Vibration measurement of the Cryostat at the KAGRA site

Toshiro Ochi
K. Yamamoto[A], S. Miyoki[B], N. Kimura[C], S. Koike[C], T. Suzuki[C],
T. Tomaru[C], The KAGRA cryogenic payload group[D]

Department of Physics, Faculty of Science & Graduate School of Science,
The University of Tokyo
University of Toyama[A], ICRR The university of Tokyo[B], KEK[C],
The KAGRA cryogenic payload group[D]

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abstract

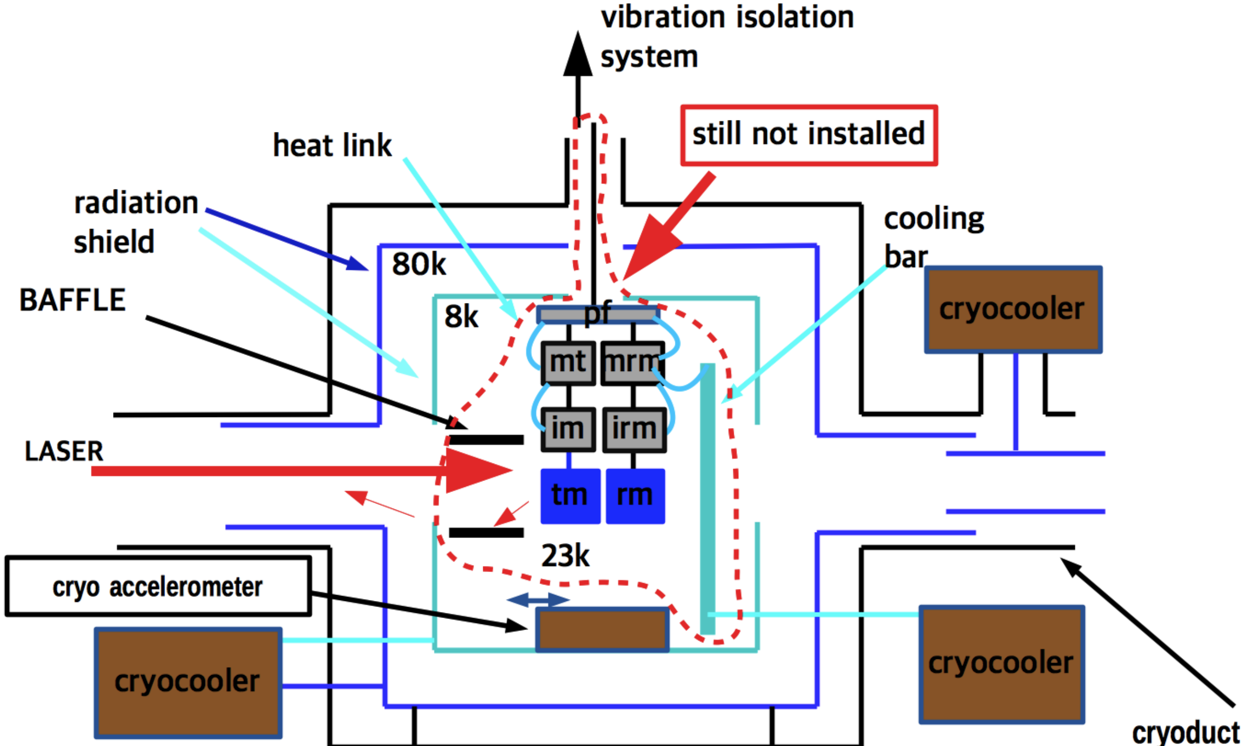
KAGRA is large cryogenic gravitational telescope.

The characteristics of KAGRA is cooling mirror at 20 K
to reduce thermal noise,
and built in the place of more than 200 meters underground
to reduce seismic noise .

Vibration by cryocoolers could be a source of noise.

We installed cryo-accelerometer in cryostat at KAGRA site
to measure radiation shield vibration.

Purpose



<u>Radiation shield vibration measurement at KAGRA site</u>

vibration could cause noise as follows;

1.transferring from cooling bar and payload to mirror

2. modulating scattering light

We measure the vibration on cryocooler running.

⇨We are going to calculate noise due to cryocooler running.

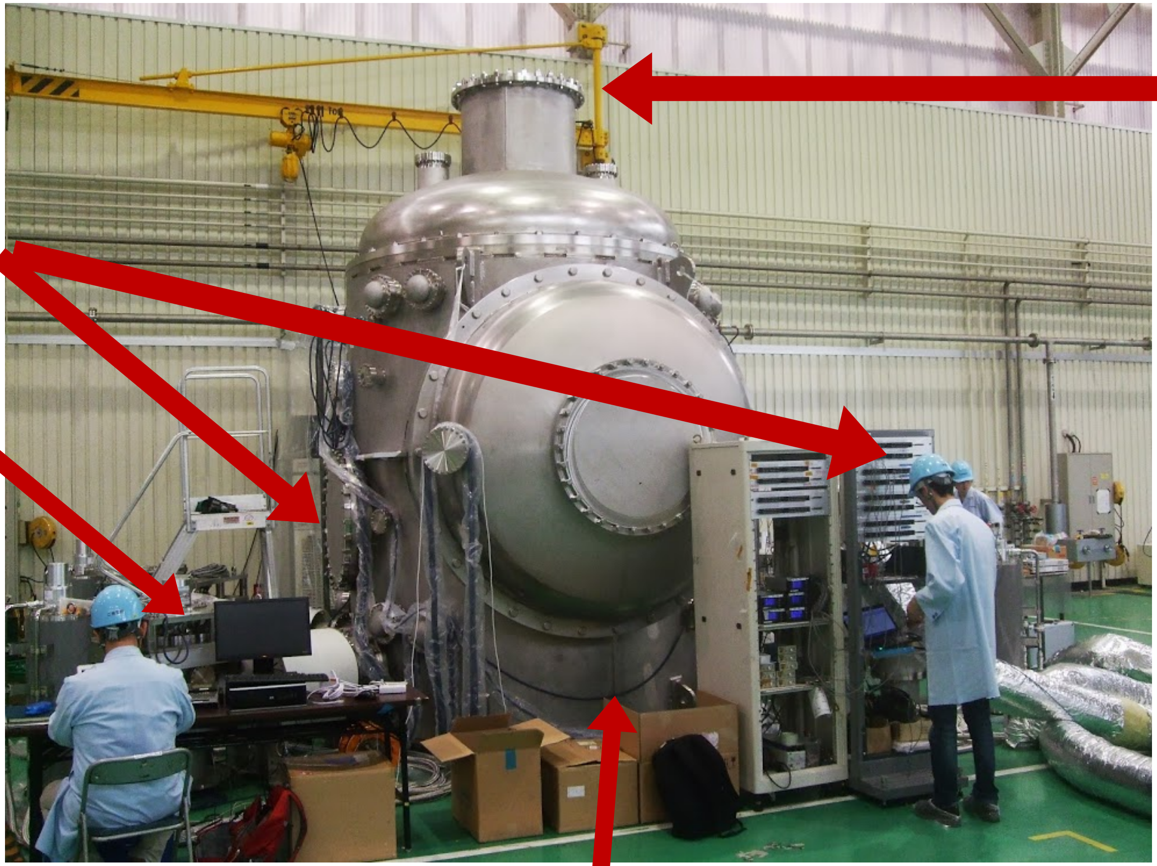
preceding study -measurement at Toshiba Keihin Product Operations

Dan chen measured vibration of inner shield at Toshiba Keihin Product Operations (Yokohama) in 2013.

Cryostat of difference at site and Toshiba

3 Km Duct has been NOT attached yet

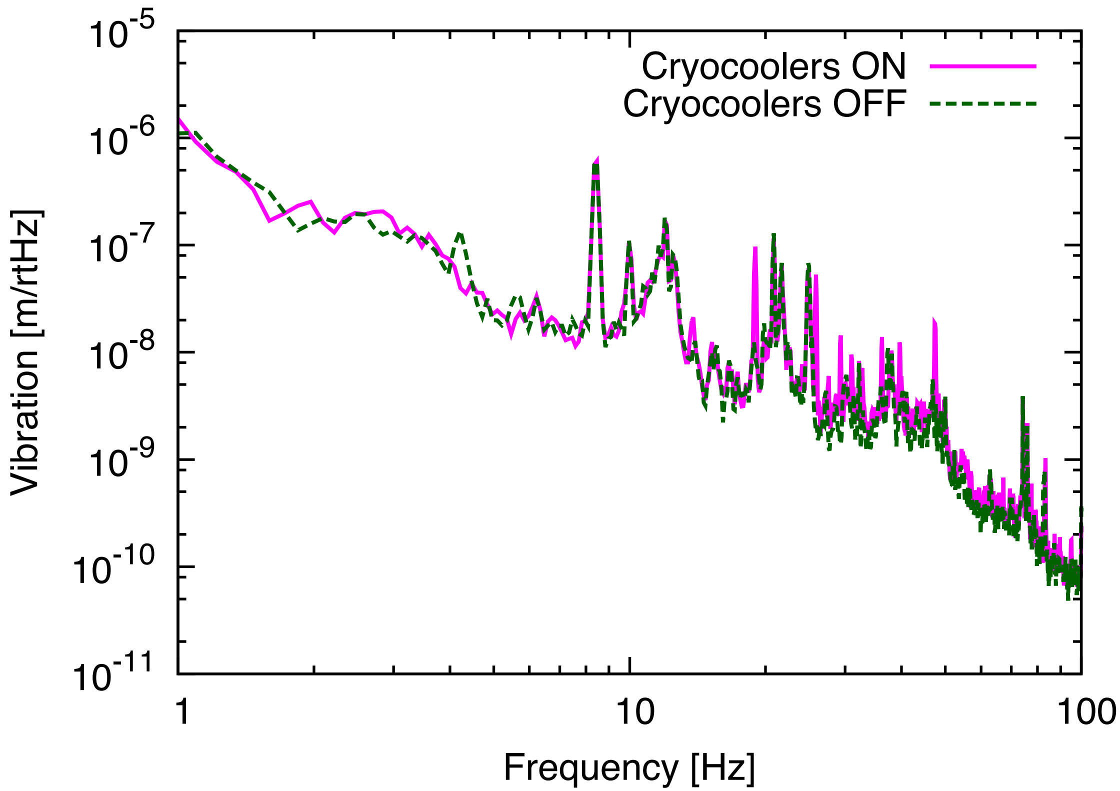
cryocooler



Duct for Vibration Isolation System has been NOT attached yet

Vacuum chamber

preceding study -measurement at Toshiba Keihin Office



cryocoolers in operation	4 (shield＋payload)
Degree of vacuum	1.0×10^{-7} mbar
temperature	10 K
duct	Not attached yet

<u>Problems and difference points</u>

・seismic vibration level is 100 times larger than Kamioka so vibration of the cryocooler is buried in ground vibration.

・duct has been not attached yet.

So we re-measured at KAGRA site.

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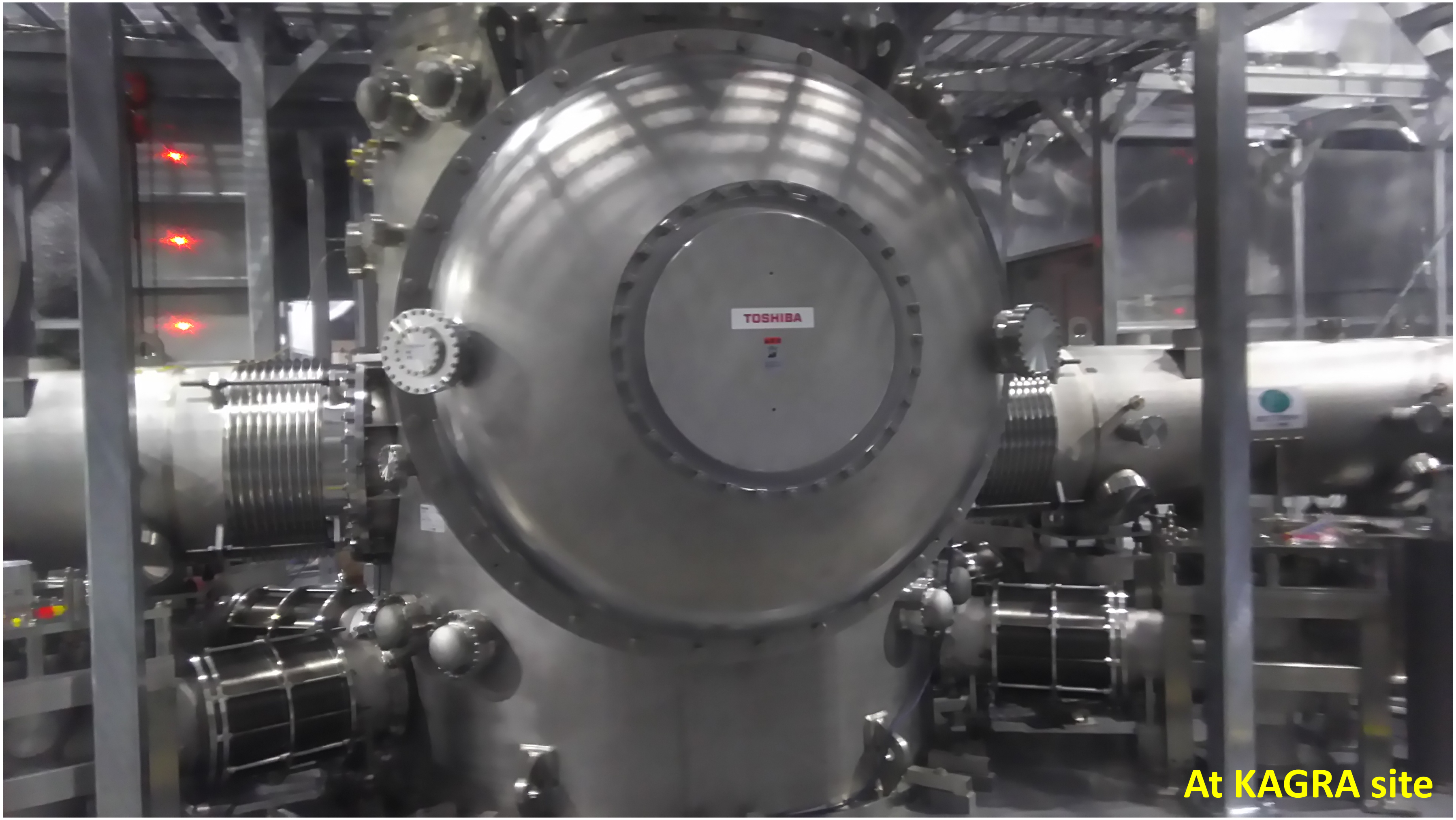
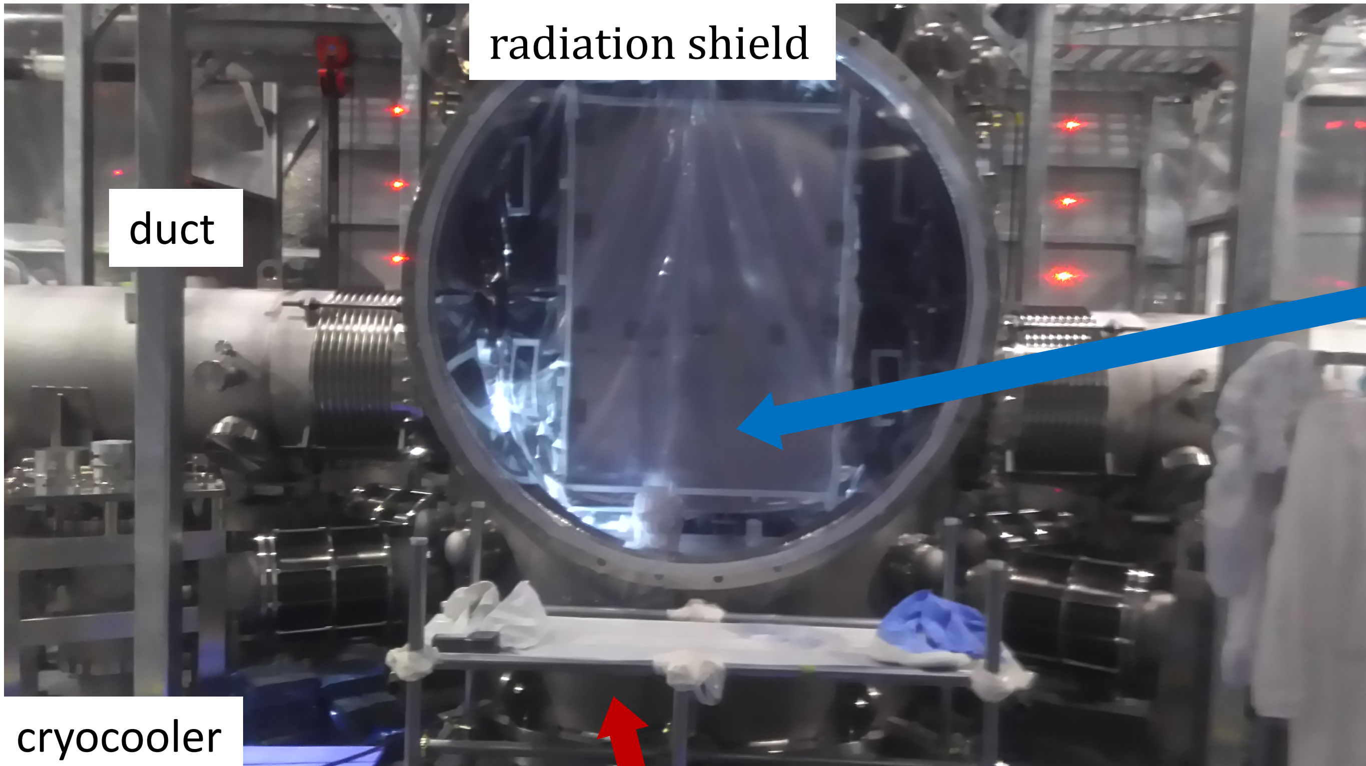
This study - we are measuring radiation shield at KAGRA site. Vacuum ducts are connected to cryostat.

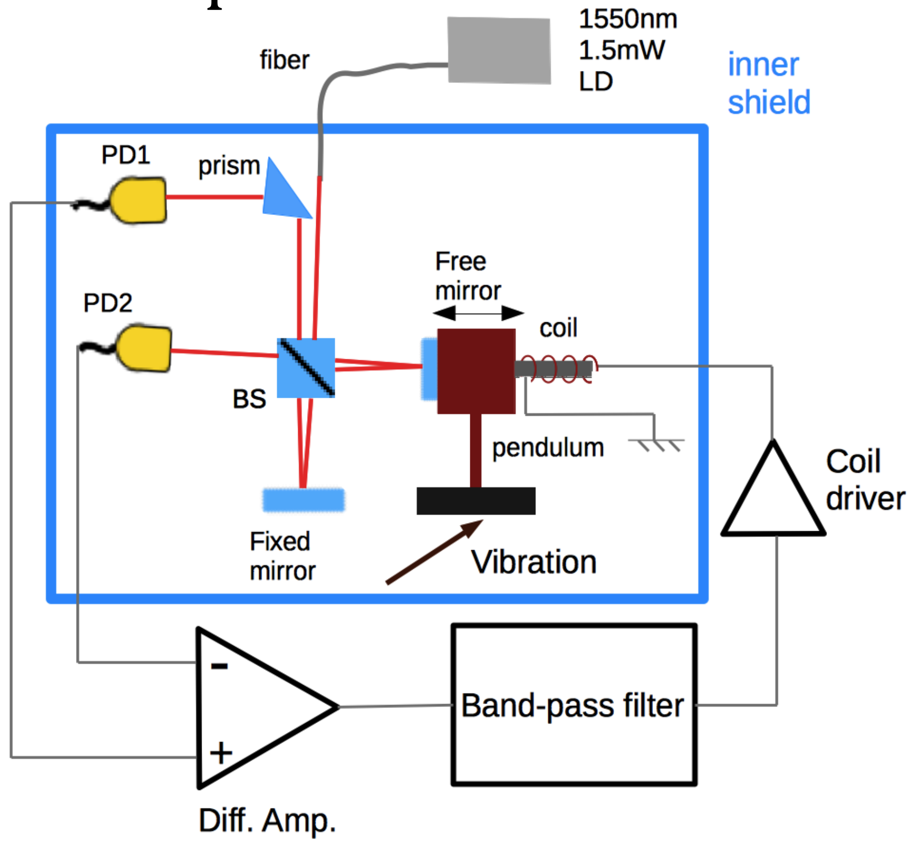


Installing cryo-accelerometer



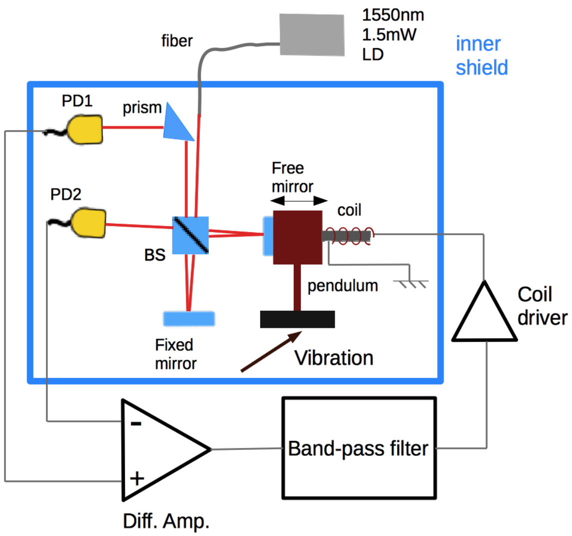
At KAGRA site
(Cryostat lid opened)

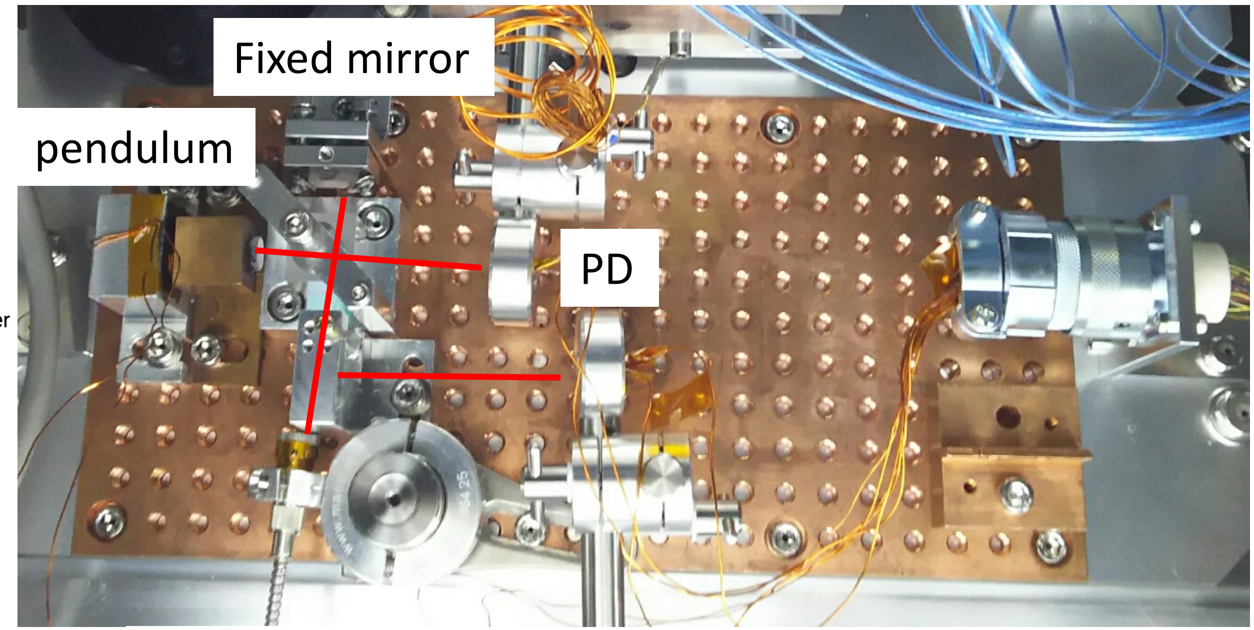
Principle of accelerometer



This Michelson interferometer consists of
inverted pendulum as free mass and fixed mirror.
Laser is introduced through the fiber from the outside.
Output of the interferometer is sent to inverted pendulum for feedback.
Then this pendulum follows seismic vibration.
Feedback signal is proportional to seismic motion.

Install cryo-accelerometer

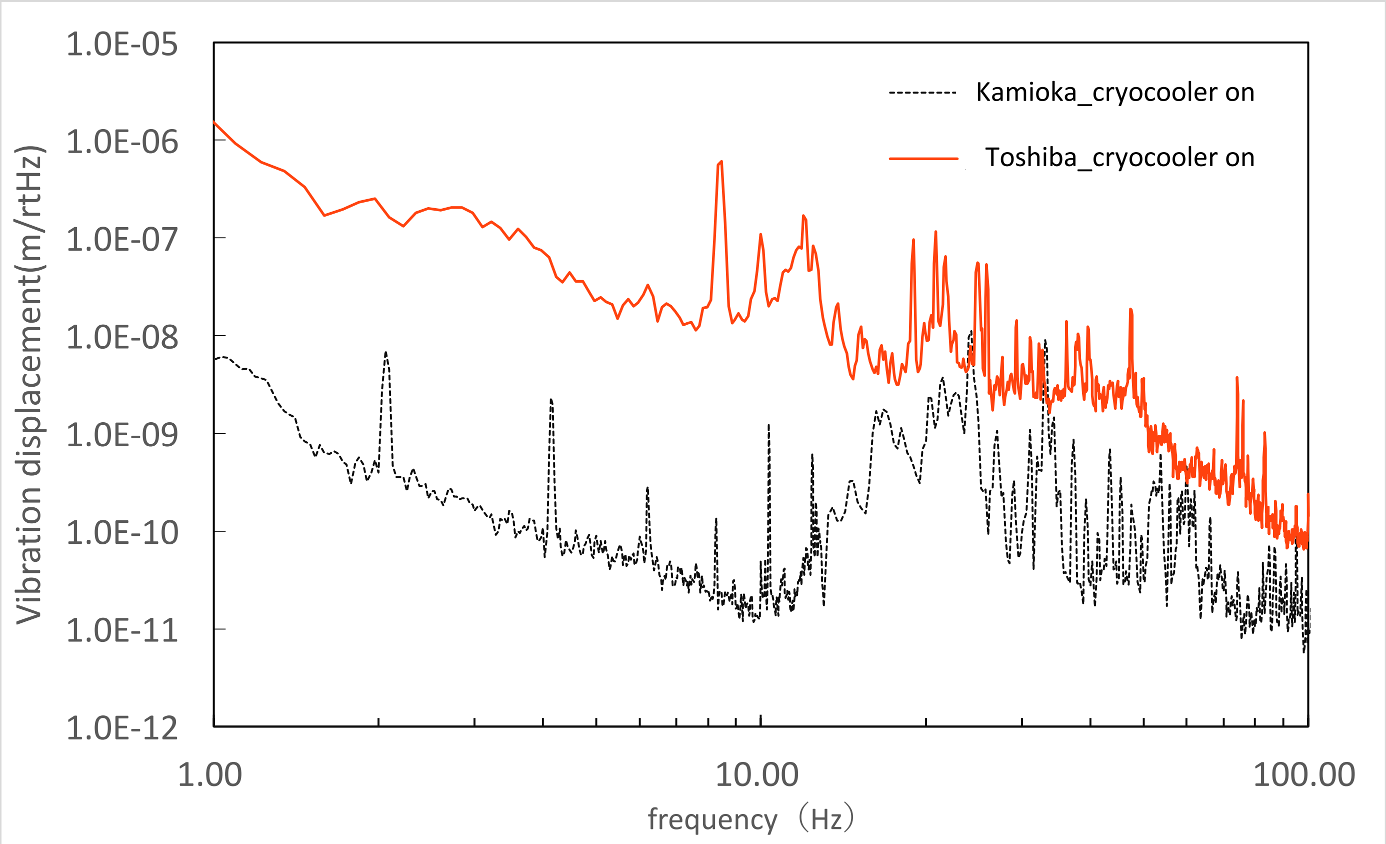




optical fiber

We installed cryo-accelerometer developed by Dan Chen at bottom surface of 8K inner shield by December 22, 2016.
On December 26 and 27, we measured vibration with cryocooler temporary operating around room temperature.
Cooling test was started on February 27, 2017.

Comparison with measurement at Toshiba



<u>Comparison with measurement at Toshiba</u>

The vibration level in the cryostat of Kamioka is about 100 times smaller than the measurement by Toshiba below 10 Hz.

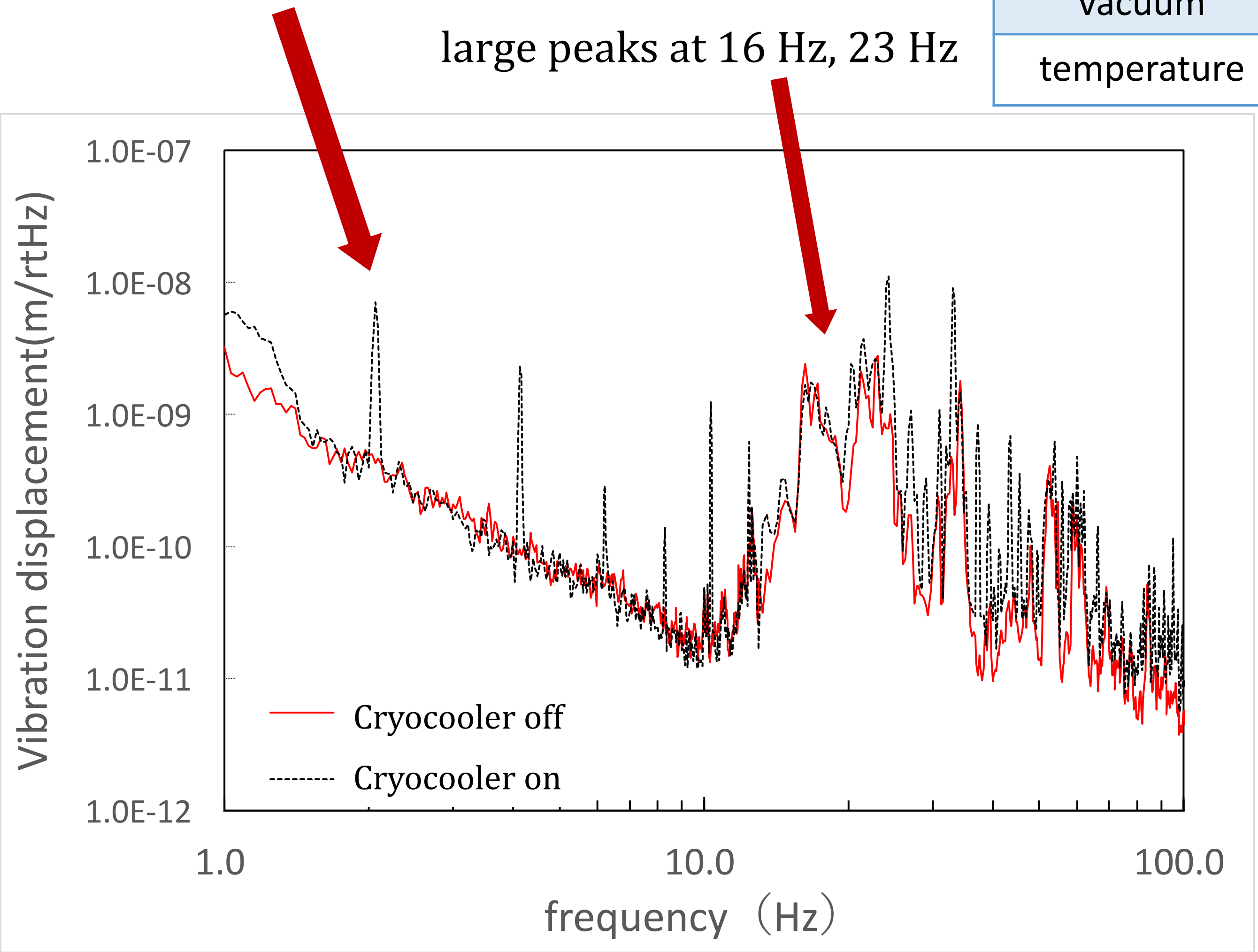
It was lower than the vibration at Toshiba in all frequency bands.

Measurement result at site

cryocooler	2 (to cool radiation shield)
Degree of vacuum	1.0×10^{-7} mbar
temperature	300 K

2 Hz Vibration of cryocooler and harmonics

large peaks at 16 Hz, 23 Hz



About vibration analysis of vacuum chamber and radiation shield

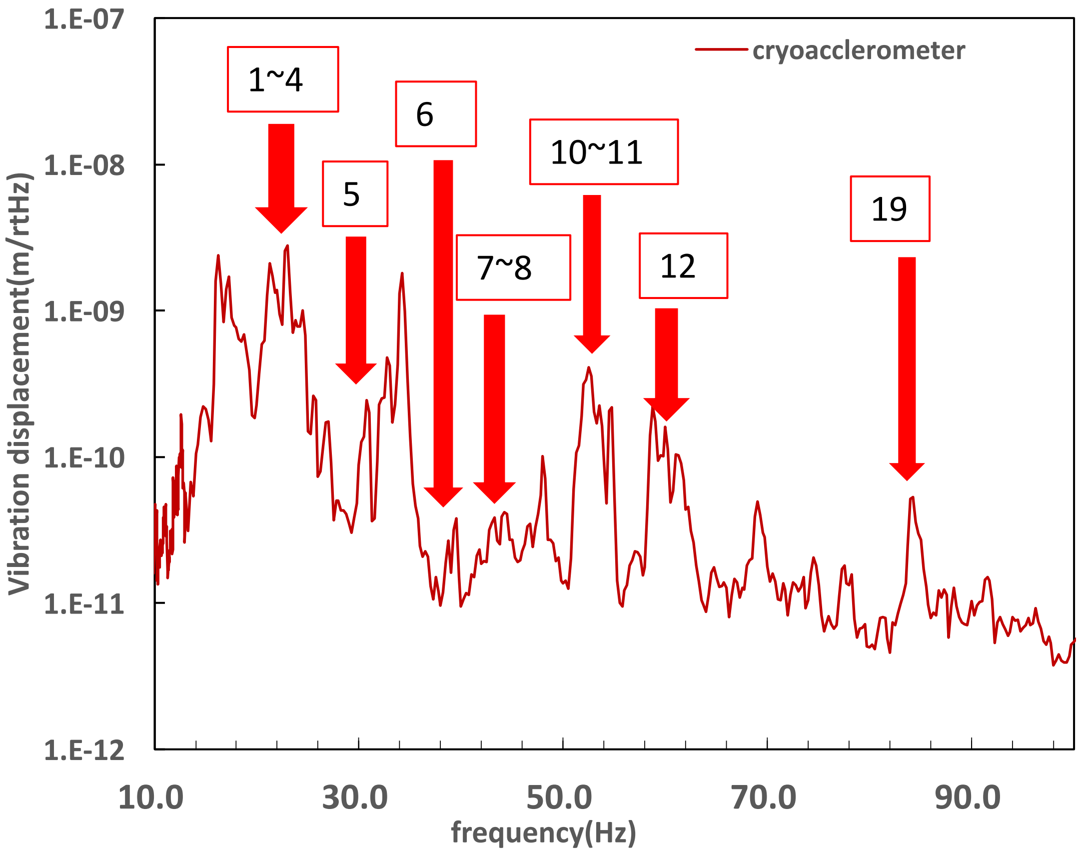
S. Koike investigated vibration modes and mechanical response of radiation of cryostat using ANSYS, application software of Finite Element Method

He divided it into a radiation shield and a vacuum chamber and evaluate the eigenmode.

He evaluated shield vibration spectrum; product of mechanical response and ground and cryocooler vibration

Comparison with structural analysis results (radiation shield)

measuementat KAGRA site by cryocooler stoppoed.

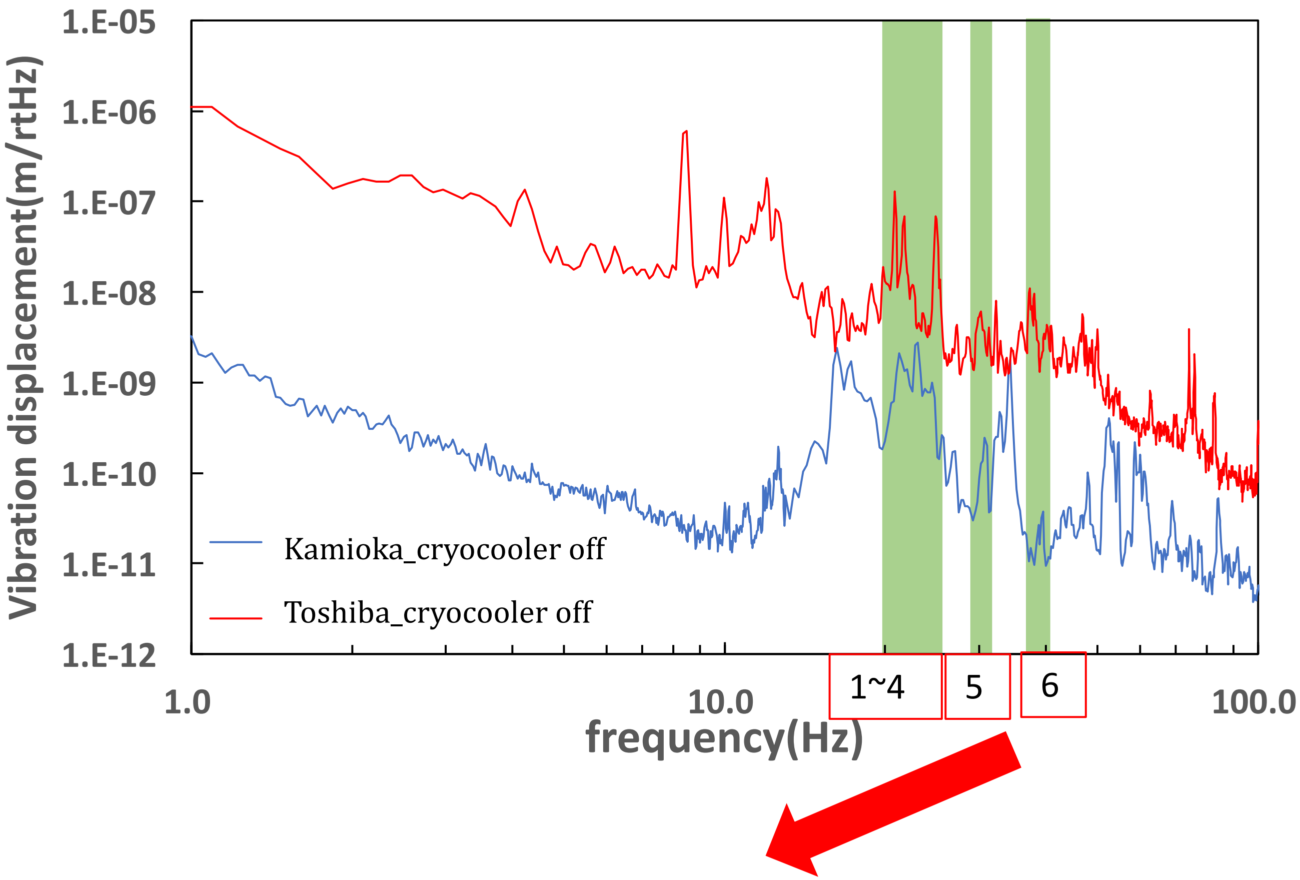


Consistent radiation shield mode among eigenvalue analysis	
mode	frequency(Hz)
1	**20.7**
2	**23.9**
3	**24.7**
4	**24.9**
5	**30.8**
6	**38.2**
7	**42.2**
8	**45.1**
10	**51.4**
11	**51.7**
12	**61.1**
19	**83.8**

KEK Koike-san

Many large peaks of the measurement result are consistent with analysis results of the radiation shield.

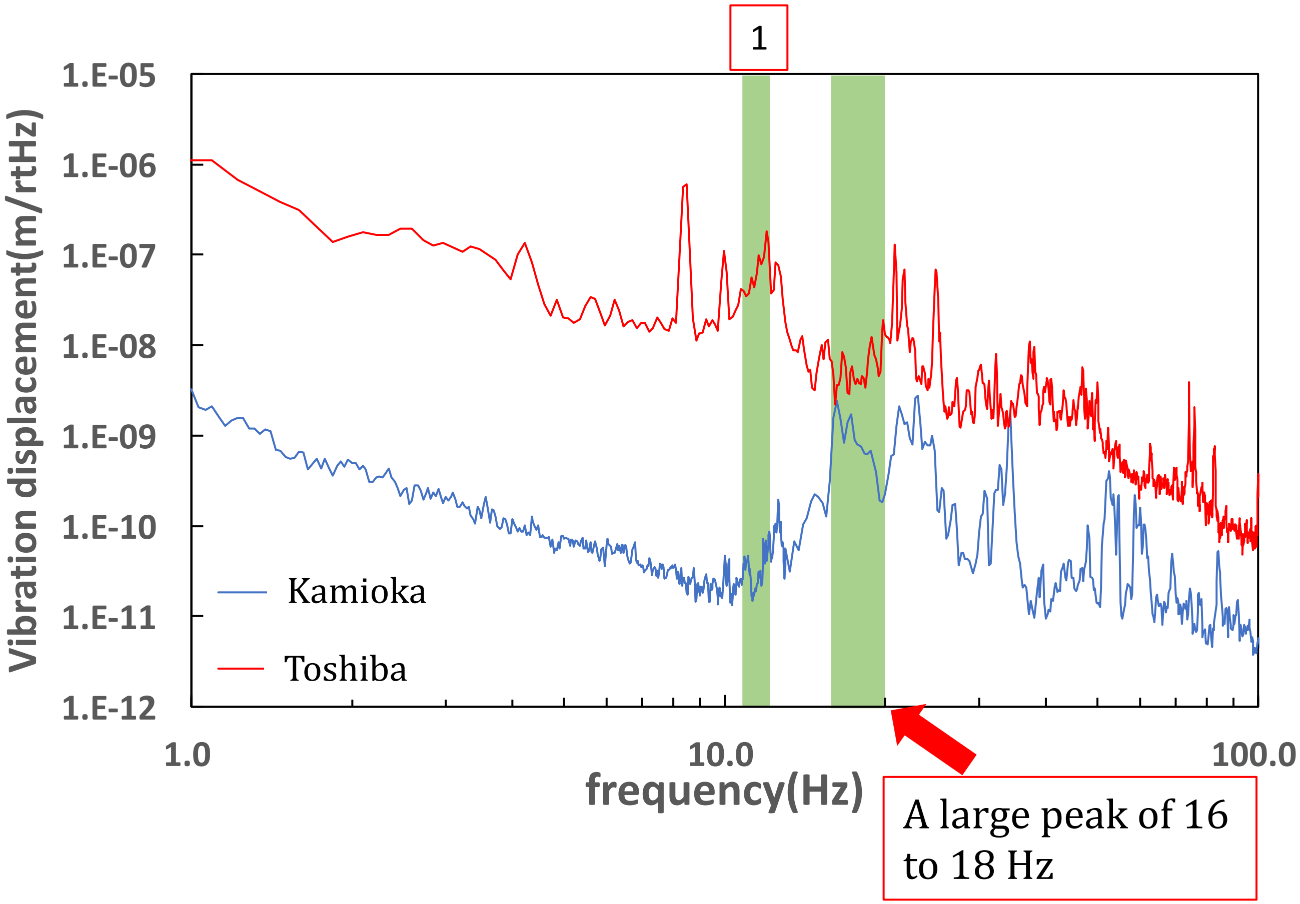
Comparison the measurement result of Toshiba and Kamioka at cryocooler off



Consistent radiation shield mode	
mode	frequency(Hz)
1	20.7
2	23.9
3	24.7
4	24.9
5	30.8
6	38.2

Dan Chen also mentions eigenmode of radiation shield was observed at Toshiba. (Number of observed is from 1th to 6th modes)

Comparison with results in Toshiba(vacuum chamber)



Calculated Vacuum chamber mode	
mode	**frequency(Hz)**
1	**11.0**
2	**22.2**

We didn't observe large peak of 11 Hz.
Instead, we observed large peak of 16 to 18 Hz.

➡ It could be due to connection of 3 km ducts and Cryostat is fixed on ground.(At Toshiba , Cryostat was not fixed.)

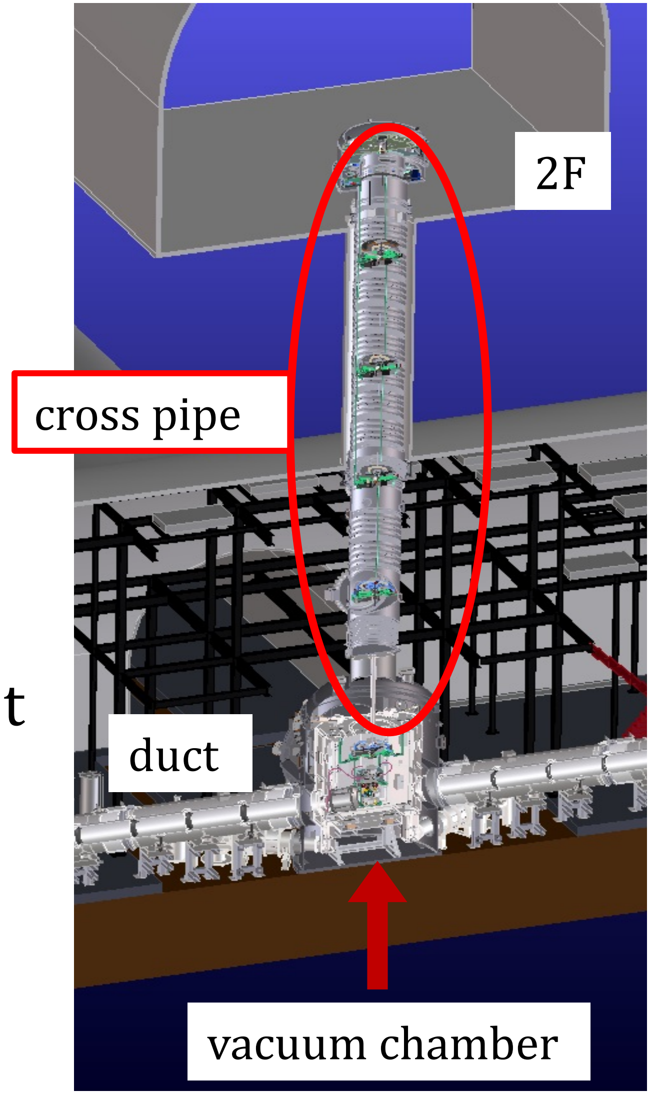
Plan for re-measurement with cross pipe

Currently no cross pipe is installed on the cryostat cryo-accelerometer installed .

Eigenmodes of cryostat with cross pipe could be different from that without the duct.

Vibration measurement and hamming test to invstigate eigenmodes are necessary after cross pipe is connected to cryostat.

We would like to perform the cooling test again.



KEK Hagiwara-san

Problems of cryo-accelerometer

Contrast of interferometer got smaller owing to cooling down.
It is not easy to measure vibration.

↓

We consider to install stage to adjust alignment.

Summary

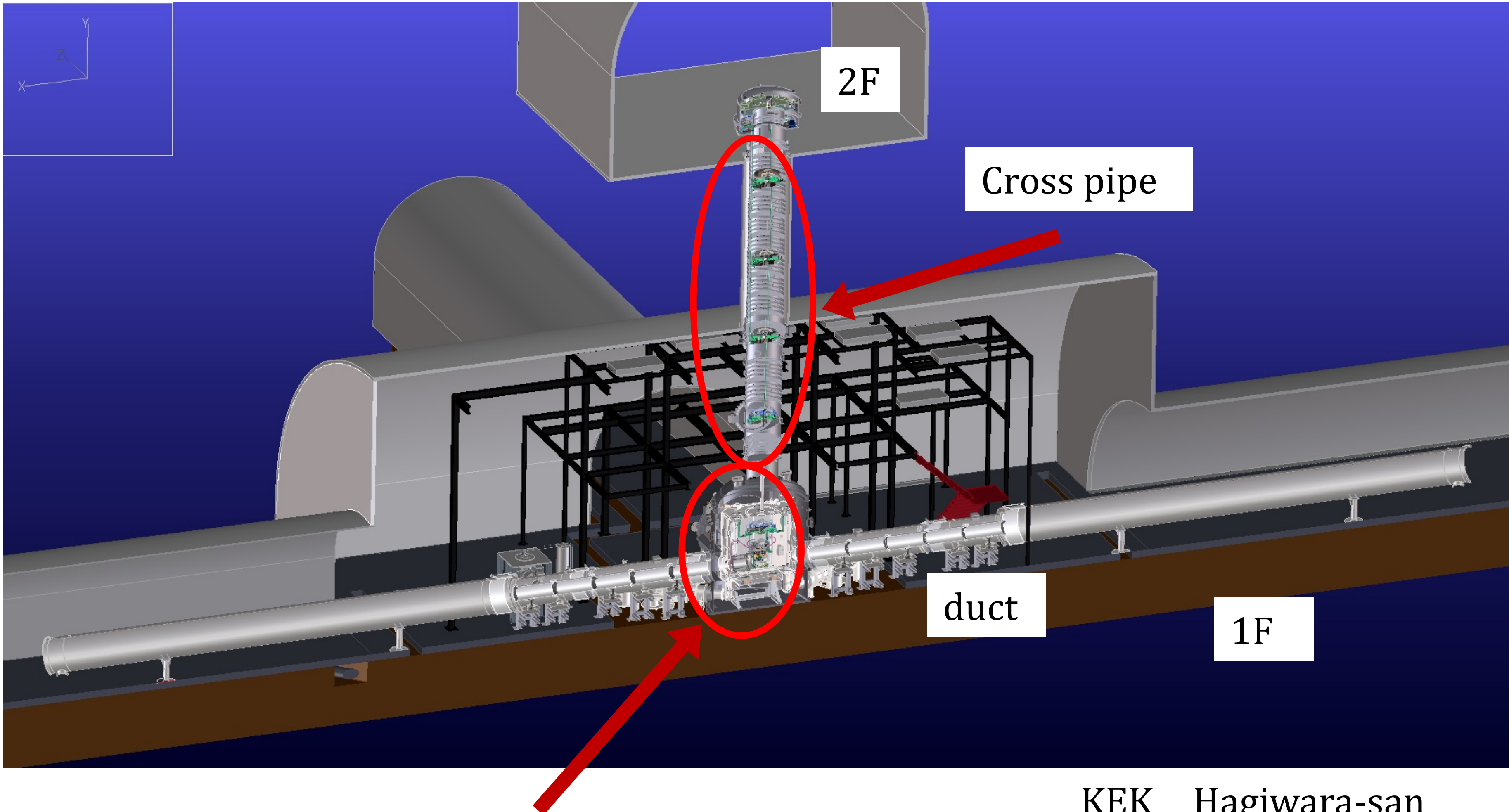
・The cryo-accelerometer was installed in the radiation shield of the cryostat installed KAGRA.
・Vibrations by the cryocooler in the shield were measured in vacuum and at room temperature.
・Harmonics of cryocooler vibration at 2 Hz were observed.
・Many large peaks of the measurement result are consistent with stractual analysis results of the radiation shield

Future Challenges

After cross pipe connection will be
・perform a cooling test once again with a vacuum
・find the eigenfrequency of the vacuum chamber by the Hammering test
・shield vibration measurement

Preliminary slide

Cryostat



Vacuum chamber

KEK　Hagiwara-san

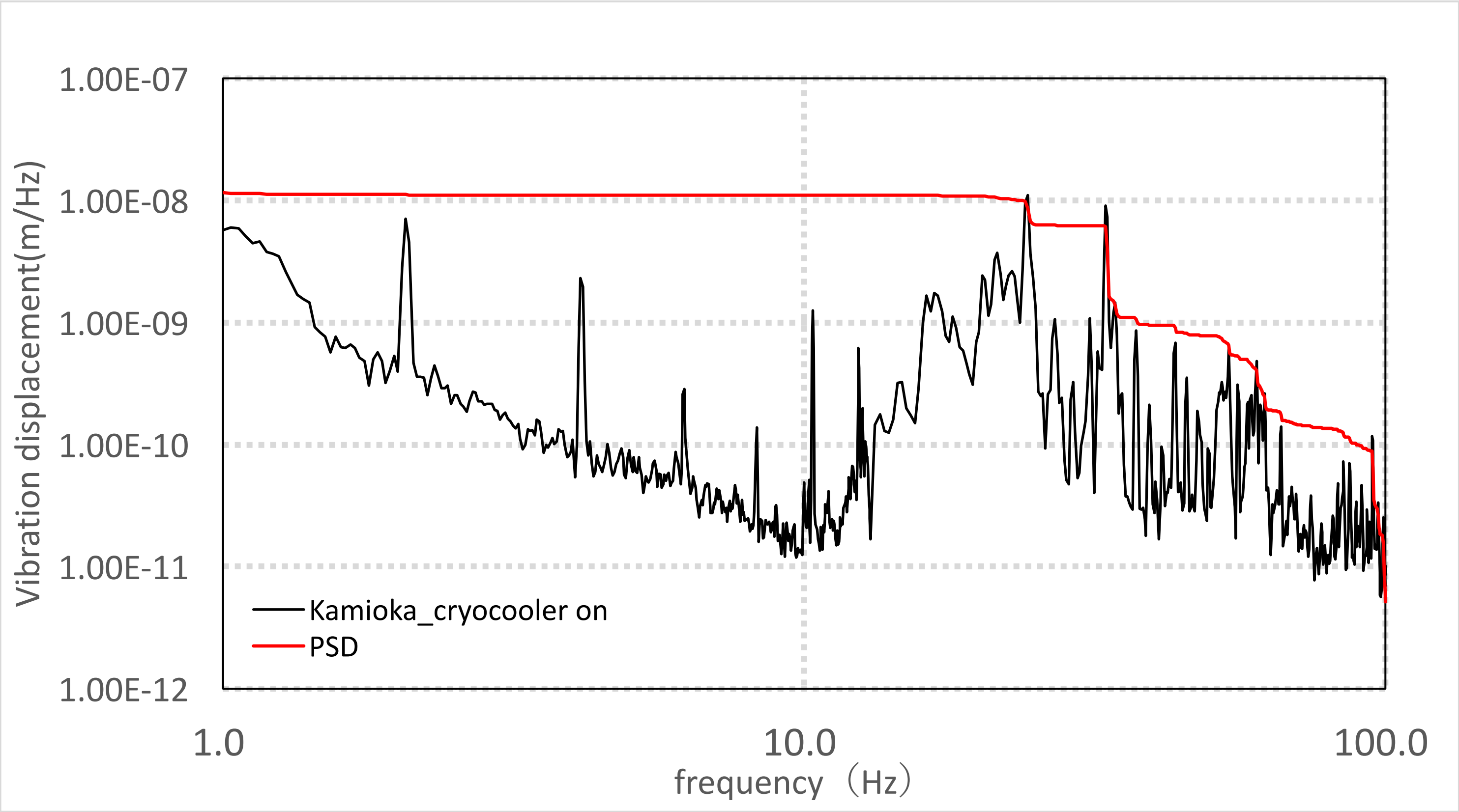
Comparison with RMS result

RMS result			
	Cryocooler off	cryocooler on	difference
analysis	2.3 nm	220 nm	217.7 nm
measurement	14 nm	16 nm	2 nm

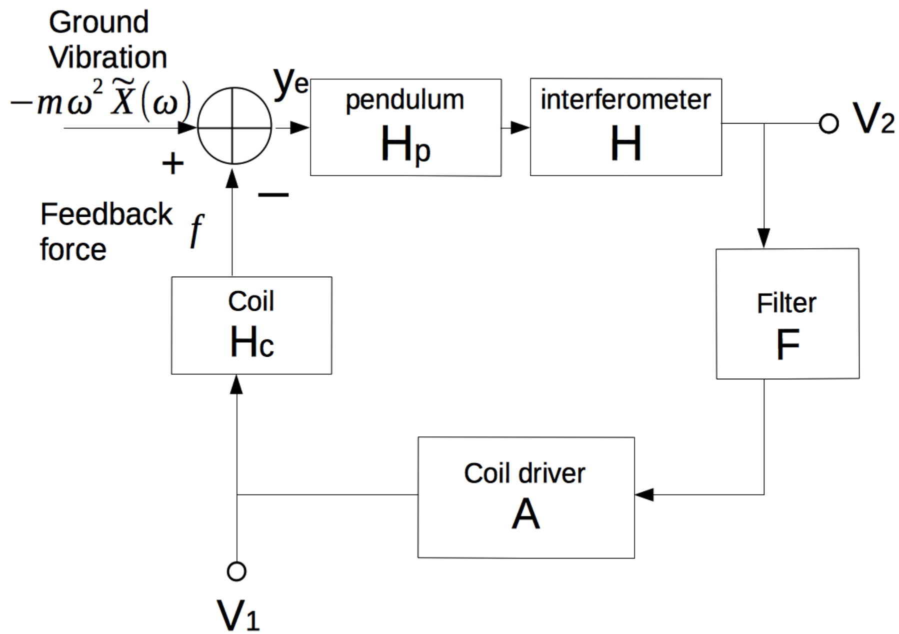
In the analysis, it increases when the cryocooler is in operation, but the measurement result does not change very much.

→ Results were largely different from the analysis.

Power spectral density



Vibration：calibration



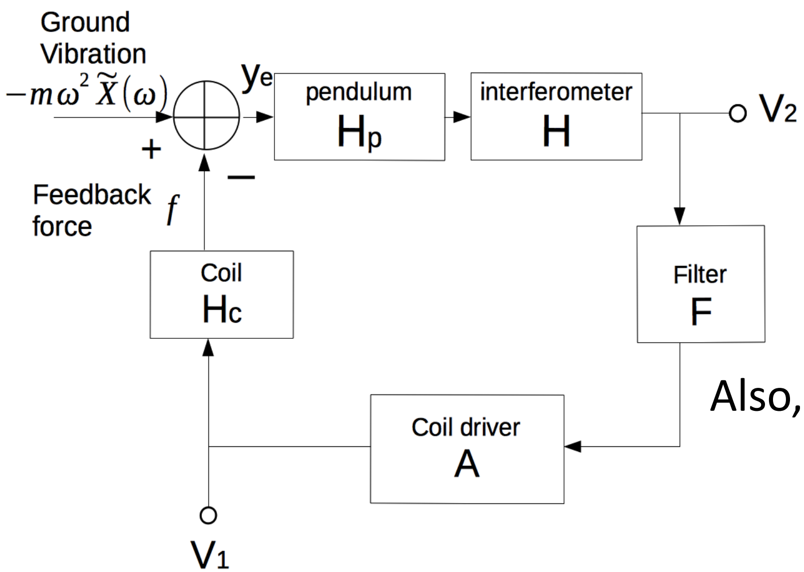
Input;y_e

$$y_e = -m\omega^2 \tilde{X}(\omega) - f$$
$$= -m\omega^2 \tilde{X}(\omega) - H_p H F A H_c y_e$$

$G = H_p H F A H_c y_e$:   open loop gain

$$y_e = \frac{G}{1+G}\left(-m\omega^2 \tilde{X}(\omega)\right)$$

Vibration ：calibration



Also, the measured voltage V_1 , V_2 is

$$V_1 = H_p H F A y_e$$
$$= \frac{G}{1+G} H_c(-m\omega^2\tilde{X}(\omega))$$
$$V_2 = H H_p y_e = \frac{H H_p}{1+G}(-m\omega^2\tilde{X}(\omega))$$

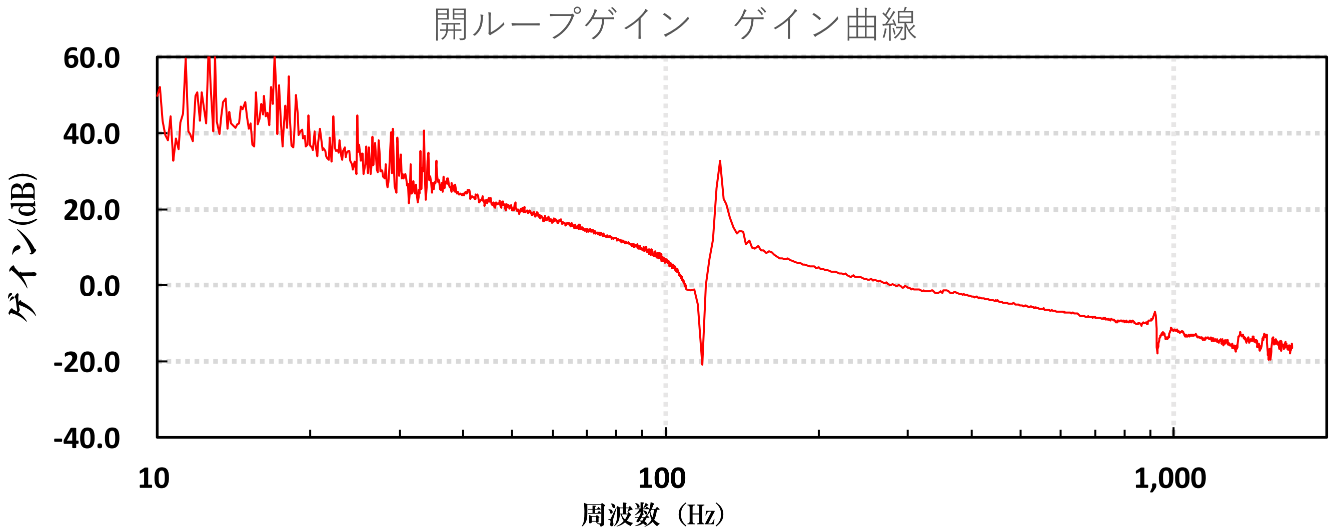
. Therefore, Vibration displecement is

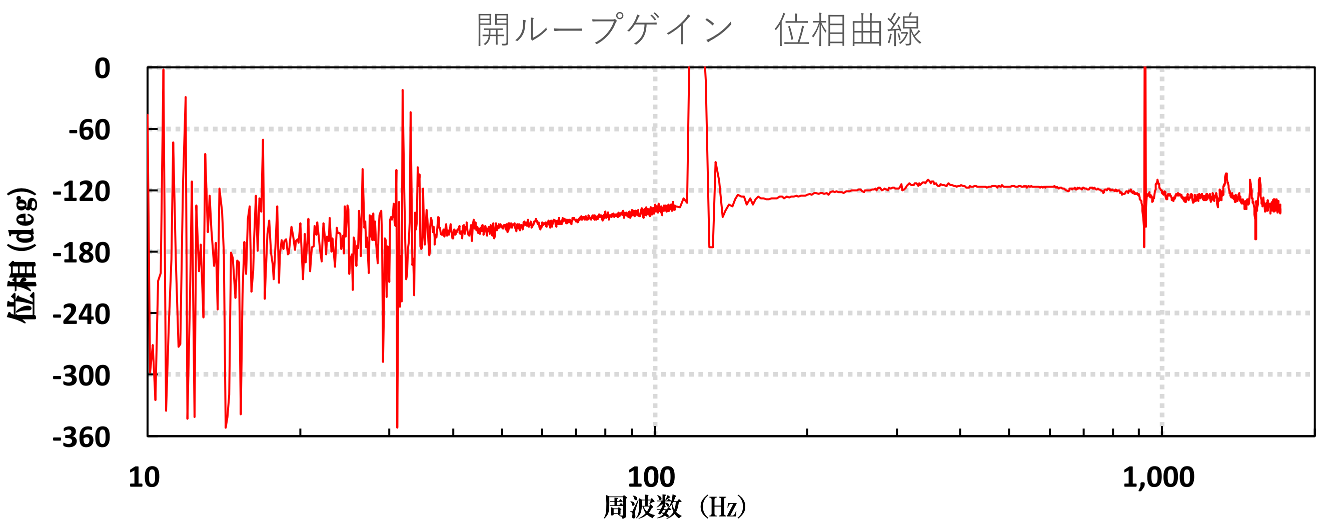
$$\left|\tilde{X}(\omega)\right| = \frac{1}{m\,\omega^2}\left|\frac{1+G}{G}\right| H_c V_1 \quad (*1)$$
$$\left|\tilde{X}(\omega)\right| = \frac{1}{m\,\omega^2}\left|\frac{1+G}{H H_p}\right| V_2$$

.

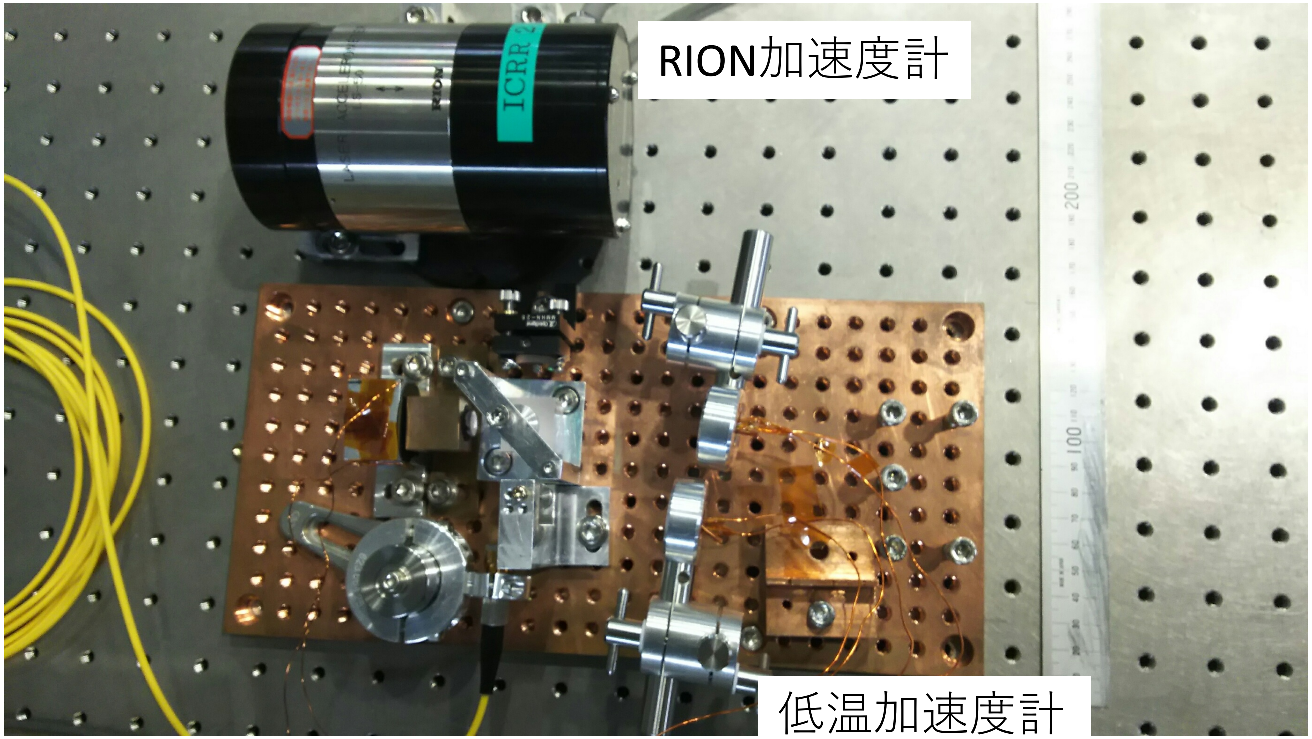
For this time, find the displacement from the above formula.

Open loop gain



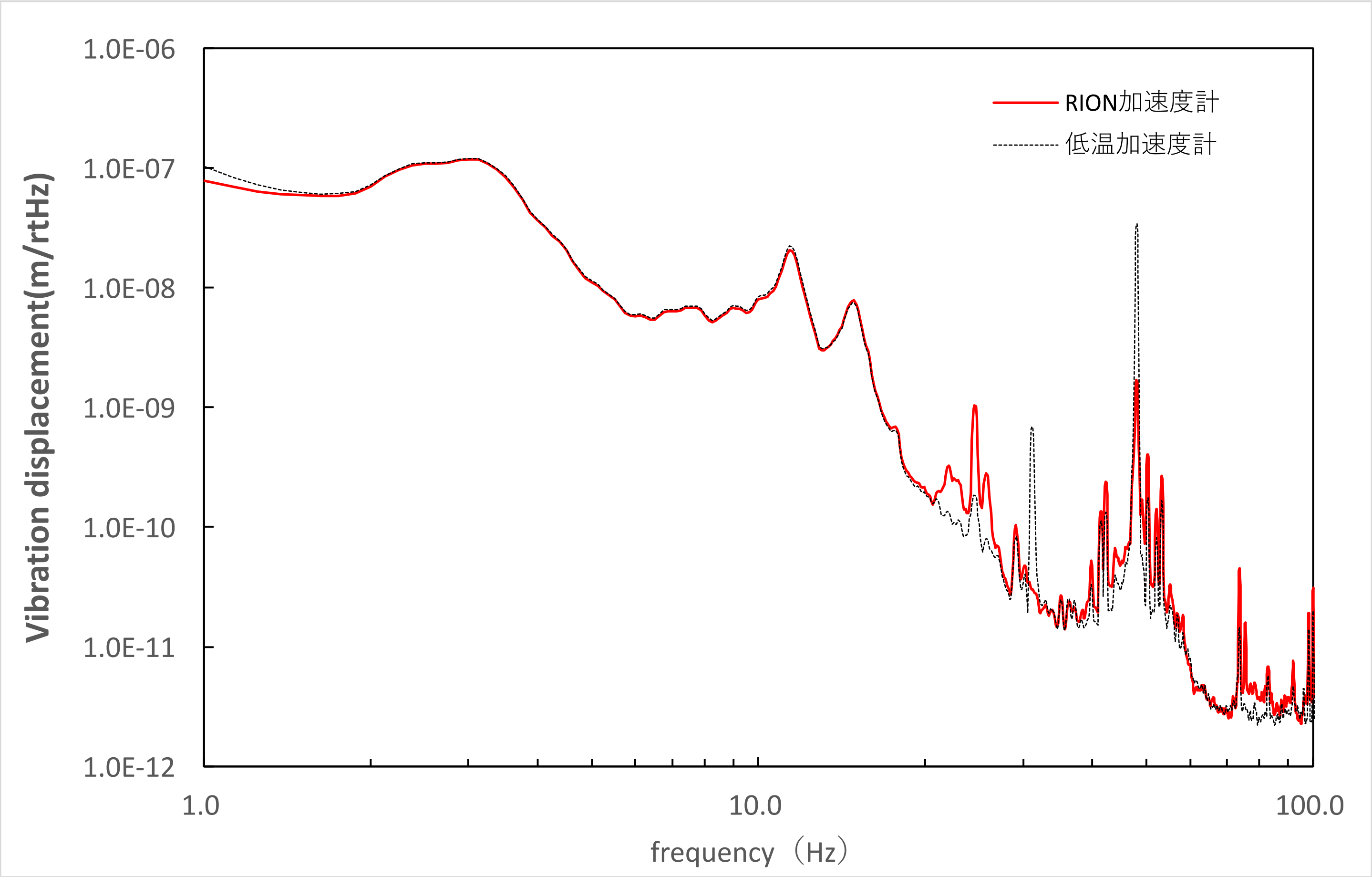


Simultaneous measurement with commercially available accelerometer (RION)



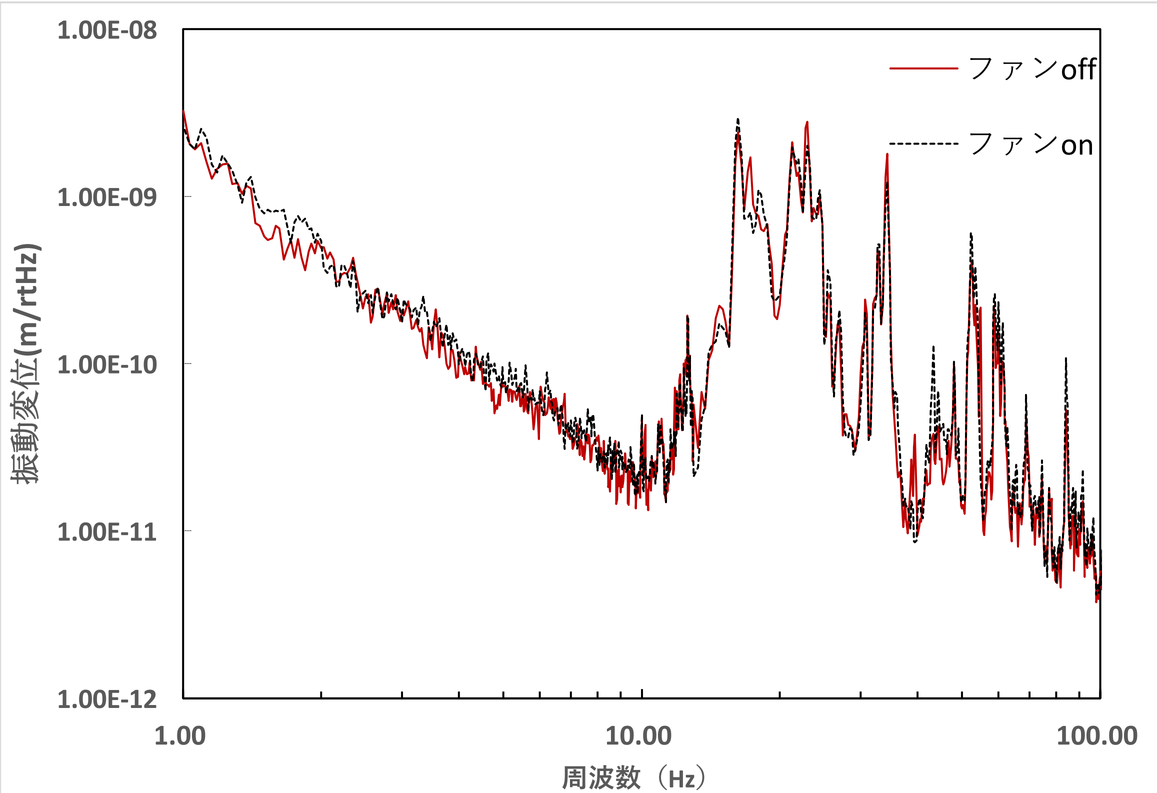
Simultaneous measurement with RION accelerometer on optical platen at Kashiwa

Simultaneous measurement with commercially available accelerometer (RION)



Almost consistent up to 100 Hz

クリーンブースのファンのon offによる変化

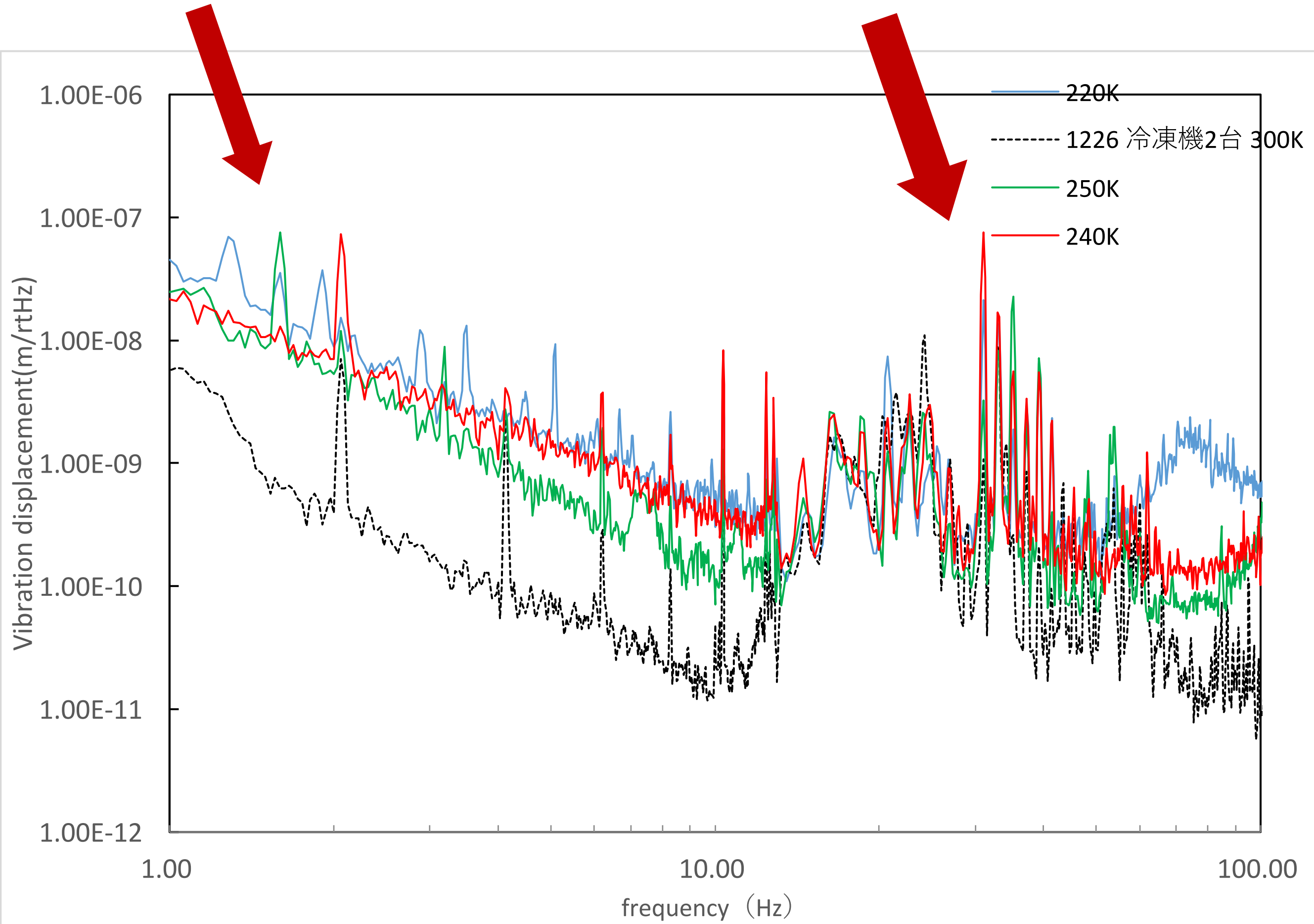


ファンによる影響を測定
ほとんど影響なし
→風による影響はほとんどない

Measurement among cooling test

Vibration of Cryocooler for cryoduct cooling （1.6 Hz） is also observed

Peaks at 30 Hz – 40 Hz rise about 10 times



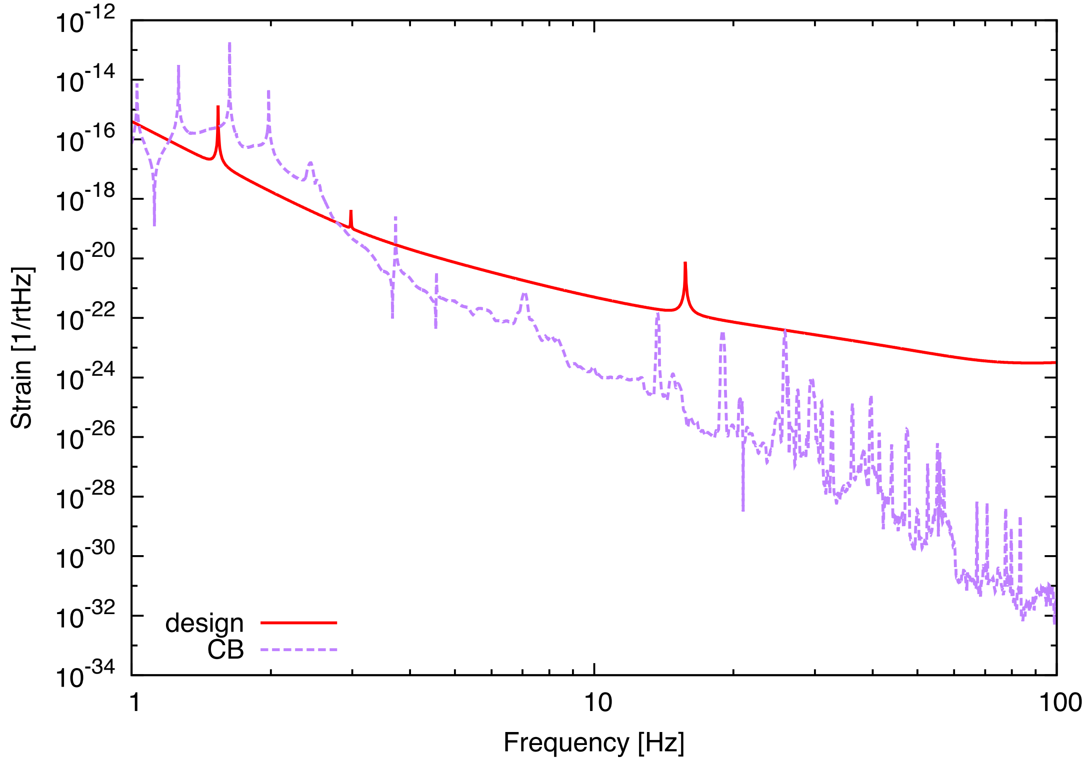
Cryostat at Toshiba

Duct was nothing

cryocooler

Vacuum chamber

preceding study -measurement at Toshiba Keihin Office : comparing to KAGRA design sensitivity



We inject the calculated vibration at the KAGRA site into the payload and analysis vibration response.

Problem and difference points

- Vibration of cryocooler may be buried under seismic vibration.
- Duct and vacuum chamber was not connected with Cryostat.

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モーダル解析結果

自由振動

周波数の値

F1	37.41 Hz
F2	40.95 Hz
F3	42.92 Hz
F4	43.15 Hz
F5	43.66 Hz
F6	56.56 Hz
F7	77.60 Hz
F8	79.33 Hz

底板全周固定

周波の値

F1 21.52 Hz
F2 35.28 Hz
F3 43.23 Hz
F4 48.79 Hz
F5 49.10 Hz
F6 56.02 Hz
F7 56.35 Hz
F8 66.96 Hz

2箇所固定結果

周波数の値

F1	3.58 Hz
F2	20.76 Hz
F3	24.97 Hz
F4	35.87 Hz
F5	42.17 Hz
F6	43.75 Hz
F7	55.79 Hz
F8	55.96 Hz

3箇所固定結果

周波数の値

F1	11.07 Hz
F2	22.22 Hz
F3	34.72 Hz
F4	38.03 Hz
F5	43.02 Hz
F6	44.81 Hz
F7	55.97 Hz
F8	56.14 Hz

4箇所固定の場合

モード	周波数 [Hz]
1	14.557
2	31.281
3	35.963
4	42.53
5	52.414
6	53.655
7	64.279
8	76.052
9	85.882
10	87.376
11	91.379
12	101.41