Development of tilt adjustment mechanism for KAGRA cryogenic mirror suspension

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KAGRA gravitational wave telescope

KAGRA is interferometric gravitational wave detector

KAGRA has two main features

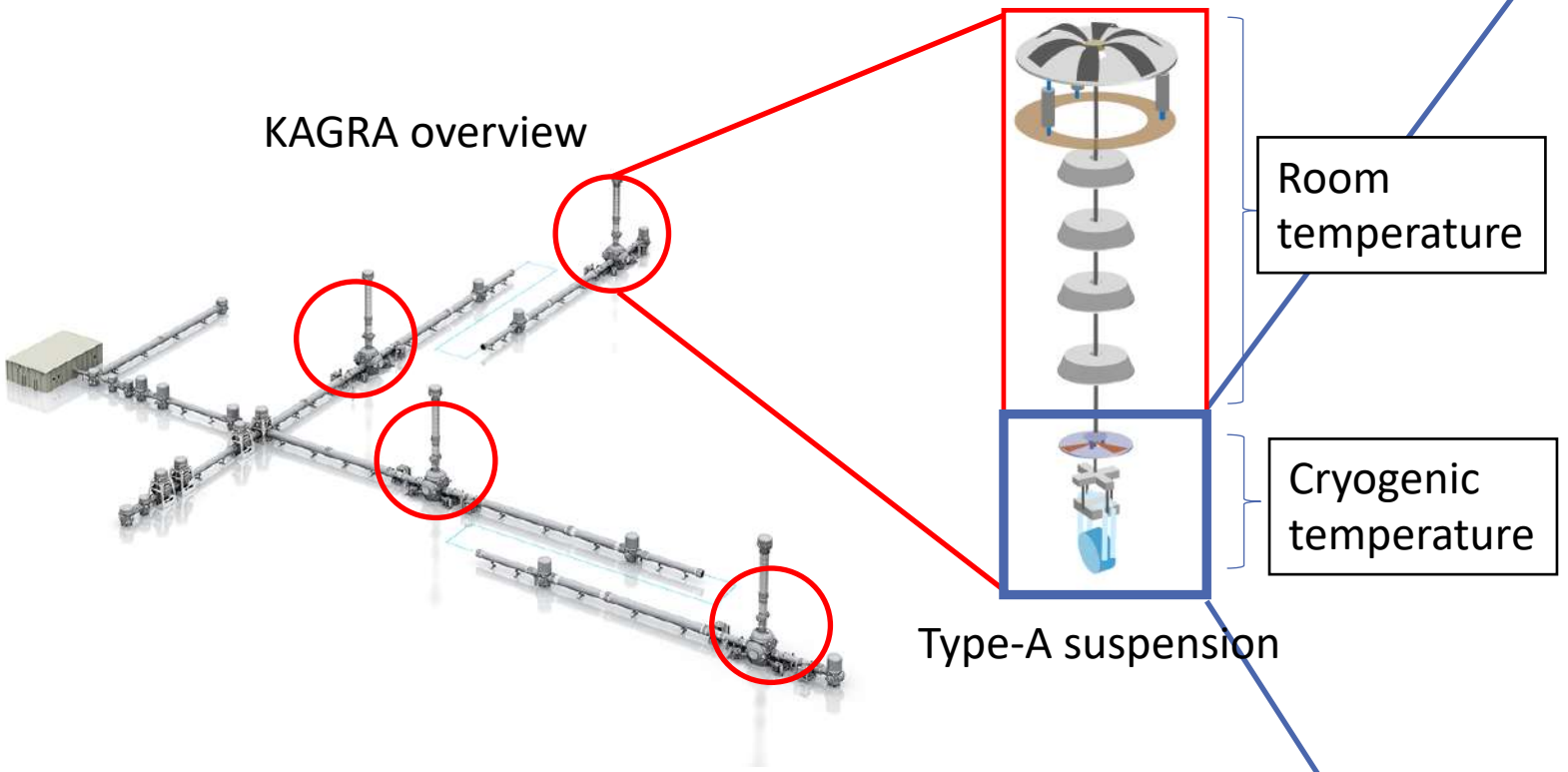
1.Located in underground site
(for suppression of ground vibration)

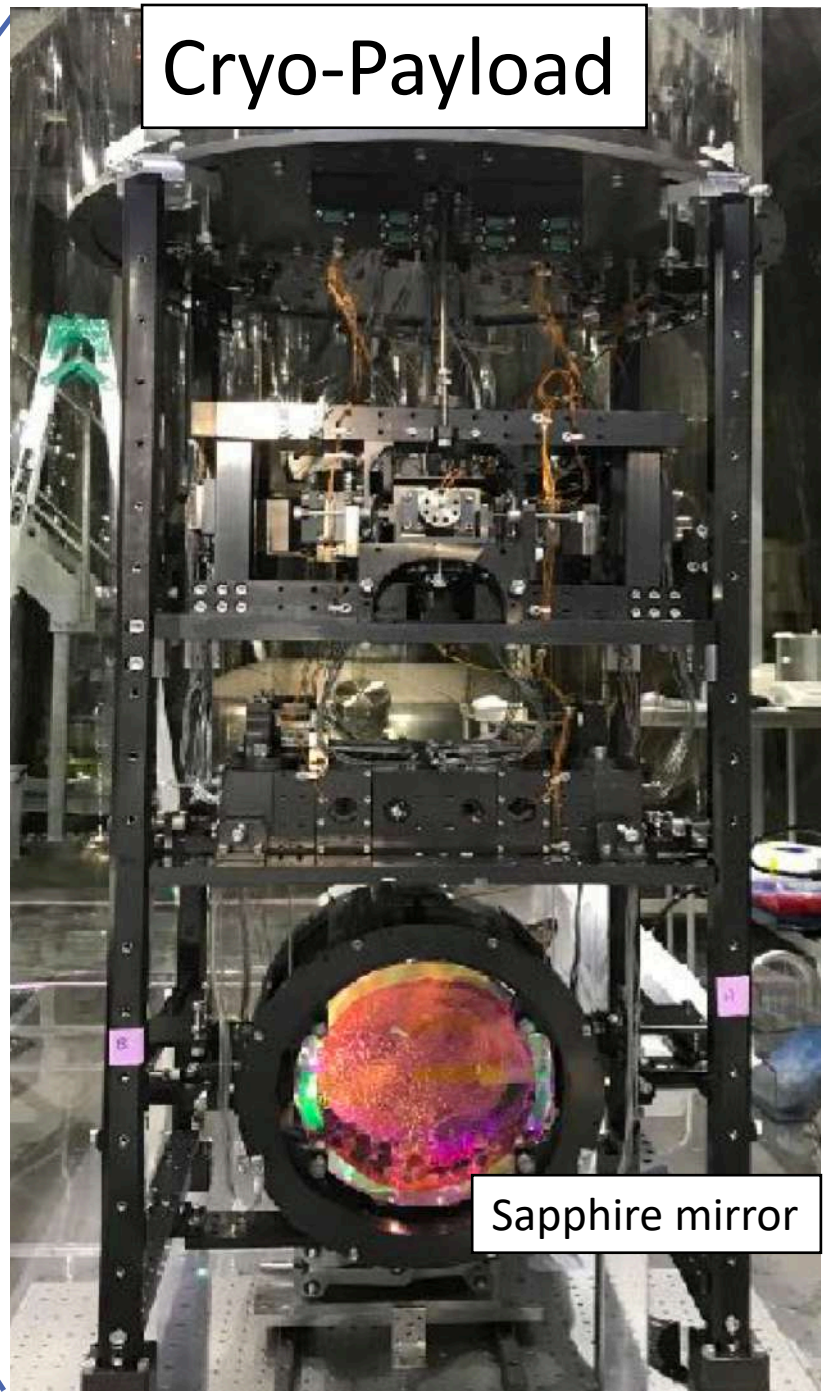
2.Main mirrors are cooled to 20K
(for suppression of thermal noise)

Cryogenic system

Cryogenic payload

KAGRA overview





KAGRA has 4 main sapphire mirrors and they are cooled to 20K.

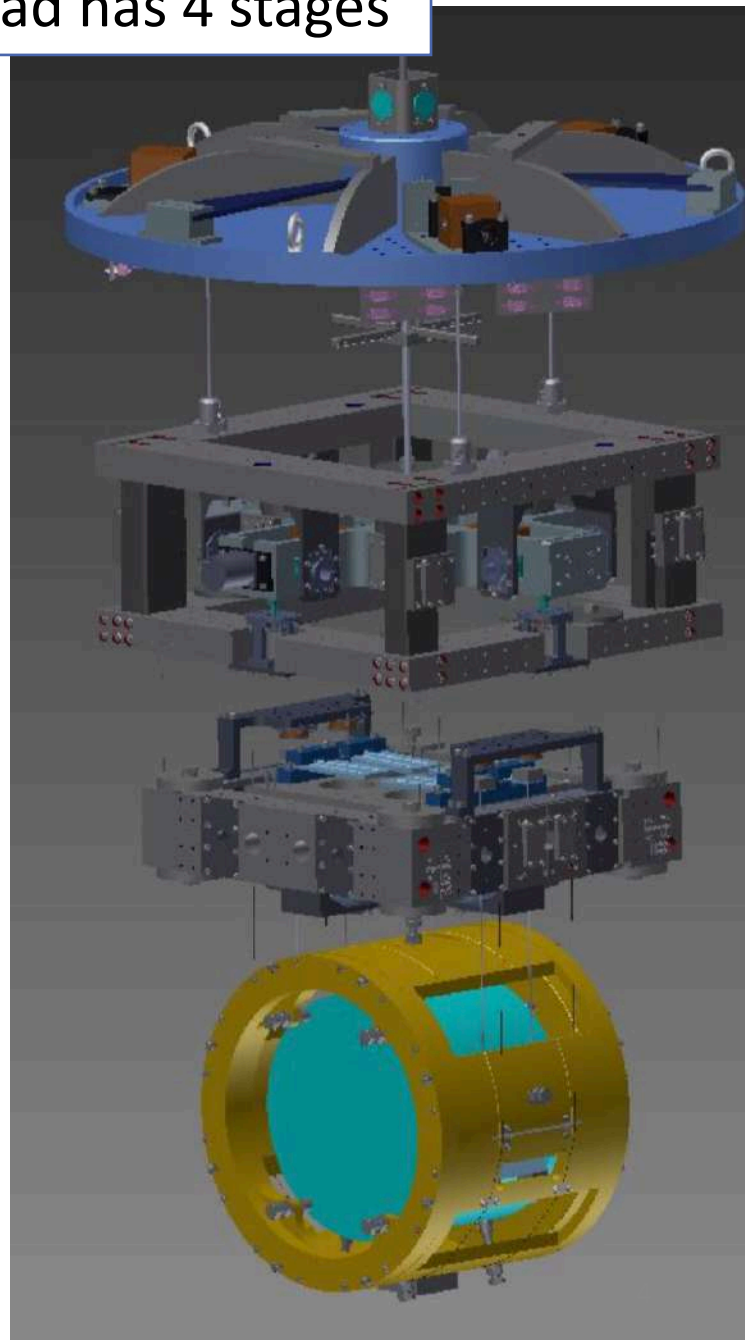
The cryogenic part of mirror suspension is called Cryogenic payload

Role of Cryo-payload for interferometer operation

1.Alignment control
Moving mass and Coil-Magnet actuator on MN stage

2.Damping control
Coil-Magnet actuator of each stage

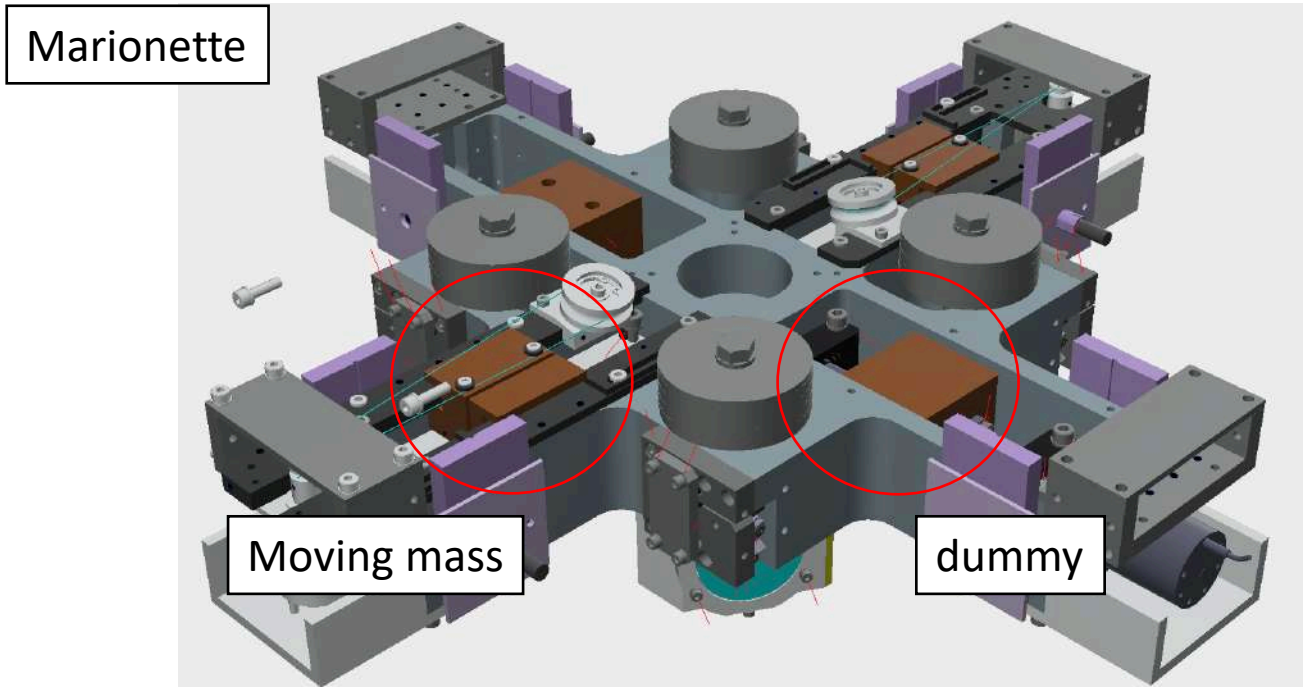
Cryo-payload has 4 stages

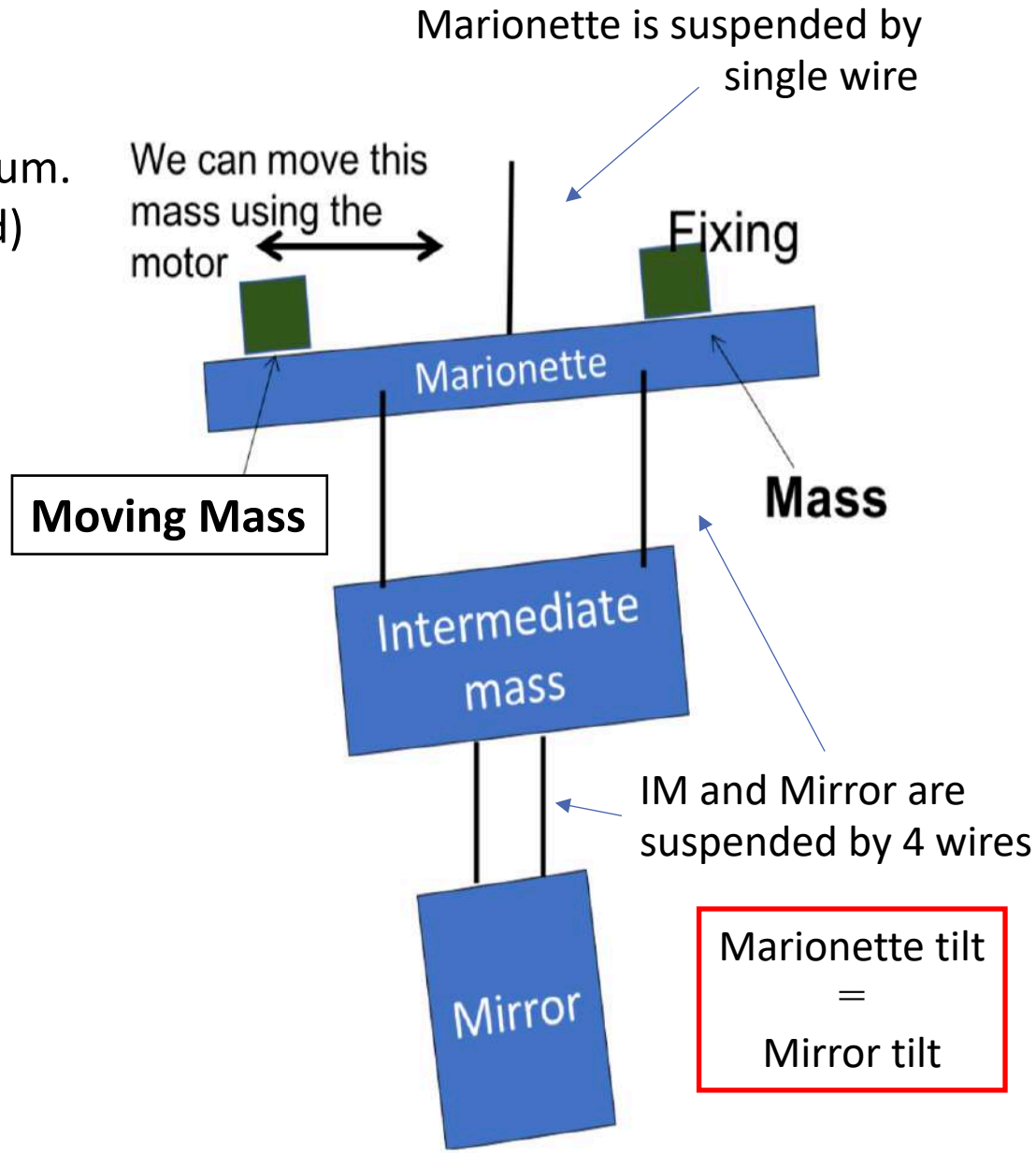


Moving mass

Cryo-payload is in vacuum chamber and at 20K and high vacuum.
Mirror suspension drift for thermal expansion.(about 100urad)
a mechanism to adjust mirror's tilt remotely is essential.

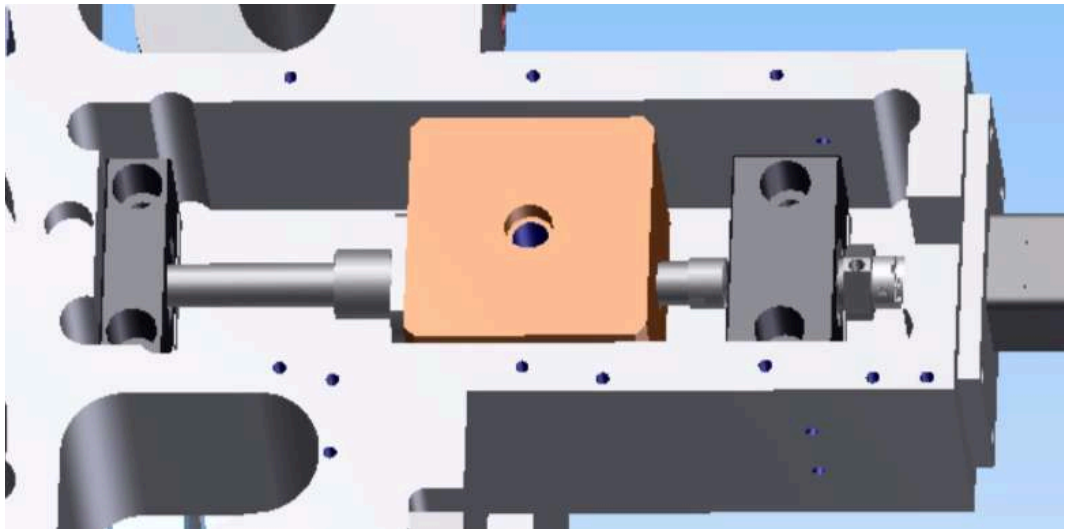
The mechanism is called moving mass.
Moving mass is used for rough alignment of mirror.





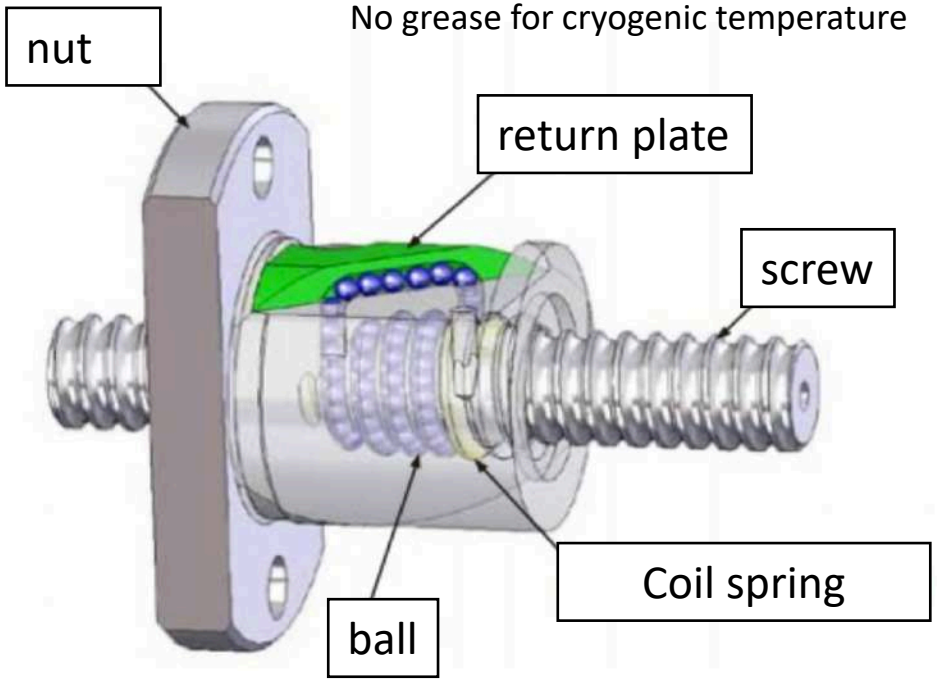
Initial moving mass design

Ball screw-type moving mass
installed in current KAGRA



motor

No grease for cryogenic temperature



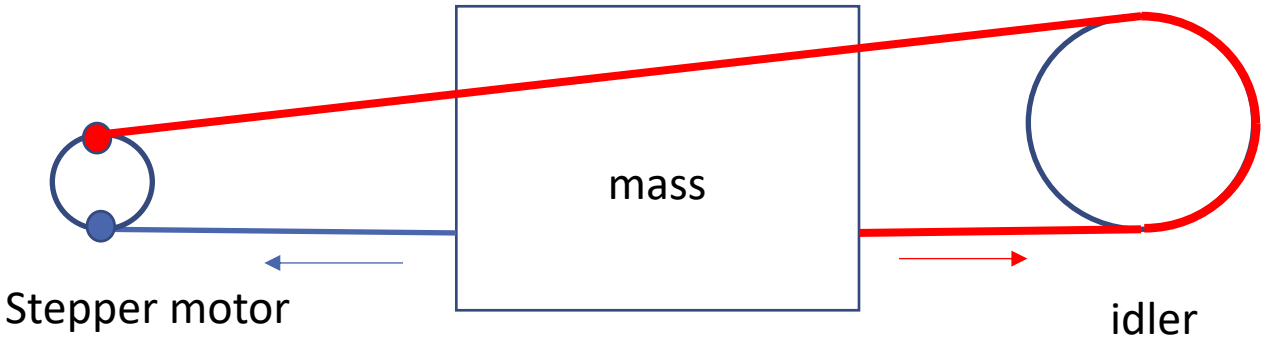
Using a ball screw and motor, the rotation of the screw convert into linear motion of the mass.

The structure of ball screw is complex. Moving mass sometime stuck at cryogenic temperature and high vacuum.

⇨Initial alignment is impossible. It is fatal problem.

Developing new structure moving mass is urgent task.

Concept of new type moving mass



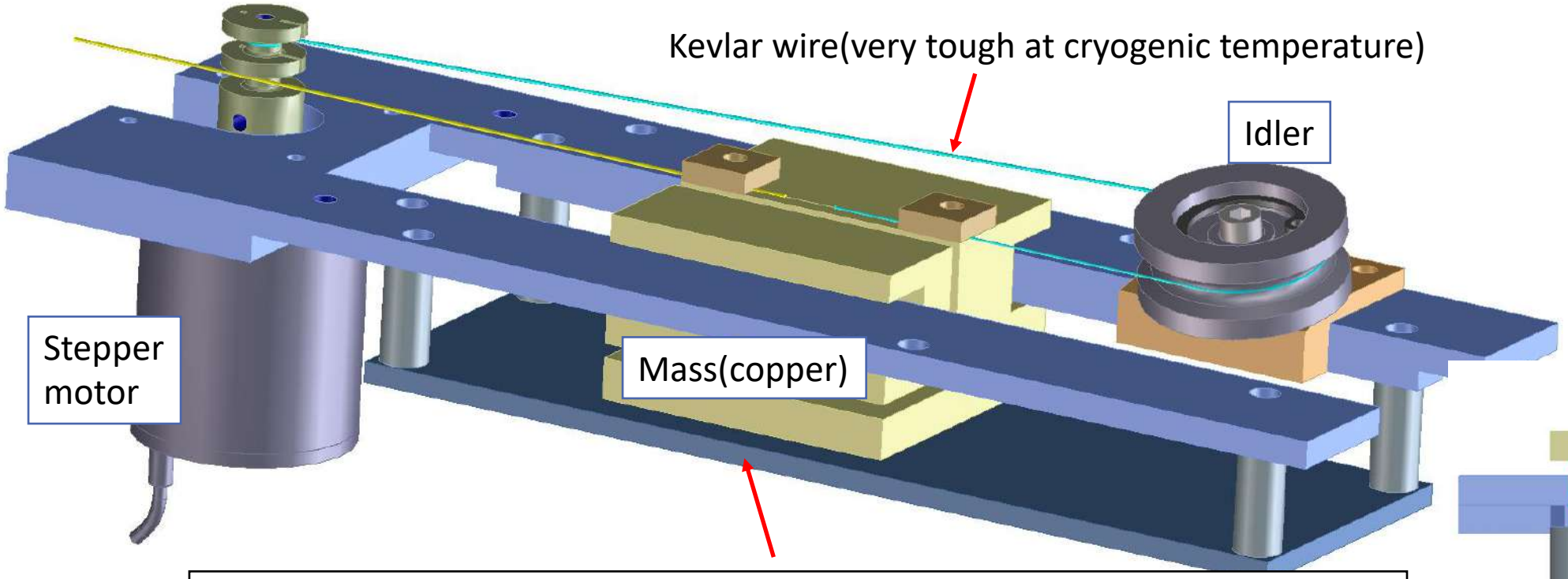
Advantages
- Less chance of getting stuck since ball screws are not used
- Required torque to move mass is small

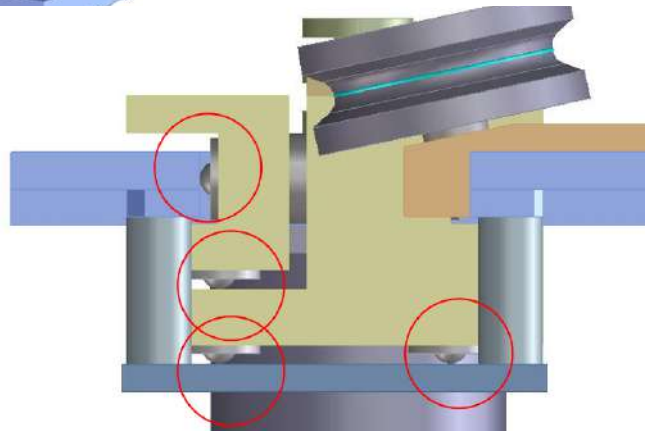
Disadvantages
- Holding power is small
- Possibility of wire deterioration

Two wires (red,blue) are connected to mass and stepper motor

When motor rotate clockwise, blue wire pull mass and mass move left
When motor rotate counterclockwise, red wire pull mass and mass move right

Actual structure(CAD)





Ball rollers are attached to mass to reduce the ground contact area.
Mass is shaped like “c” to prevent it from coming off the upper plate.

The movement principle is similar to a ropeway.
So, this moving mass is named ropeway-type moving mass

Requirement for moving mass

1.Maximum amount of tilt ⇨ 3mrad
KAGRA tunnel has 1/300(3mrad) slope for water drainage.
Moving mass needs to adjust this slope.

2.Minimum amount of tilt ⇨ several urad
Fine alignment by coil-magnet actuator.
But the control range is narrow(less than 100urad).
Considering this range, Moving mass needs to adjust with several urad accuracy.

The requirement for ball screw-type moving mass

3.Endurance at Cryogenic temperature and ultra high vacuum
Moving mass needs to work fine at Cryogenic temperature and ultra high vacuum for long time

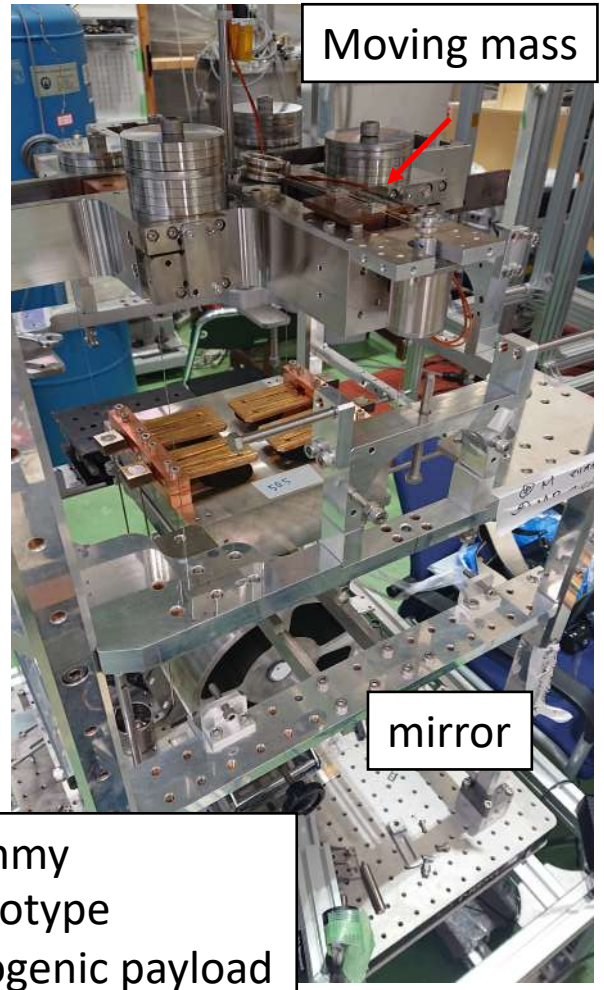
New requirement for new moving mass

Evaluation of Ropeway-type moving mass

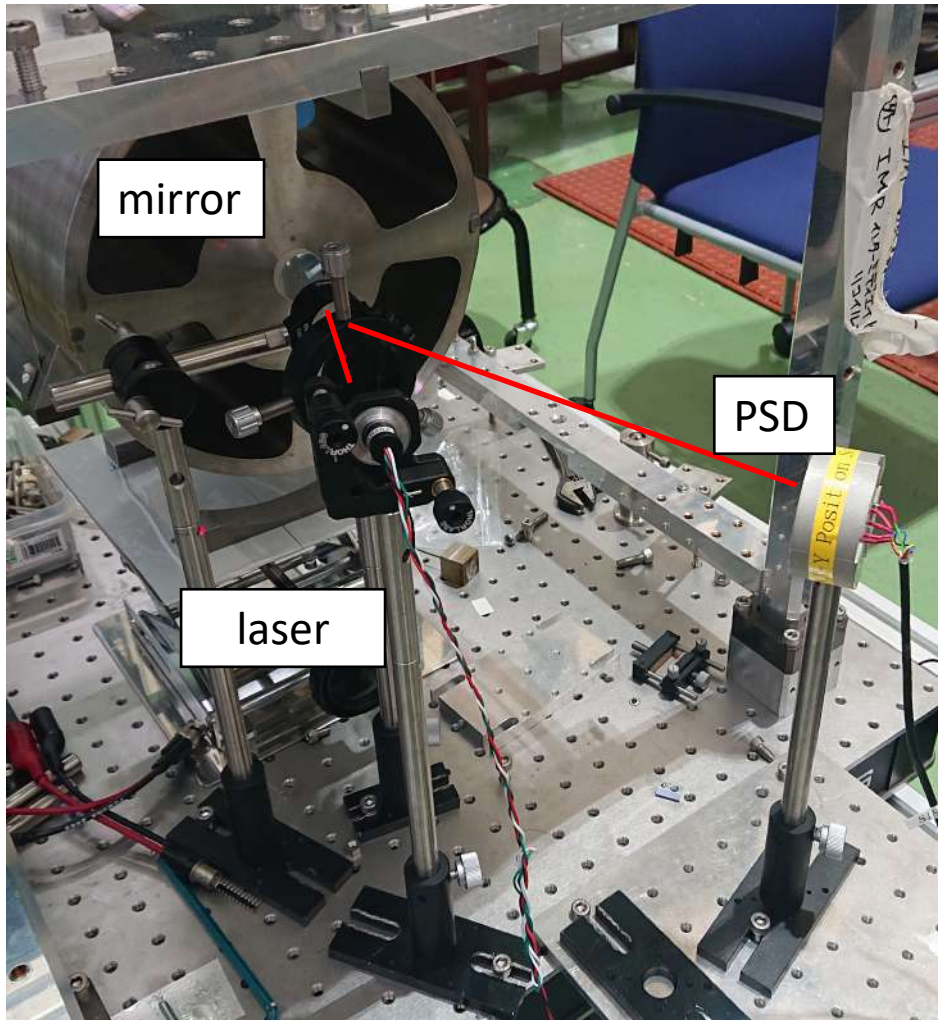
Requirement 1 :Maximum amount of tilt ⇨ 3mrad

Requirement 2 :minimum amount of tilt ⇨ several urad

I measured Max. and min. amount of tilt using dummy cryogenic payload



Dummy
Prototype
Cryogenic payload



Max measurement

Move mass in Maximum range(50mm) and measure amount of mirror's tilt using optical lever(Oplev).

Set up of Oplev is right figure.
Mirror's tilt is measured as position of the laser on PSD.

min measurement

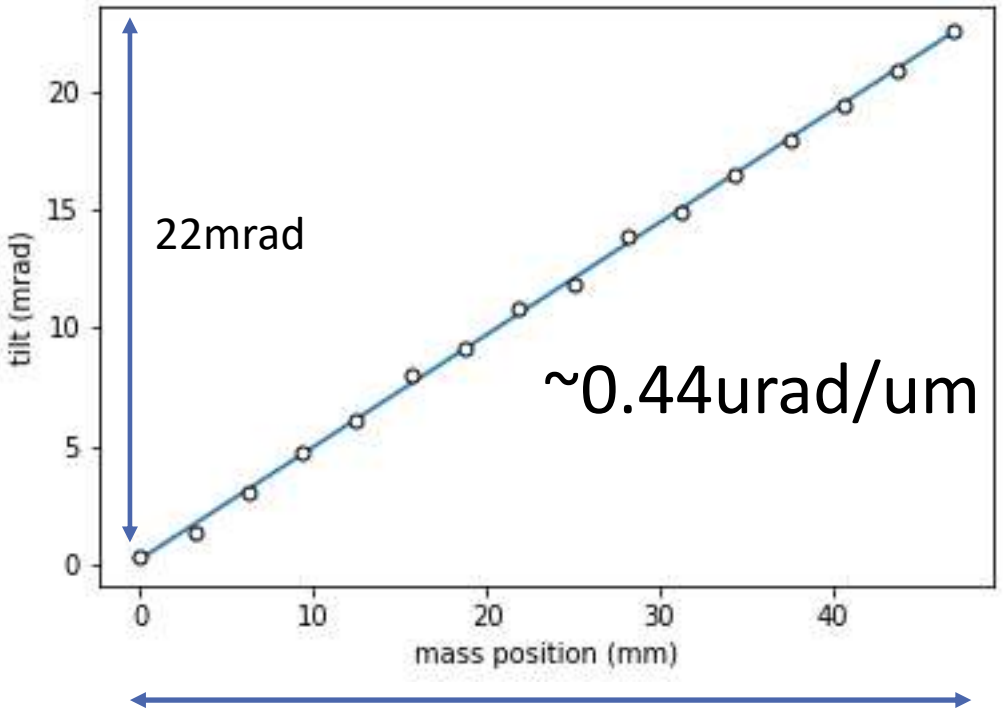
Move mass
with minimum step of stepper motor and measure in the same way.

Result of Max and min test

Requirement 1:

Clear!!

Max range is about 22mrad(>3mrad)

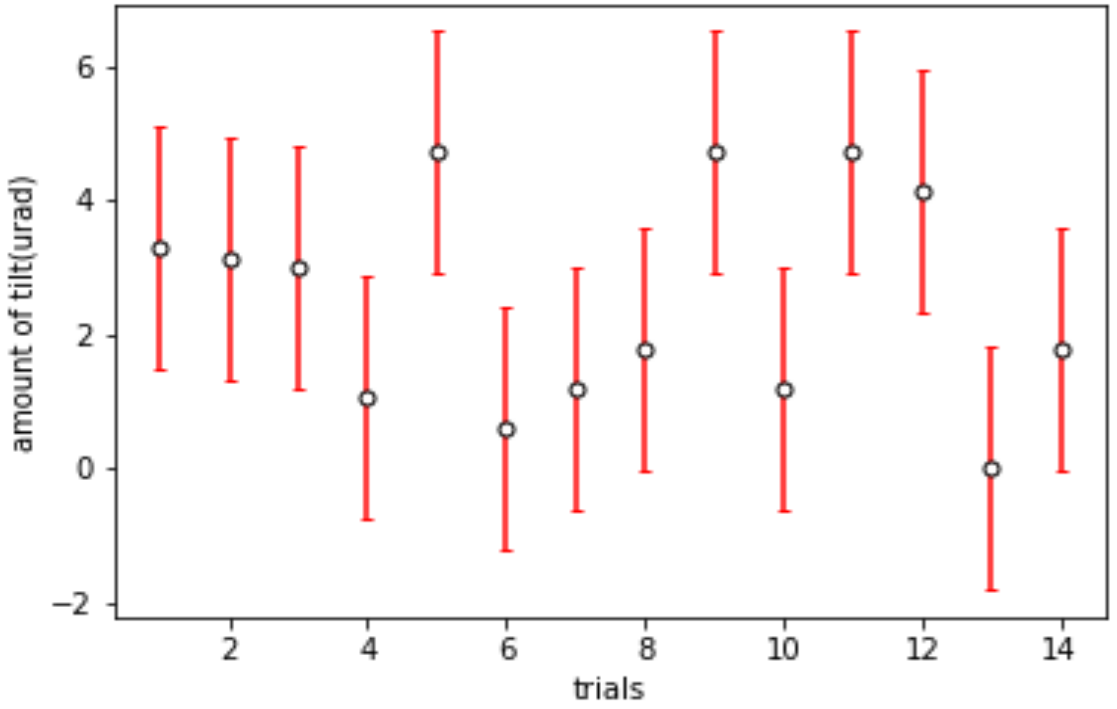


Max range of mass motion(50mm)

Requirement 2:

Clear!!

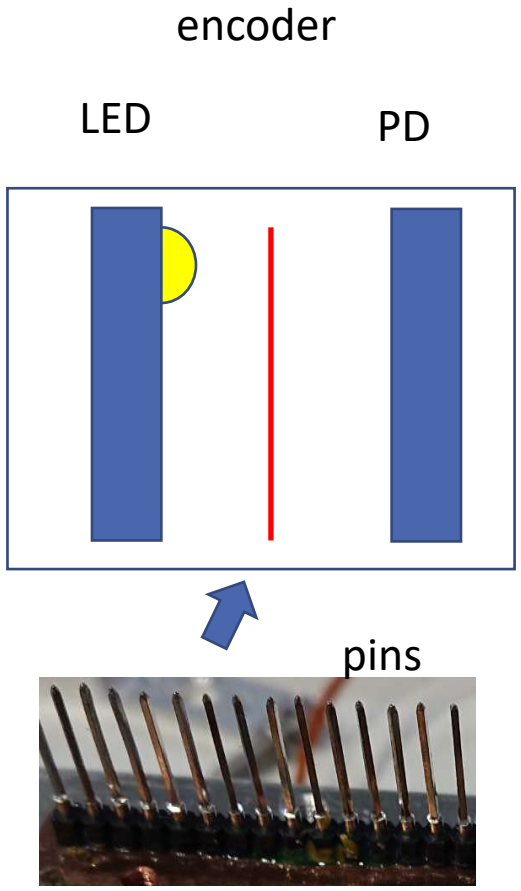
Min amount of tilt is several urad



Number of times I moved the mass with minimum step

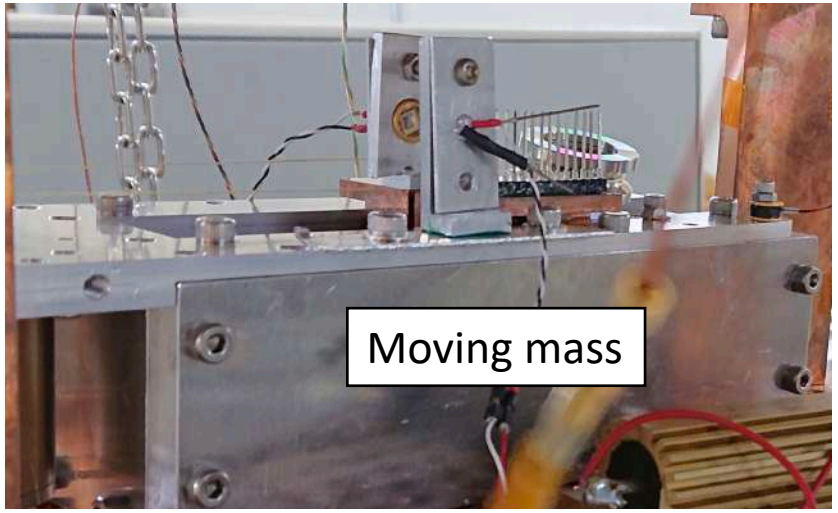
Requirement3:Endurance at cryogenic temperature and ultra high vacuum

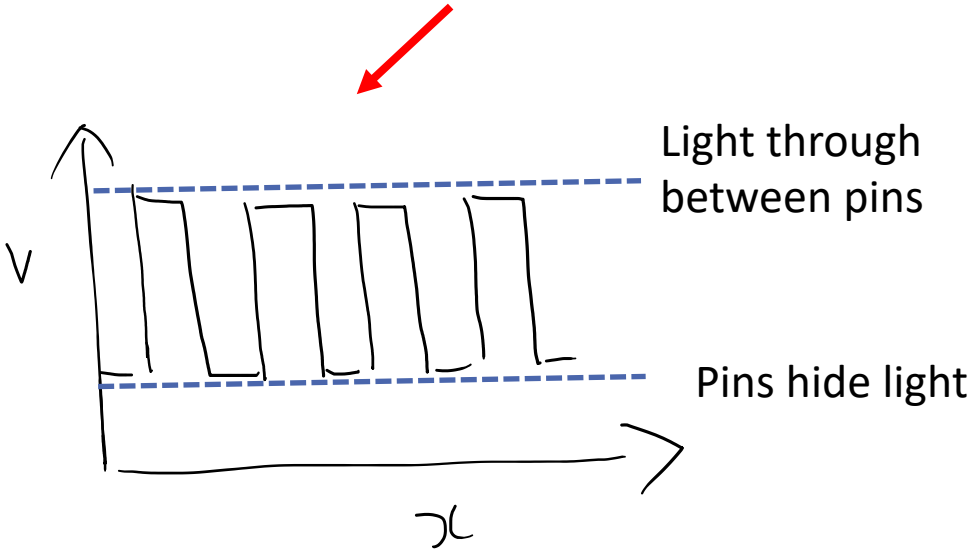
I kept to move mass for 100hours(mass move about 6000raps)
at 16K and high vacuum
and checked if moving mass works well or not



The way of measuring mass motion

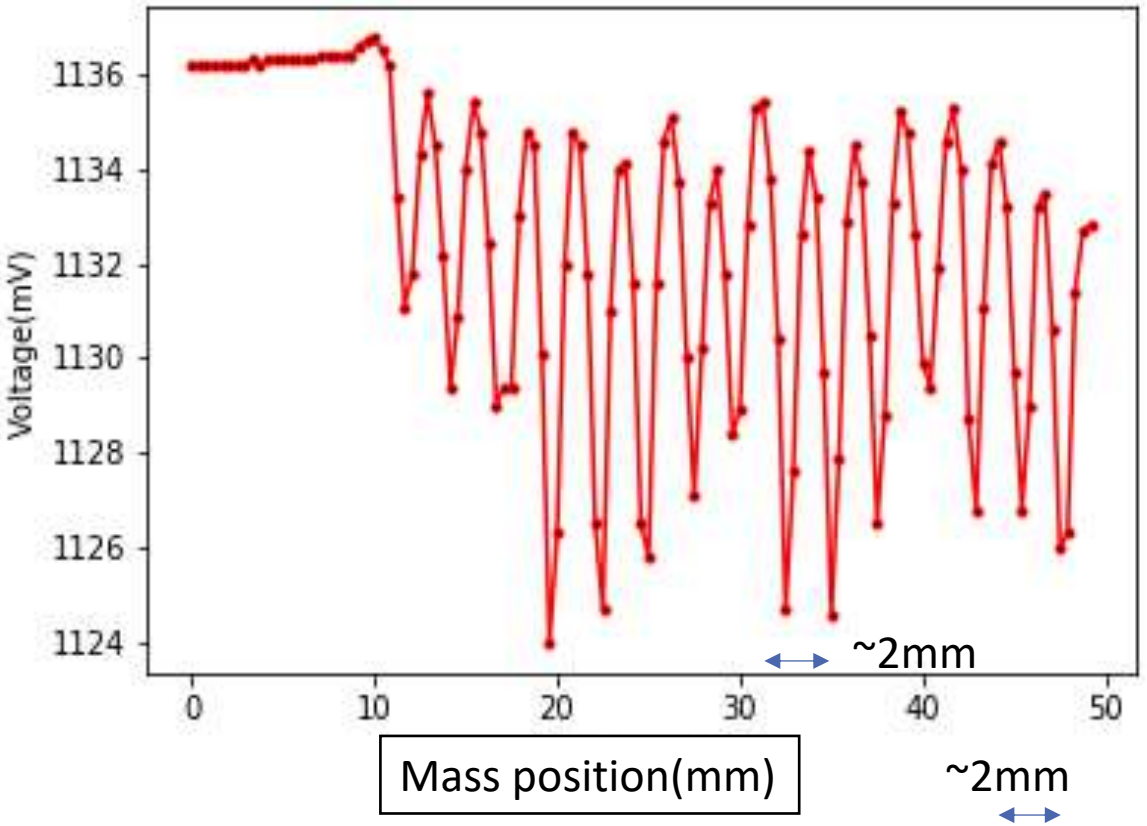
I attached pins on mass and put it between LED and PD.
When mass move correctly, voltage of PD vs mass position graph is like zigzag.





Result of endurance test

Mass motion after 100hours endurance test
at 16K and high vacuum



After 100hours endurance test(6000raps),
I moved mass end to end and measured voltage of PD.

The result shows zigzag shape and gap of peaks are same as gap of encoder pins.

It means the mass moves correctly.

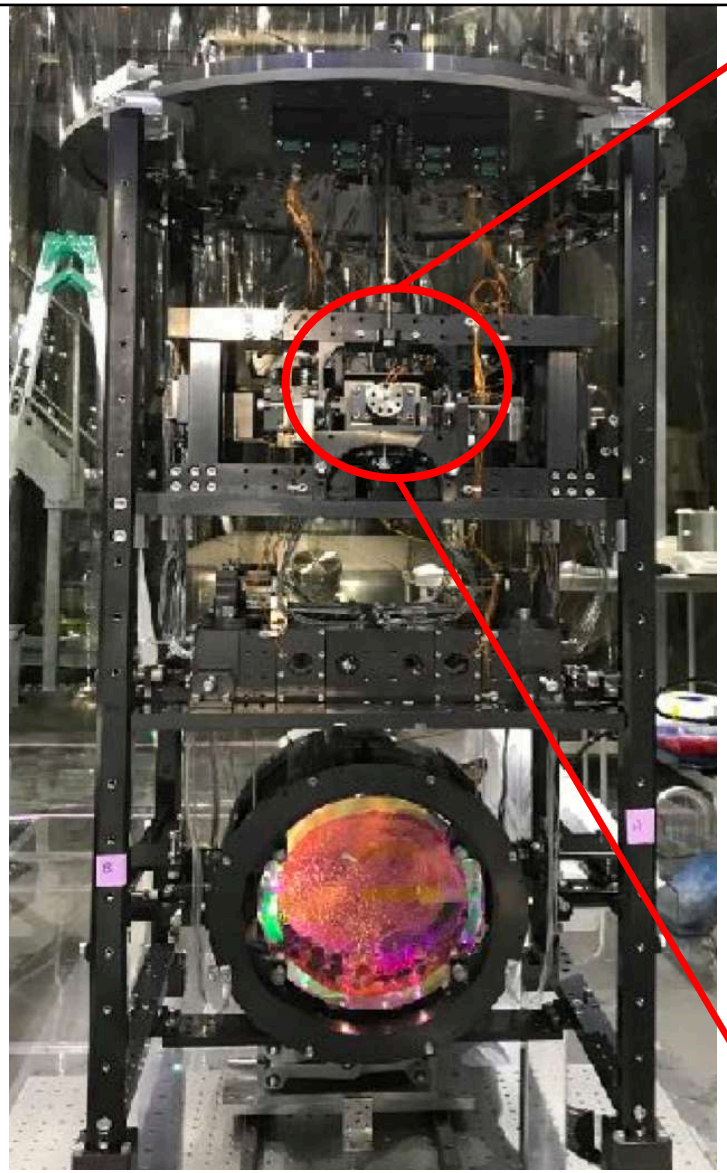
Requirement 3:

Endurance test is clear!!

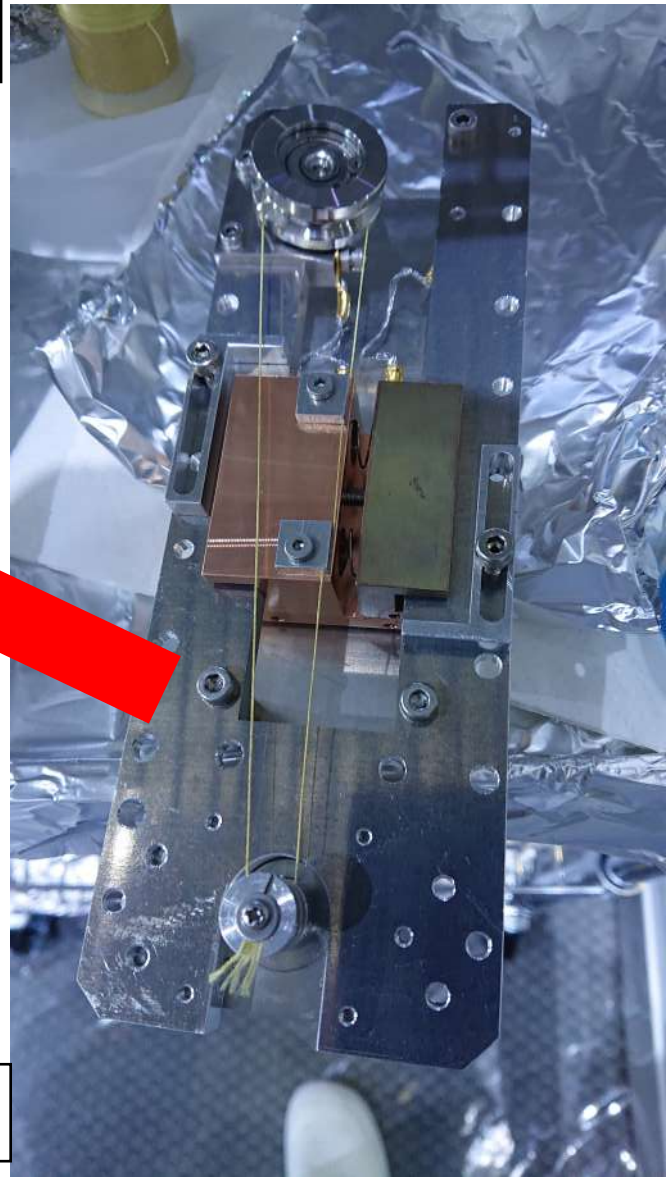
I confirm requirement1~3 are satisfied in pre-test

Installation to actual Cryo-payload in KAGRA

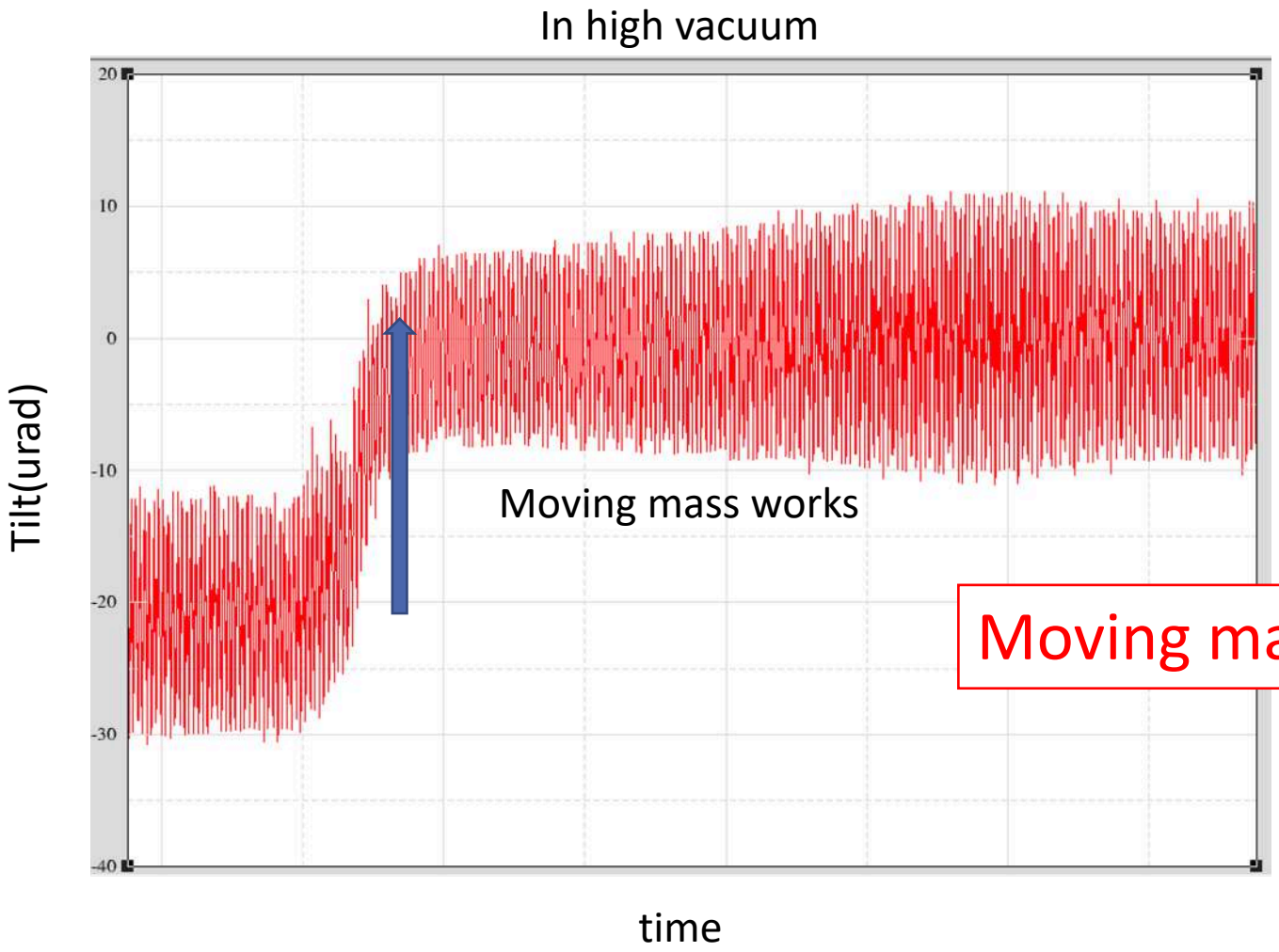
I installed new moving mass on a real Cryo-payload in KAGRA



Marionette of Cryo-payload



Performance test in KAGRA



I did performance test in high vacuum.

In left graph, I controlled moving mass and adjust mirror's tilt to best position

Moving mass works well in high vacuum!!

Performance test at cryogenic temperature is ongoing now

Summary

- Moving mass is used for rough alignment of sapphire mirror.
- Initial moving mass sometimes stuck at cryogenic temperature and high vacuum.
- I developed new type moving mass and installed real cryo-payload.
- New type moving mass works well in high vacuum.

Thank you for listening!