The stand-alone cryomodule of 3rd harmonic cavity for synchrotron light source

Junho Han[1], Younguk Sohn[2], Eiji Kako[3], Heesu Park[1], Eun-San Kim[4] and Sangkwon Jeong[5]

[1] KAT Co., Ltd. / Kiswire Advanced Technology Co., Ltd., Daejeon, Republic of Korea
[2] KBSI / Korea Photon Source, Korea Basic Science Institute, Cheongju, Republic of Korea
[3] KEK / High Energy Accelerator Research Organization, Tsukuba, Japan
[4] KU / Department of Accelerator Science, Korea University, Sejong, Republic of Korea
[5] KAIST / Department of Mechanical Engineering, Korea Advanced Institute of Science and

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Presented by Junho Han

Vice President / Ph.D

Kiswire Advanced Technology Co., Ltd.

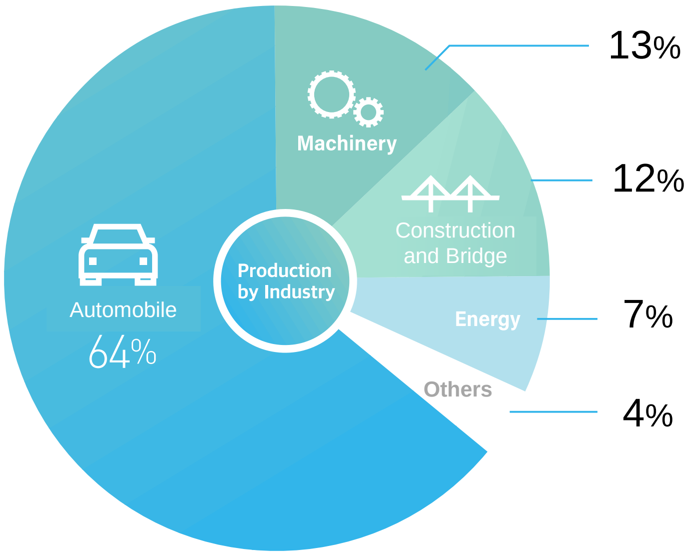
Contents

- Introduction of KAT
- 1.5 GHz 3rd Harmonic Cavity
- Design of Stand-Alone Cryomodule
- Summary and Future Works

Global Specialty Wire Company

Founded in 1945, Kiswire manufactures specialty steel wire products for a diverse range of industries including automotive, bridge, energy, construction and electronics. Kiswire exports to customer in over 80 countries.

Establishment	1945	Headquarters	Busan,Korea
Export countries	80	Annual total production capacity	1,200,000t
Worldwide employees	6,000	Annual sales	2.1 B USD (FY 2023)



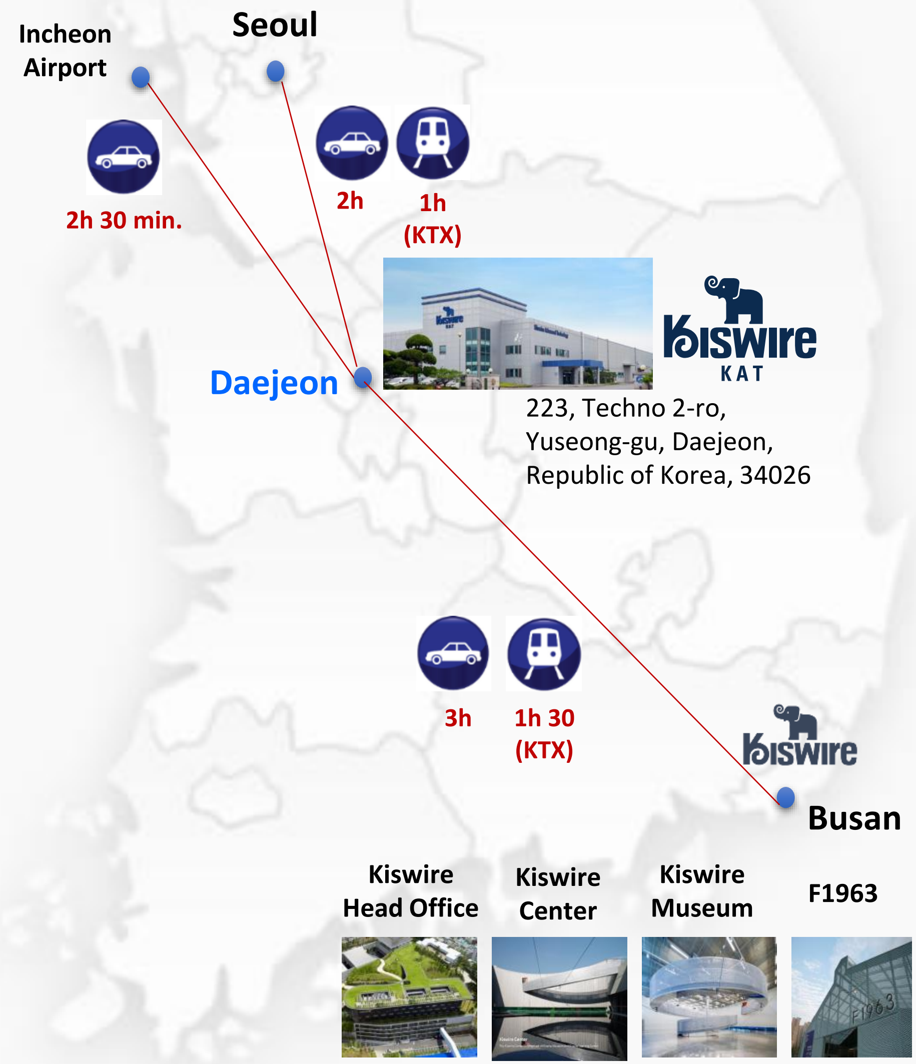
KAT (Kiswire Advanced Technology Co., Ltd.)

KAT is a wholly owned subsidiary of Kiswire.
Established in 2004, KAT is a global leading superconducting wire company located in **Daejeon**, South Korea.

KAT develops and offers **high-performance superconducting wires** (Nb_3Sn, NbTi, and MgB_2) and supplied its wire various fusion reactors including K-STAR, ITER, and most recently DTT. KAT has been also developing a High Jc Nb_3Sn superconducting wire for the FCC project in collaboration with CERN.

From 2018, KAT has supplied the HWR **cryomodule** prototype of IBS-RAON/Korea and QWR cryomodule cryostat of RIKEN-SRILAC/Japan.
y2021-y2023, 1.5 GHz 3rd harmonic **superconducting cavity** for synchrotron light source has been fabricated and tested successfully by using the vertical test facility in SARI/China. In y2024-y2025, two **1.3 GHz single-cell R&D cavities** have been fabricated with collaboration with KEK and KU. Those two cavities showed good results in vertical test by KEK.

- Hwang(Korea University)'s presentation in WG1 (12:00, 09-Apr, Wed) shows the detail about the VT results of two 1.3 GHz single-cell cavities.



About KAT

KAT has been developing the superconducting technologies over 20 years.

Superconducting Devices

2010
Start R&D of SC MRI magnet

2015
Supply **1.5T MRI magnet** to TCL and SEC (Samsumg Elec.)

2018
Supply HWR B **Cryomodule** prototype For RAON

VT in SARI

Qo=3.47e08 @ 4.0 MV/m, 4.2 K
(Spec. : Qo=2.99e08 @ 4.0 MV/m, 4.2 K)

2021-2023
R&D for **1.5 GHz superconducting cavity and tuner** (Collaboration with KU)

VT in KEK

Qo=1.49e10 @ 37 MV/m, 2 K
(Spec. : Qo=0.8e10 @ 35 MV/m, 2 K)

2024-2025
R&D for **1.3 GHz single-cell cavity** (Collaboration with KEK and KU)

2024-2027
SSR2 cryomodule prototype for RAON (Collaboration with IHEP)

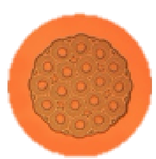
Superconducting Wires

1998
Start R&D of Nb_3Sn superconducting wire (Kiswire R&D Center)

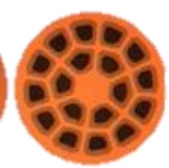
2004
Foundation of KAT

2006
Supply Nb_3Sn of 2 tons for KSTAR (PF Coil)

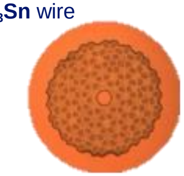
2009
Supply Nb_3Sn of 137 tons for ITER (TF, CS Coils, 2009-2016)



2014 - 2021
Start R&D project of **NbTi** and MgB_2 wires funded by Korean Government

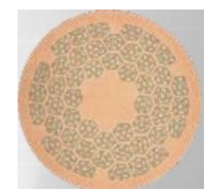


2017 - Now
R&D with CERN for **High Jc** Nb_3Sn wire



2019-2022
Supply Nb_3Sn of 55 tons for DTT TF coil

2023-
Working on **SUCCEX** project in KOREA



Contents

❖ Introduction of KAT

❖ 1.5 GHz 3rd Harmonic Cavity and Tuner

❖ Design of Stand-Alone Cryomodule

❖ Summary and Future Works

Design of Stand-Alone Cryomodule

Introduction of Stand-Alone 3rd Harmonic Cryomodule

- 1.5 GHz 3rd harmonic cavity (double-cell cavity)

Design Parameters	Value
f_{res} (Resonance frequency)	1499.631 MHz @ 4.5 K
Operation type	Passive
V_{acc} (RF voltage)	1.04 MV
$(R/Q)_{per\ cell}$, double-cell cavity	94.5 Ω
Q_o @ E_{acc} in operation	2.99×10^8 @ 5.2 MV/m

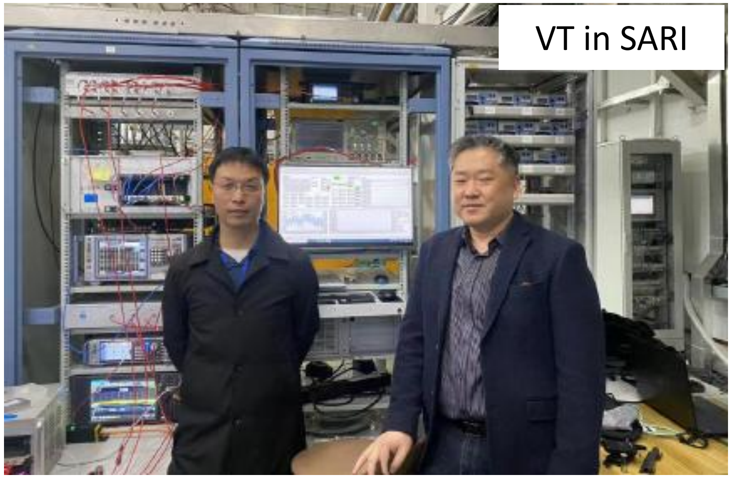
J. Y. Yoon (IRIS), E. S. Kim (KU), J. H. Han (KAT), H. S. Park (KAT) and E. Kako (KEK), "Design study of the 3rd harmonic superconducting cavity for a bunch lengthening," *in Proc. 13th Int. Particle Accelerator Conf. (IPAC 2022),* pp. 1258-1260, 2022.

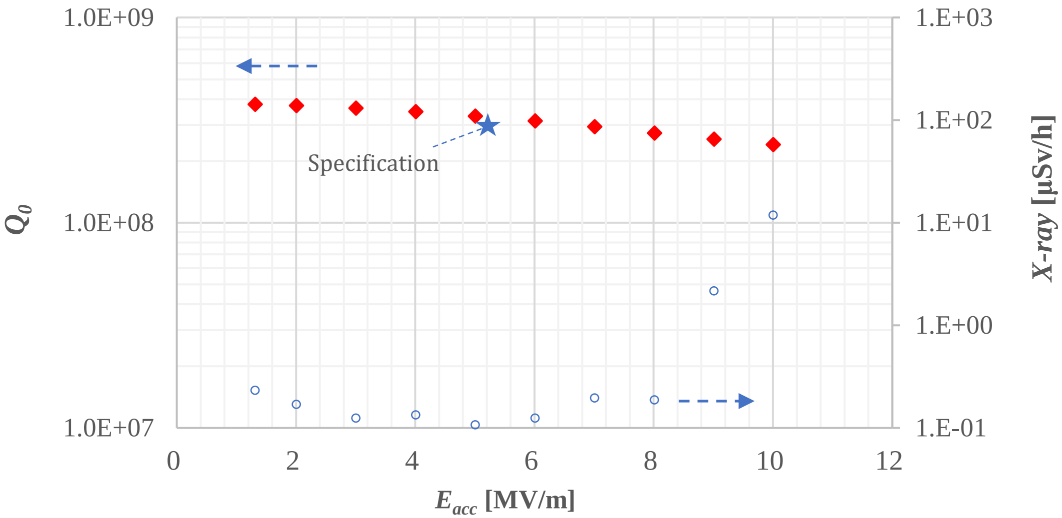
Design of Stand-Alone Cryomodule

Introduction of Stand-Alone 3rd Harmonic Cryomodule

- 1.5 GHz 3rd harmonic cavity (double-cell cavity)
  The fabricated cavity has been tested in SARI. (Dec. 2023)

Parameters	Target	VT Results
E_{acc}	≥ 5.2 MV/m	No Quench until 10 MV/m
Q_o	≥ 2.99 x 10^8 at 5.2 MV/m	3.3 x 10^8 at 5.2 MV/m

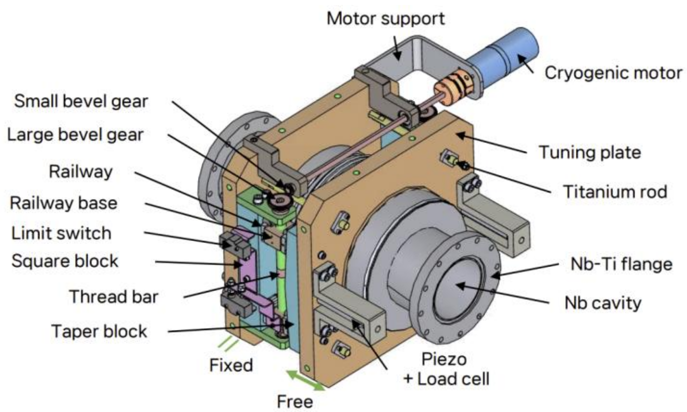


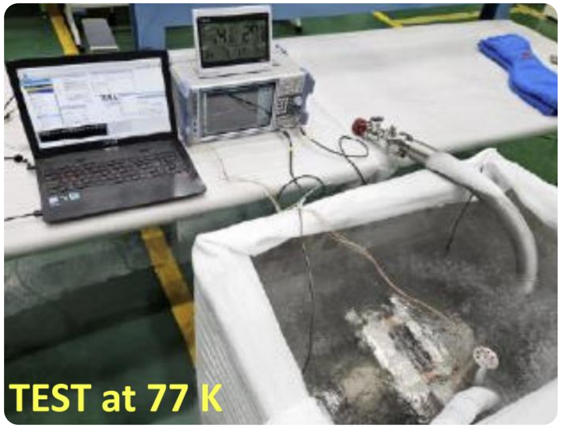


Design of Stand-Alone Cryomodule

Introduction of Stand-Alone 3rd Harmonic Cryomodule

- Frequency tuner (for 1.5 GHz 3rd harmonic cavity)





Parameters	Unit	Required @ 77K	Measured @ 77 K
Tuning range	kHz	≥ 500	532
Tuning sensitivity	Hz/step	≤ 3.0	1.0

This R&D has been supported by the funding of Korean local government, Chungchengbik-do and collaborated by Korea University.

Contents

❖ Introduction of KAT

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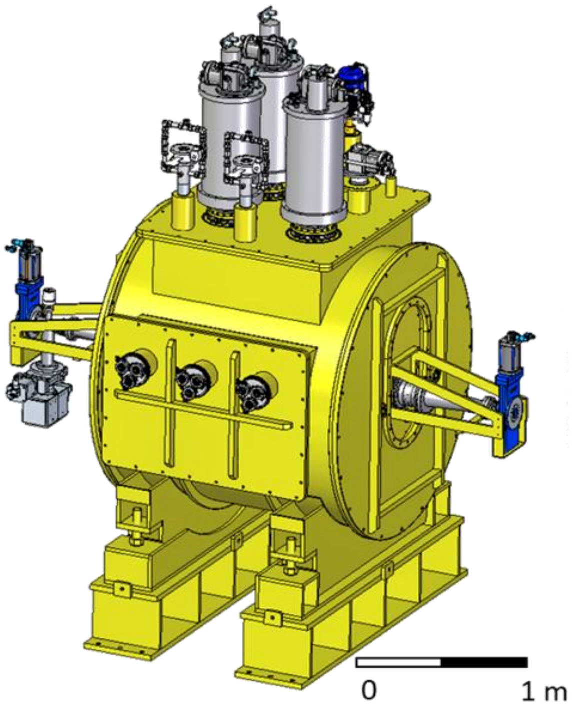
❖ Summary and Future Works

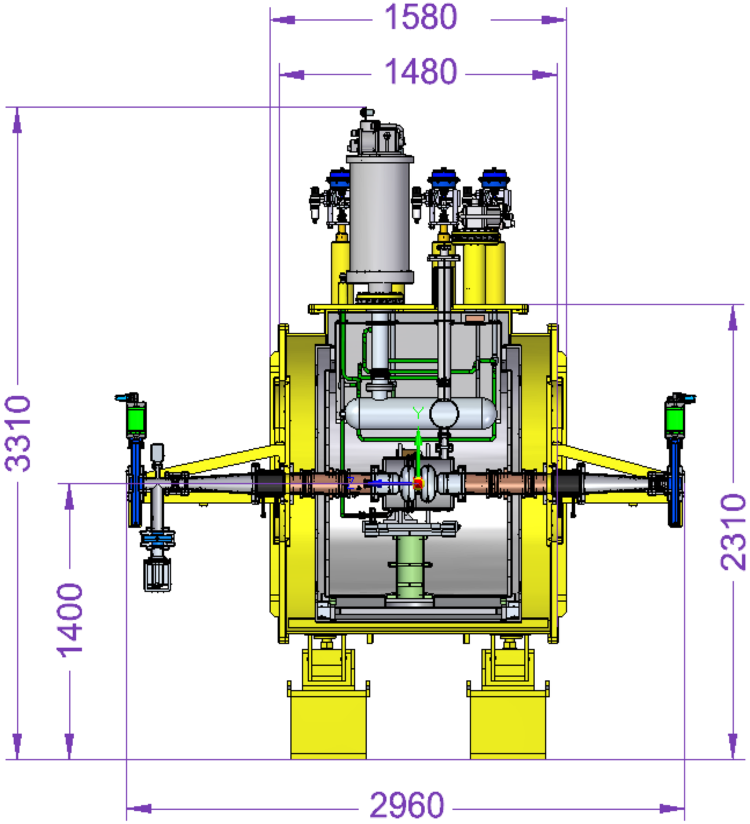
Design of Stand-Alone Cryomodule

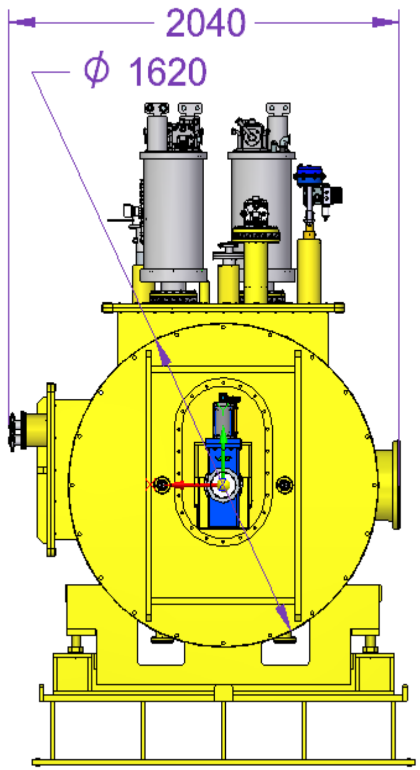
Liquid Helium ZBO Cooling System

- The Stand-Alone 3rd Harmonic Cryomodule
  Liquid Helium ZBO (Zero-Boil-Off) Cooling System is applied on the cryomodule design.

  Dimensions
  - Overall : 2,960 (L) x 2,040 (W) x 3,310 (H) [mm]
  - Vacuum Chamber : Φ 1,620 x 1,580 (L) [mm]



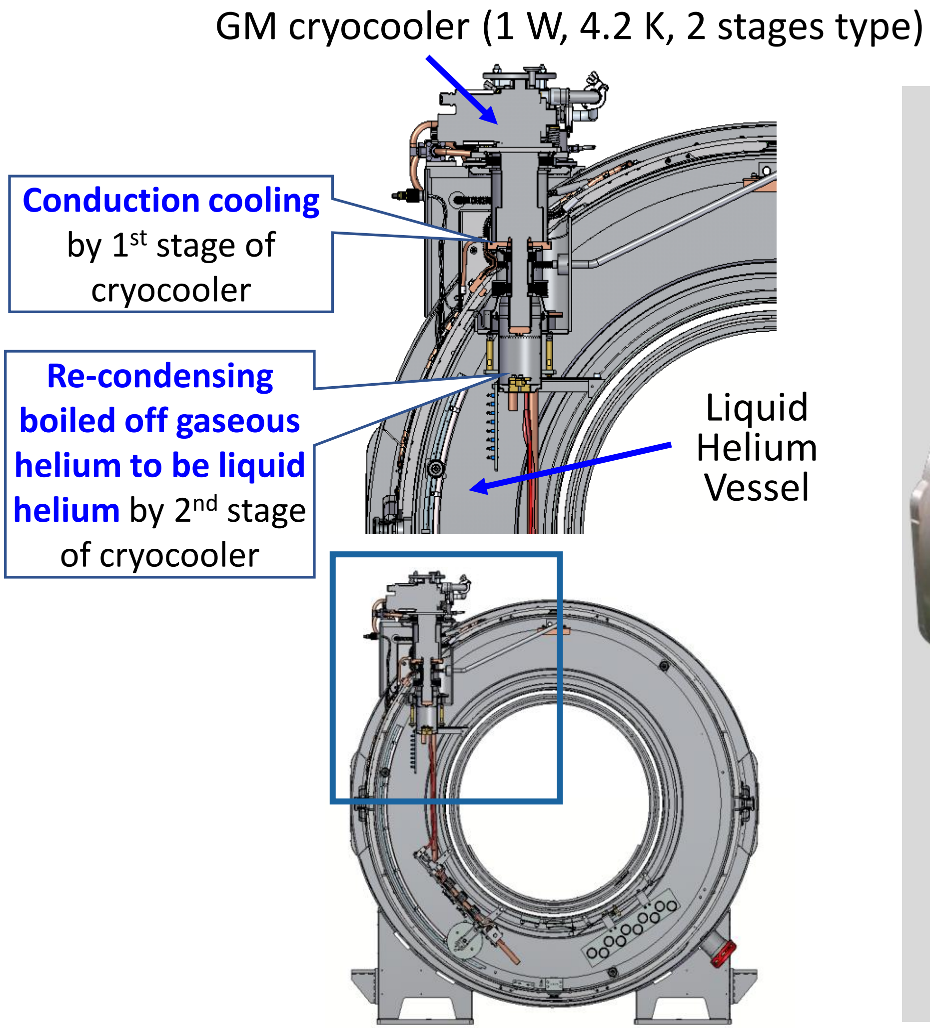




Design of Stand-Alone Cryomodule

Liquid Helium ZBO Cooling System

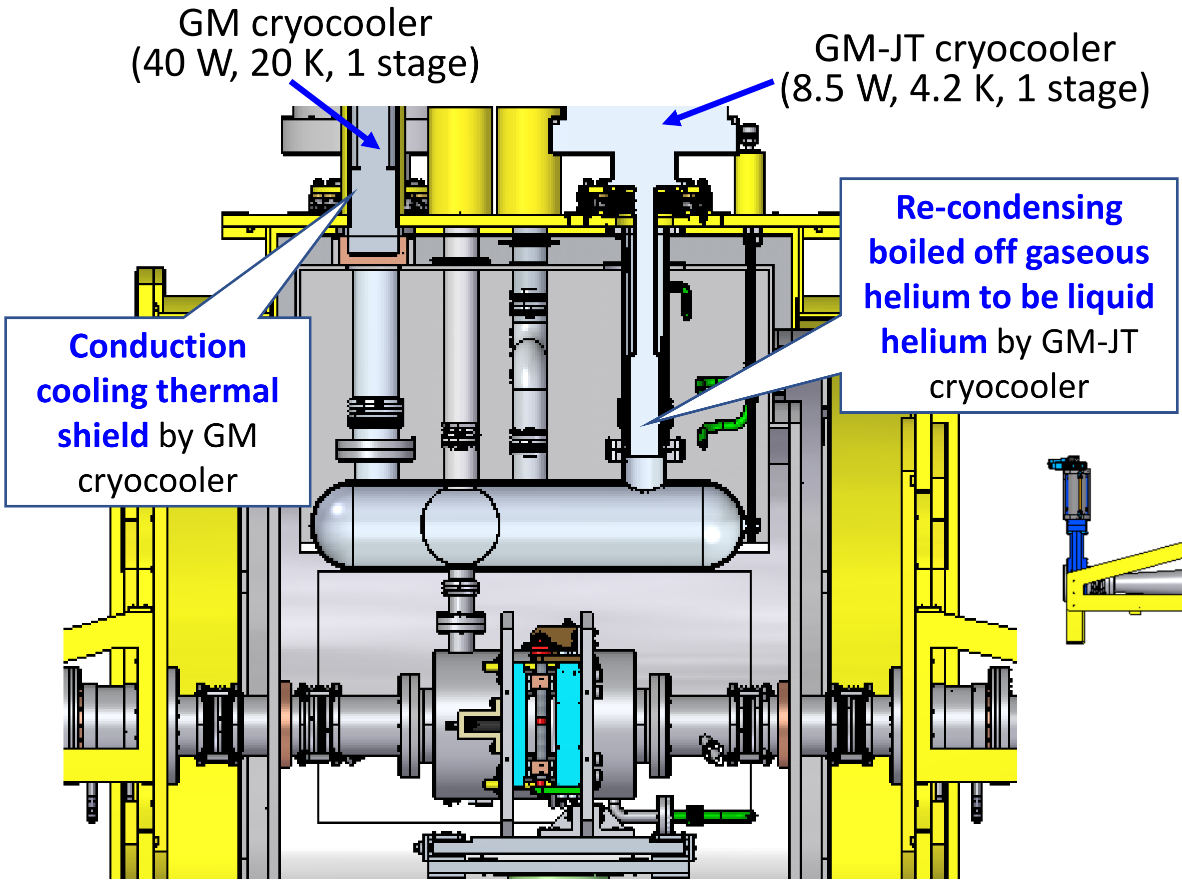
- Liquid Helium ZBO (Zero-Boil-Off) cooling system in superconducting MRI magnet

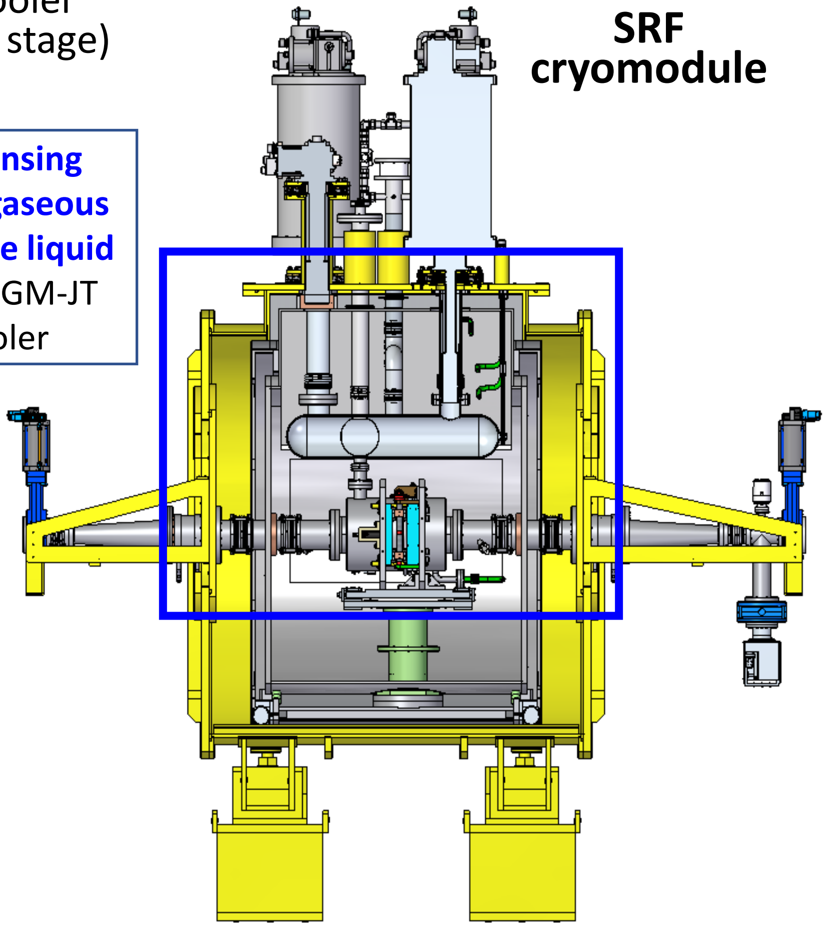


Design of Stand-Alone Cryomodule

Liquid Helium ZBO Cooling System

- The idea of Liquid Helium ZBO (Zero-Boil-Off) cooling system in SRF cryomodule

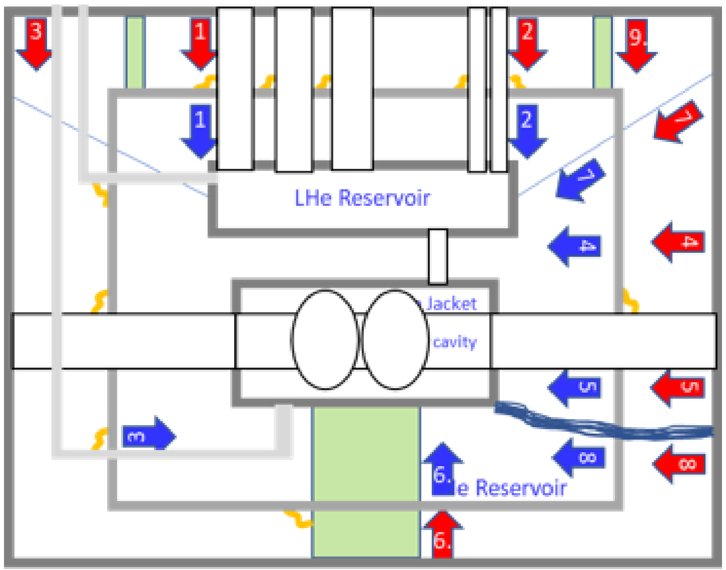




- This design has been reported in ICEC/ICMC 2024.
  "Investigation of the stand-alone cryomodule for the 3rd harmonic cavity of the synchrotron light source"
- It can be a kind of solution to some Institute which has no helium liquefaction facility.

Design of Stand-Alone Cryomodule

Heat Load Calculation / Applied Cryocoolers



Blue : 4.5 K heat load
Read : 50 K heat load

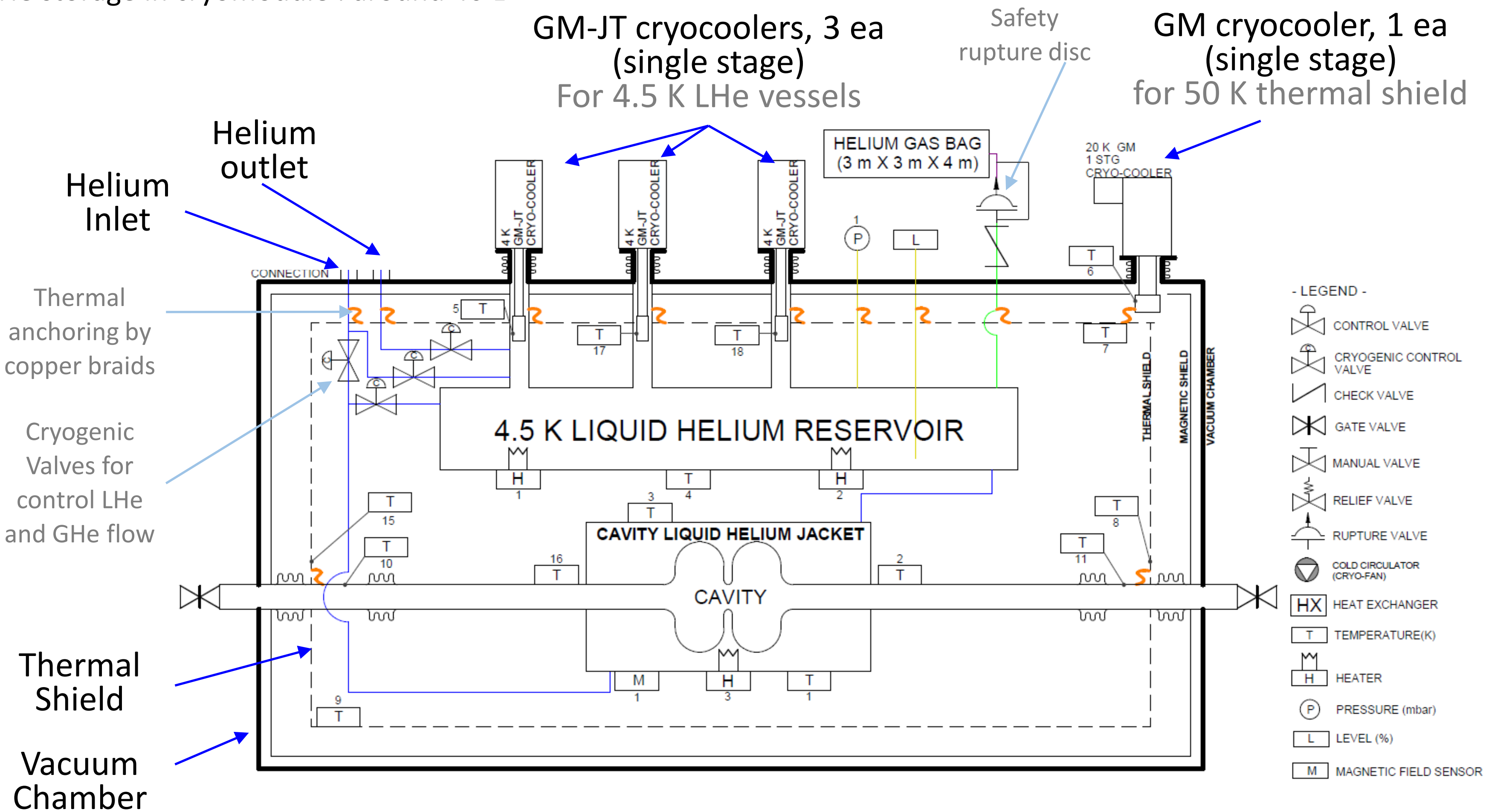
	Components	Heat load @ 50 K [W]	Heat load @ 4.5 K [W]
1	Cryocooler interface tubes (3 places)	18.4	0.4
2	GHe outlet, LHe level and pressure meter pipes (3 places)	10.2	0.2
3	GHe inlet/outlet for GHe circulation pipes (2 places)	1.2	< 0.1
4	Thermal radiation	18.8	0.3
5	Beam pipes (Cu coated SS 314 pipes, 2 places)	17.9	2.7
6	Cavity support (GFRP, thin tube)	6.0	0.2
7	Support of LHe reservoir	3.9	0.2
8	Wirings (constantan, Cu, co-axial)	6.5	1.0
9	Thermal shield support	23.6	-
	Total (Static Heat Load)	**94.7**	**4.4**

- The dynamic heat load induced by 3rd harmonic cavity : 17.3 W at Eacc=5.2 MV/m
- Total Heat load : 17.3 + 4.4 = 21.7 W at 4.5 K
- Three GM-JT Cryocoolers, 25.5 W (8.5 W at 4.2 K per unit, SRJT-100ST) and one GM Cryocooler, > 120 W at 50 K (40 W at 20 K per unit, RDK-500B2)

Design of Stand-Alone Cryomodule

Piping and Instruments Diagram of the Stand-Alone Cryomodule

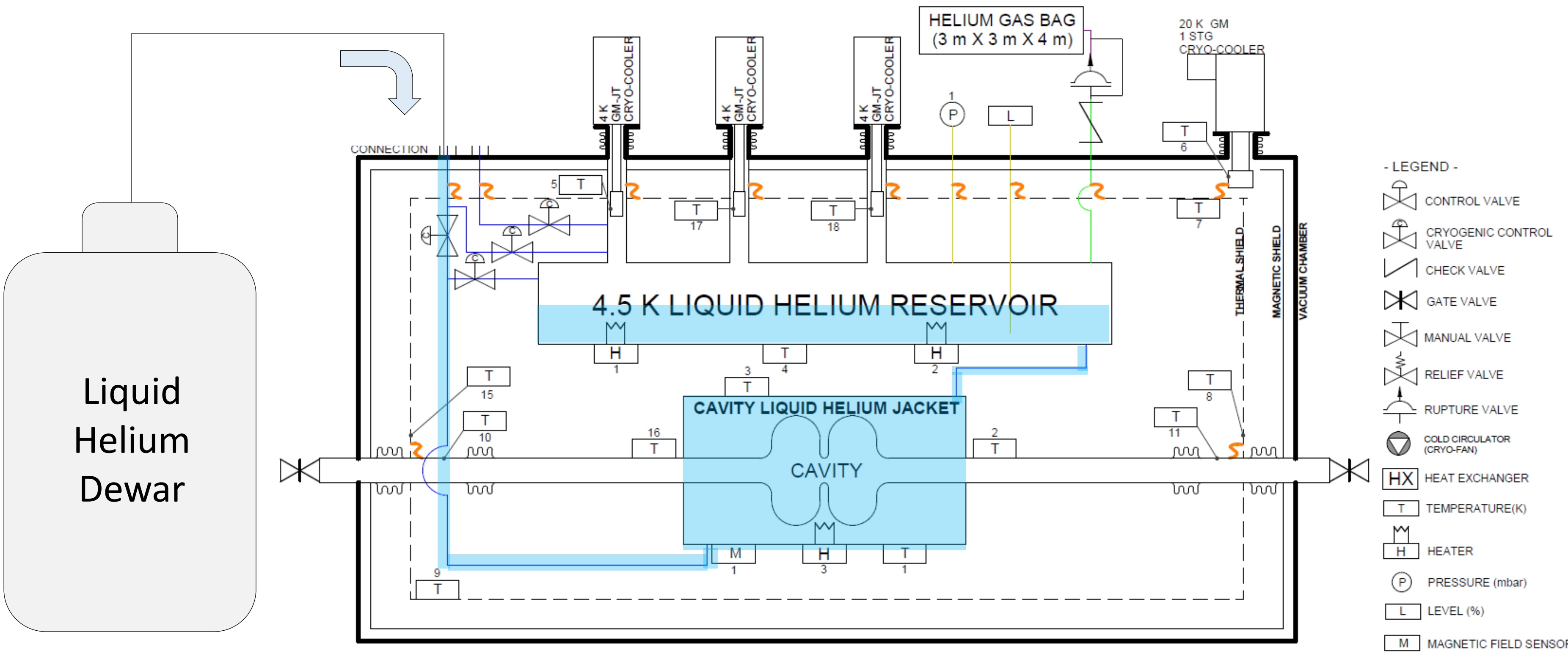
- Three GM-JT cryocoolers and One GM cryocooler are applied
  - Estimated electric power consumption : 65 kW / normal operation, 32 kW / saving operation
  - LHe storage in cryomodule : around 40 L



Design of Stand-Alone Cryomodule

Piping and Instruments Diagram of Cryomodule

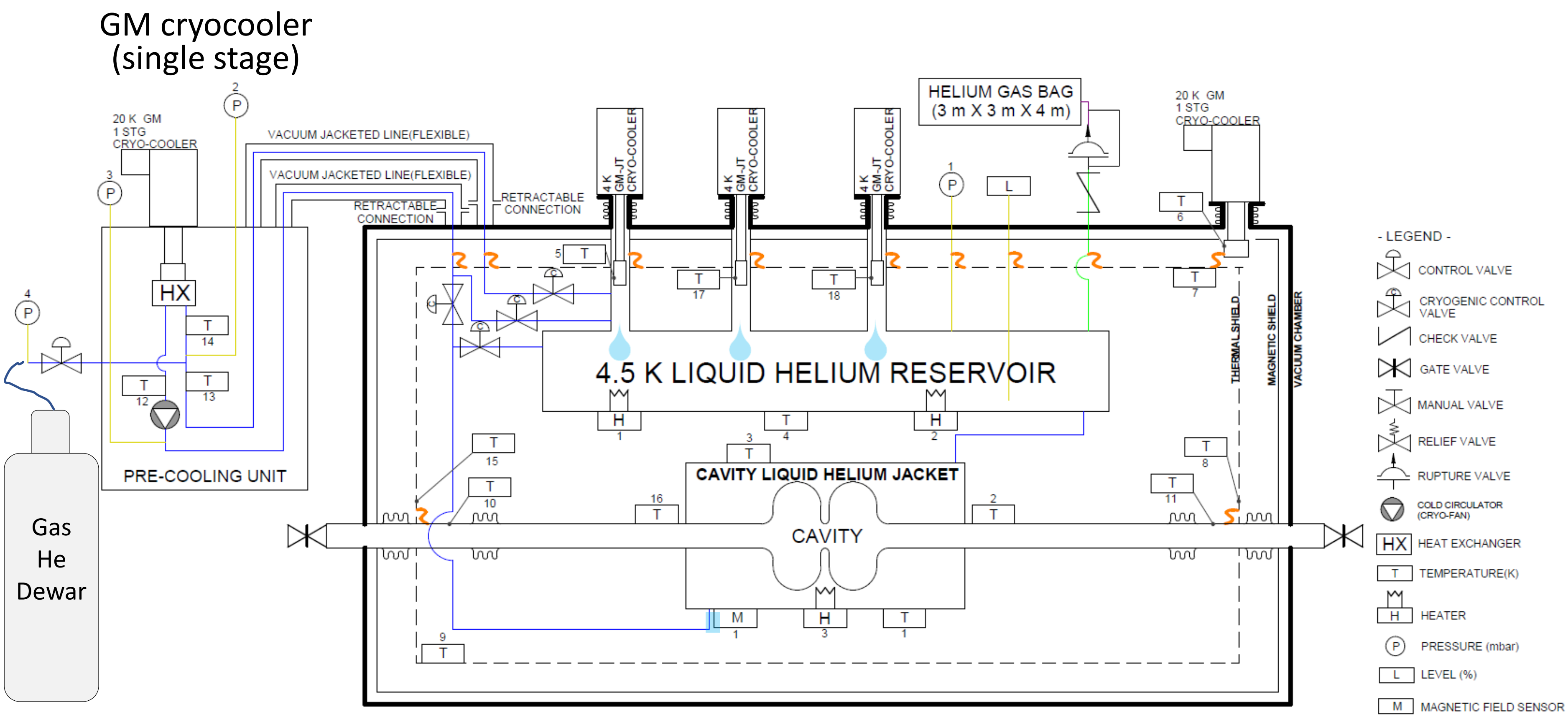
- Fast Cool-down by liquid helium (Option 1)
  - After pre-cooling by LN2, 80 K - 4.2 K cooling by LHe



Design of Stand-Alone Cryomodule

Piping and Instruments Diagram of Cryomodule

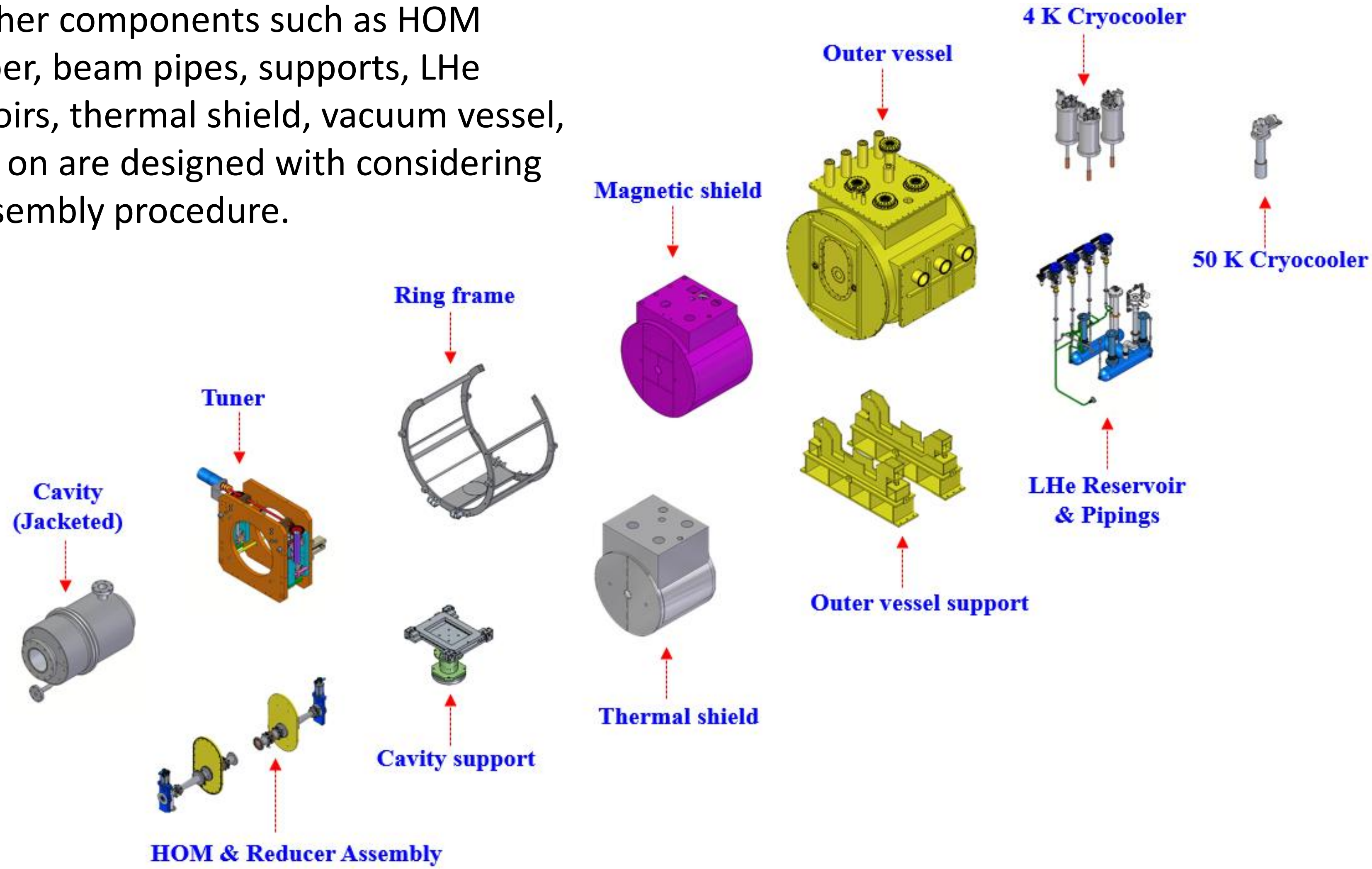
- Cool-down by gaseous helium circulation (Option 2) with extra PRE-COOLING unit



Design of Stand-Alone Cryomodule

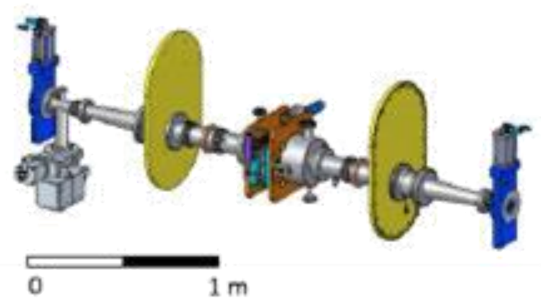
Components and Assembly

- Cavity and tuner are designed and manufactured.
- The other components such as HOM absorber, beam pipes, supports, LHe reservoirs, thermal shield, vacuum vessel, and so on are designed with considering the assembly procedure.

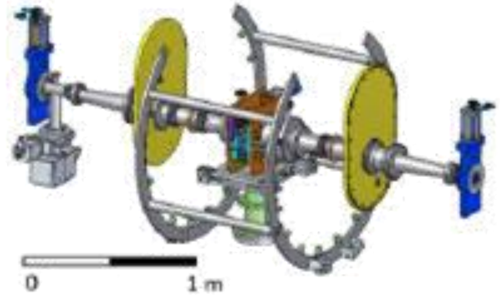


Design of Stand-Alone Cryomodule

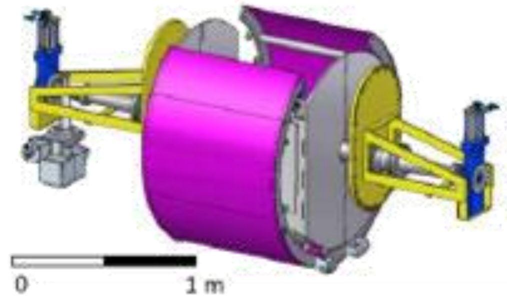
Components and Assembly



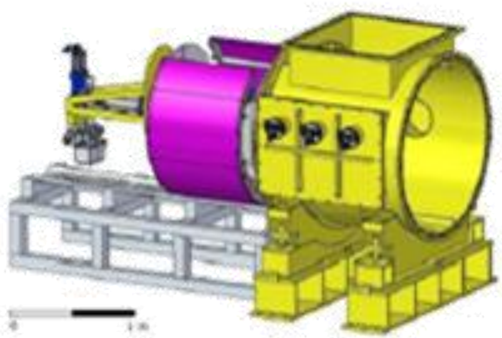
(a)
CAVITY ASSEMBLY including beam lines and HOM absorbers



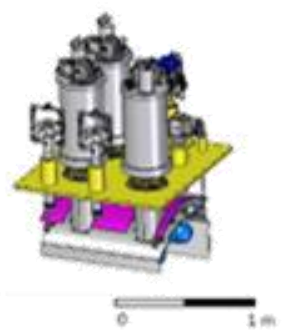
(b)
Assembling (a) with RING FRAME and cavity support.



(c)
Thermal shield and magnetic shield assembly on (b)



(d)
(c) and vacuum vessel assembly by using sliding jig



(e)
Preparing top flange assembly including cryocoolers and LHe reservoir

(f)
Assembling (d) and (e)

Contents

❖ Introduction of KAT

❖ 1.5 GHz 3rd Harmonic Cavity

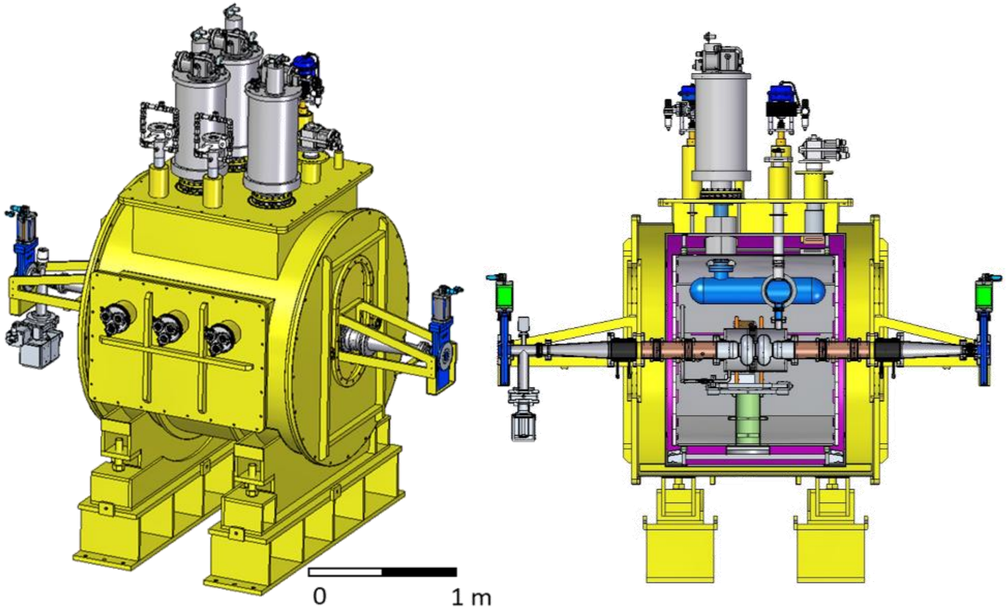
❖ Design of Stand-Alone Cryomodule

❖ Summary and Future Works

Summary and Future Works

- The proposed design of 1.5 GHz 3rd harmonic stand-alone cryomodule is adopted the helium ZBO cooling system which has been commercially utilized in MRI manget.
- It can provide two cooling options. (Liquid He cooling / Gas He circulation cooling)
- The design of components with considering the assembly procedure is completed.

- The proposed design shows the new concept of cooling system for stand-alone SRF cryomodule, we expect that it can be a good solution to Institutes which has no helium liquefaction plant.



Superconducting the Future
Thank you very much

Special thanks to

Prof. Kako (KEK) for detail review of the development of cavity, tuner and cryomodule

Dr. Yoon (IBS currently, 2021 in KU) and **Prof. Kim** (KU) for design cavity and tuner

Prof. Hou (SARI) for VT of the cavity

Prof. Jeong (KAIST, Cryogenic Eng. Lab.) for advices about cooling system

Dr. Sohn (KBSI) for review of conceptual design

Back up slides

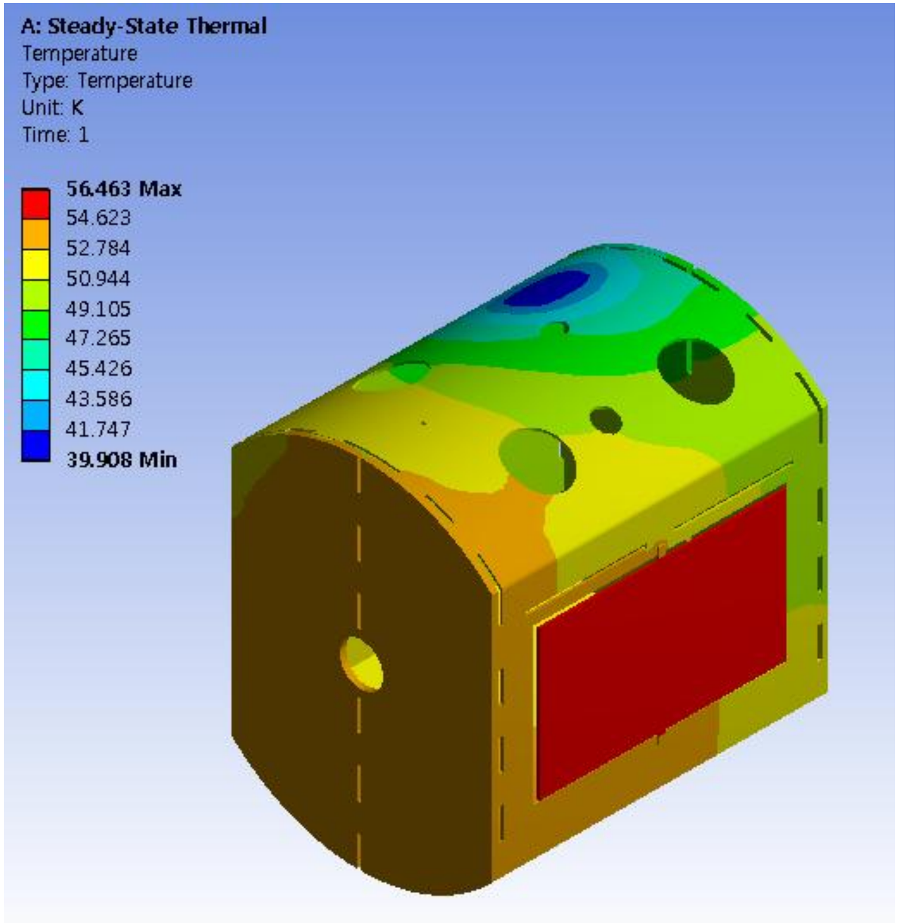
Design of Stand-Alone Cryomodule

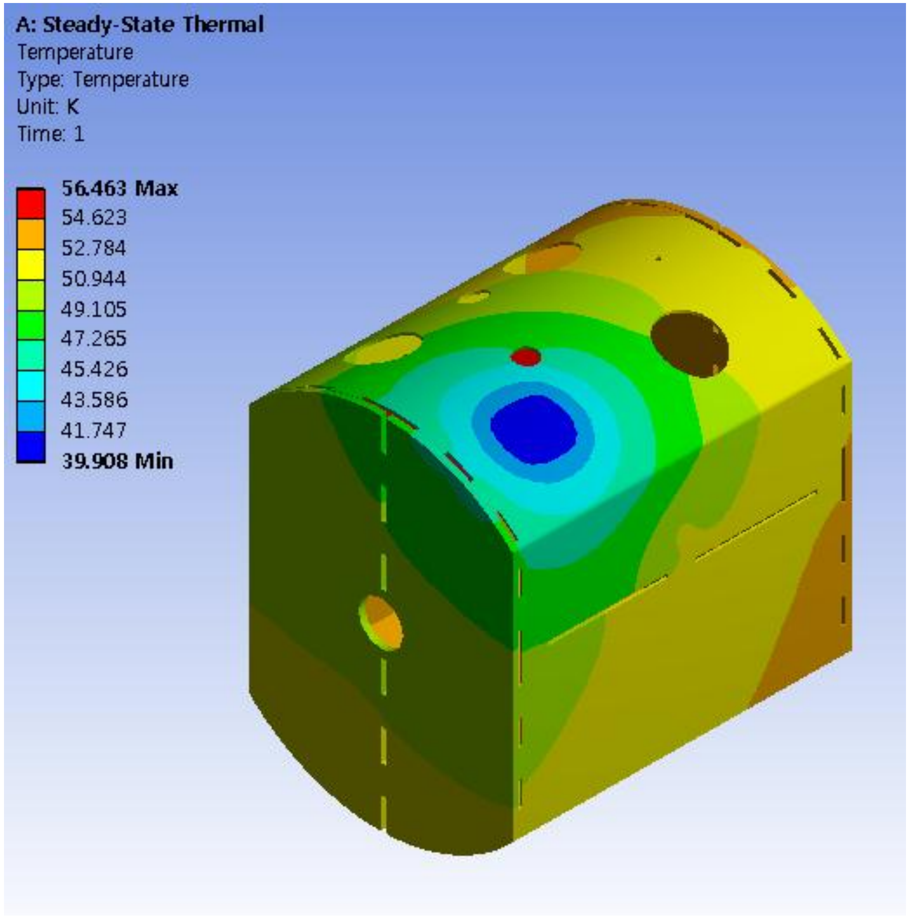
Introduction of Stand-Alone 3rd Harmonic Cryomodule

- 1.5 GHz 3rd harmonic cavity (double-cell cavity) fabrication by KAT

Temperature Distribution of Thermal Shield

Applying 100 W heat load on thermal shield
(Cooling Power : 100 W at 40 K, RDK-500B2)





Design of Stand-Alone Cryomodule

Comparing with conventional cryomodule

	Conventional cryomodule	ZBO stand-alone cryomodule
Helium liquefaction Plant (He plant)	◦ Requires helium liquefaction plant (including separated building) ◦ Requires pipe lines including helium supply / return, helium distribution system, and so on	◦ Not required
Man-power, cost and time for He plant	◦ Required - Man-power (including expert), cost, time for design / construction / installation / operation / managing for He plant	◦ Not required
Cryomodule location change	◦ Additional work for pipe lines ◦ Sometimes it has limitation.	◦ Easy in changing cryomodule location
Cooling temperature (2 K / 4 K)	◦ 2 K or 4 K cooling are OK	◦ 4 K is OK ◦ For 2 K, the cooling system can be complicated. (embedded cooling system is not easy)

Design of Stand-Alone Cryomodule

Comparing with conventional cryomodule

	Conventional cryomodule	ZBO stand-alone cryomodule
Apply on accelerator	◦ All accelerators - 2 K / 4 K cooling (both OK) - lots of cryomodules	◦ Some accelerators - 4 K cooling - low β heavy ion, light source
Installation, Operation and maintenance	◦ Installation cost - cryomodule + He Plant (building) + He distribution system + pipes + Man-power & time (design, installation) ◦ Operation cost - Man-power (cryogenic experts) ◦ Maintenance - If He Plant has mal-function, accelerator should be shut-down.	◦ Installation - cryomodule + embedded ZBO cooling system cost - No cost for He Plant, He distribution system, pipes, man-power for He Plant design/installation, etc. ◦ Operation - No cryogenic expert required ◦ Maintenance - For cryogenic system, just replacing cryocooler without shut-down of accelerator

Design of Stand-Alone Cryomodule

Comparing with conventional cryomodule

	Conventional cryomodule	ZBO stand-alone cryomodule
Summary	◦ For the large accelerators to be newly constructed, conventional cryomodule should be better option. ◦ 2 K and 4 K both operational temperature are OK.	◦ Accelerators below - 4 K operational temperature - low β heavy ion, light source - especially, upgrading or adding SRF cryomodules for accelerator which uses only normal conducting RF system ◦ Overall cost reduction - without He liquefaction plant - without man-power for design, installation, operation and maintenance for He liquefaction plant and distribution system ◦ Easier maintenance of cryogenic system