Paper No. 2EPoE1-03 CEC/ICMC 2013 Anchorage, AK

Cryogenic System for the Interferometric Cryogenic Gravitational Wave Telescope, KAGRA -- Design, Fabrication, and Performance Test --

C.Tokoku[1], N. Kimura[2], S. Koike[2], T. Kume[2], T.Suzuki[2], Y. Sakakibara[1], K. Yamamoto[1], D. Chen[1], S. Goto[3], M. Tanaka[3], S. Ioka[4], K. Nakamoto[4], H. Nezuka[4], T. Uchiyama[1], M. Ohashi[1], and K. Kuroda[1]

1: ICRR, The University of Tokyo, 2: KEK, High Energy Accelerator Research Organization, 3: JECC Torisha Co., Ltd, 4: Toshiba Co.

ABSTRACT

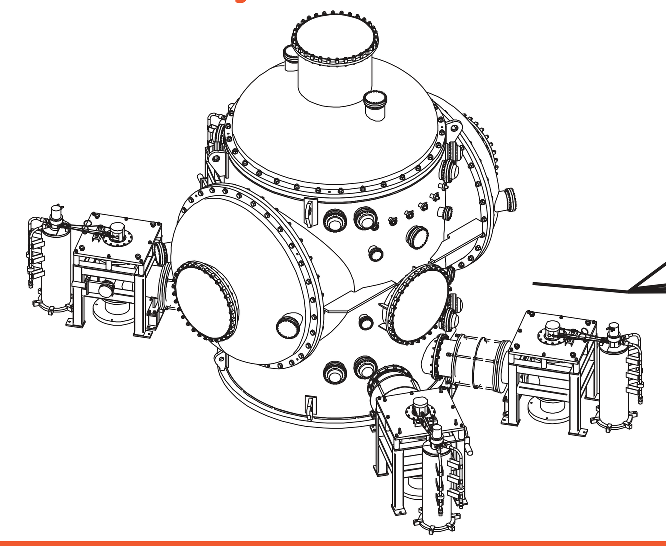
KAGRA is the cryogenic interferometric gravitational wave telescope designed for the direct detection of the gravitational waves from the astronomical sources. To achieve the best sensitivity, one of the most challenging task is to cool and keep the mirrors at the cryogenic temperature to reduce the thermal noise. We developed four cryostats and sixteen very-low-vibration cryocooler units to accomplish our purpose. In this poster, we describe the outline of the cryogenic design, fabrication, and the results of the cryogenic performance test of the cryostats and cryocooler units.

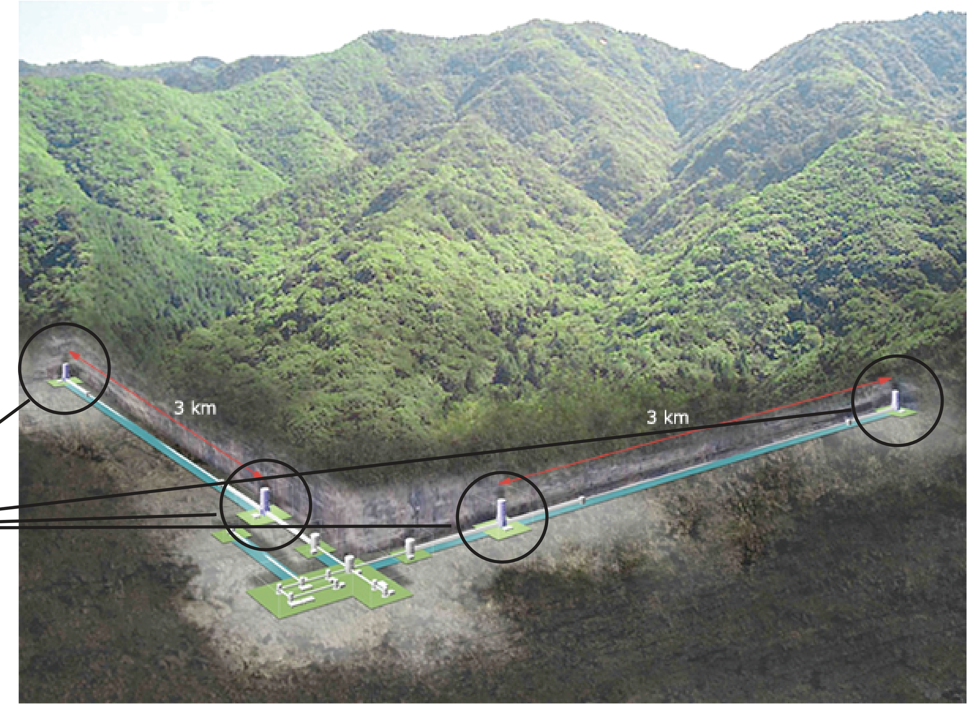
COOLING SYSTEM DESIGN

The main design objectives of the KAGRA cooling system are to cool and keep the mirrors at 20K to suppress the thermal noise, and at the same time, to reduce the mechanical vibrations resulting from the cryocoolers smaller than sub-um order. A mirror is made of sapphire and has a diameter of 220mm, thickness of 150mm, and weight of about 22.8kg. It will be installed in the payload in a cryostat. Since four cooled mirrors are used for the cryogenic dual-recycled Fabry-Perot Michelson interferometer, we prepare four cryostats. Meanwhile four cryocooler units is required to cool each cryostat, so that a total number of the cryocooler units is sixteen. We use only cryocoolers to cool the cryostats, without using any cooling medium (gas nor liquid).

CONCEPT

Cool Large Thermal Mass in Extremely Quiet Environment

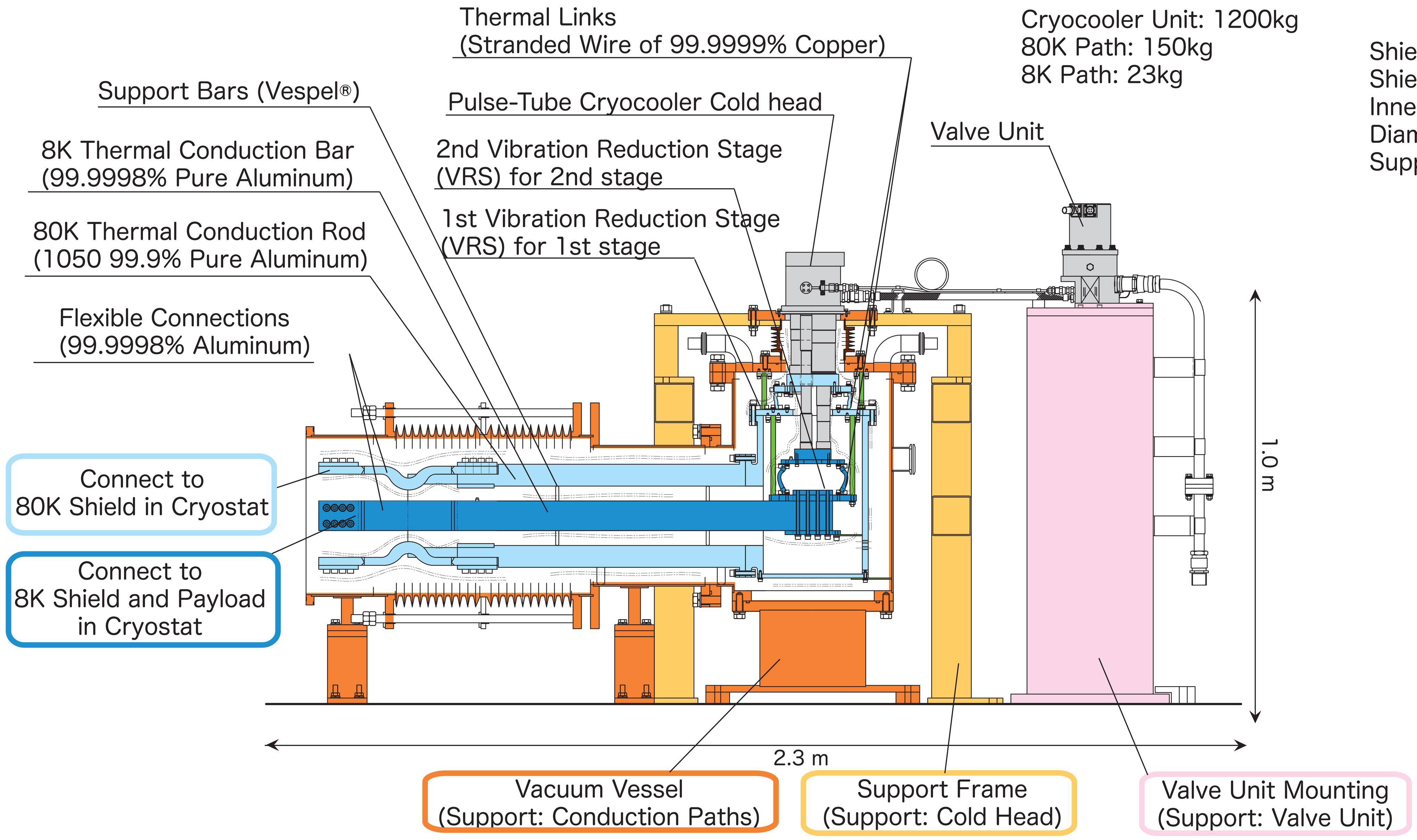




KAGRA is under construction at Kamioka Mine in Japan.

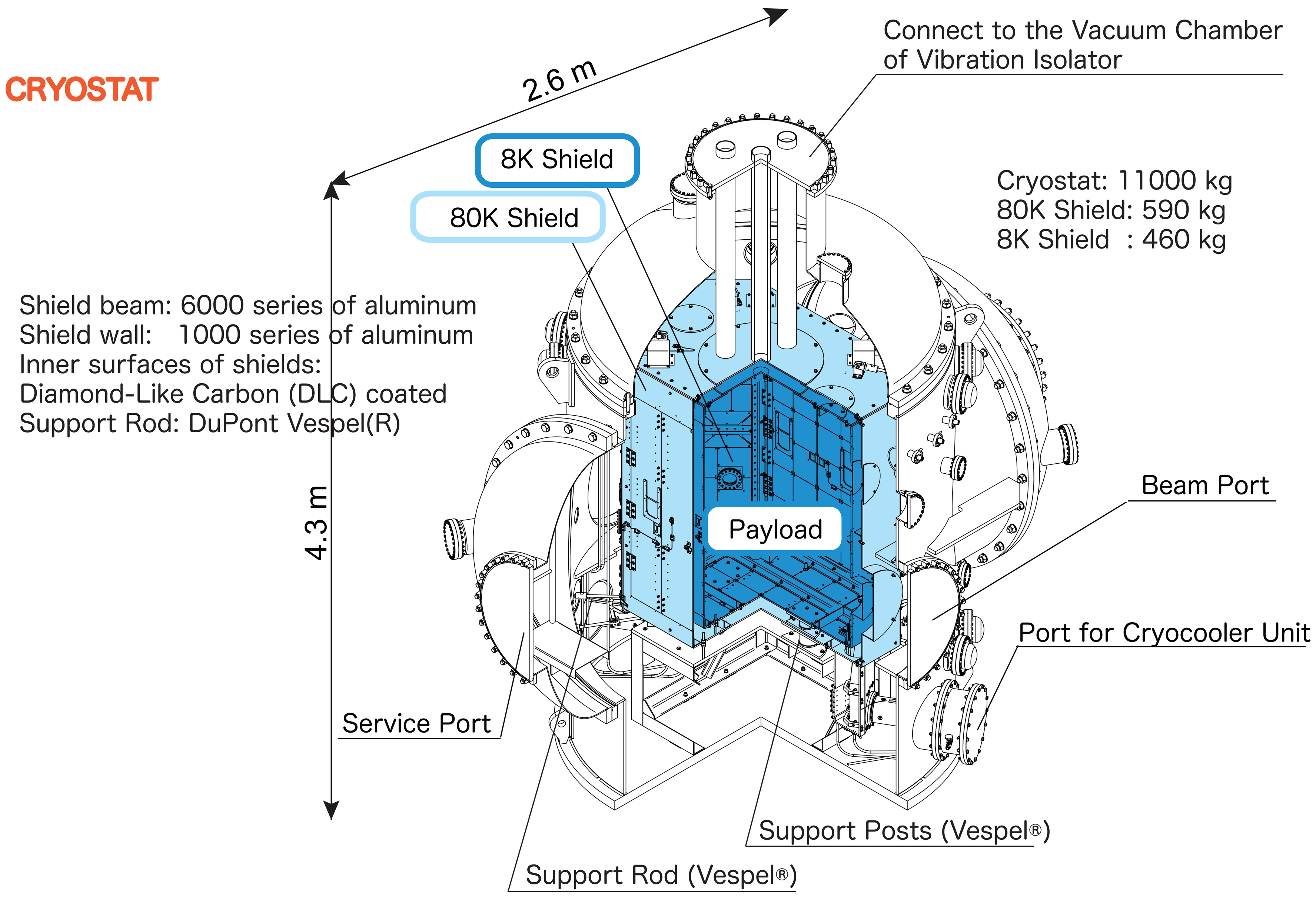
VERY-LOW-VIBRATION CRYOCOOLER UNITS

Pulse-Tube (PT) cryocooler is known for relatively low vibration in comparison to that of other type of cryocoolers such as Gifford-McMahon (GM) cryocooler, since PT cryocooler has no moving displacer. While it is reported that the typical displacement of cold head of PT cryocooler is about ±10μm at the 1st stage and ±15μm at the 2nd stages (Nakano et al., 2012), our requirement for the vibration performance is that the maximum amplitude is not larger than 0.1μm at the thermal connecting area between the cryocooler units and cryostats. Thus, the cryocooler units are required to maximize the heat transfer, and at the same time, to reduce the vibration from the cold head less than one-hundredth.



Structurally isolated three structures

CRYOSTAT



Pic2: Cryostat

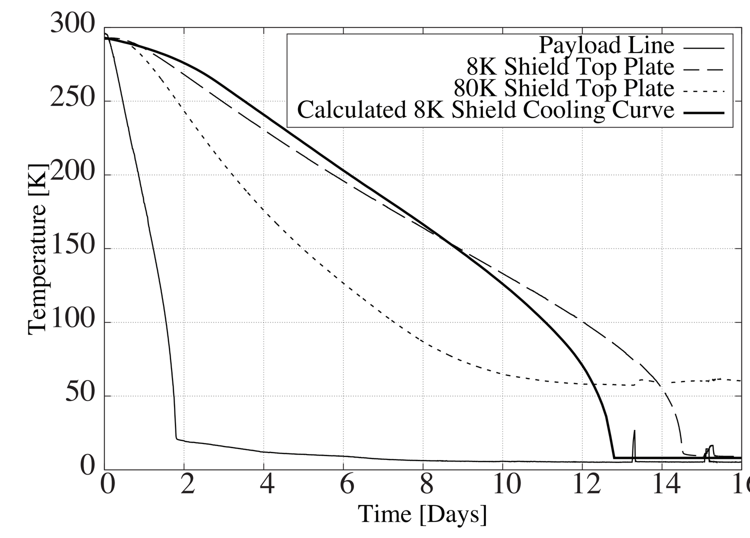


Fig6: Typical cooling time of the cryostat with estimated cooling curve.

PERFORMANCE TEST ON CRYOCOOLER UNITS

Thermal Performance Test

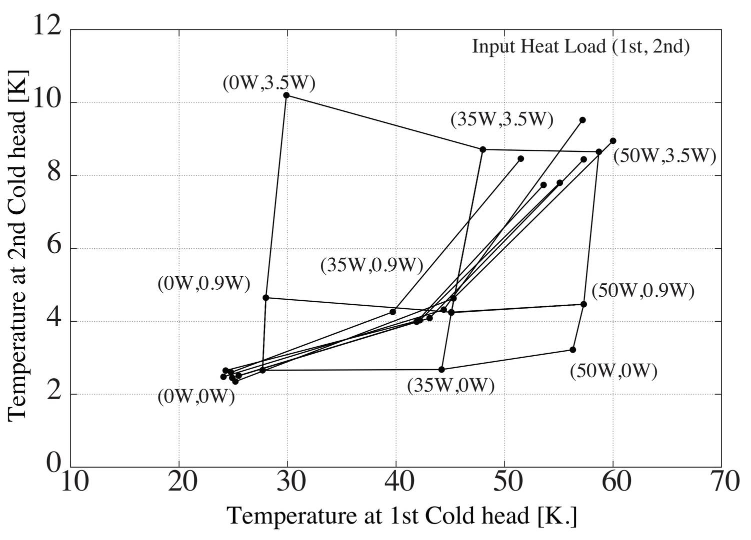


Fig1: Measured load map of the PT cryocoolers.

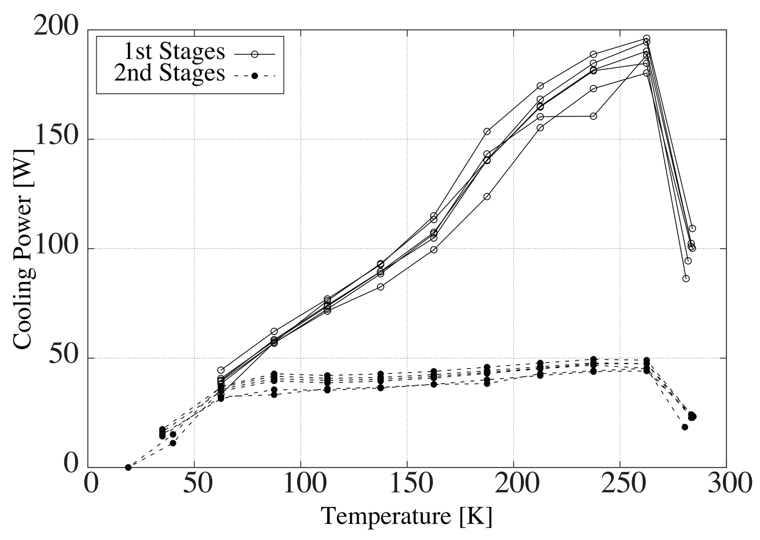


Fig2: Measured cooling power of Cryocooler Units.

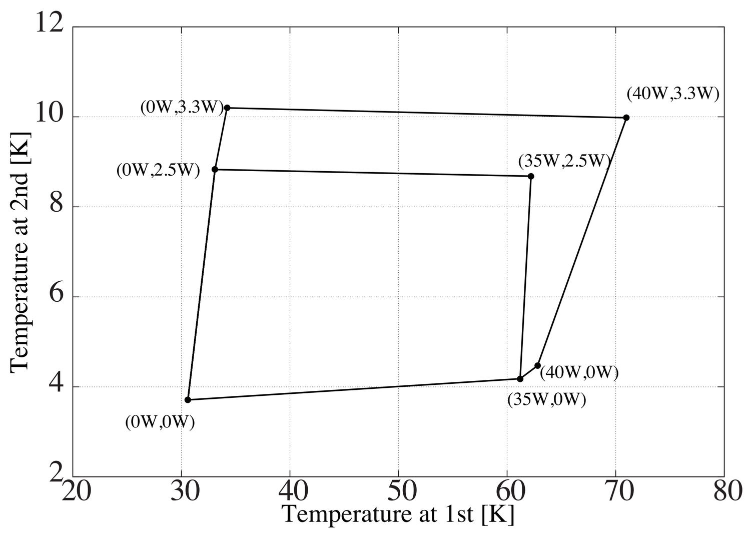
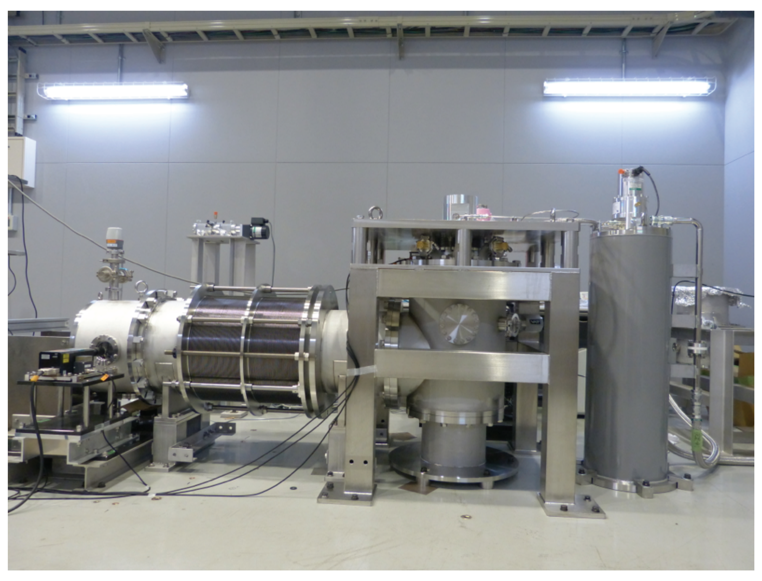


Fig3: Measured typical load map of the Cryocooler Unit.



Pic1: Cryocooler Unit

Vibration Test and Hammering Test

To suppress the vibration at 1.7 Hz below 0.1 μm/Hz$^{1/2}$, we made some improvements on the support structure design.

Investigated the frequency response function to enhance the stiffness of structure.

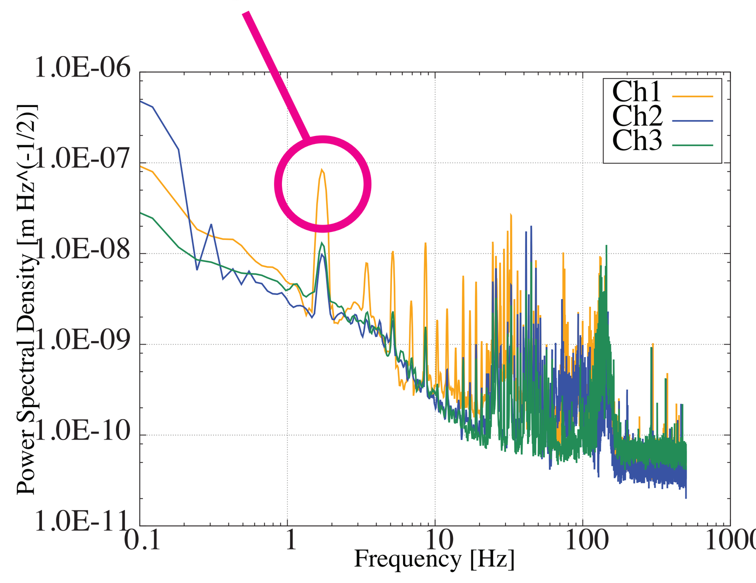


Fig4: Measured Power Spectral Density at the connecting area.

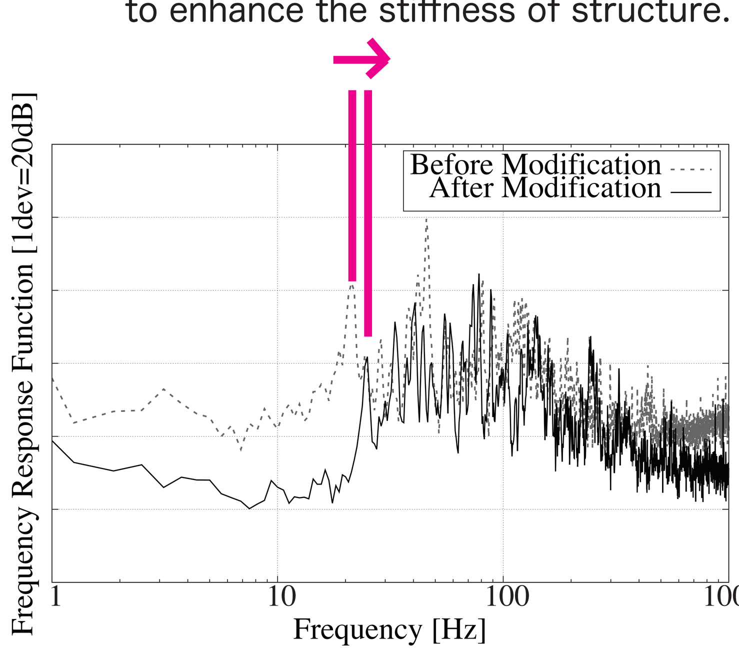


Fig5: Measured Frequency Response Function.

PERFORMANCE TEST ON CRYOSTAT

Confirmed the cooling performance of all the four cryostats. See also 2EOrD4-03 (Sakakibara) about study of cooling time reduction of the payload. The vibration performance tests are also conducted and will be appear on another paper.

Estimated and Measured Thermal Budget

		Estimated Heat Load [W]	Measured Heat Load [W]
1st Cold Stage	**80K Shield**	94 (116)	125
	Load per Cryocooler	23 (29) W/Unit	31 W/Unit
	(breakdown)		
	- Eleven (11) View Ports	(22)	-
	- Radiation from 300K	70	-
	- Support Post/Rods	24	-
	- Electrical Wires	0.0003	-
2nd Cold Stage	**8K Shield**	5 (10)	< 2.0
	Load per Cryocooler	2.5 W/Unit	< 1.0 W/Unit
	(breakdown)		
	- Duct Shields	(> 0.05)	-
	- Eleven (11) View Ports	(0.4)	-
	- Radiation from 80K	2.2	-
	- Support Posts/Rods	2.4	-
	- Electrical Wires	0.0003	-
	- Scattering Light	(Several Watts)	-
	Payload	1	
	Load per Cryocooler	0.34 W/Unit	0.4 W/Unit
	- Mirror Deposition	(1)	-

( ) are excluded from these tests.

CONCLUSION

1. Main concept of KAGRA cooling system is to the cool large thermal mass down to cryogenic temperature in extremely quiet environment.
2. KAGRA cooling system, including four (4) cryostats and sixteen (16) very-low-vibration cryocooler units, were designed, fabricated, and tested their performances during 2011 and 2012.
3. Confirmed the cooling and vibration performance of sixteen (16) cryocooler units. The dominant vibration from cryocooler suppressed to lower than 0.1μm at the cnnection area of the cryocooler units.
4. Confirmed the cooling performance of all the four (4) cryostats.

ACKNOWLEDGEMENTS

This work is supported by the Leading-edge Research Infrastructure Program (JSPS). We would like to thank Professor Takaaki Kajita, the director of Institute for Cosmic Ray Research, and Professor Atsuto Suzuki, the director general of High Energy Accelerator Research Organization (KEK), for their understanding and a lot of great support for our development environment. We would also like to appreciate Mr. Y. Kobayashi from the KEK Mechanical Engineering Center for making components for the performance tests.

REFERENCES

-S. Miyoki et al., Class. Quantum. Grav. 23, S231-S237 (2006)
-Y. Saito and R. Takahashi, J.Vac. Soc. Jpn 54, 35-40 (2011)
-T. Omori et al. J. Cryo. Super. Soc. Jpn., 46, 408 (2011)
-K. Nakano et al., Advances in Cryogenic Engineering, 1434, 532-539 (2012)
-T. Kume et al., ICEC24/ICMC2012, 399-402 (2012)
-Y. Sakakibara et al., CEC/ICMC2013, 2EOrD4-03 (2013)