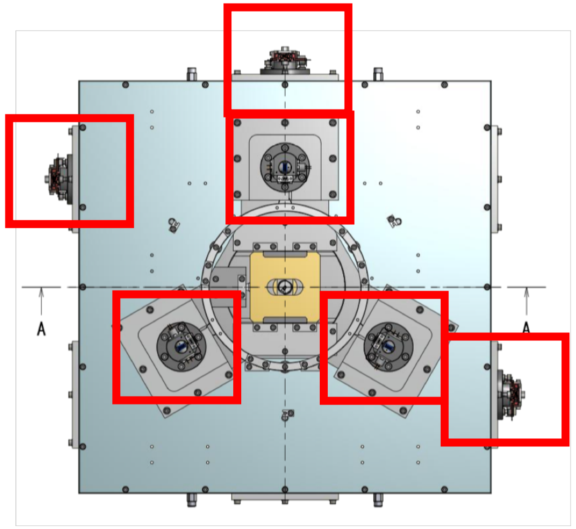




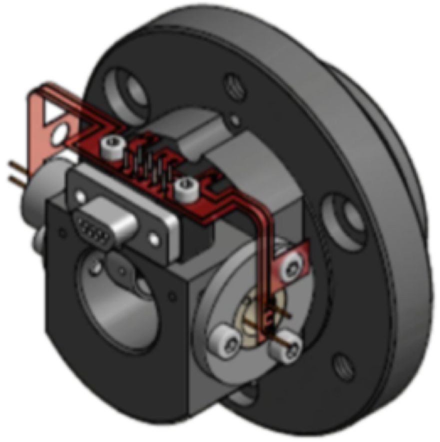
Payload actuators

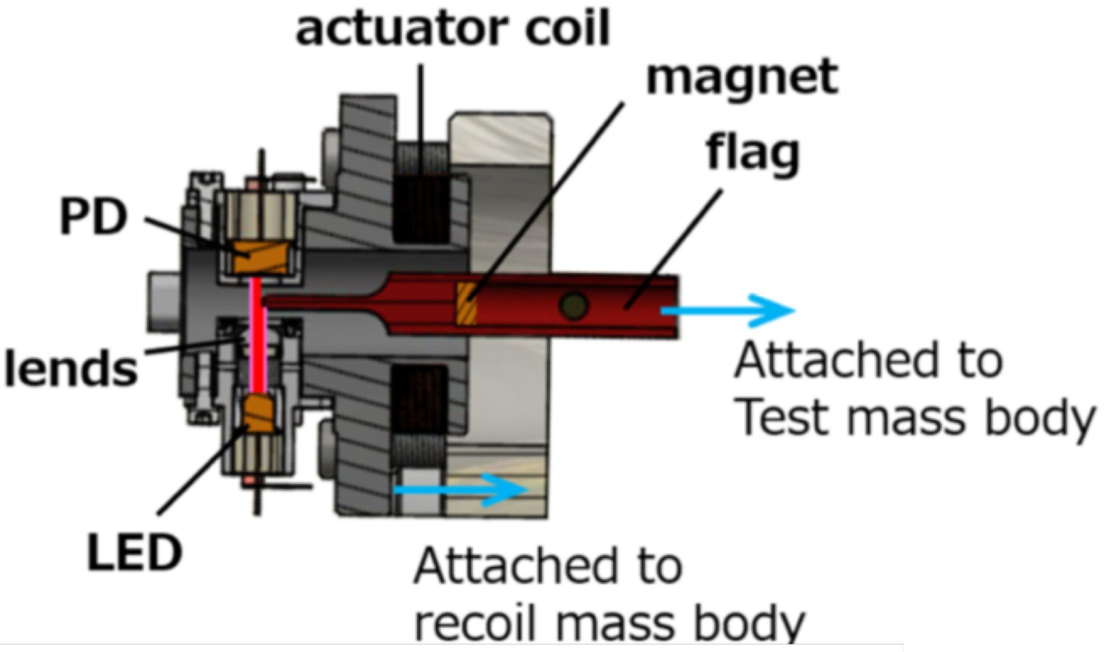




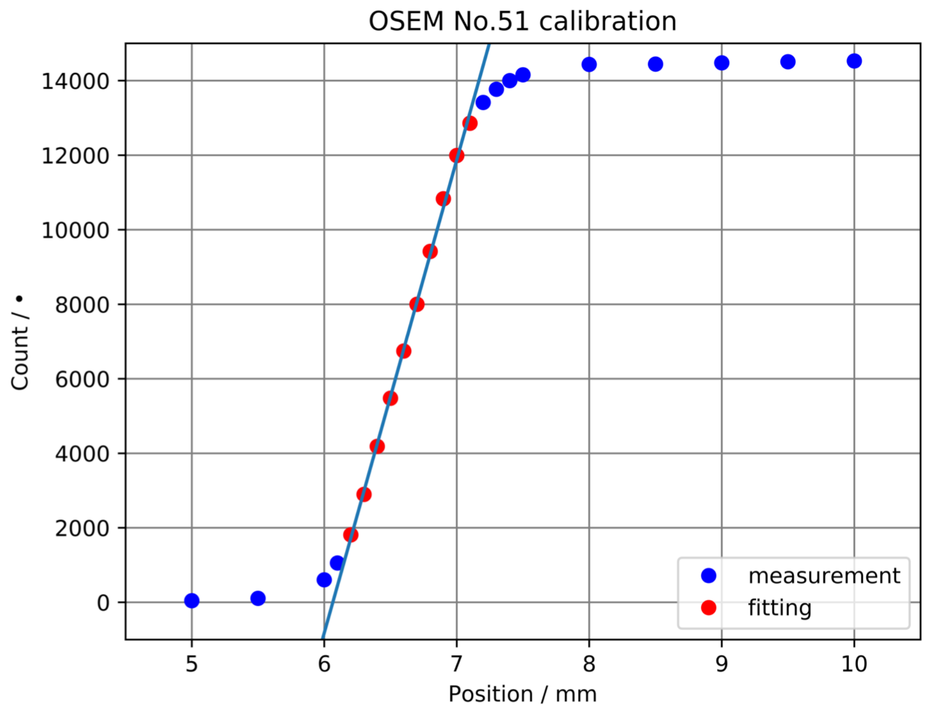


OSEM

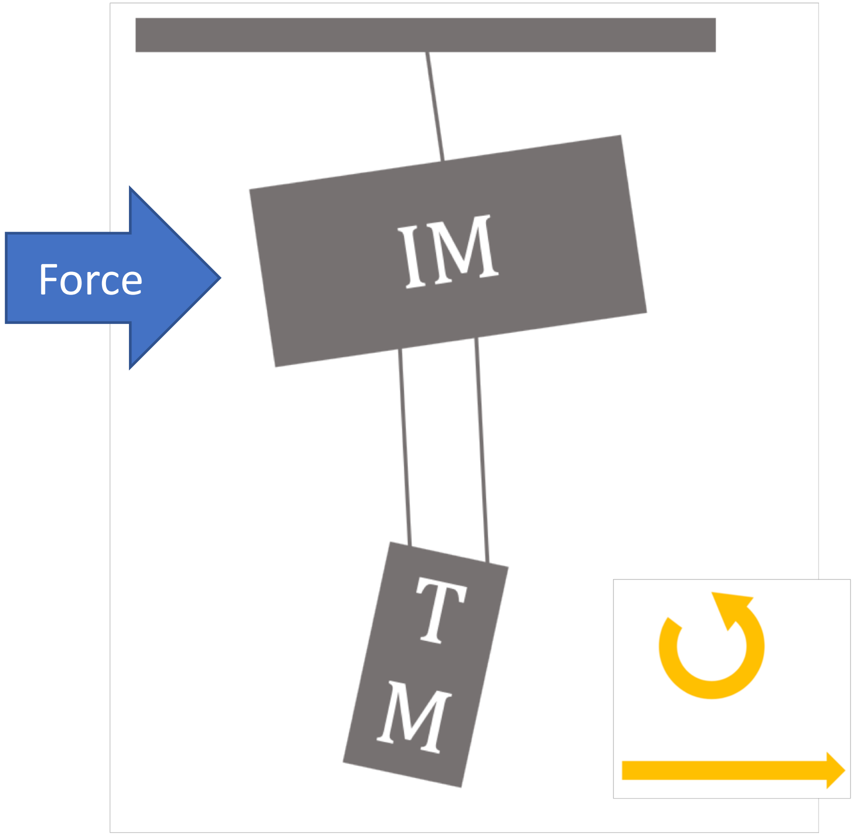




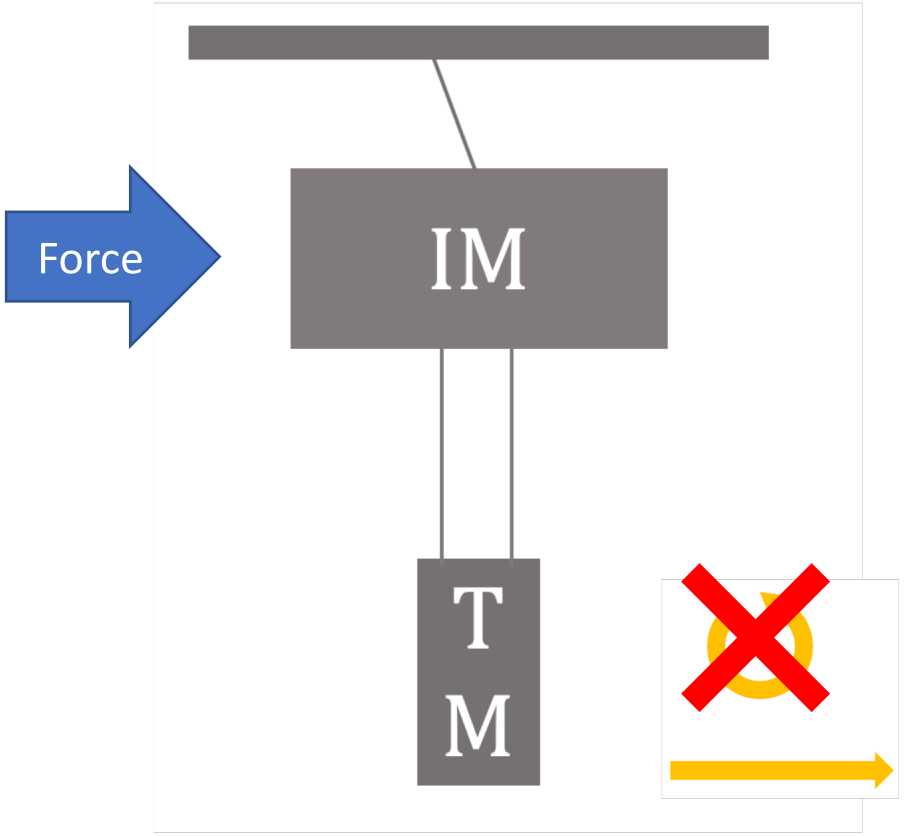
Optical Sensor ElectroMagnet (OSEM) is a sensor and actuator. It measures the relative distance of IM and actuate IM by a coil.



Cross coupling cancellation

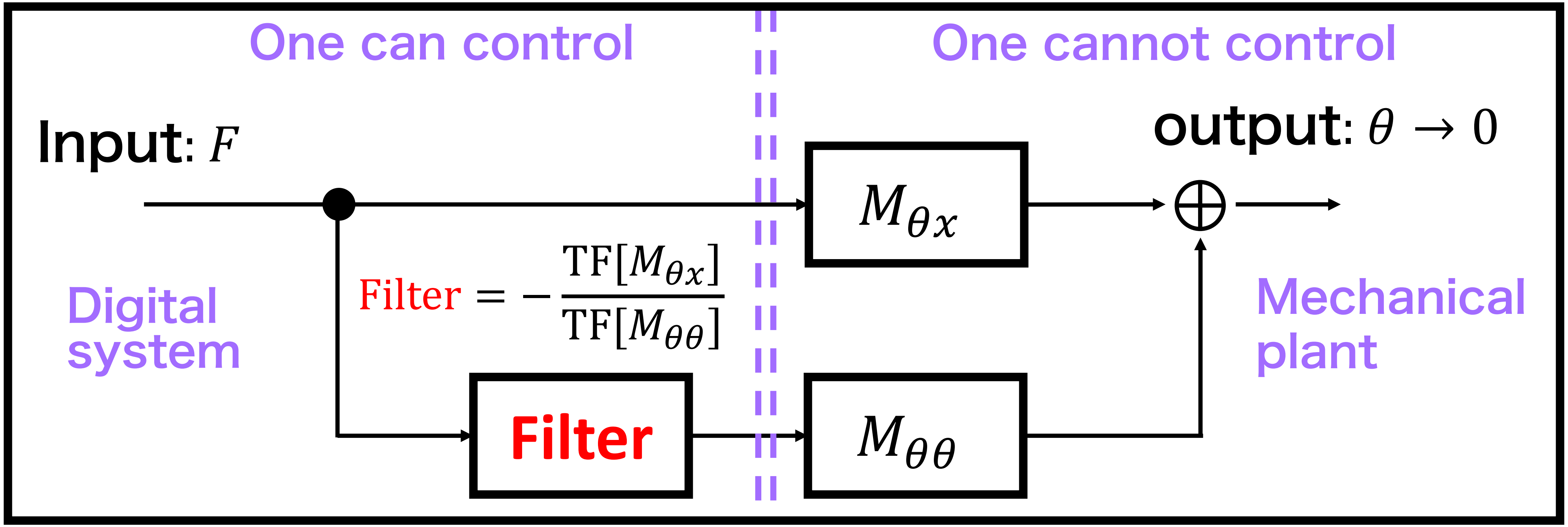


Without control filters

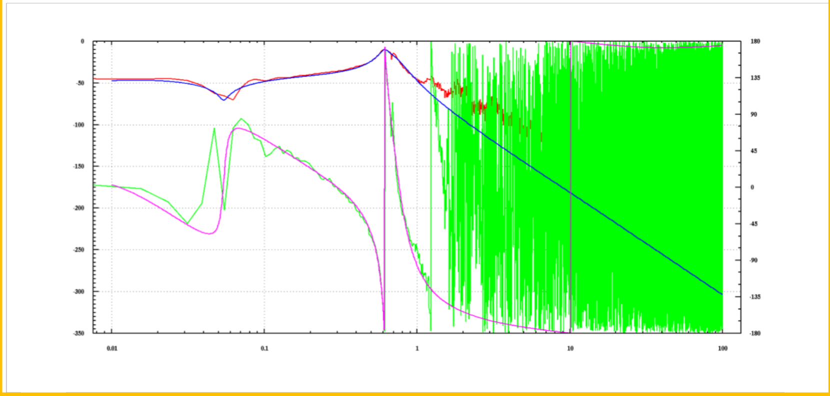
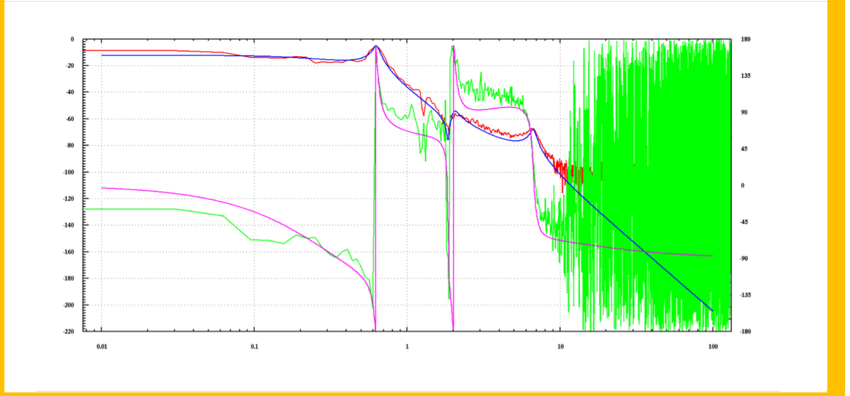
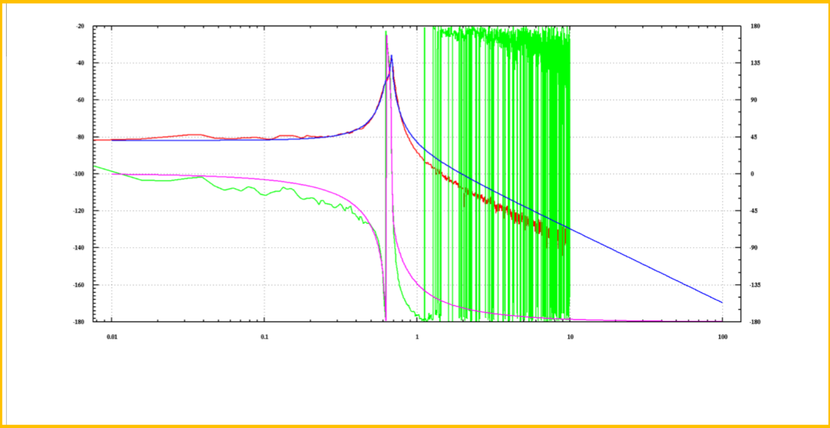
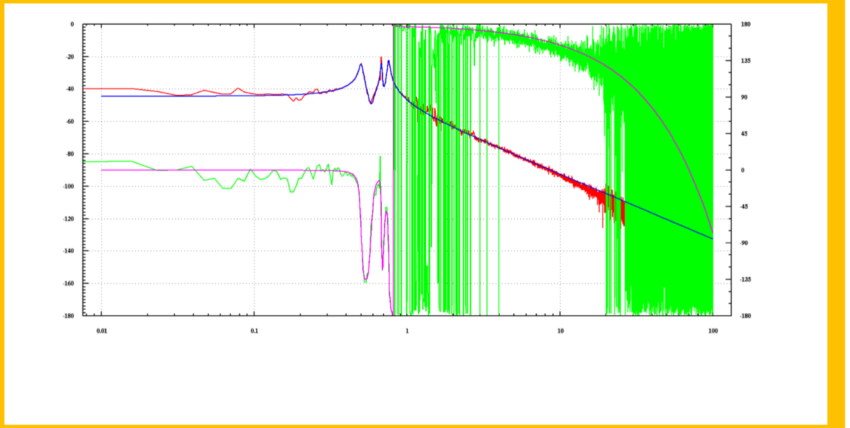


With control filters

How do we install a filter?

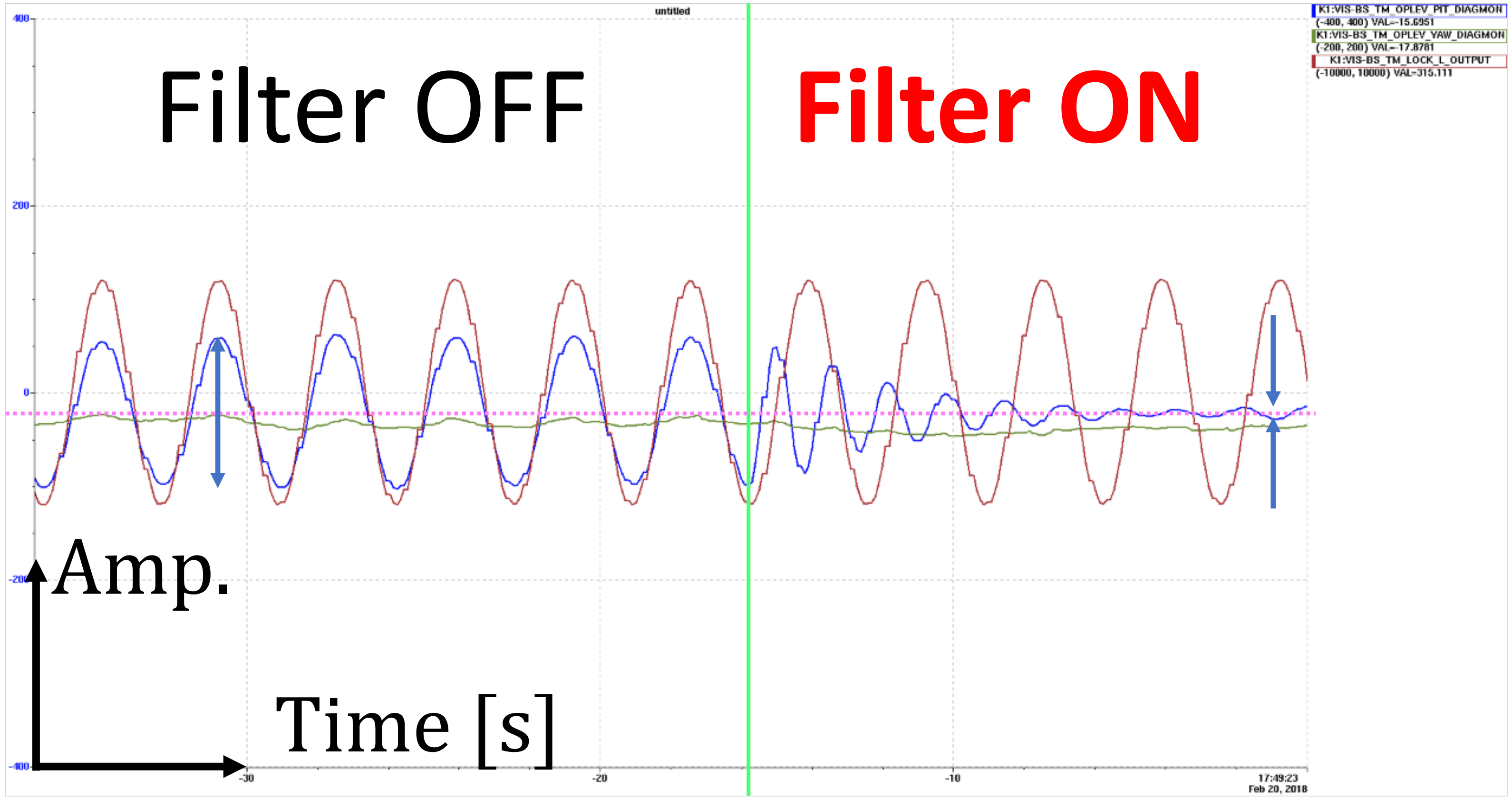


Result

	L→P	P→P
IM to TM		
TM to TM		

Damped transfer functions and its fitting

Result (time vs amp.)



Input signal vs TM pitch at 0.3 Hz. The amplitude became 1/10 times smaller.

State Space Approach

EOM of suspensions

- Since the suspension moves around the equilibrium points, we can use an Taylor approximate Lagrangian around the equilibrium points.

$$\frac{\mathrm{d}}{\mathrm{d}t}\frac{\partial \mathscr{L}_{\mathrm{apr}}}{\partial \dot{X}} - \frac{\partial \mathscr{L}_{\mathrm{apr}}}{\partial X} = 0$$

$$\mathscr{L}_{\mathrm{apr}}(X) = \mathscr{L}(X_{\mathrm{eq}}) + \left.\frac{\partial \mathscr{L}}{\partial X}\right|_{X=X_{\mathrm{eq}}} X + \frac{1}{2}\left.\frac{\partial^2 \mathscr{L}}{\partial X^2}\right|_{X=X_{\mathrm{eq}}} X^2.$$

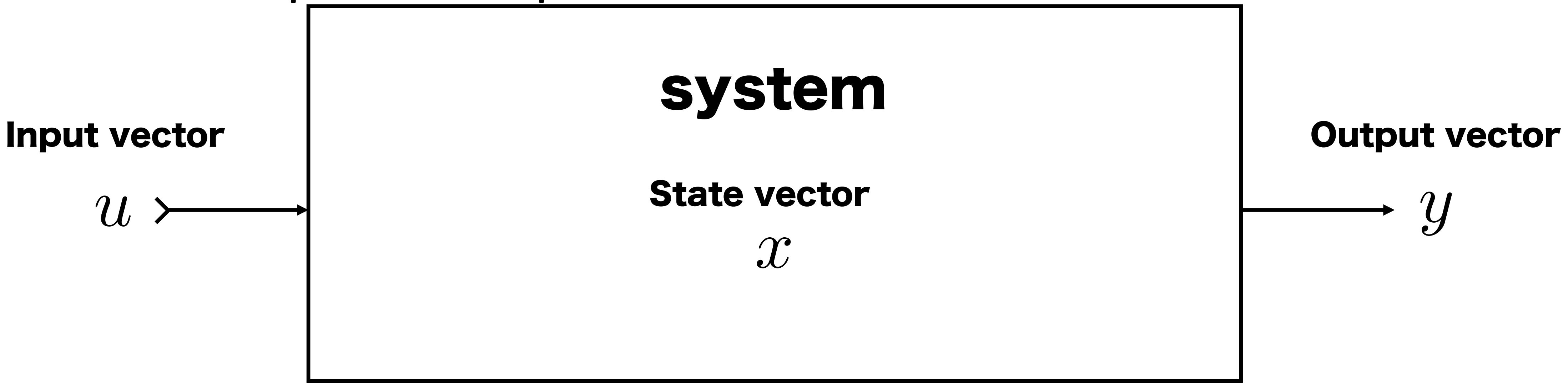
EOM of suspensions

- From this approximation, one can get the linearized equation of motion around the equilibrium points.

$$M\ddot{\boldsymbol{x}} + C\dot{\boldsymbol{x}} + K(\boldsymbol{x} - \boldsymbol{x}_{\mathrm{eq}}) = 0$$

M is the inertia matrix
C is the damping matrix
K is the stiffness matrix

State space representation



$$
\begin{cases}
\dot{x} = Ax + Bu \\
y = Cx + Du
\end{cases}
$$

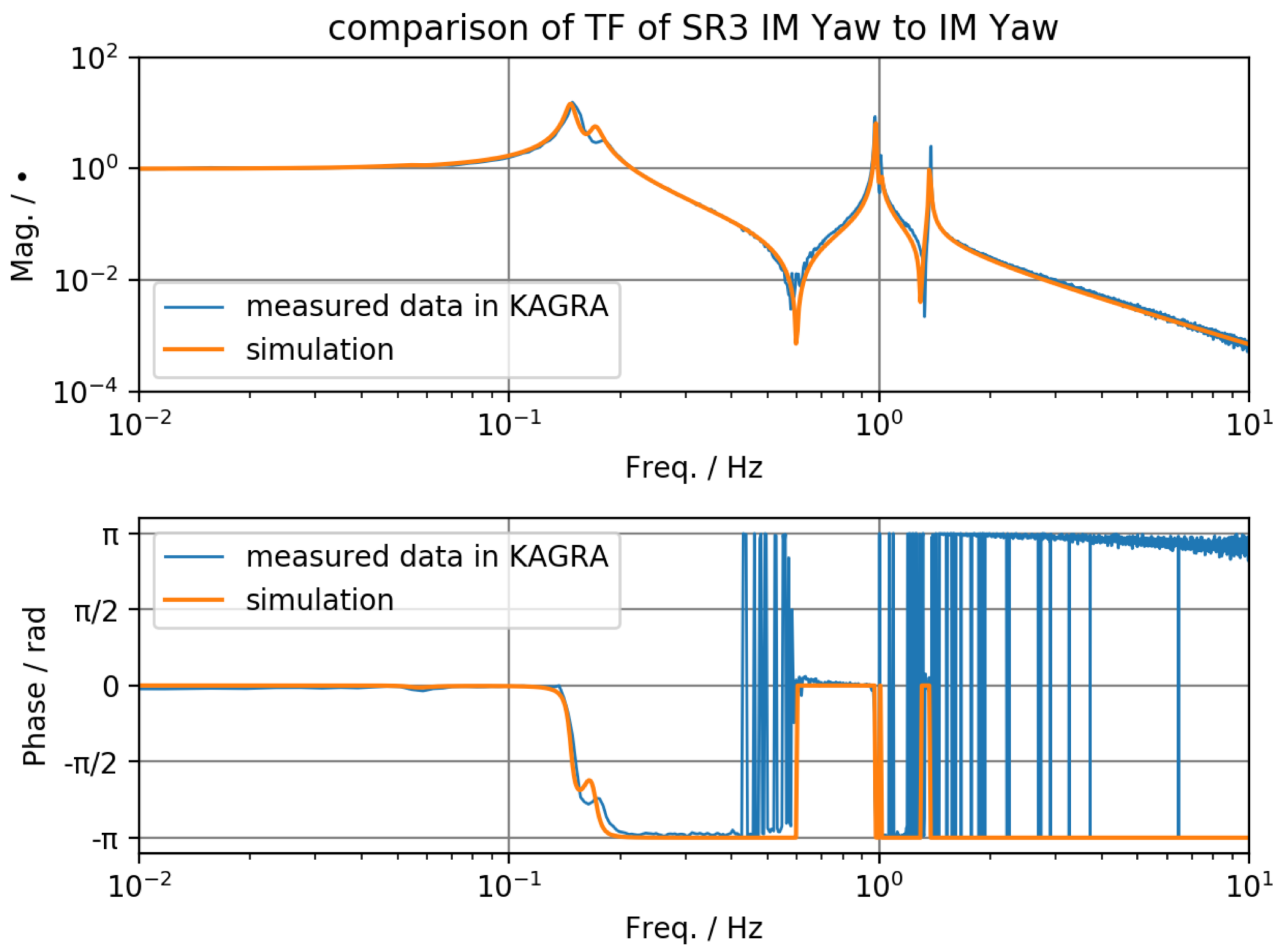
A **: State matrix**

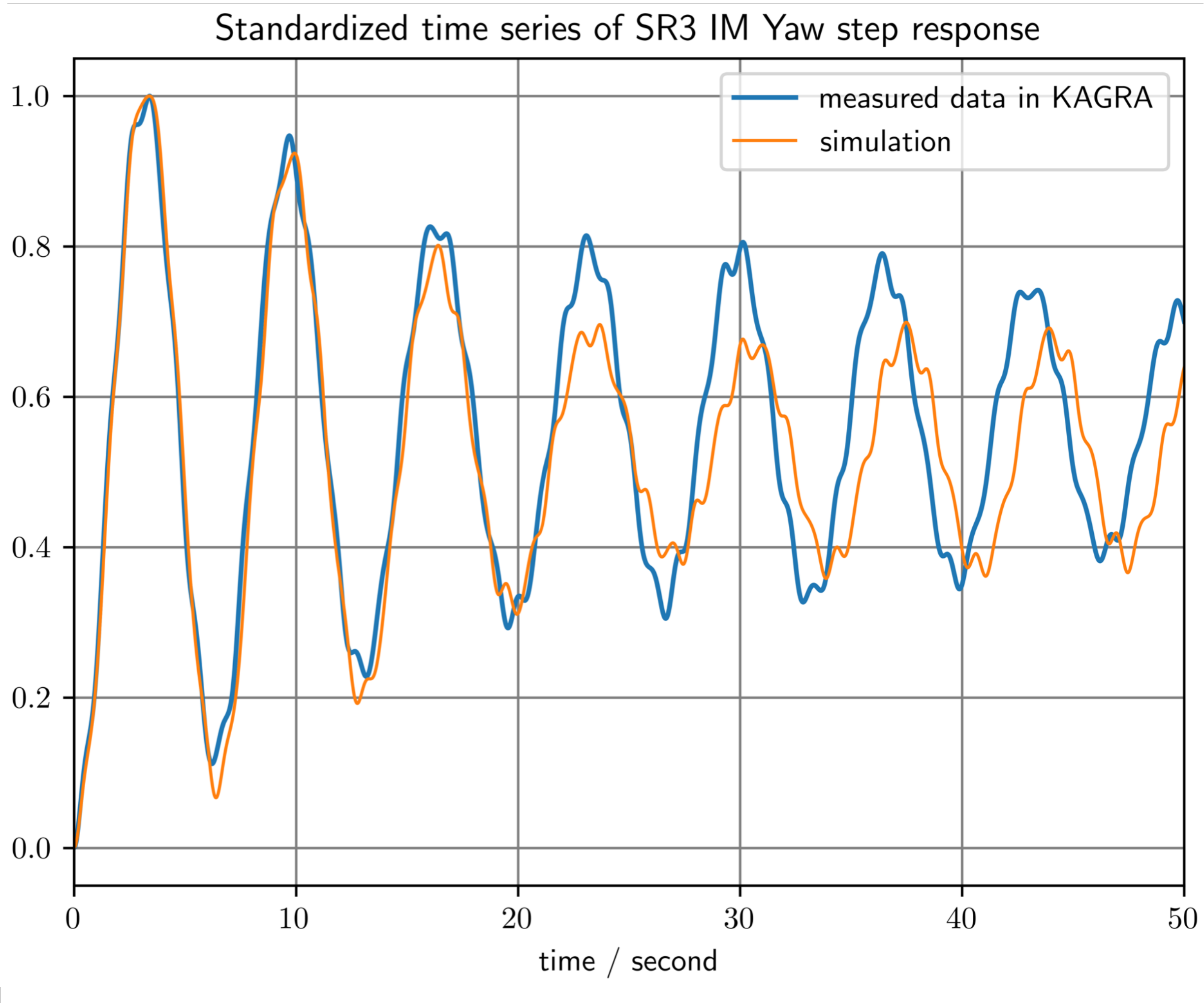
B **: Input matrix**

C **: Output matrix**

D **: Feedthrough matrix**

Transfer function(SR3 IM Yaw)





Thank you!!
Grazie!!