The 4th Asian School on Superconductivity Cryogenics for Accelerators

Korea University Sejong, Korea, February 13-19, 2023

Special Lecture, 13:30 ~ 14:50, 18th Feb 2023

Kiswire Advanced Technology Co. Ltd.

Junho Han (Principal Research Engineer, Facility R&D Team Leader)

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Kiswire
KAT

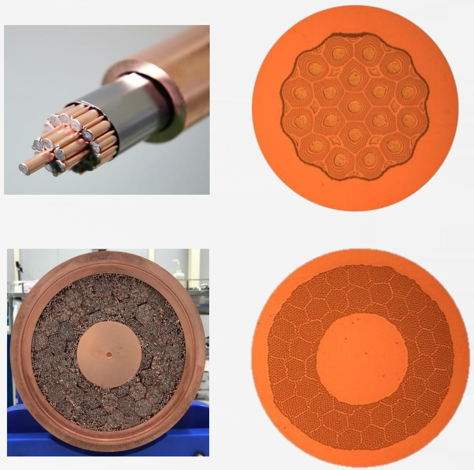
Contents

* Introduction of KAT (R&D, products)
* Superconducting 1.5 GHz 3rd Harmonic Cavity Fabrication
* Superconducting Cryomodules

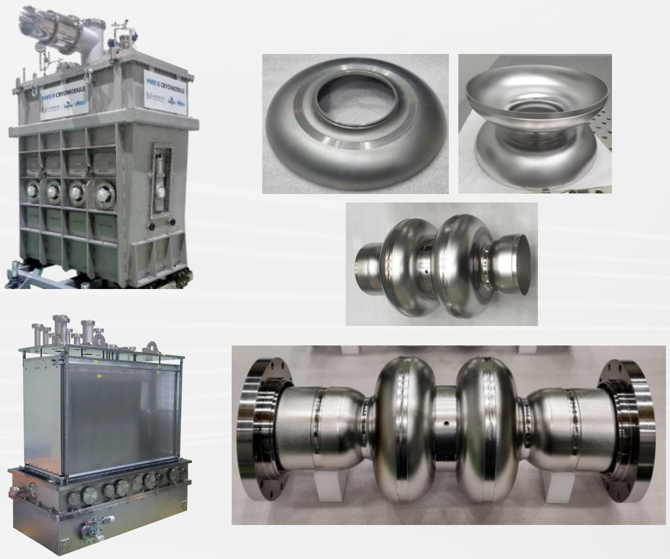
KAT

Kiswire Advanced Technology Co., Ltd.
223, Techno-2ro, Yuseong-gu, Daejeon, Republic of Korea

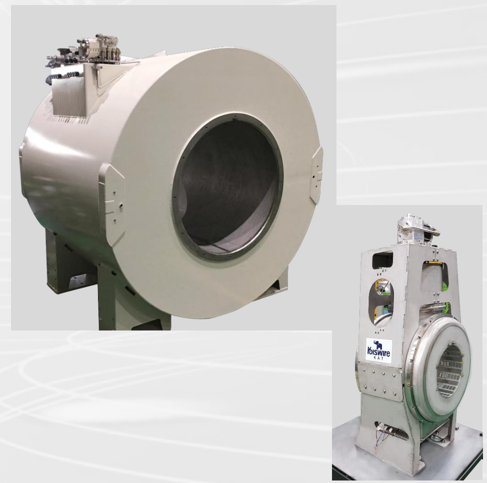
KAT continues to develop high-performance superconducting wires and expands its business to superconducting cavity and cryomodule.



Superconducting Wire



Superconducting cavity and cryomodule



Superconducting MRI magnet

KISWIRE

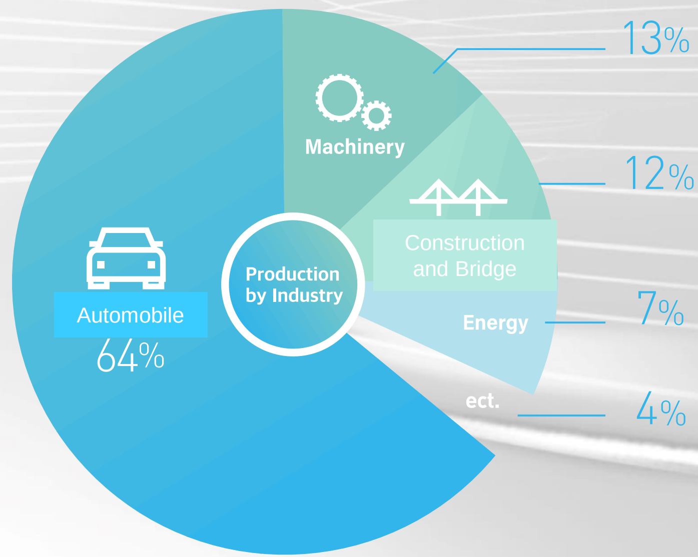
Wire Connects the World

KAT is a wholly owned subsidiary of Kiswire.

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	1.7B USD (FY 2021)



Global Network

Kiswire

Global Presence

Global solution – 15 countries, 6,000 people
No matter where you are, Kiswire will be there.

Global network

15 Countries **15** Offices **39** Factories

Office 15

Factory 39

R&D Center 3

Service Center 6

Training Center 2

KAT History

Established in 2004, KAT is a global leading superconducting wire company and wholly owned subsidiary of Kiswire.

Superconducting & Cryogenic Applications

Super-conducting Wires

1998

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

Foundation of KAT

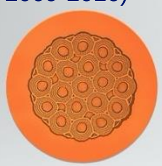
2004

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)



Start R&D of SC MRI magnet

2010

2014 - 2021

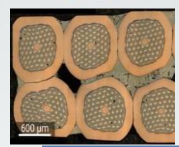
Start R&D project of NbTi and MgB_2 wires funded by Korean Government

Supply 1.5T MRI magnet to TCL, China (KAT NbTi wire applied)

2015

2016 - Now

R&D contract with CERN for High Jc Nb_3Sn wire (2016 ~)



Supply HWR B Cryomodule prototype for RAON

2018

2019 - 2022

Manufacturing Nb_3Sn of 55 tons for DTT project in Italy

2021 - Now

1.5 GHz Superconducting cavity

Superconducting Wire

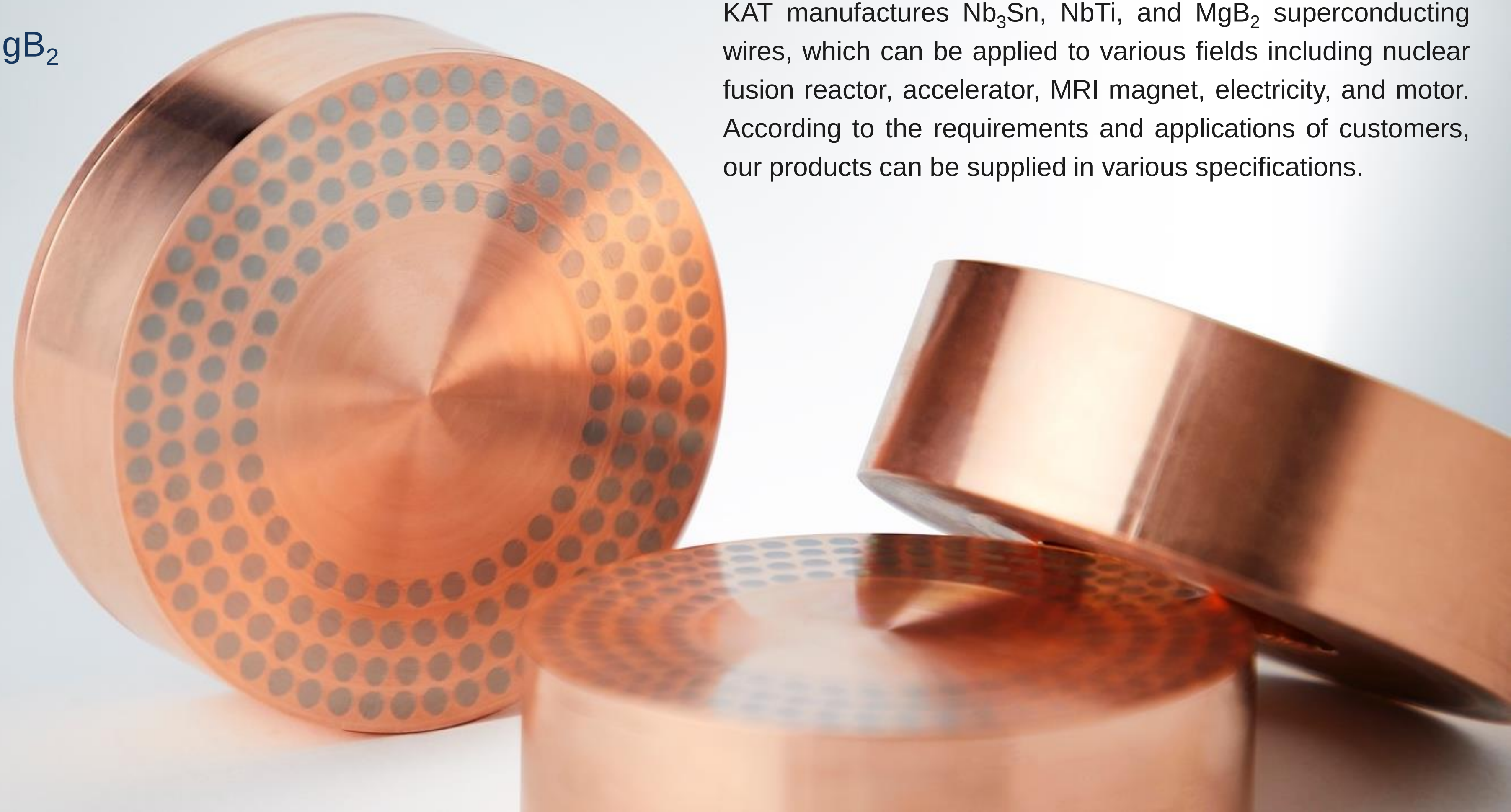
Nb_3Sn

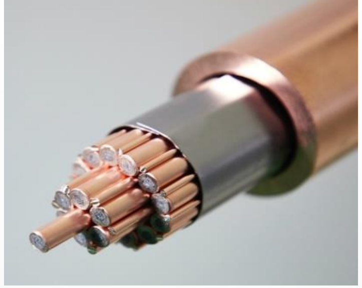
NbTi

MgB_2

Low-temperature superconducting wires have zero electrical resistance below a specific temperature and an external magnetic field. This characteristic makes the superconducting wires can transport a large amount of current without energy losses.

KAT manufactures Nb_3Sn, NbTi, and MgB_2 superconducting wires, which can be applied to various fields including nuclear fusion reactor, accelerator, MRI magnet, electricity, and motor. According to the requirements and applications of customers, our products can be supplied in various specifications.





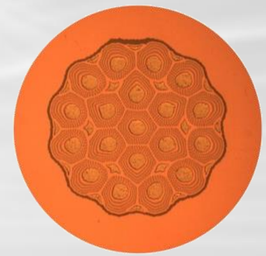
Nb_3Sn

The most commonly used wires for fusion reactors are manufactured with a diameter of 0.82 mm, the critical current of 250 A to 360 A at 4.2 K, 12 T, and the magnetization loss less than 1,000 mJ/cc.

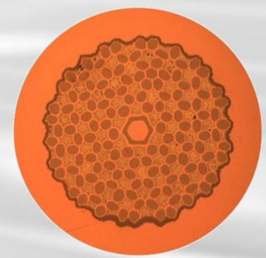
High J_c Nb_3Sn wire with a higher critical current is designed to have a critical current of 600 A or more and an effective diameter less than 50 μm with the same diameter.

Number of Filaments	Cu/NonCu	Bare Diameter (mm)	Critical Current Density (Jc @4.2K)		Qh mJ/cc (±3T)	RRR
			12T	16T		
> 3,000	1.0 ± 0.1	0.82 ± 0.005	> 900	> 400	< 600	> 100
> 3,000	1.0 ± 0.1	0.82 ± 0.005	> 1,200	> 500	< 1,000	> 100
> 25,000	1.0 ± 0.1	1.0 ± 0.005	> 2,500	> 1,200	-	> 150

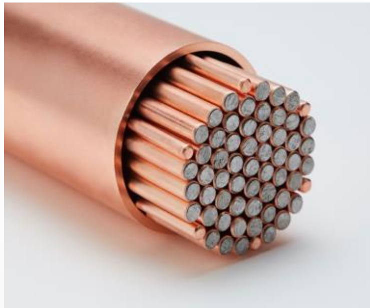
According to customer requirements, our products can be supplied in various specifications.

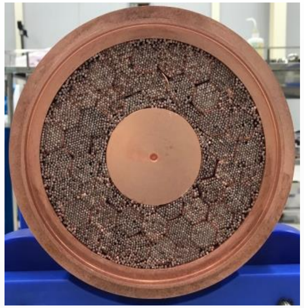


Nb_3Sn Wire



High Jc Nb_3Sn Wire
20,000 filaments in 0.82 mm

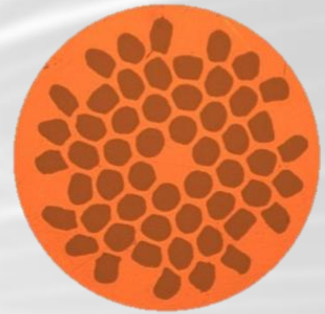




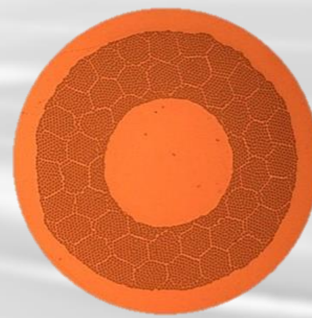
NbTi

KAT has developed NbTi wires for MRI, NMR, nuclear fusion reactor, and accelerator.
To meet customer demands, KAT customizes NbTi wire to various specifications according to our client's requirements.

Number of Filaments	Cu/Sc	Bare Diameter (mm)	Filament Diameter (µm)	Critical Current (A @4.2K)			RRR
				3T	5T	7T	
54	1.3	0.92	83	>1070	>750	>470	>100
		0.85	76	>920	>640	>410	
		0.70	63	>620	>450	>280	
	2.0	1.00	79	>980	>680	>420	
		0.92	73	>830	>570	>360	
		0.70	55	>480	>330	>210	
		0.60	47	>350	>240	>150	
4250	1.6	0.82	8	>750	>500	>300	
		0.72	7	>590	>390	>240	
	1.9	0.82	7	>670	>460	>270	
7446	1.9	0.82	6	>670	>450	>270	
		0.72	5	>520	>350	>210	

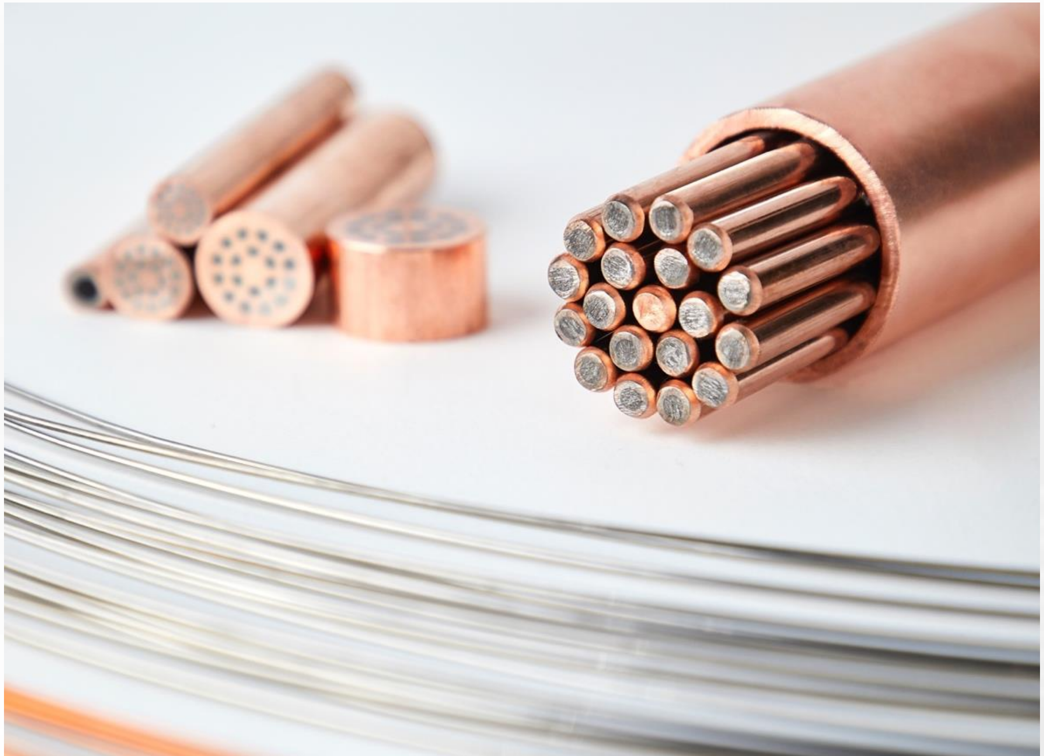


NbTi Wire
with 54 filaments in 0.82 mm



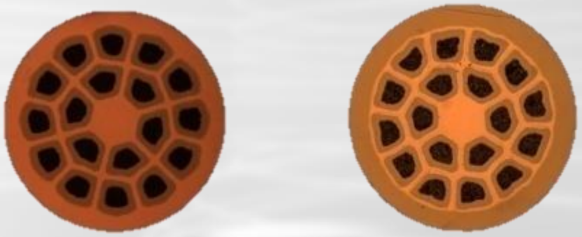
NbTi Wire
with 4,250 filaments in 0.82 mm

MgB_2



MgB_2 wire is a cost-effective superconducting material as it's critical temperature of 39 K. MgB_2 wire maintains superconductivity with lower cost liquid hydrogen or cryocooler instead of using expensive liquid helium.

Since 2011, KAT has developed a various types of MgB_2 wire and 4 km and longer piece length wire can be produced.



Product	18-filamentary MgB_2 wires Un-doped(Φ0.90)						18-filamentary MgB_2 wires C doped(Φ1.46)				7-filamentary MgB_2 stranded wires (Φ0.90)		
Temperature (K)	4.2			20			4.2				4.2		
Magnetic field (T)	3	4	5	2	3	4	4	6	8	10	3	4	5
Ic (A)	>460	>230	>110	>240	>80	>20	>410	>210	>110	>60	>490	>250	>110
Jc (A/mm^2)	>3,510	>1,770	>850	>1,870	>680	>190	>1,710	>890	>480	>250	>3,670	>1,850	>880

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  Design

  Fabrication Process

  Process Verification – Cu cavity fabrication

  Superconducting cavity fabrication

* Assembly of Superconducting Cryomodule

Superconducting 1.5 GHz 3rd Harmonic Cavity Fabrication

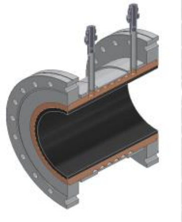
Design

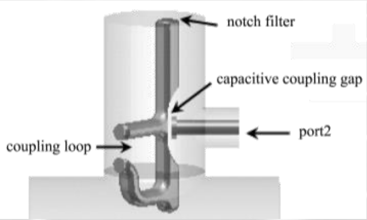
Design Input from CDR of 4GSR

Parameter	Value
RF frequency	1499.631 MHz (3rd harmonic) 499.877 MHz (Main)
Type	Passive, Superconducting
RF voltage	800 kV

Selection of HOM absorber

HOM damping method	✓ HOM Absorber	• Relatively simple design • Broadband work frequency • Difficult to clean
	HOM coupler	• Relatively easy to clean, Strong damping • Static heat radiation, Large power losses • Risk of breakage due to multipacting

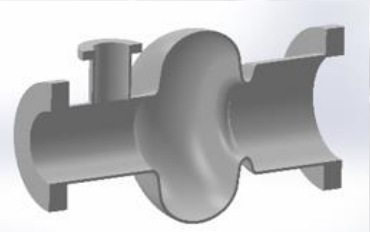




Selection of Beam-tube shape

Beamtube shape	✓ Enlarged waveguide	Easier to design and fabrication
	Pi waveguide	Difficult to design and fabrication

KEK-B



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Design

Electro-Magnetic Analysis (Determination of number of cell)

Table 2: Performance of the cavities

Parameters	Single cell	Double-cell
Resonant frequency	1499.631 MHz	1499.647 MHz
E_{peak}/E_{acc}	2.07	2.23
H_{peak}/E_{acc}	4.08 mT/(MV/m)	
$(R/Q)_{percell}$	95.7 Ω	95.4 Ω
Required V_{acc}	800 kV	
E_{acc} in operation	8 MV/m	4 MV/m
B_{peak} in operation	32.5 mT	16.35 mT

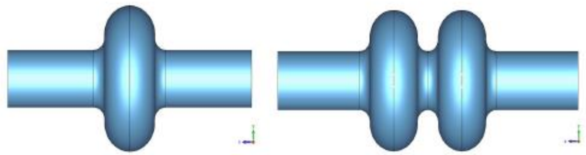


Figure 2: Geometry of the cavity: (left) Single-cell and (right) Double-cell

Thermal & Mechanical Analysis (Frequency tuning table, Checking Max. stress)

Table 5: Frequency Tuning Table

	Process	Δ f [kHz]	f_π [MHz]
0	Operation (4.5 K)	N/A	1499.631
1	Cool down (293 K to 4.5 K)	-2126.22	1497.505
2	Vacuum pumping (0.13 MPa)	-35.24	1497.469
3	BCP (200 μ m)	2985.88	1500.455

Detail descriptions of 3rd HSC design is published in IPAC22 proceeding paper

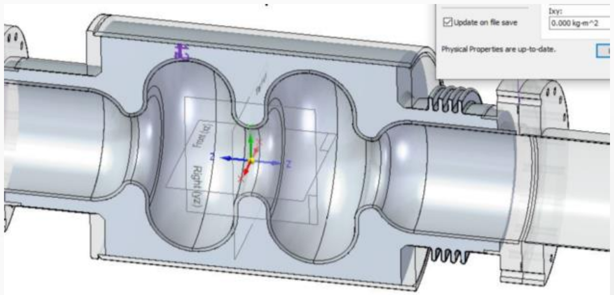
DESIGN STUDY OF THE 3RD HARMONIC SUPERCONDUCTING CAVITY FOR A BUNCH LENGTHENING

Junyoung Yoon[1], Eun-San Kim*, Dept. of Accelerator Science, Korea University, Sejong, South Korea
Jun-ho Han, Hee-Su Park, [1]Kiswire Advanced Technology Ltd, Daejeon, South Korea
Eiji Kako, High Energy Accelerator Research Organization (KEK), Tsukuba, Japan

Superconducting 1.5 GHz 3rd Harmonic Cavity Fabrication

Design

Ti-jacket design
(considering pressure vessel regulation requirement)

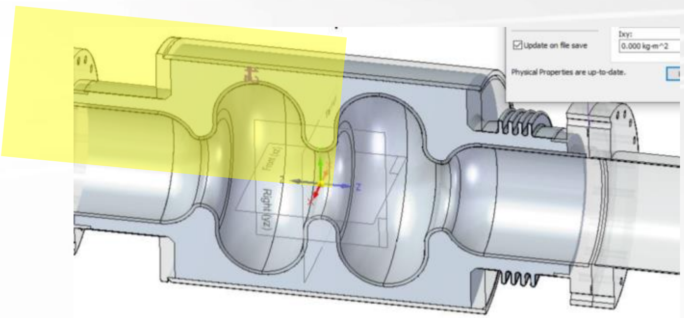


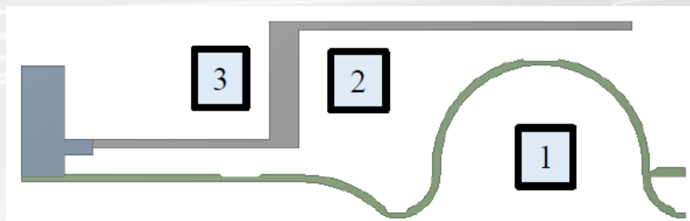
KGS (Korean Gas Safety) code for pressure vessel

- non-pressure vessel condition

: Design Pressure (MPa) x Volume (m^3) < 0.004

Finite Element Model for thermal / mechanical analysis
(1/4 axis-symmetric, ANSYS)



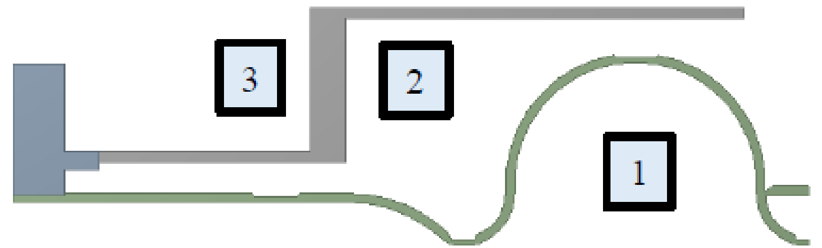


1 : Inside cavity pressure
2 : Inside Ti-jacket pressure
3 : Outside pressure

Superconducting 1.5 GHz 3rd Harmonic Cavity Fabrication

Design

FEA results for various situation



Case	Condition	Cavity Status	Boundary Condition						Allowable stress (S) [MPa]	Previous geometry Peak stress [MPa]	Modified geometry Peak stress (Membrane stress) [MPa]	Note
			Temp. [K]	Pressure [MPa] (abs) 1	2	3	Jacket Support	Tuner Disp.				
1	Leak test (Bare Cavity)	Undressed	300	0	0.1	N/A	N/A		< 47.0 (S) 70.5 (1.5S)	**25.244**	**24.564**	**OK**
2	Vertical test	Undressed	4.5	0	0.1	0.1	N/A		< 211.9 (S) 317.9 (1.5S)	**88.421**	**86.092**	**OK**
3	Leak test (Cavity)	Dressed	300	0	0.1	0.1	N/A		< 47.0 (S) 70.5 (1.5S)	**27.072**	**26.339**	**OK**
4	Leak test (Jacket)	Dressed	300	0	0	0.1	N/A		< 47.0 (S) 70.5 (1.5S)	**38.182**	**51.168 (22.008)**	**OK**
5	Pressure test	Dressed	300	0	0.22[1)]	0.1	N/A		< 47.0 (S) 70.5 (1.5S)	**54.208**	**63.316 (23.258)**	**OK**
6	Cooldown	Dressed, Assembled	4.5	0	0.2	0	Not applied yet		< 211.9 (S) 317.9 (1.5S)	**112.08**	**140.17**	**OK**
7	Horizontal test	Dressed, Assembled	4.5	0	0.2	0	Not applied yet		< 211.9 (S) 317.9 (1.5S)	**112.08**	**140.17**	**OK**
8	Horizontal test w/ Tuning	Dressed, Assembled	4.5	0	0.2	0	Not applied yet	Yes, $\pm 0.2\ mm$	< 211.9 (S) 317.9 (1.5S)	**205.71**	**235.96 (111.96)**	**OK**
9	Cold Operation	Dressed, Assembled	4.5	0	0.13	0	Not applied yet		< 211.9 (S) 317.9 (1.5S)	**72.851**	**91.109**	**OK**
10	Cold Operation w/ Tuning	Dressed, Assembled	4.5	0	0.13	0	Not applied yet	Yes, $\pm 0.2\ mm$	< 211.9 (S) 317.9 (1.5S)	**166.49**	**186.92**	**OK**

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    - Design
    - Fabrication Process
    - Process Verification – Cu cavity fabrication
    - Superconducting cavity fabrication
* Assembly of Superconducting Cryomodule

Fabrication Process

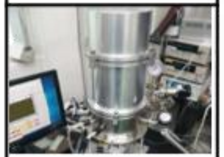
Material Inspection → EDM Wire Cut → Deep Drawing → Machining → Etching → EBW → RF Test (Room Temperature) →

Continue to the next page


Ultrasonic Thickness Gauge


Surface Roughness Measurement


Hardness Tester


RRR Measurement


Wire cut Machine


Hydraulic Press Machine


3D Scanner


Lathe


Milling Machine


Coordinate Measuring Machine


Chemical Fume Hood


Ultra Pure Water Generator


Ultrasonic Cleaner


Clean Room


EBW Machine


Network Analyzer

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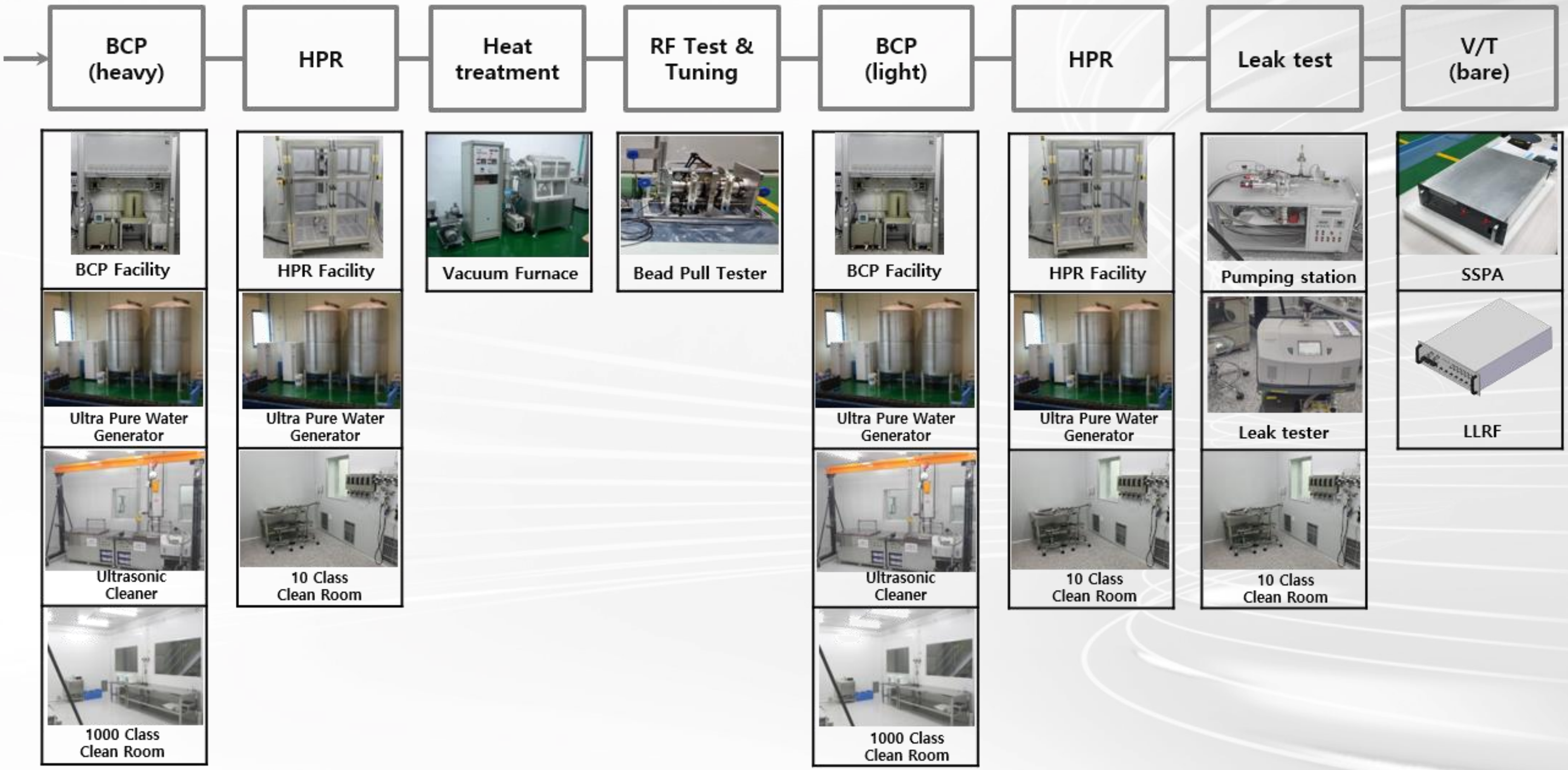
Fabrication Process



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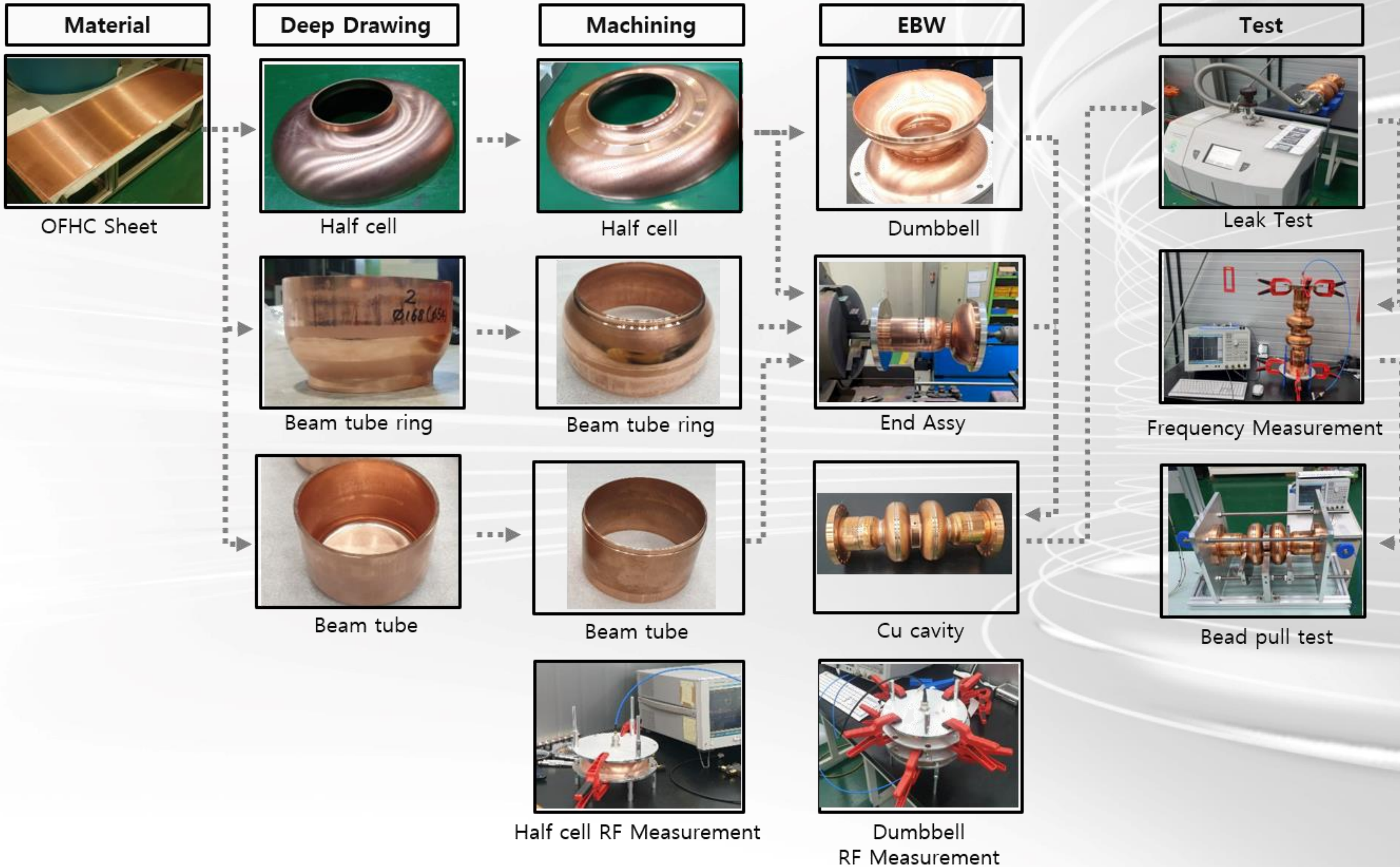
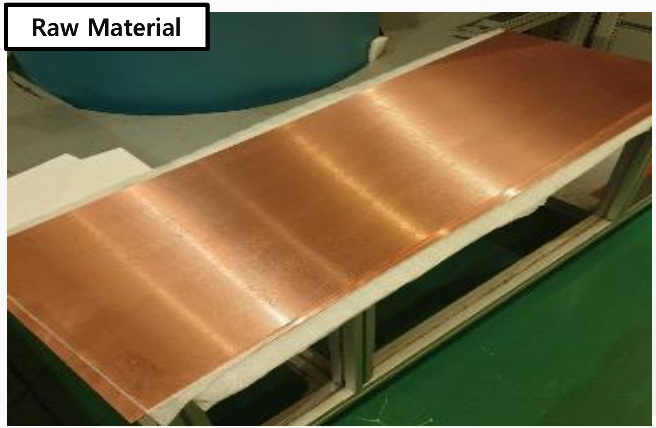
Process Verification – Cu Cavity Fabrication

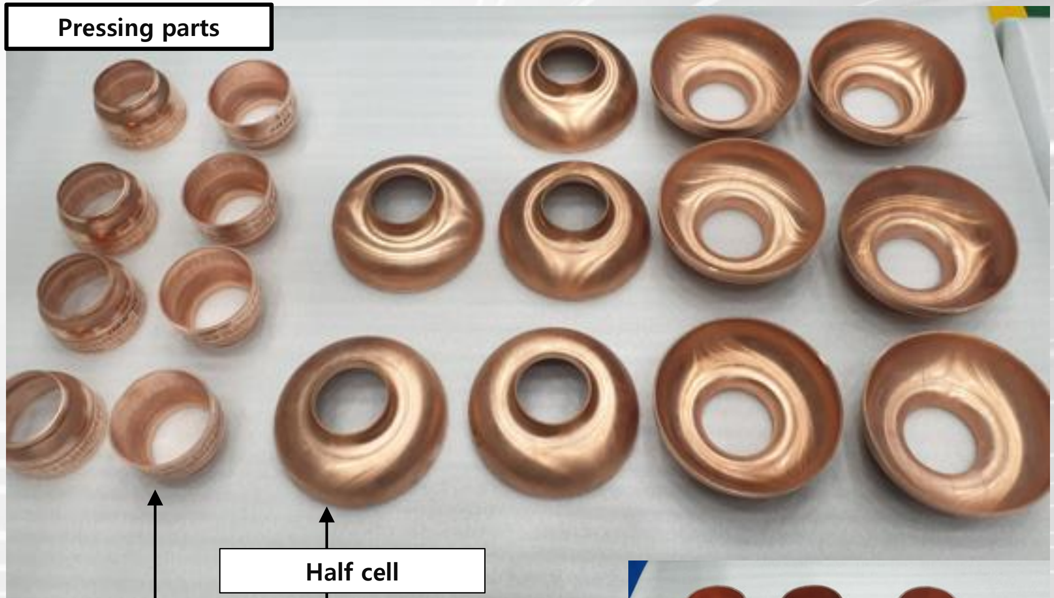


Process Verification – Cu Cavity Fabrication

Raw Material

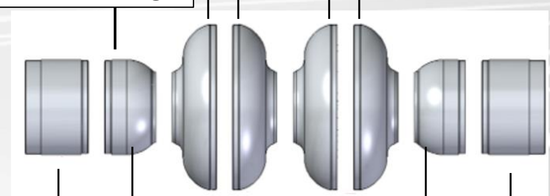


Pressing parts



Half cell

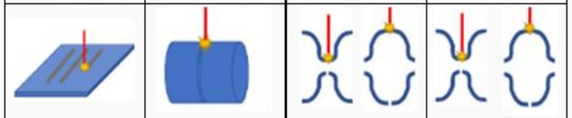
Beam tube ring



Beam tube

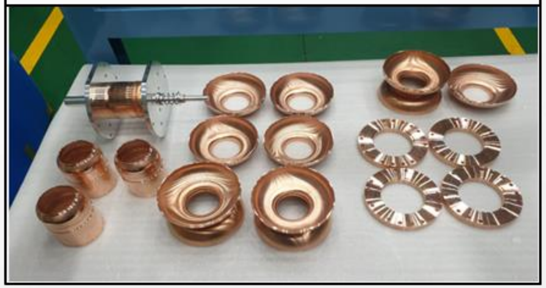
Process Verification – Cu Cavity Fabrication

EBW Test			
평판	튜브(3가지 직경)	Mock-up	본용접

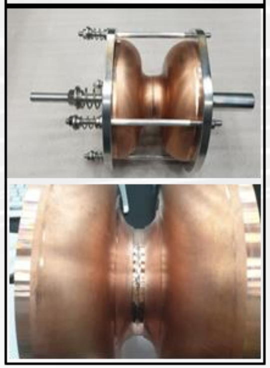


Cu 시험 완료, Cu cavity 용접 적용

Machining, Before EBW



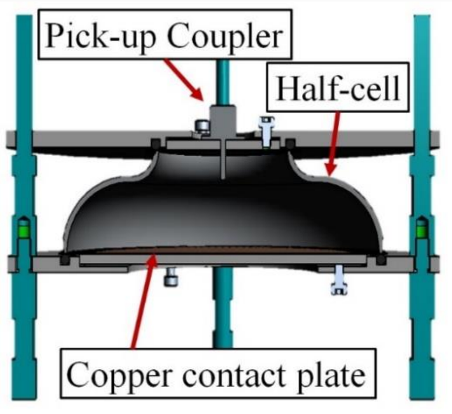
Dumbbell Welding



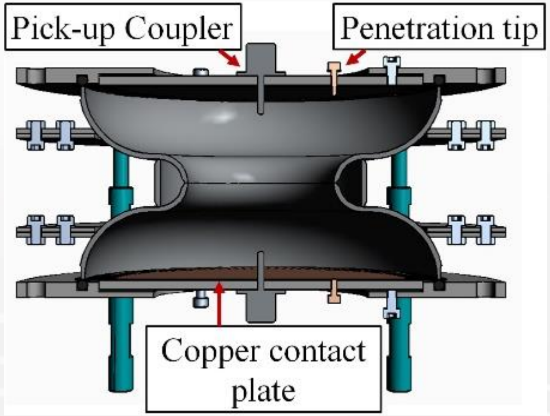
End Assy Welding

Electron Beam Welding

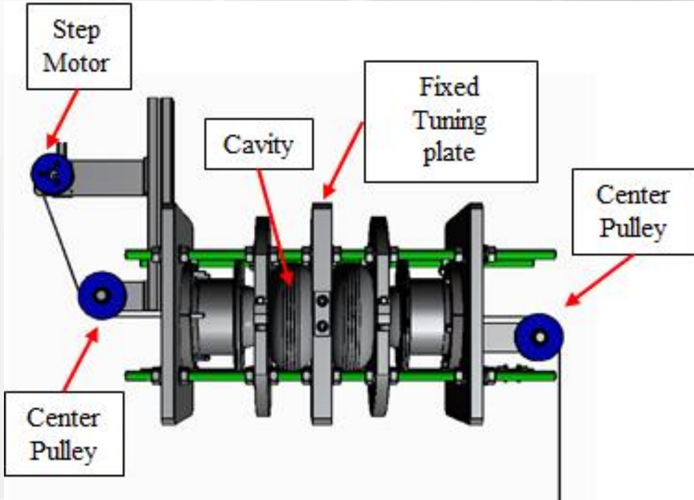
Process Verification – Cu Cavity Fabrication



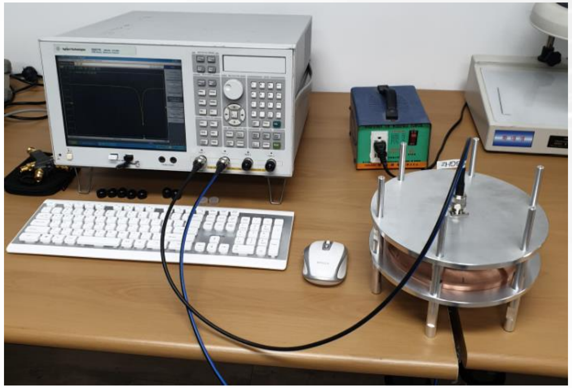
Half cell measurement

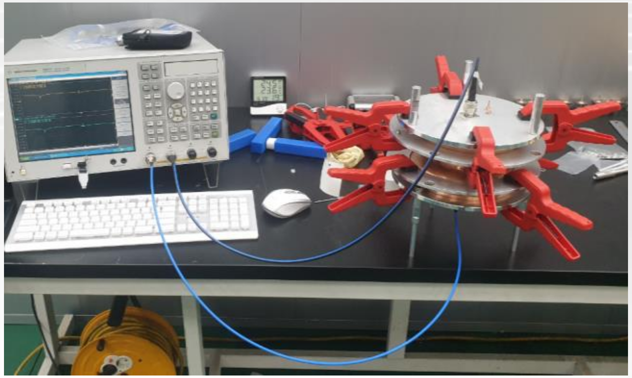


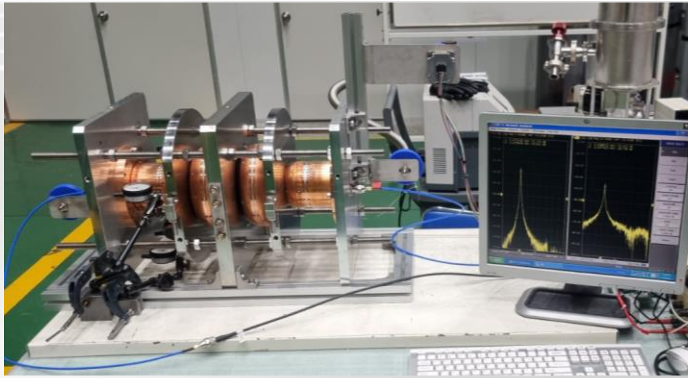
Dumbbell measurement



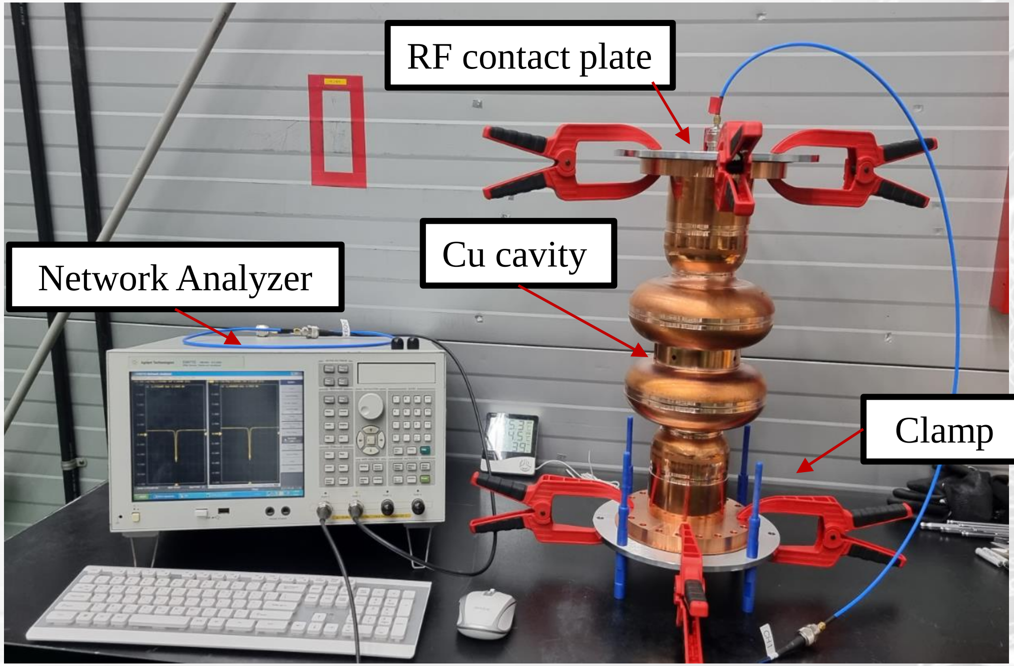
Bead Pull Test







Process Verification – Cu Cavity Fabrication

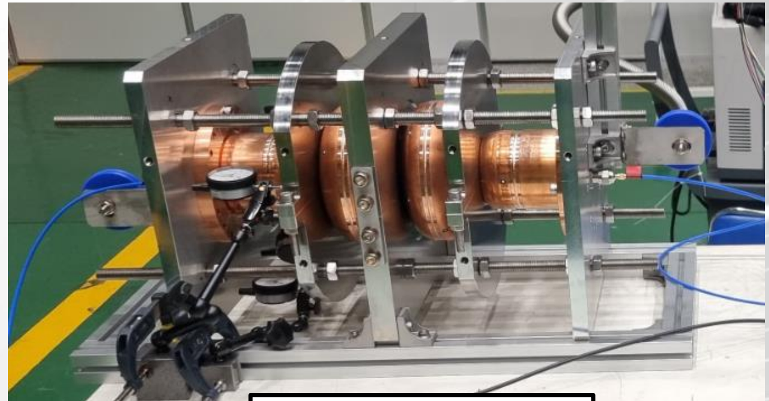


No.	Target Freq. [MHz]	Measured [MHz] (Before Tuning)	Different [MHz] (Target – Measured)	Error [%]
Cu cavity #1	1499.841 (adjusted by temp.)	1498.764	-1.077	-0.1
Cu cavity #2		1494.887	-4.954	-0.3

Process Verification – Cu Cavity Fabrication

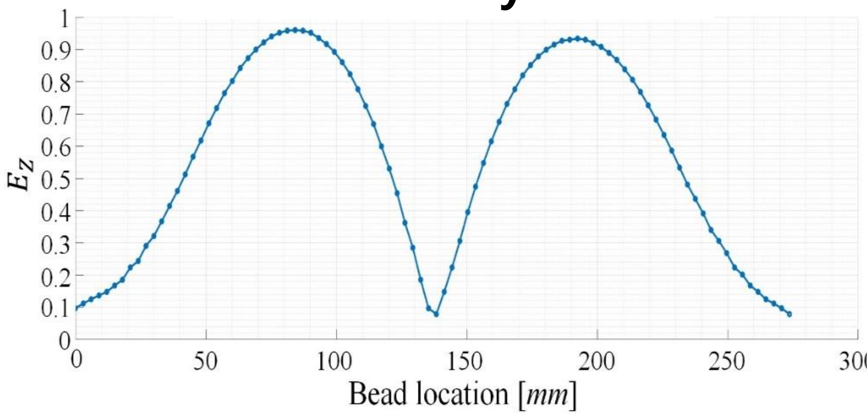
Cu cavity 1

Cu cavity 2



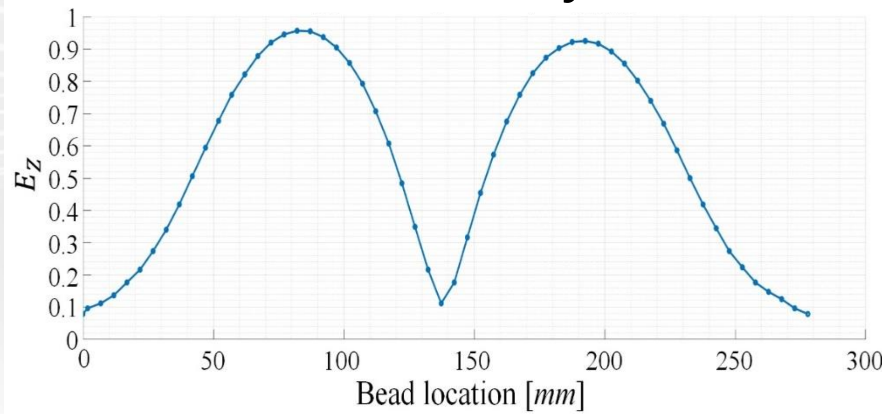
Bead pull test bench

Cu cavity 1



Field flatness: 97.25 %
(Before Tuning)

Cu cavity 2



Field flatness: 96.39 %
(Before Tuning)

Contents

* Introduction of KAT (R&D, products)

* Superconducting 1.5 GHz 3rd Harmonic Cavity Fabrication

    Design

    Fabrication Process

    Process Verification – Cu cavity fabrication

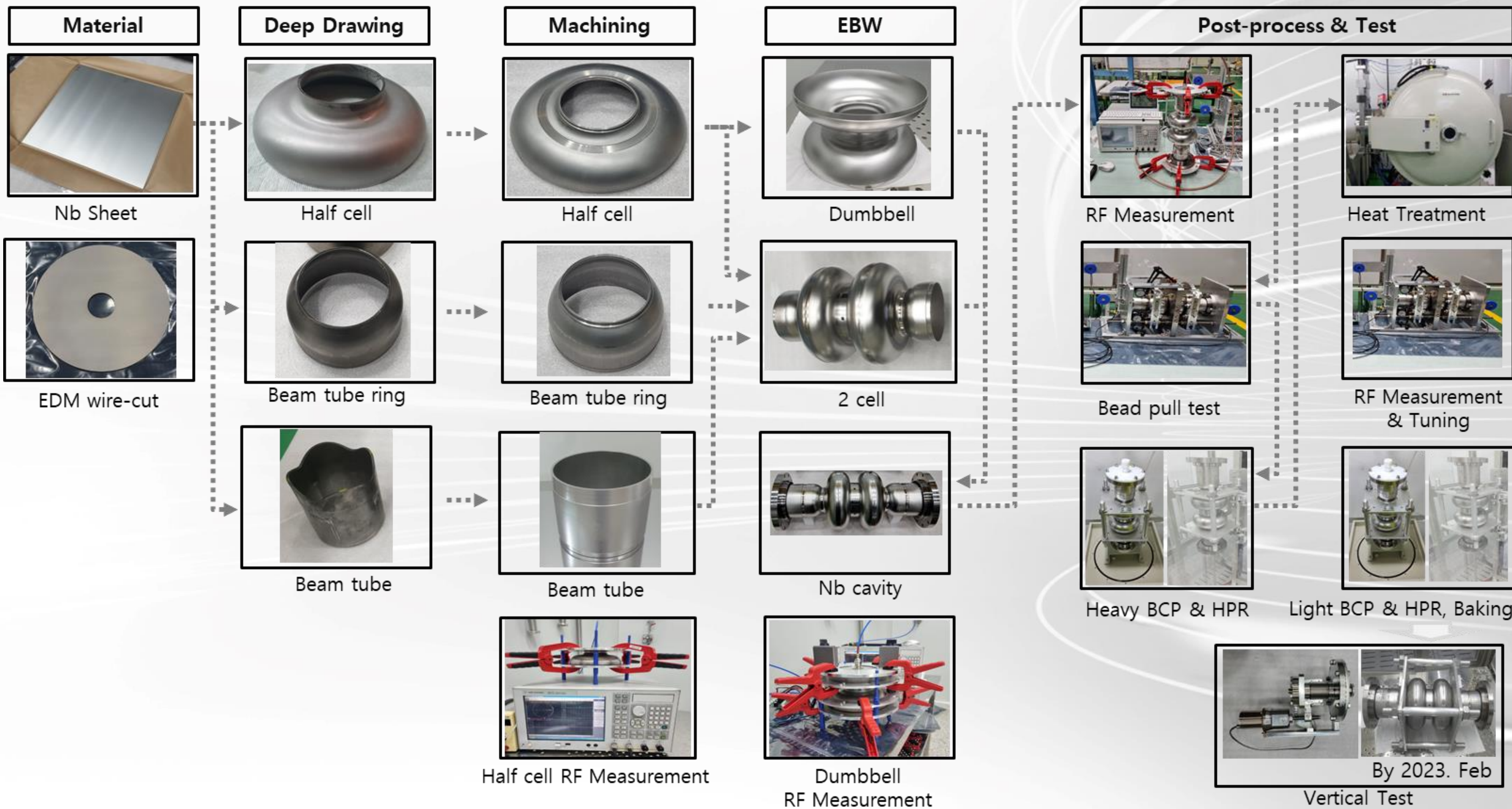
    Superconducting cavity fabrication

* Assembly of Superconducting Cryomodule

The 4th Asian School on
Superconductivity Cryogenics for Accelerators
Korea University Sejong, Korea, February 13-19, 2023

Superconducting Cavity Fabrication

Process

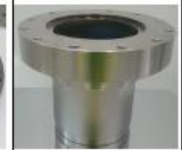


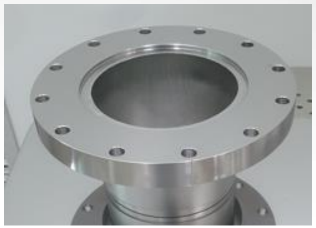
Superconducting Cavity Fabrication

Machining

Superconducting Cavity Fabrication

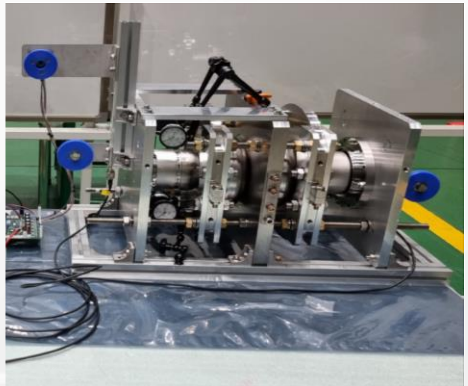
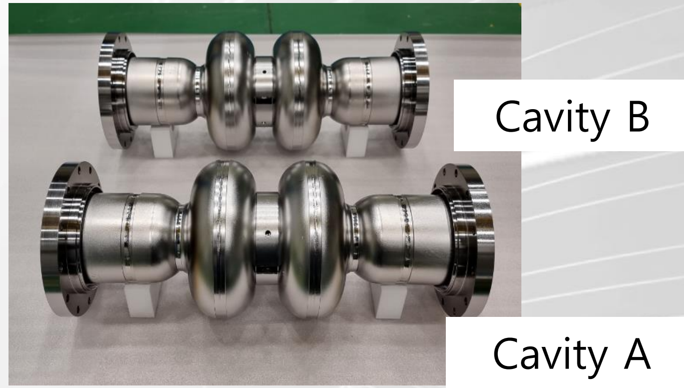
Electron Beam Welding

Item	Half cell	Dumbbell	2 cell	Beam tube ring	2 cell+beam tube ring	Beam tube	NbTi Flange	Beam tube+ NbTi Flange
Before etching								
After etching								



Superconducting Cavity Fabrication

Frequency measurement (Cavity, RT, before tuning)

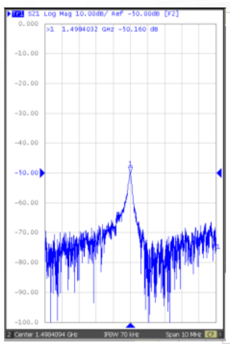
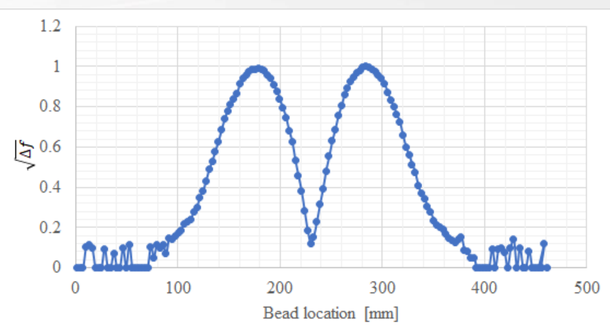




$f_{target,RT}$ = 1500.455 MHz, RT

< Cavity A >

f = 1498.403 MHz (-2.052 MHz, -0.14%)

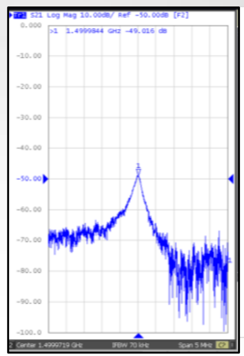
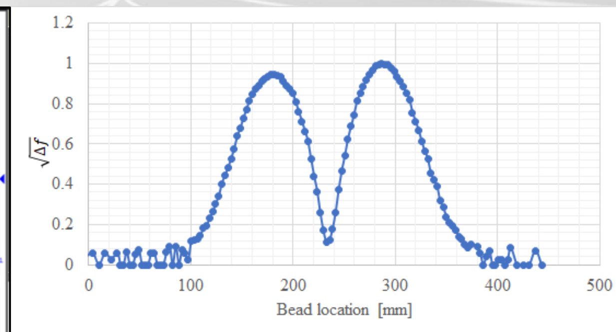
Field flatness = 99.67 %

< Cavity B >

f = 1499.984 MHz (-0.472 MHz, -0.03%)

Field flatness = 93.96 %

Superconducting Cavity Fabrication

Heavy BCP & HPR

BCP facility, CLASS 1000 clean room, KAT

HPR facility, CLASS 10 clean room, KAT

Contents

* Introduction of KAT (R&D, products)
* Superconducting 1.5 GHz 3rd Harmonic Cavity Fabrication
* Superconducting Cryomodules

HWR B cryomodule prototype for RAON

Fabrication parts of cryostat

Assembly in clean room

Assembly of cryomodule

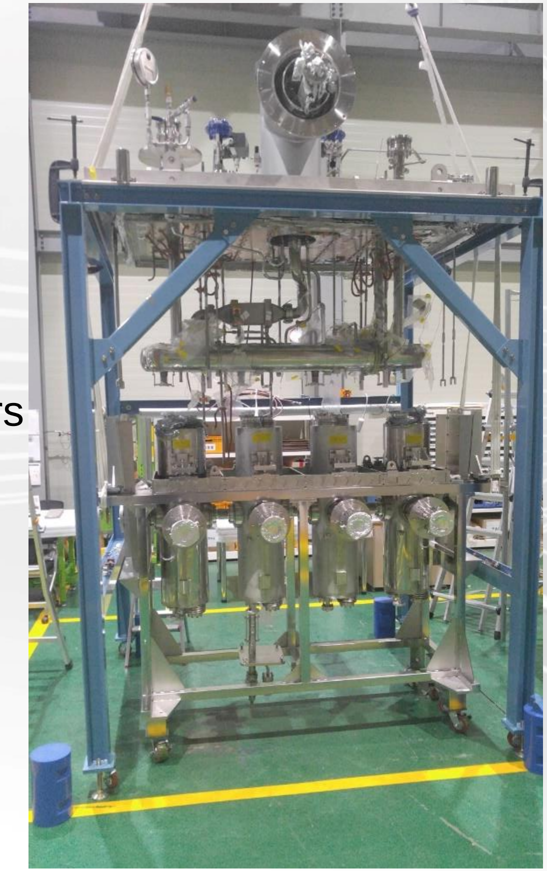
Superconducting Cryomodules

HWR B cryomodule prototype for RAON

← Assembly of cavities on the strongback after cleaning cavities

↓ Assembly couplers with cavities

↓ Connecting 2 K lines with cavities



Assembly tuners on cavities ↓

Superconducting Cryomodules

HWR B cryomodule prototype for RAON

- Wrapping 2 K MLI
- Assembly 50 K thermal shield
- Assembly top-down cryostat
- Transporting cryomodule
- Installation at the horizontal test bed

QWR cryomodule for RIKEN (Collaboration with MHI-MS)

Cryostats for QWR cryomodule in RIKEN

KAT supplied cryostat parts to MHI-MS.

Cool-down process of cryomodules has been successfully done in 2019.

Thank you

Have a safe journey!

Kiswire

KAT

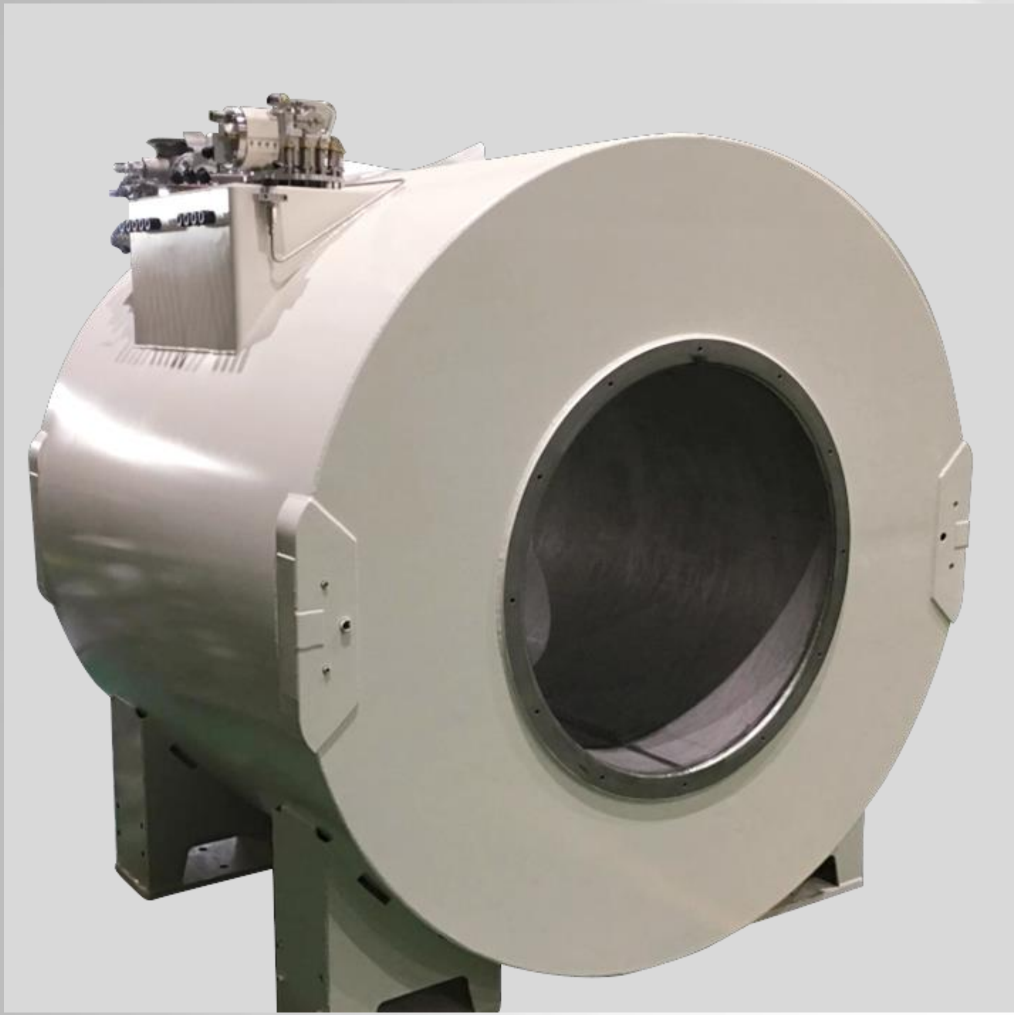
Superconducting Magnet

A superconducting magnet is a crucial device for medical MRI. KAT has secured overall technology for manufacturing, testing, and evaluation of superconducting magnet since 2010.

KAT successfully commercialized a 1.5T whole-body magnet in 2015 and the world's first 1.5T helium-free extremity magnet in 2018.

KAT's first prototype MRI Magnet developed in 2013

Whole body MRI Magnet



MRI Magnet consists of NbTi superconducting wires, liquid helium vessel, thermal shield, outer vacuum can, cryocooler interface, and main neck turret, etc.

It has been certificated by ASME Sec.VIII Div.1, ISO-9001, IEC-60601.

Items	Spec & Dimension
Center Field	1.5 Tesla
Stability of magnetic field (Drift rate)	≤ 0.1 ppm/hr
Fringe field	≤ 4 m(Z) x 2.5 m(R)
Homogeneity after shimming (Vrms)	≤ 10 ppm
Liquid Helium consumption	0 L/hr
Width	1,916 mm
Length	1,600 mm
Height	2,042 mm
Bore ID	902 mm
Ceiling Height	2,400 mm
Weight	4.6 tons

1.5T helium-free extremity MRI Magnet

1.5T helium-free extremity Magnet consists of NbTi superconducting wires, conductive cooled former, thermal shield, outer vacuum can, cryocooler interface, and HTS current lead, etc.

The world's first commercialized helium-free superconducting magnet by KAT is widely used for imaging of extremities not only at large hospitals, but also at small and medium-sized hospitals, orthopedic clinics and imaging centers.

Items	Spec & Dimension
Center Field	1.5 Tesla
Stability of Magnetic Field(Drift Rate)	≤ 0.1 ppm/hr
Fringe Field	≤ 1.85 m(Z) x 1.15 m(R)
Homogeneity after Shimming (Vrms)	≤ 10 ppm
Width	702 mm
Length	527 mm
Height	1,486 mm
Bore ID	300 mm
Ceiling Height	2,000 mm
Weight	0.5 tons