Small Vibration Cooling and Measurement

12. 14. 2009

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Points of my talk

(from ATF2/ILC meeting at BNL in 11/24/'09)

Requirement of vibration for ATF2 test

< 50 nm position stability between final focus magnet and Shintake-monitor in vertical direction.
(*Relative positioning*)

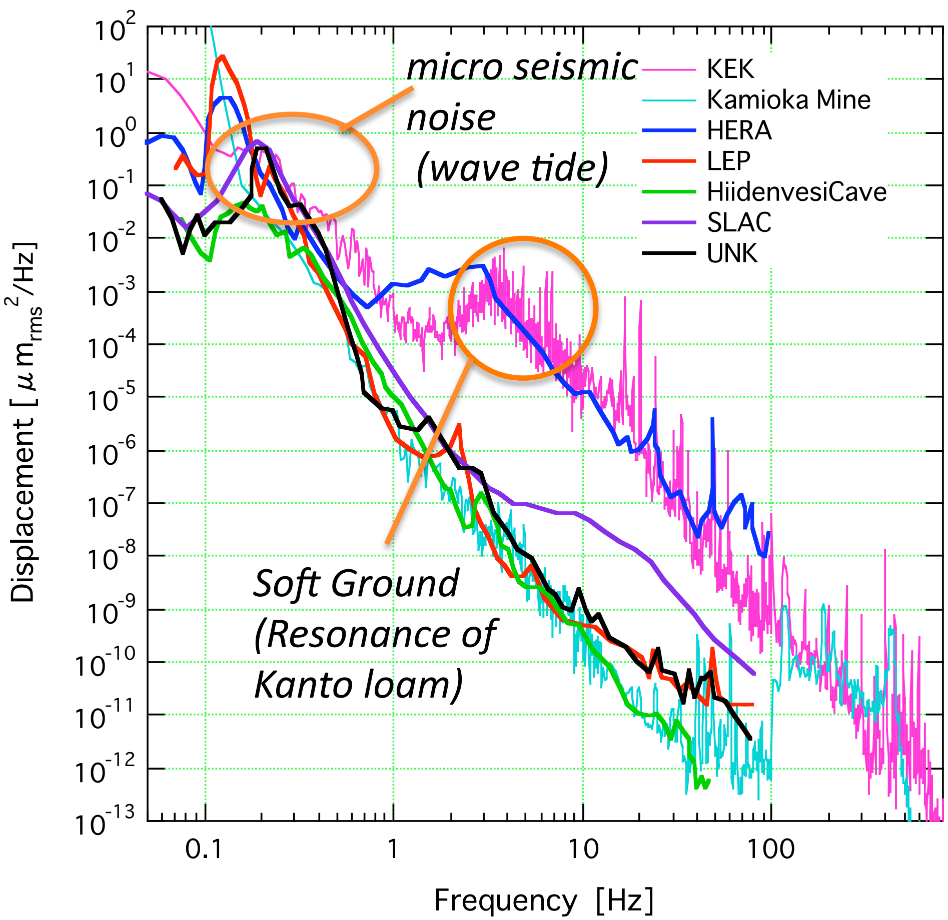
To achieve ultra-stable system

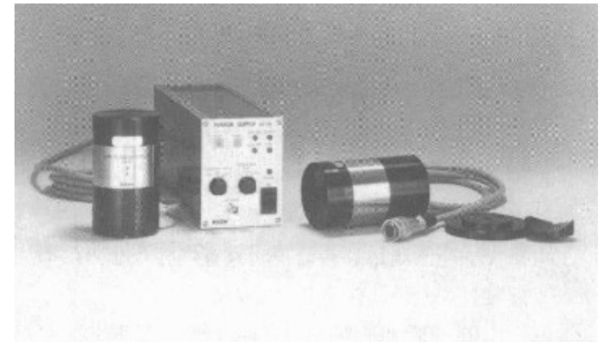
- Eliminate vibration source from the system
- Avoid coupling of mechanical resonance of each parts of system
- Temperature stabilization of surroundings

1. Environment at KEK

(1) Seismic Vibration Level

Replotted from A. Seryi, et al., "SimulationStudies of the NLC with Improved Ground Motion Models," LINAC, Monterey, California(2000), KEK and Kamioka data were measured by T. Tomaru @KEK





Measured by laser accelerometer
Sensitivity 10^-5 Gal/rHz

Ground vibration level at KEK is that of typical urban area.

The data was obtained at night.

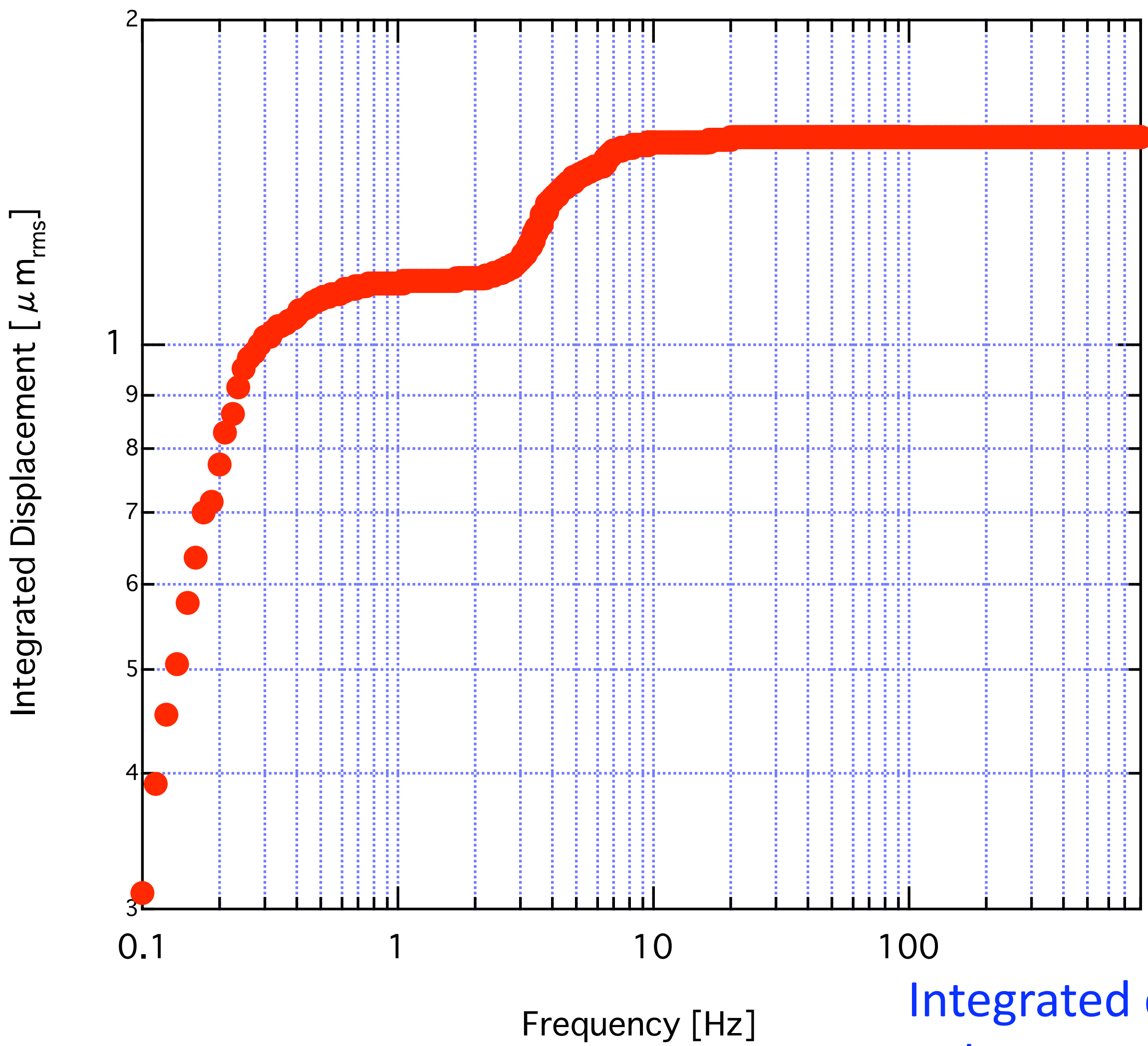
(In daytime, much noisy)

Peaks between 0.1-0.3Hz
-> micro seismic noise (wave tide)

Peaks between 1-10Hz
-> soft ground
(Resonance of Kanto loam at KEK)

Integrated Displacement of KEK Seismic Vibration

The vibration amplitude below 10Hz reached over 1μm.



Integrated displacement reaches 1μm
Below 1Hz.

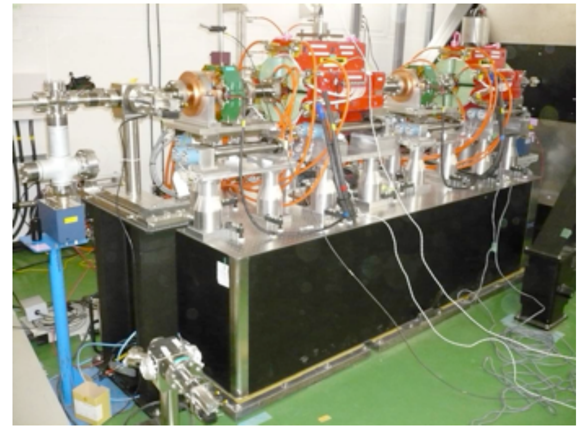
(2) Shintake-monitor

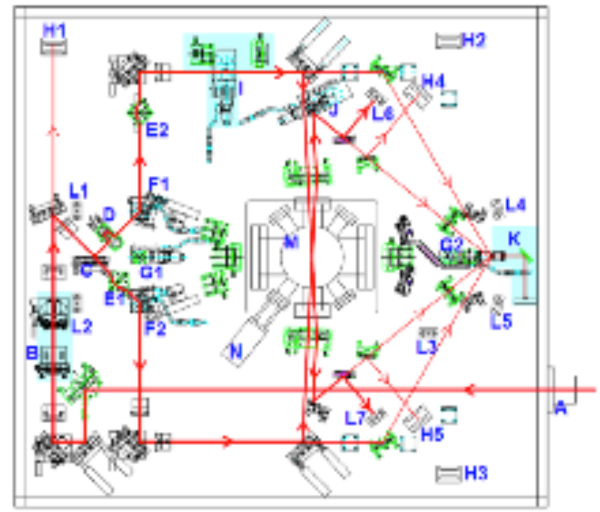
Measurement of 37μm beam size

-> Require a few nm beam stabilization

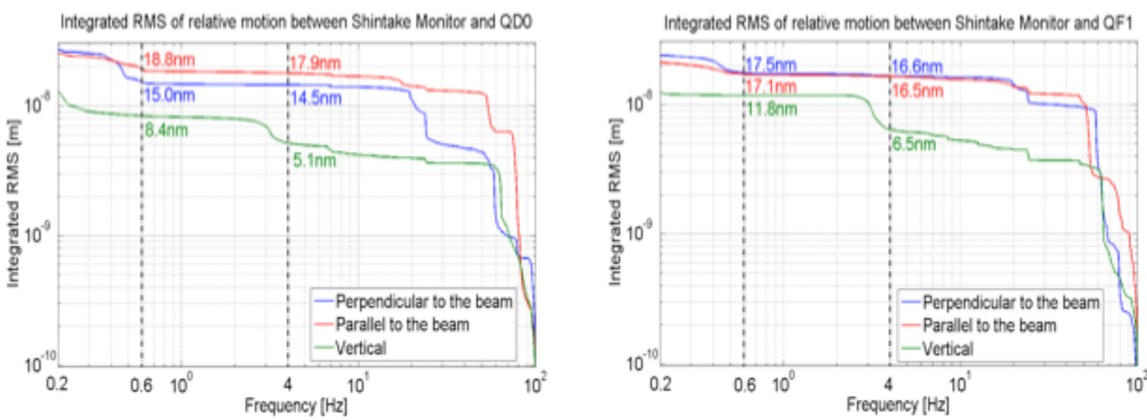
-> Introduction of beam feedback/feedforward mitigates beam stability of 50nm.

Shintake monitor and ATF magnet are located on separated rigid-table.





T. Yamanaka (2008)
T. Kume (2009)
B. Bolzon (2009)



Integrated RMS of relative motion between SM and QD0 (left) and between SM and QF1 (right)

Relative displacement between Magnet bench and Shintake monitor bench Is below 10nm at low frequency.

- Only vertical direction can be measured.
- Optics are in open air.

  -> Affect of sound is worried.

  -> Fortunately, sound affect is not observed in present stage.

  -> But we don't know whether **sound** from cryocooler affect or not.

    -> This can limit setting location of cryocooler. Test item.
- Resonant frequency of Shintake-monitor bench is 50-60Hz.
- Averaging data acquisition

  -> **Below 10Hz** is critical for Shintake monitor.

  -> We should take attention at low frequency vibration especially.
- Temperature environment is not stabilized at ATF2

  -> Normally, **temperature unstablility** cause largest error for alignment.

    (very low frequency.)

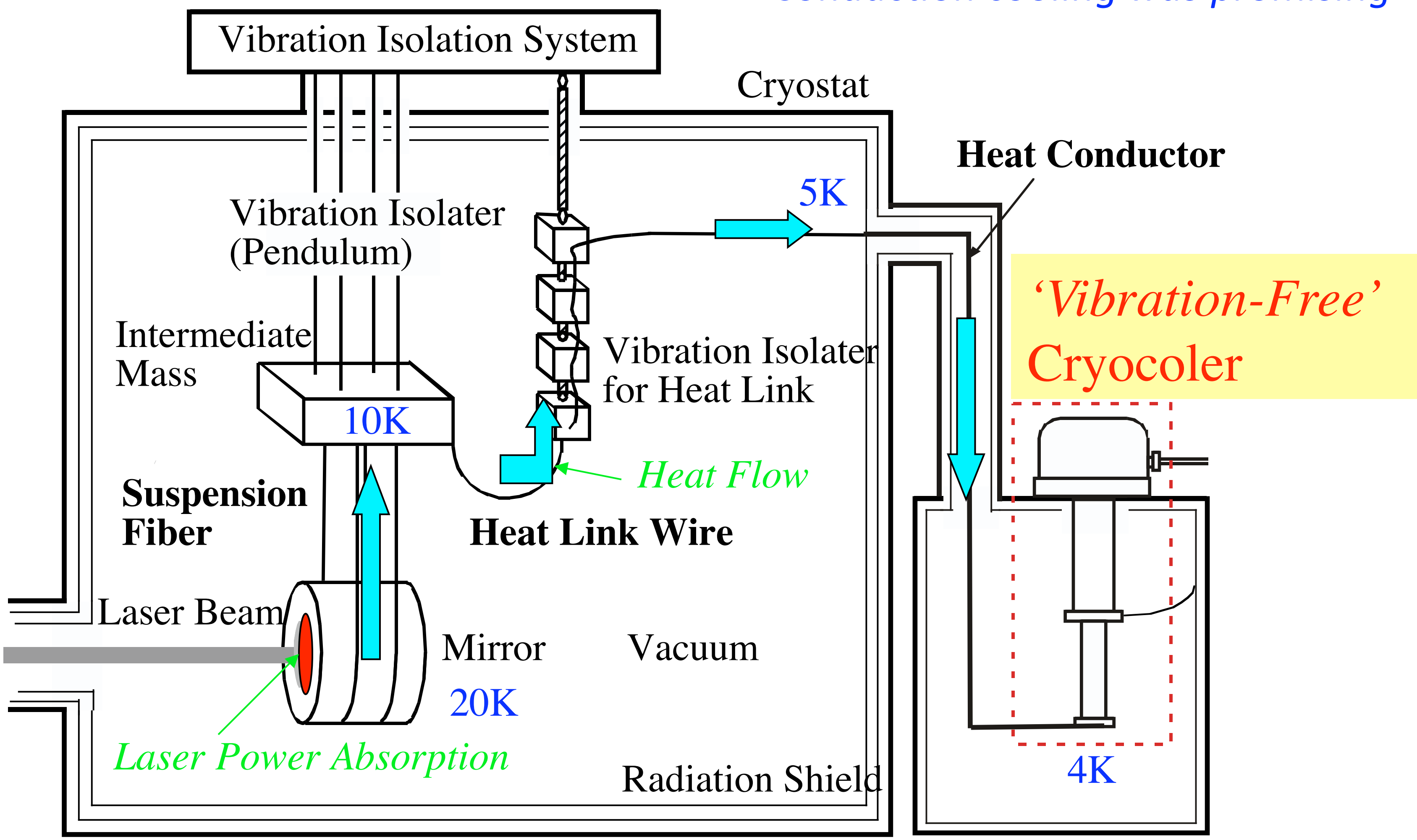
    Thermal expansion rate of steel is 10^-5.

    Inver: 10^-6, Super Inver: 10^-7

2. Ultra-low Vibration Cooling

(1) Ultra-low vibration cryocooler system for laser interferometric gravitational wave detector

Conduction cooling was promising

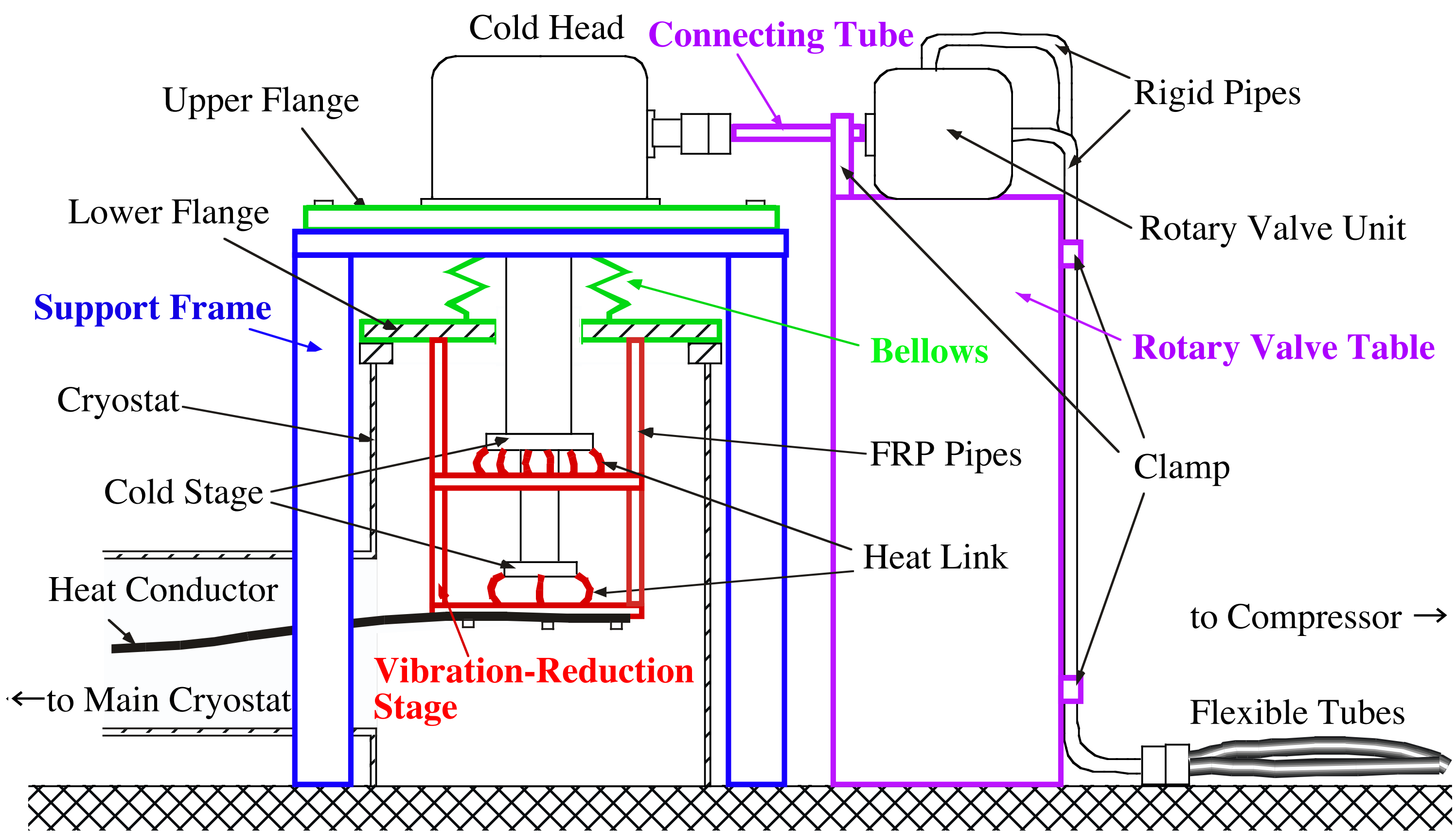


Key point of cryocooler vibration

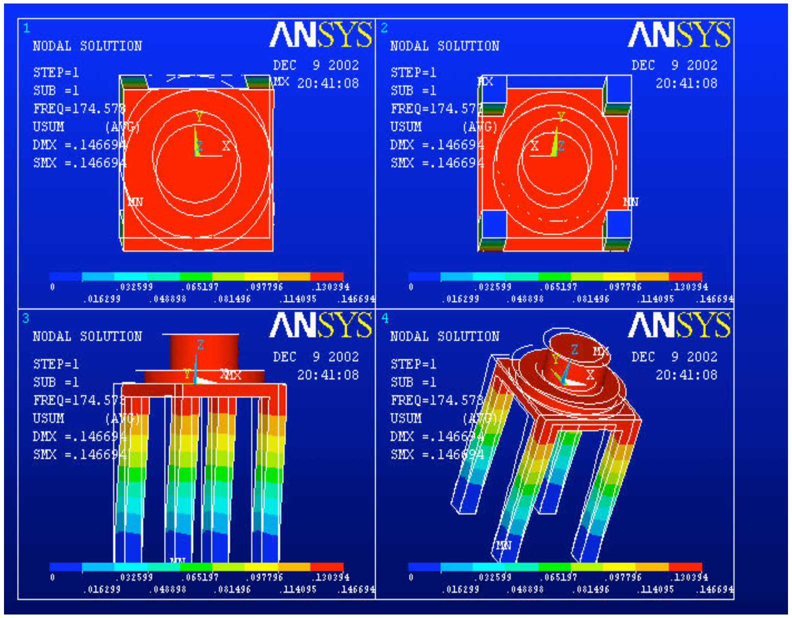
- Cold head vibration: gas reaction, rotary valve, seismic vibration, sound and stuff
  -> Cause whole vibration of the cryostat
- Cold stage vibration: due to elastic deformation of cylinder by oscillation gas
  -> vibrate heat conductor

0.5W Sumitomo PTC

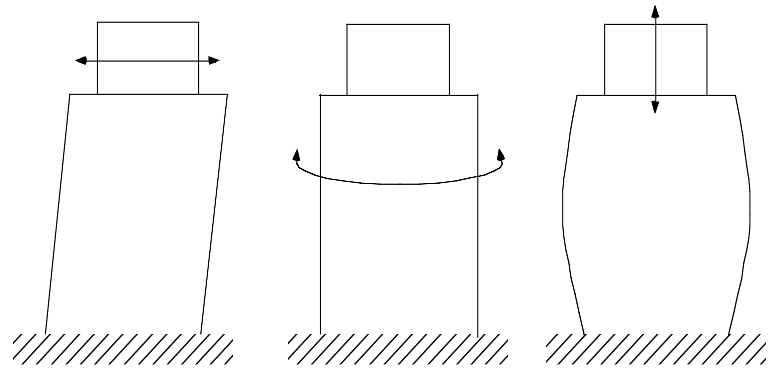
Vibration Reduction System in GW detector



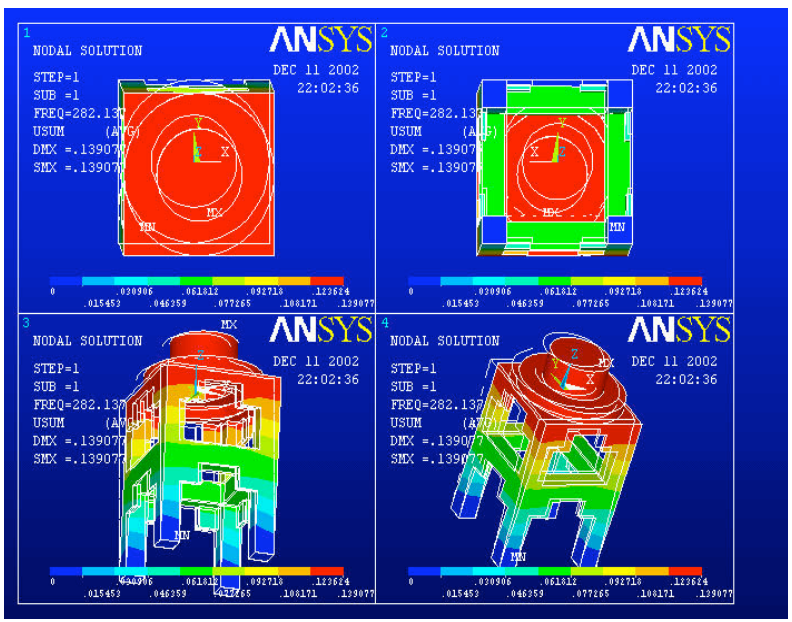
Modal Analysis of Cold Head Support



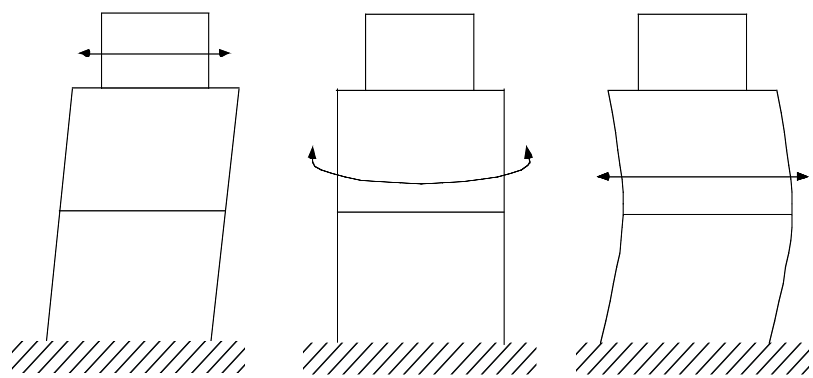
Model 1



175Hz 282Hz 973Hz



Model2



282Hz 462Hz 1038Hz

High Purity Al stranded cable

Young's Modulus Cu: 130GPa
Al: 70GPa

5N purity class Al had no SIZE effect.

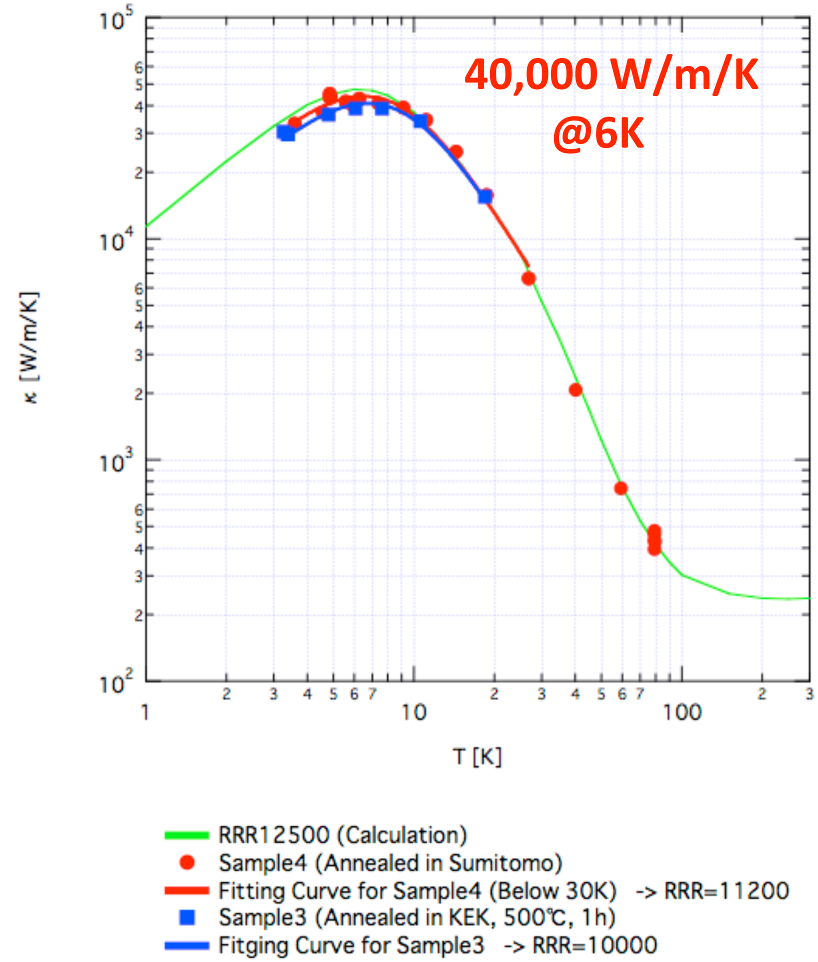
Heat Flow: $P \propto S \propto d^2 \times n$

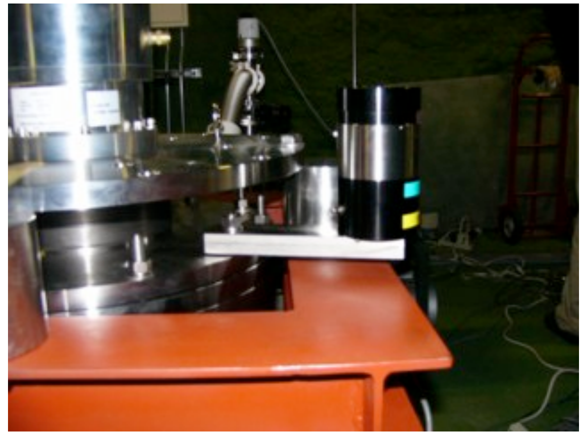
Spring Constant: $k = n \times k^{(1)} = \dfrac{3nE\pi d^4}{64 l^3}$

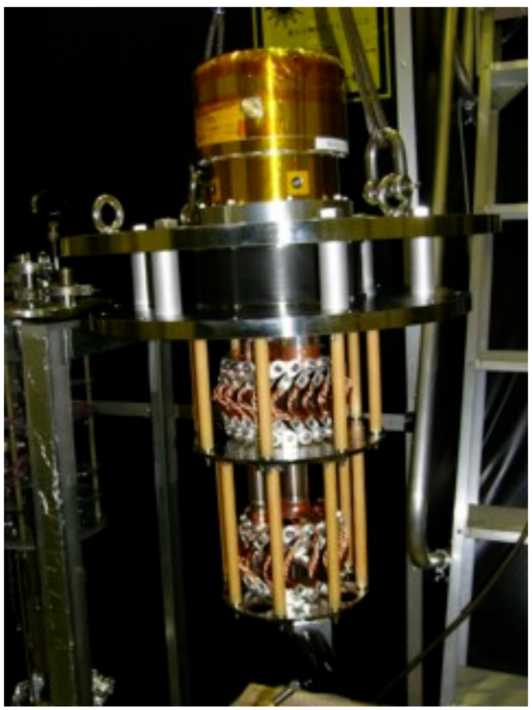
$$k \propto nd^4 \propto \frac{P^2}{n}$$

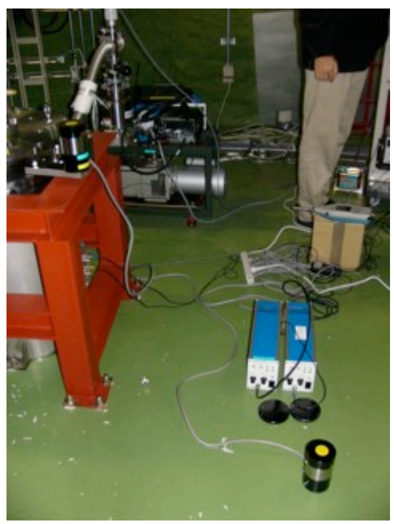
Use of many thin wire is effective.

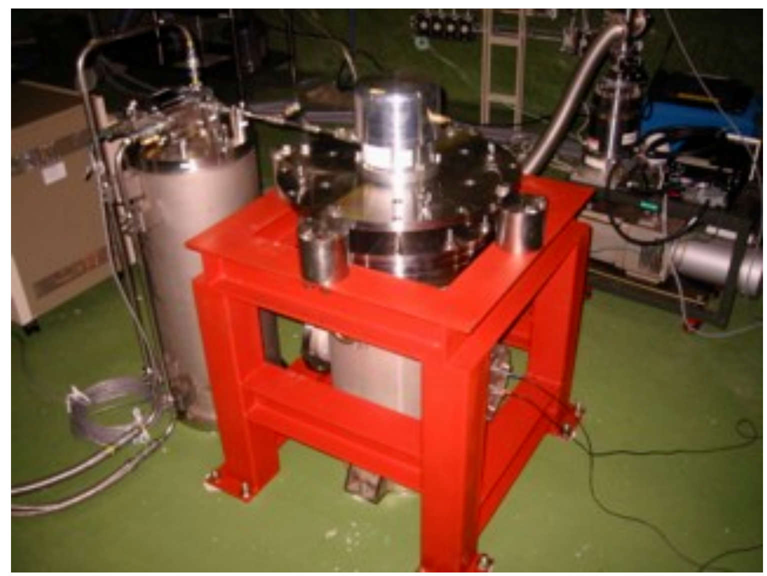
Development of 6N purity Al





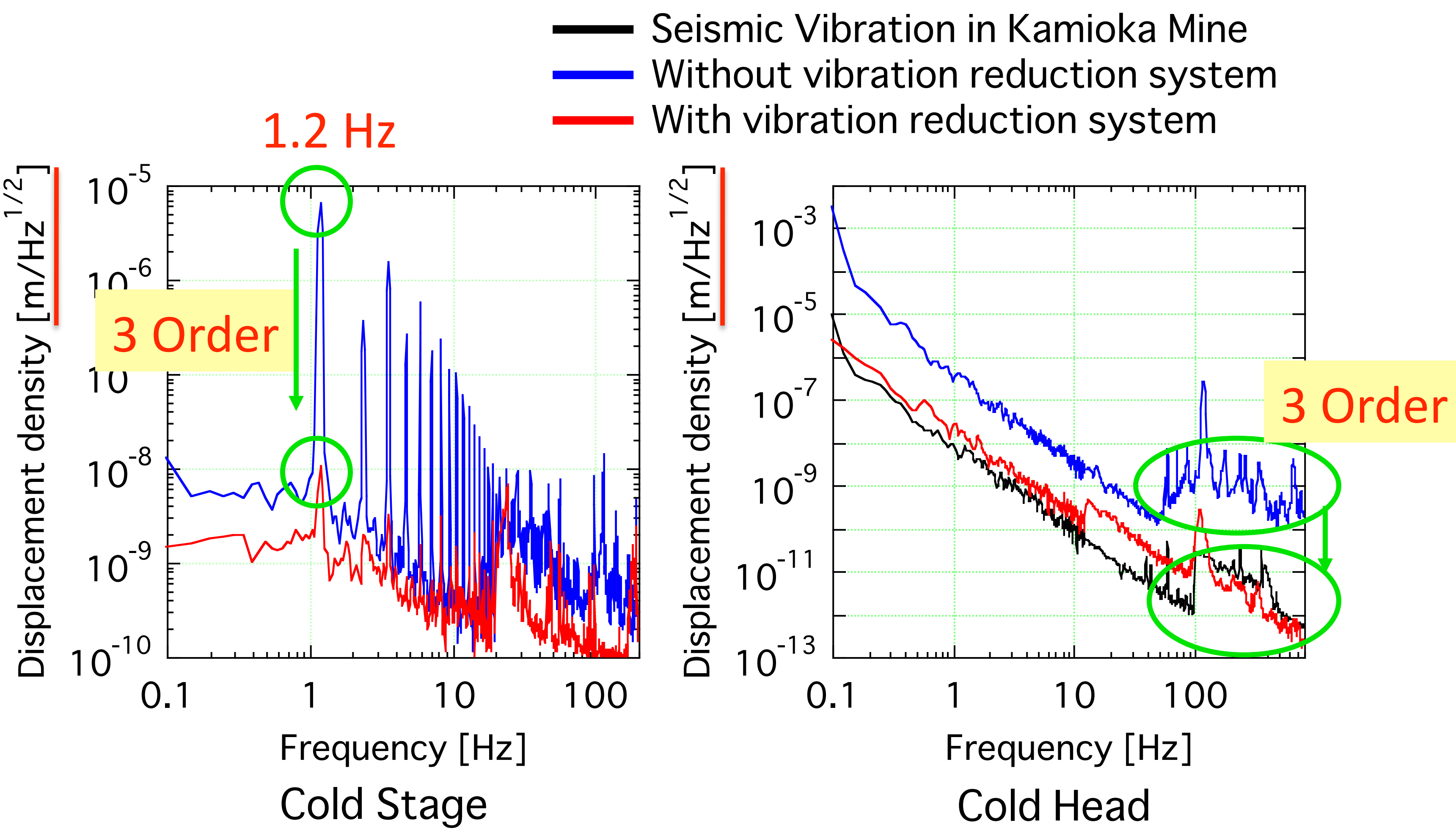






Measured Result (Vertical direction)

T. Tomaru, Cryogenics 44 (2004) 309.
T. Tomaru, Cryocoolers 13 (2005) 695.
R. Li, Cryocoolers 13 (2005) 703.

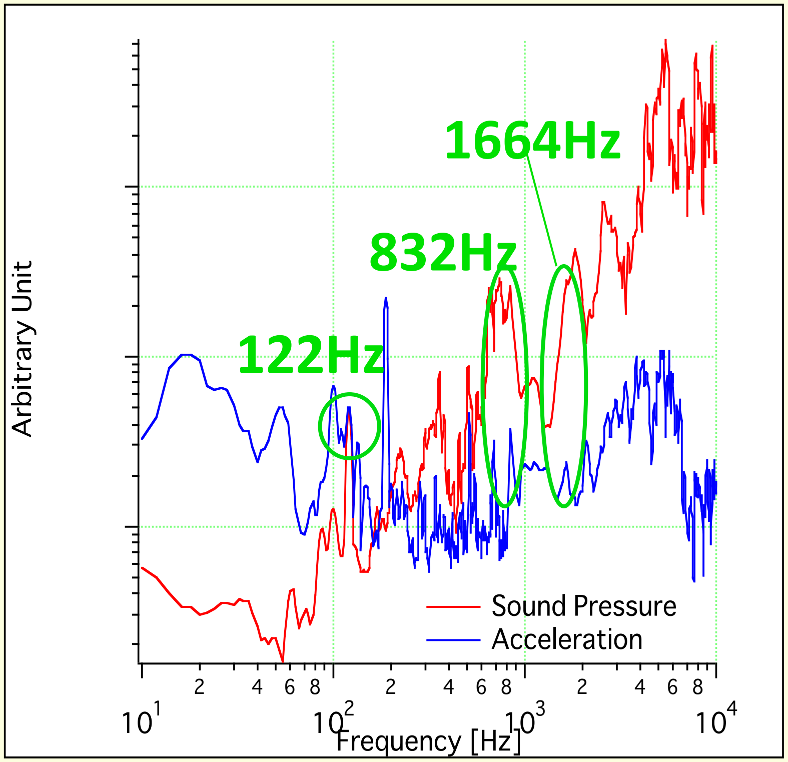


nm level cooling by using mechanical cryocooler has been successfully achieved.

・振動源の振動周波数

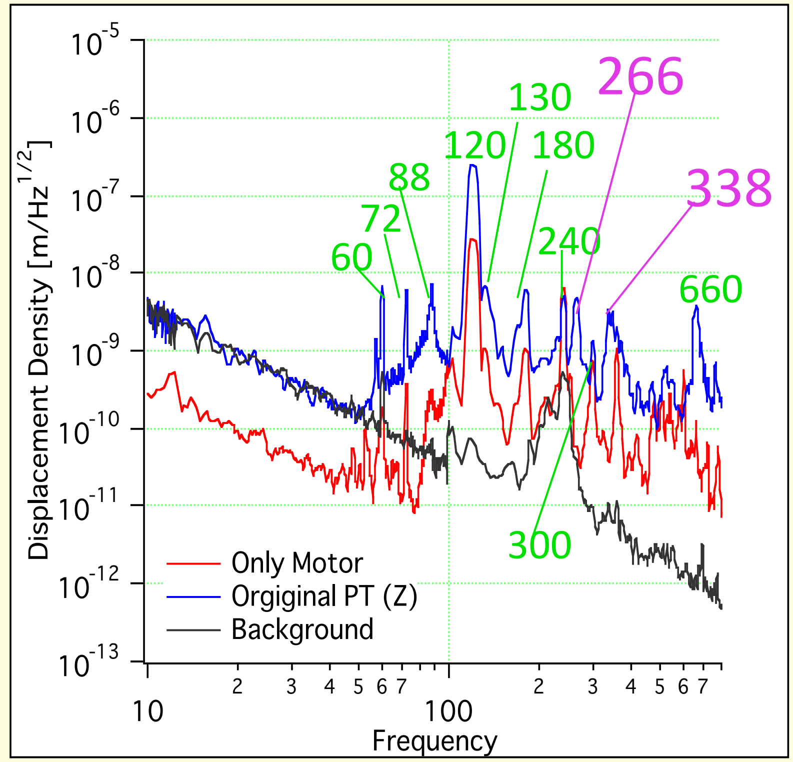
#切り替えバルブ直付けPTとの比較

音の影響



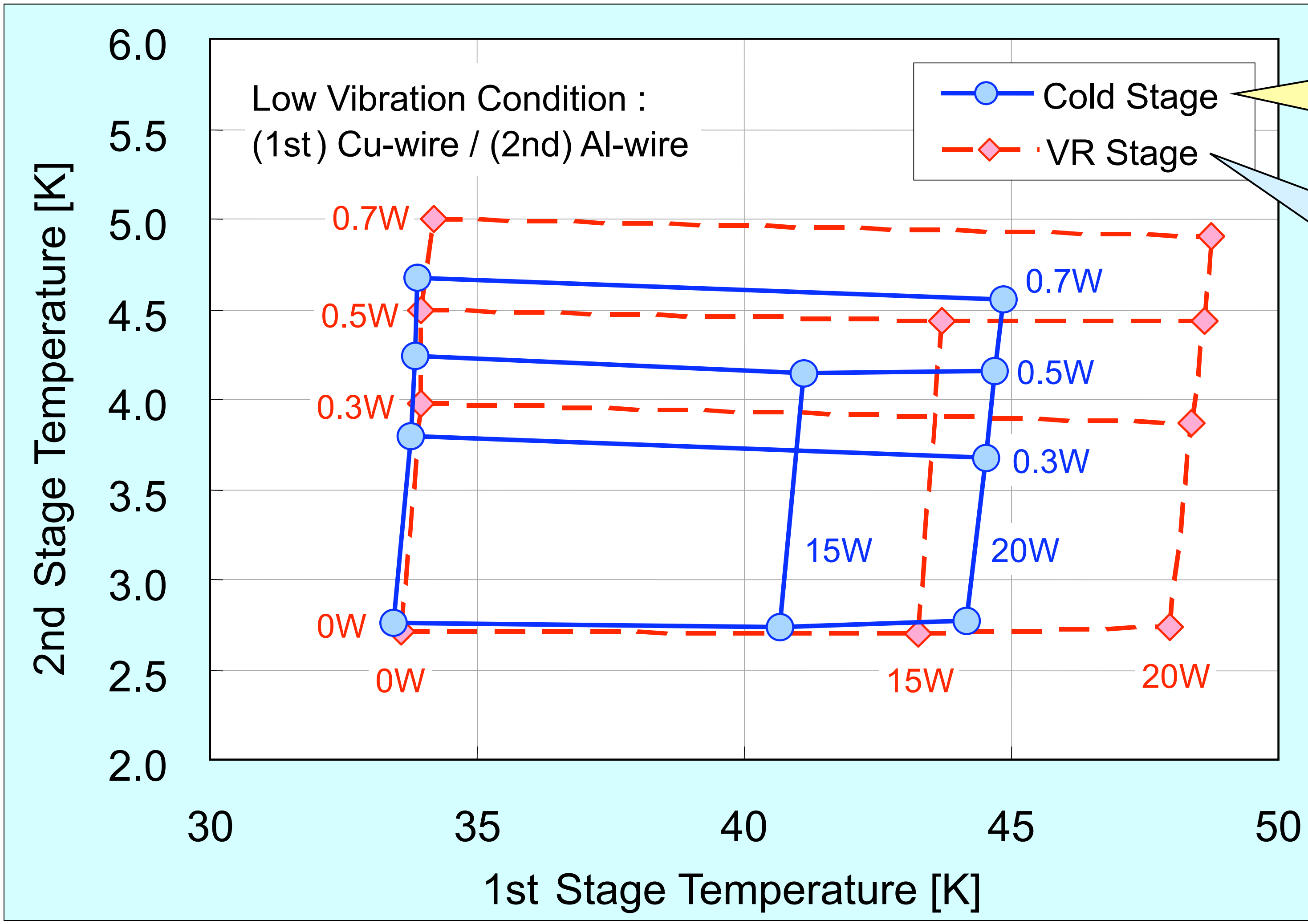
一部に相関があるが、全体的に音の影響は少ない

切り替えバルブの影響



バルブの振動周波数と冷凍機の振動には数10Hzから多くの相関がある。相関の無い266Hz, 338Hzはガスの影響か？

Load Map of New PT (VR Stage)

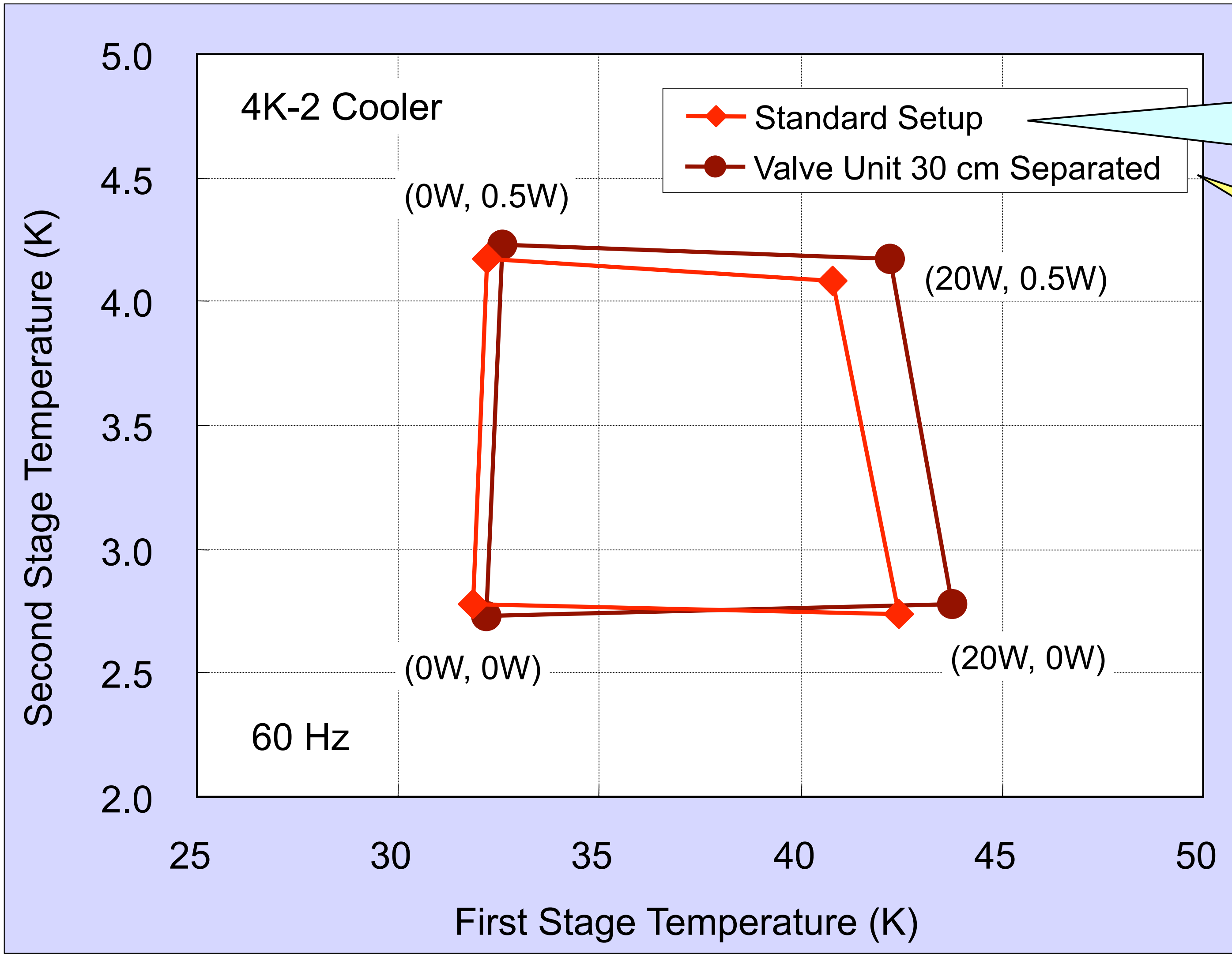


冷却ステージにおけるロードマップ

減振ステージにおけるロードマップ

VR Stageにおいて、0.5W@4.4K / 15W@43.7Kの冷凍性能が得られている

Load Map of New PT (Cold Stage)



SRP-052Aと同じの標準状態におけるロードマップ

Valve Unitを30cm離した状態におけるロードマップ

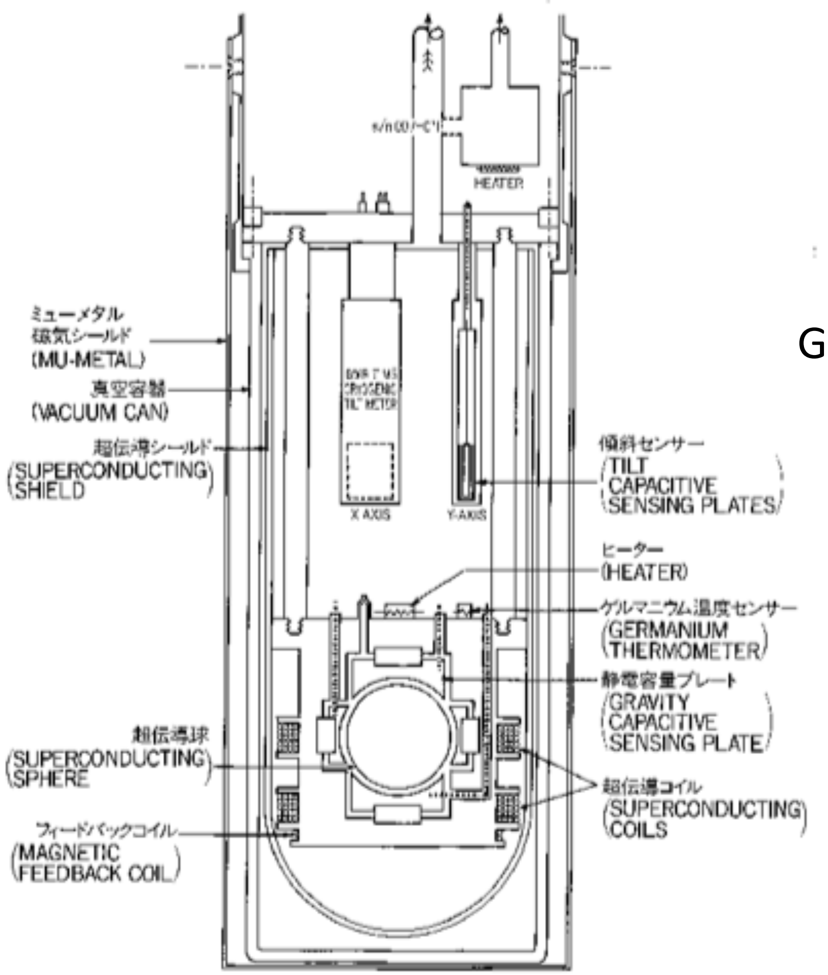
Valve Unitを30cm離しても、0.5W@4.2K / 20W@45Kの標準仕様を満たしている

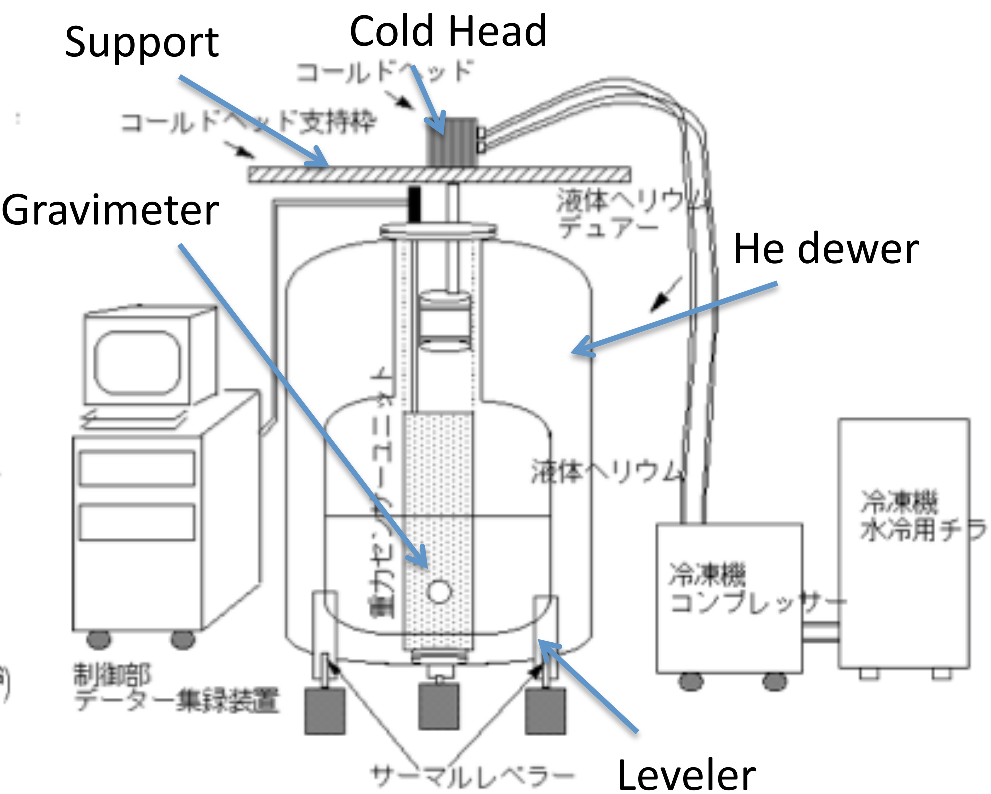
(2) Superconducting Gravimeter

GWR instruments Inc.
http://www.gwrinstruments.com/

Restrain boiling type by using cooler
（Baby sitter, re-condensation, thermo siphon）

Sensitivity $\frac{\Delta g}{g} \approx 10^{-12}$





Now one unit is sitting on Kamioka mine

3. Toward Vibration-Free Cooling of SC Mag.

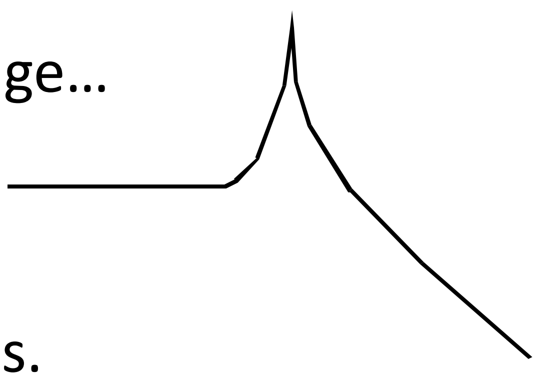
One solution for ILC/ATF2 SCM cooling

- Cooling SC magnet -> SC gravimeter type Re-condensation cooling (Baby sitter)
  One or two 1.5W@4K PTC is available.
- Cooling current lead -> GW type conduction cooling. 0.5-1W@4K

In principle, we should reach 50nm level cooling at 0.1 – 10 Hz range.

But we have to design cryocooler mounting and cryostat carefully.

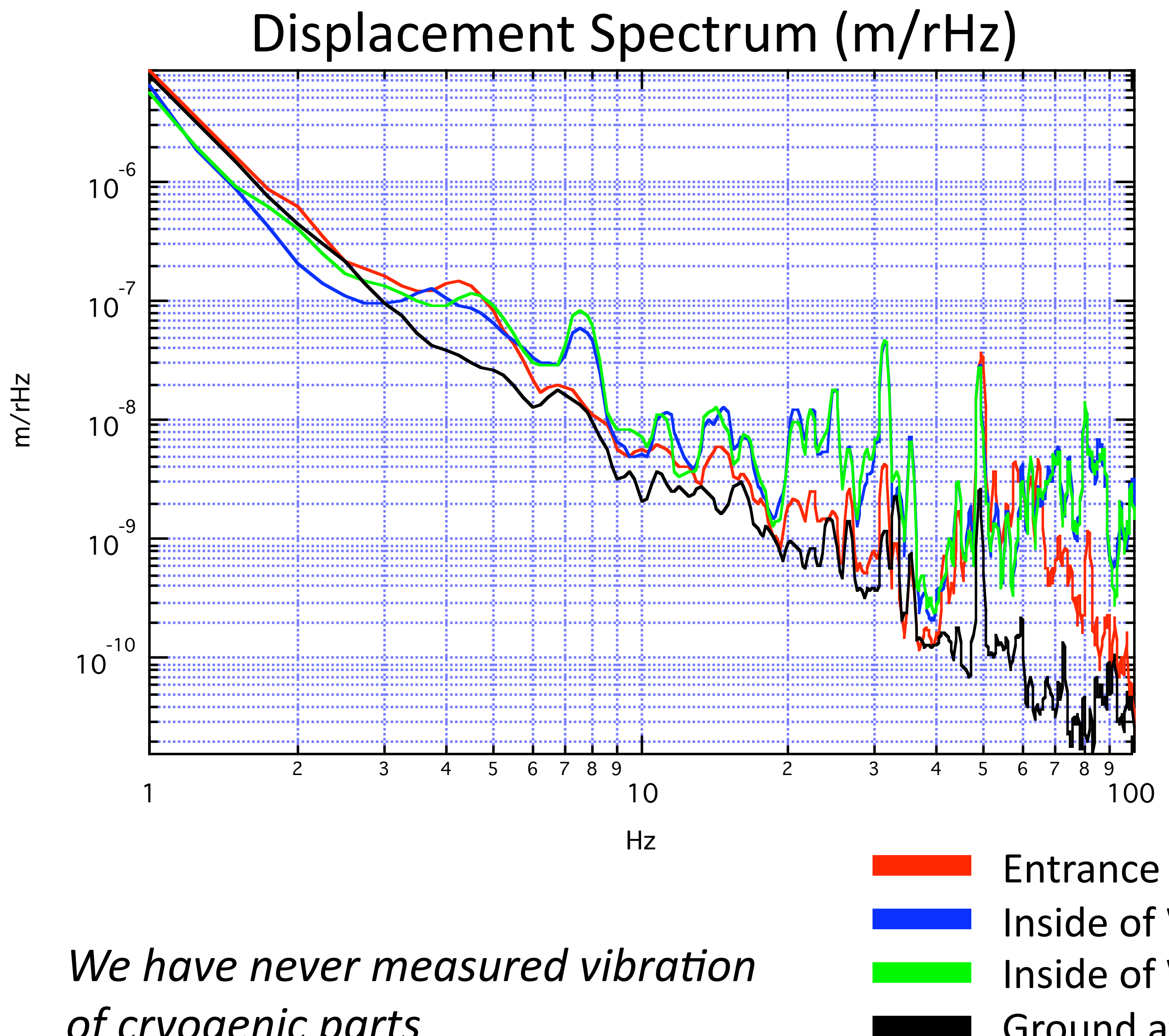
- Don’t make low frequency resonance parts, especially below 10Hz.
  -> Current lead, Cables, Gas pressure change…
- Don’t make large resonance.
  -> Mag. support, Rad. shield, pipe…
- Don’t make coupling of resonant frequencies.
  We have to know resonant frequencies of each parts.



Measured Vibration on Warm-Tube of JNU SCFM

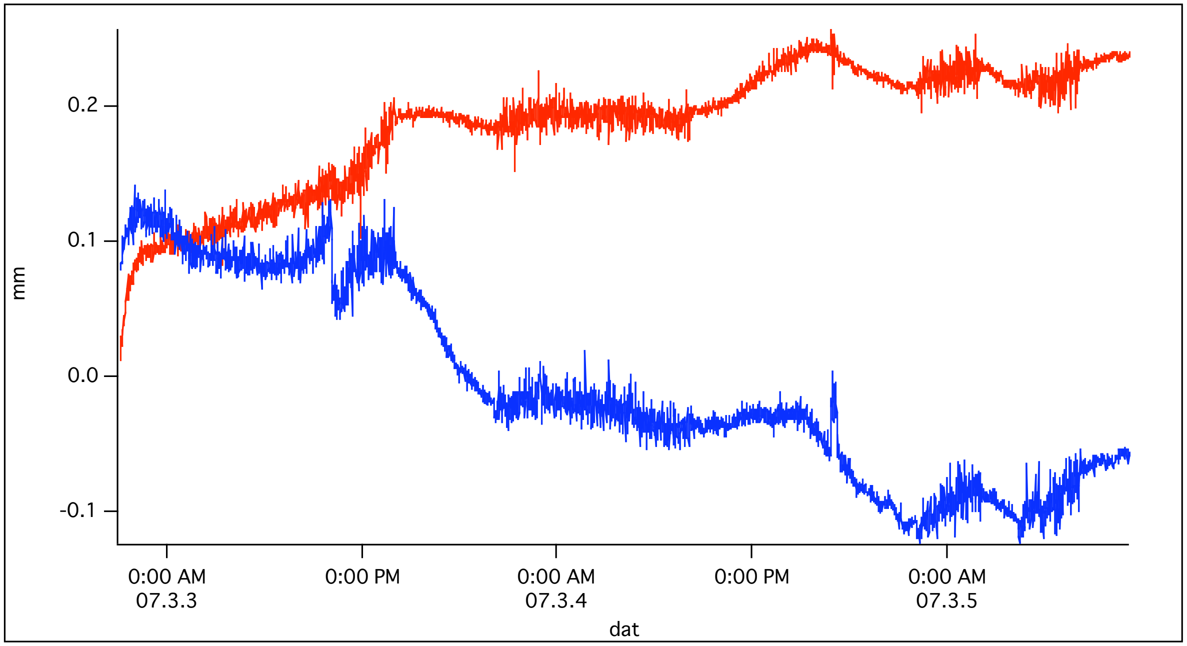
Z direction

2007.6.11
CCFM01
Sensor: TEAC 710



We have never measured vibration of cryogenic parts

Thermal Drift of Laser Position for J-PARC SCFM Magnetic Field Measurement



L~5m

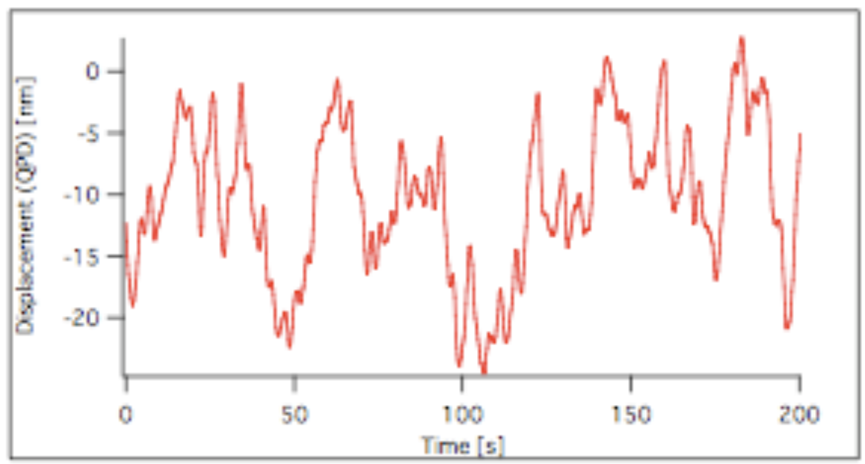
Temperature control is promising.

Thermal Drift for Laser position
At midnight

L=1-2m

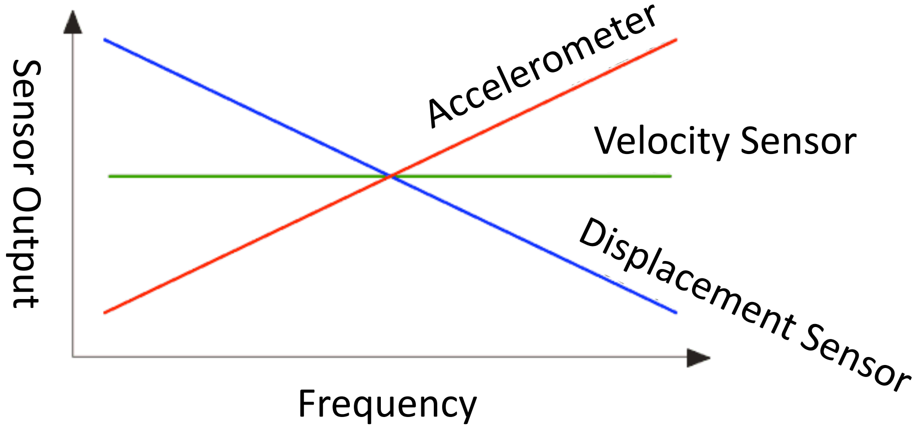
Thermal expansion rate of steel is 10^-5.

Inver: 10^-6, Super Inver: 10^-7



(1)

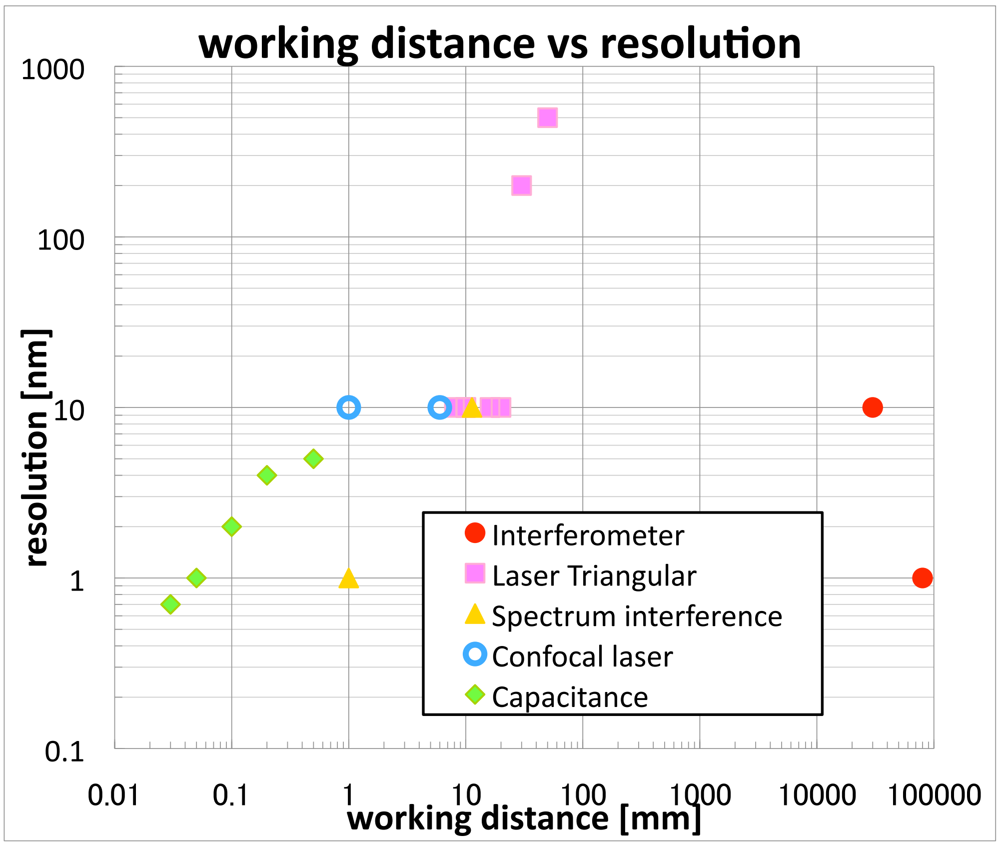
4. Vibration Measurement at Cryogenic Temperature



ILC/ATF2 test: < 10Hz

Displacement Sensor

Displacement sensor is also suitable for relative measurement.



Laser displacement sensor is promising for ILC/ATF2 due to their working distance.

A demerit of displacement sensor Is that it requires stable reference.

By T. Kume

Commercial Displacement Sensor ?

RENISHAW LX-80

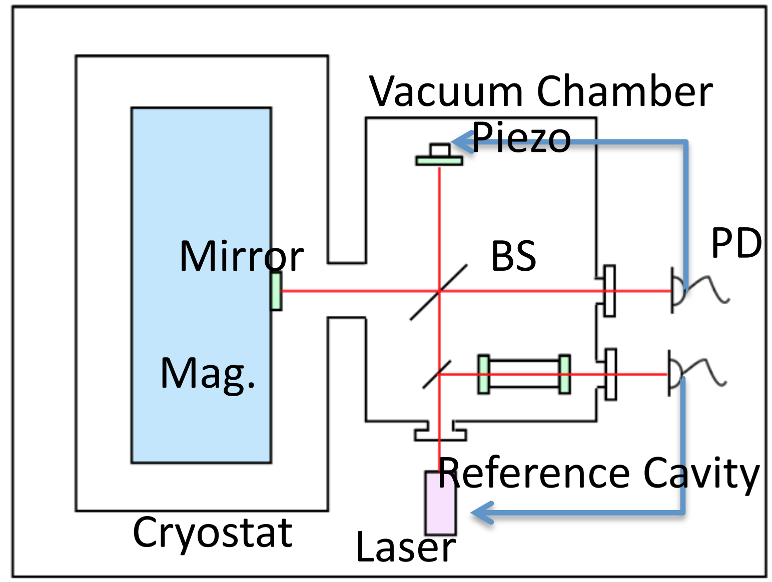
- DC – 50kHz
- nm order resolution
- Expensive $50k ?

Now investigating details by T. Kume.

BNL is using Laser Doppler sensor. It has also good sensitivity at low freq.
But expensive $750k.

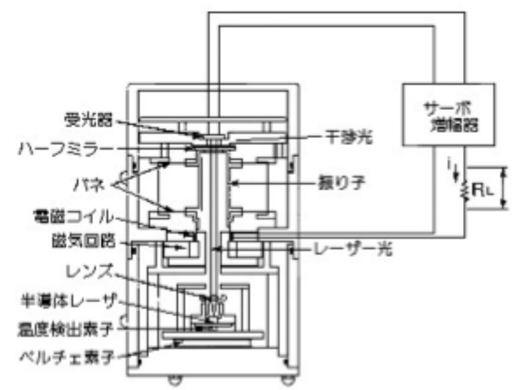
Hand-made Interferometer ?

- Frequency Stabilized Laser
  in this case, freq. stabilization
  by using reference cavity and
  feedback to laser
- AR coated windows
- Fringe lock by using Piezo electric



Accelerometer

Require NO reference position



5. Summary

To achieve ultra-stable system

- Eliminate vibration source from the system
- Avoid coupling of mechanical resonance of each parts of system
- Temperature stabilization of surroundings

Nm Level position measurement is possible by using commercial tools,
but we have to pay much attention for surrounding condition to use them.