HITACHI
Inspire the Next

Development of Superconducting Magnets for Accelerators in Hitachi

- Toward Future Magnets for Detectors -

Sept. 13, 2022

Tomoyuki Semba

Hitachi, Ltd.

Contents

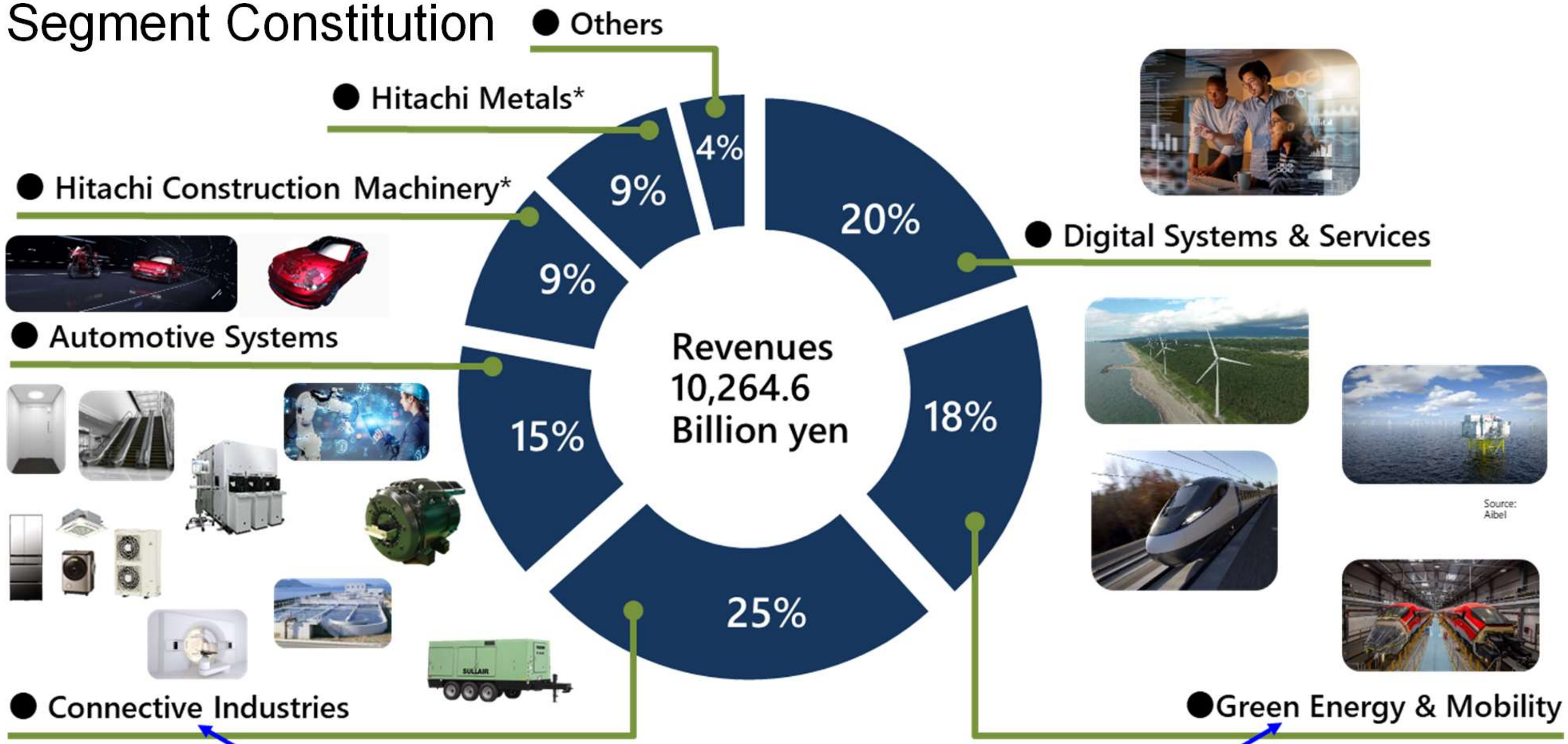
HITACHI
Inspire the Next

1. Company Profile

1-1 Company Profile

HITACHI
Inspire the Next

Business Segment Constitution (FY2021)



The figures are based on the new segment classifications effective from FY2022.
* Hitachi Construction Machinery and Hitachi Metals are scheduled to be deconsolidated in FY2022.

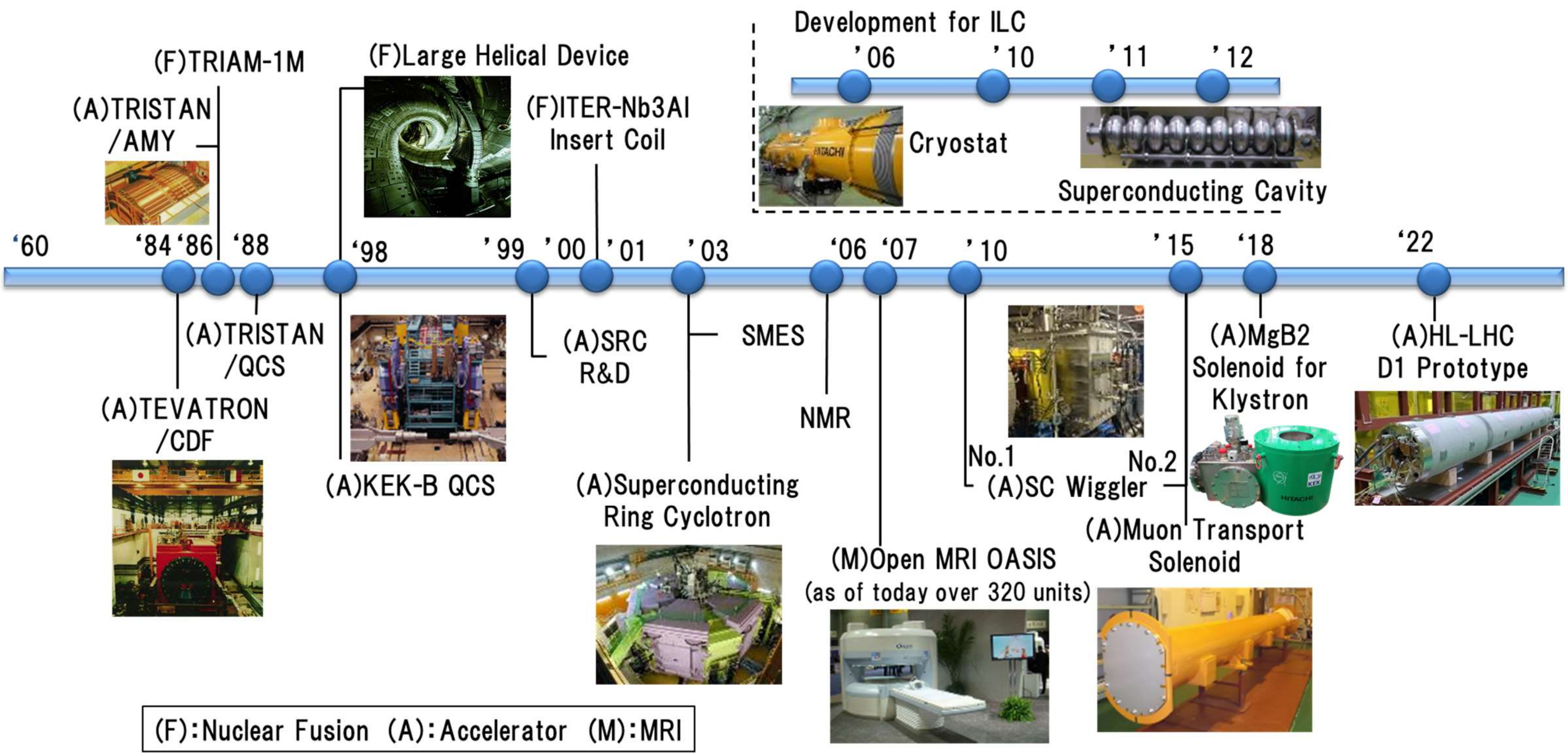
Design and Manufacture **Operation**

Fusion equipment, Accelerators, Superconducting Magnets

2. History of Superconducting Products

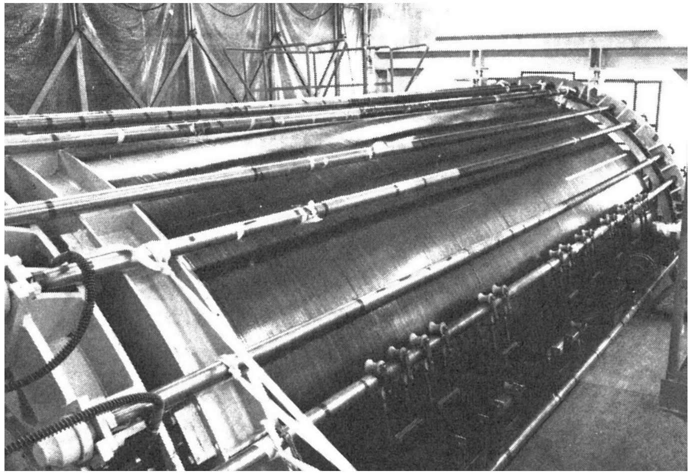
2-1 History of Superconducting Products

HITACHI
Inspire the Next



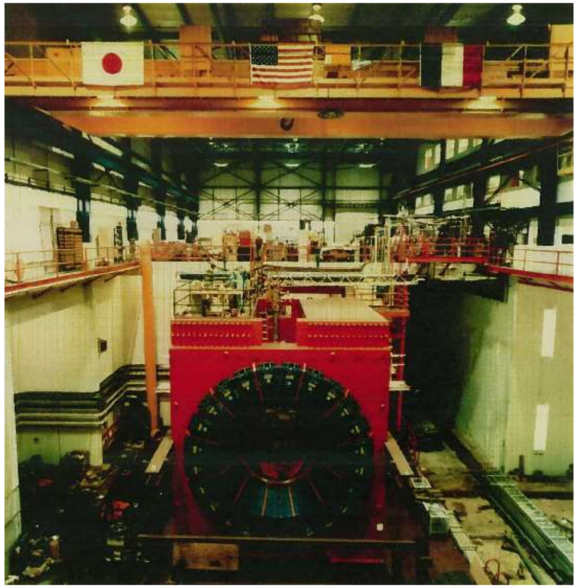
3. From the Dawn of Development to Large-Scale Equipment

3-1 CDF Solenoid



Manufacture of Solenoid

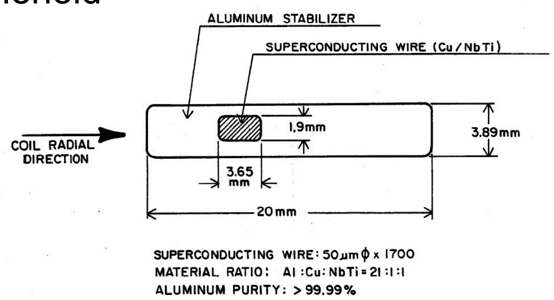
Cooling and Excitation Tests

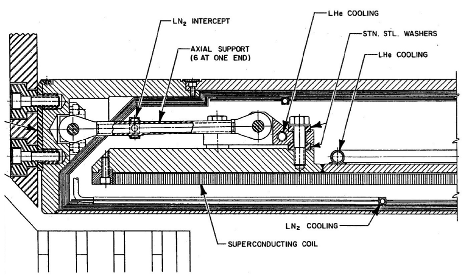


CDF @ FNAL

Main Parameters of CDF Solenoid

Winding scheme	Single layer solenoid
Inner diameter	2966 mm
Winding Length	4793 mm
Number of turns	1164
Current	5000 A
Central Field	1.5 T
Inductance	2.4 H
Stored Energy	30 MJ

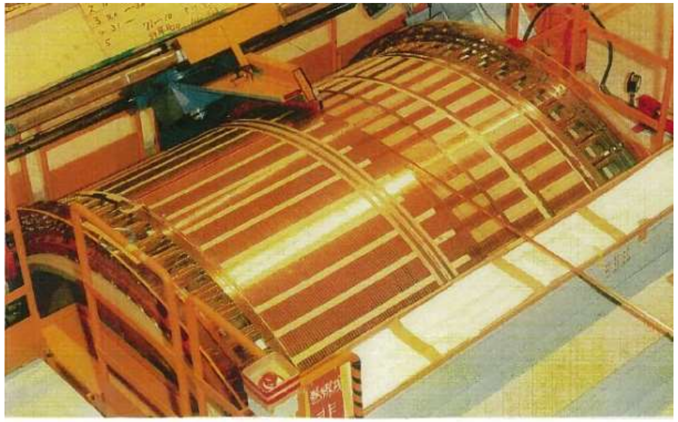




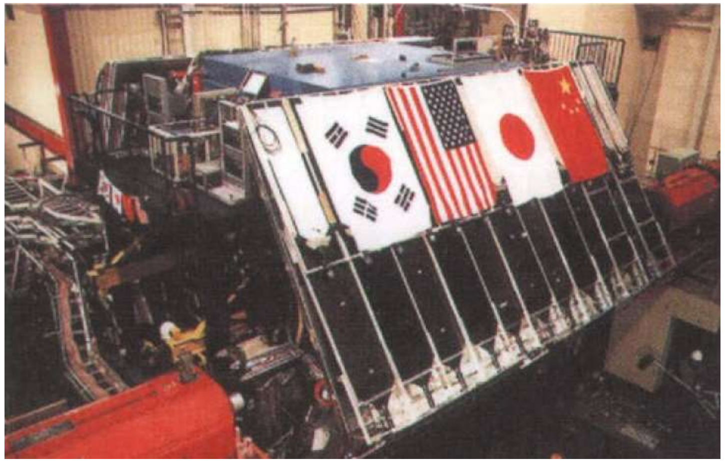
・First Manufactured in Japan Aluminum stabilized Superconducting Solenoid

・In FNAL TEVATRON used in proton-antiproton collision experiments

3-2 AMY Solenoid (TRISTAN)



Coil Winding

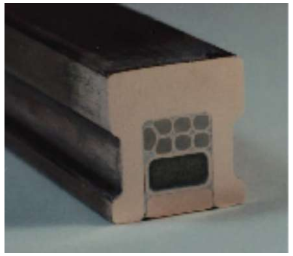


AMY Detector

AMY Detector was installed in
OHO Laboratory.

Main Parameters of AMY Solenoid

Winding scheme	Multi-layer solenoid
Inner diameter	2386 mm
Winding Length	1540 mm
Number of turns	1080
Current	5000 A
Central Field	3.0 T
Inductance	3.2 H
Stored Energy	40 MJ

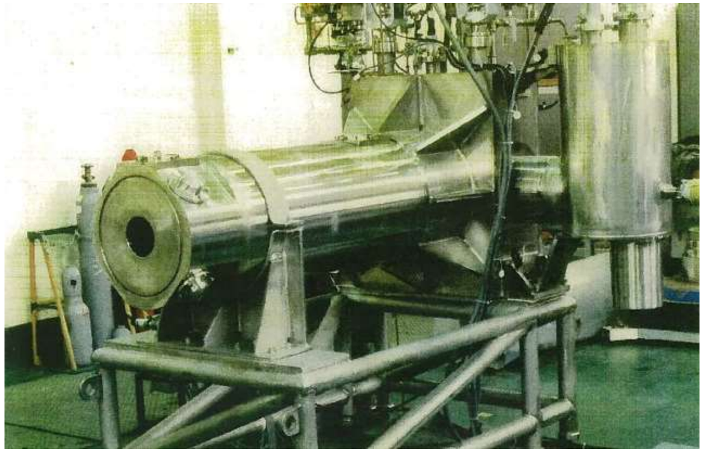


Superconducting Wire

High-purity Aluminum is used as the stabilizer, and a copper housing is used on the outside for rigidity.

3-3 QCS Magnets (TRISTAN, KEKB)

HITACHI
Inspire the Next

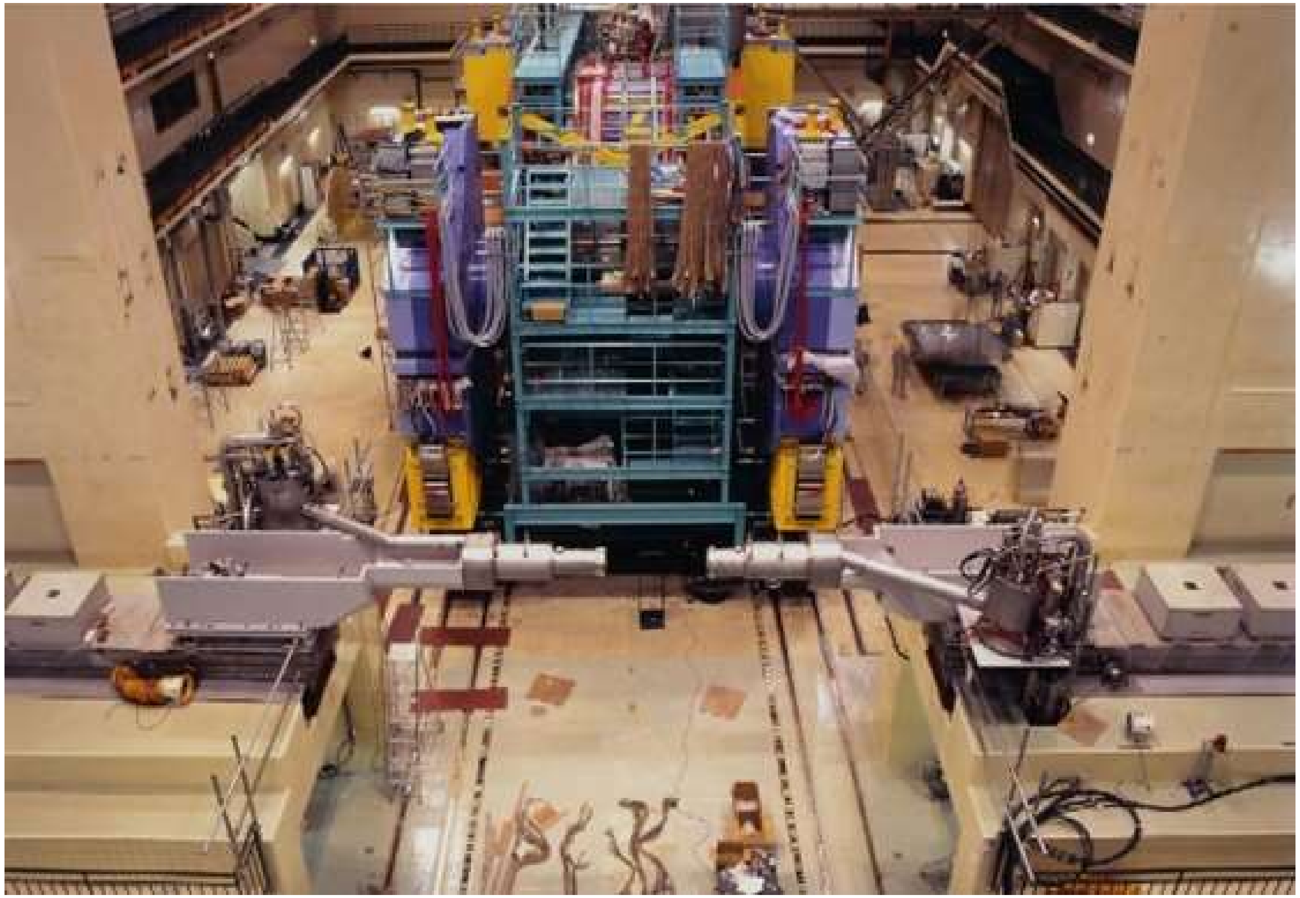


QCS Magnet for TRISTAN

Main Parameters of Quadrupole Magnets (KEKB)

	QCS-L	QCS-R
Field gradient (T/m)	21.66 (21.84)	21.73 (21.84)
Current (A)	2963	2963
Effective length (mm)	483 (486.1)	385 (387.7)
I/Ic @ 4.5K (%)	70	70
Bmax on the cable (T)	4.3	4.3
Stored energy (kJ)	87.5	69.7
Coil length (mm)	617	521
inner dia. (mm)	260	260
outer dia. (mm)	289.8	289.8
Collar outer dia. (mm)	340	340

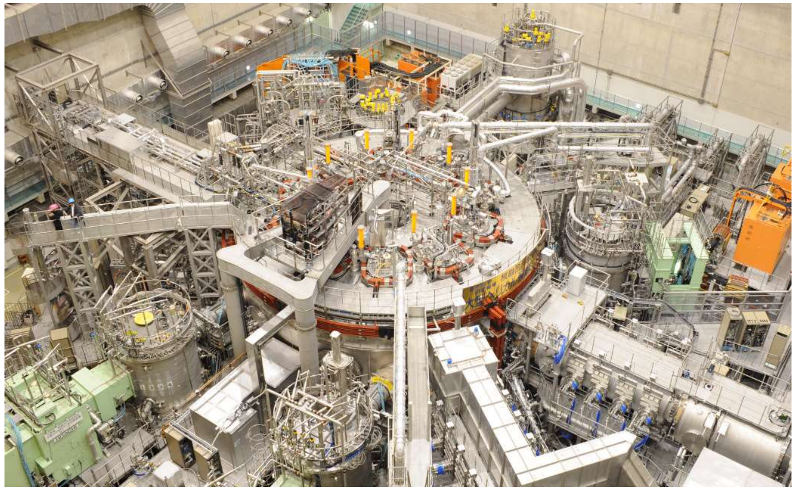
Numbers within parentheses are measured values.



QCS Magnet System for KEKB Interaction Region

3-4 LHD (Large Helical Device) Helical Coils - Nuclear Fusion -

HITACHI
Inspire the Next

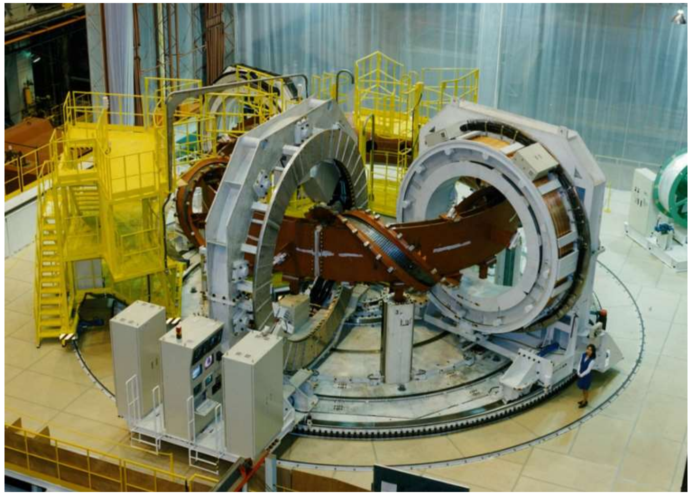


LHD (Large Helical Device)

Device parameter of LHD

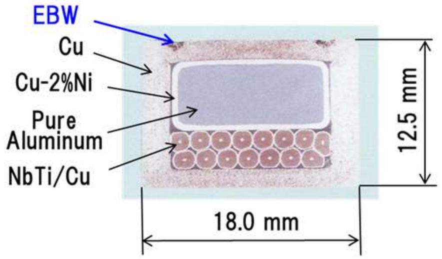
Outside diameter	13.5 m
Height	9.1 m
Major radius	3.9 m
Pitch Number (l/m)	2/10
Minor radius	0.6 m
Plasma volume	30 m3
Magnetic field strength	3 T

LHD was constructed in 1998 at the National Institute for Fusion Science (NIFS) in Japan.

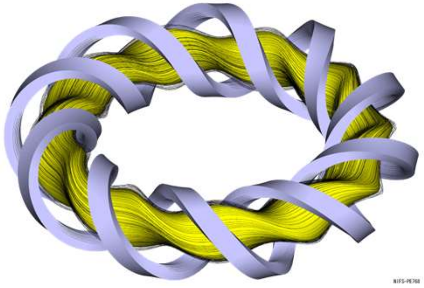


Factory Testing of Winding Machine

On-site Winding (450 turns x 2 coils)



Cross Section of the conductor

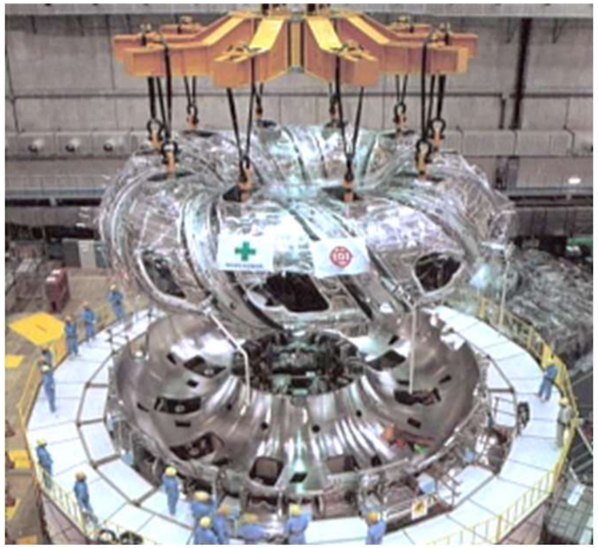


Parameters of Helical Coils

Rated Current	13 kA
Cooling Method	LHe pool boiling
Superconductor	NbTi/Cu/Al
Magnetomotive Force	5.85 MA
Field Strength	3T
Stored Energy	0.96 GJ
Averaged Diameter	7.8 m

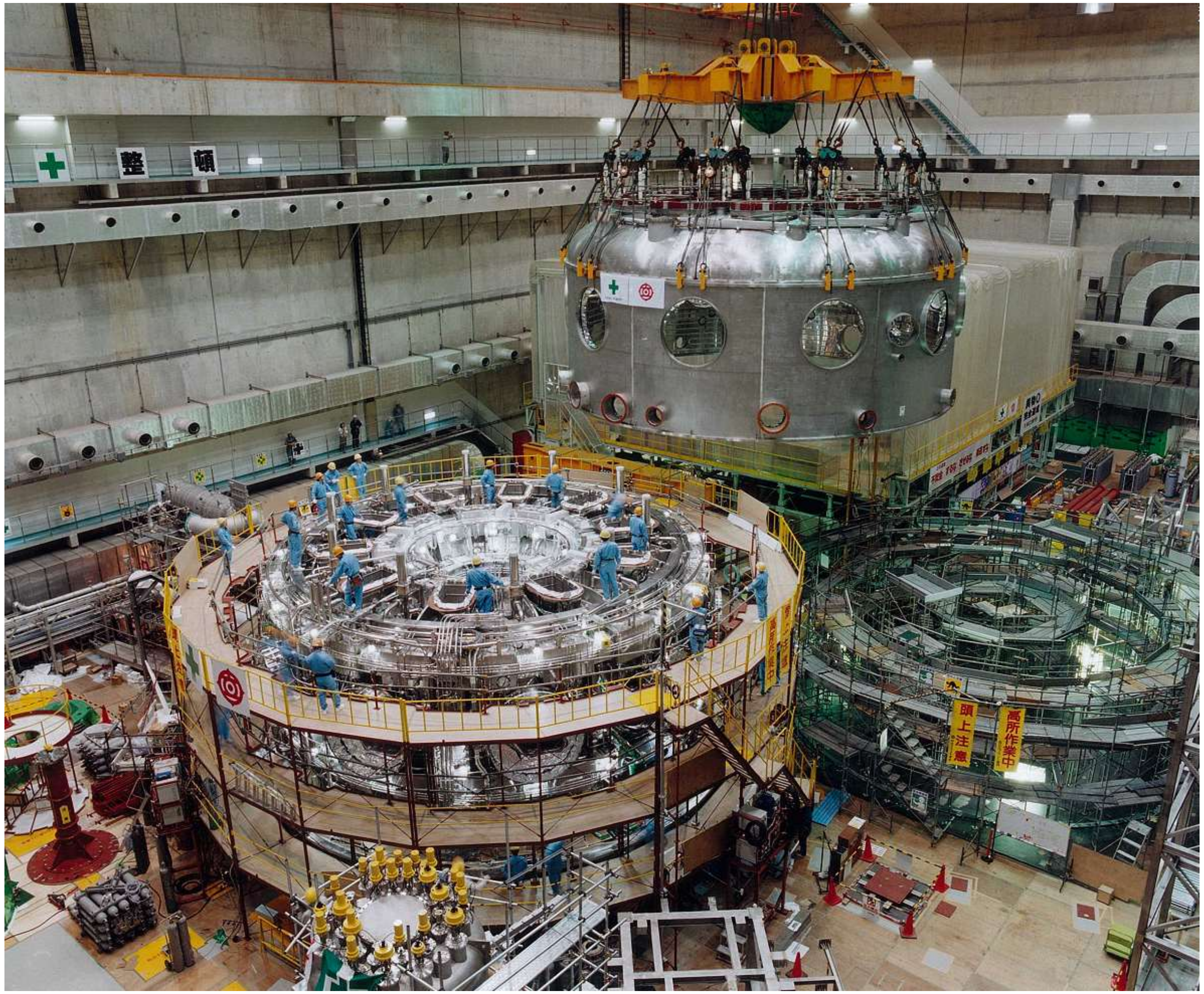
3-4 LHD (Large Helical Device) Helical Coils - Nuclear Fusion -

HITACHI
Inspire the Next



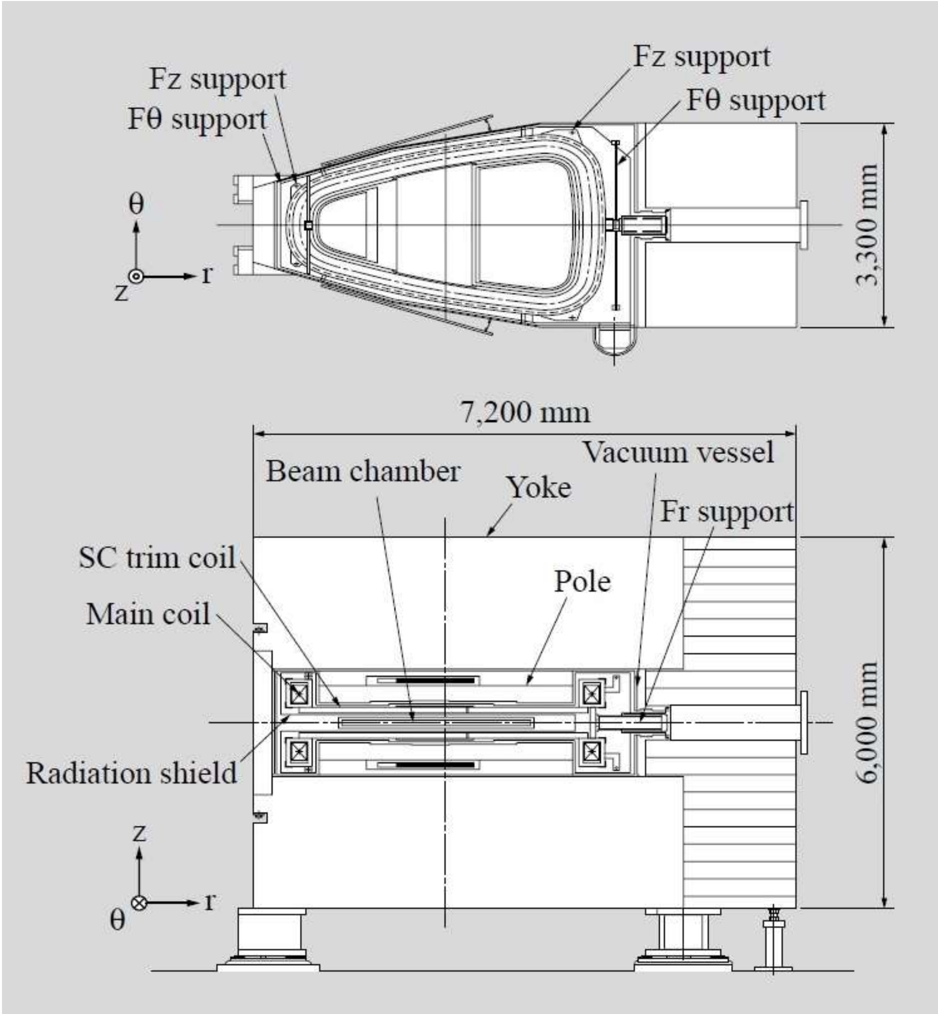
Technologies Developed (some of them)
- Dedicated EBW equipment for welding conductor Cu sheaths
- 13-axis NC helical winding machine
- Laser measuring machine for surface dimension after winding etc.

Results:
- Winding of 36km in total was completed in 18 months
- Achieved specified coil dimensional accuracy
- Stable operation since 1998 after completion of the entire machine



3-5 SRC (Superconducting Ring Cyclotron) Sector Magnets

HITACHI
Inspire the Next



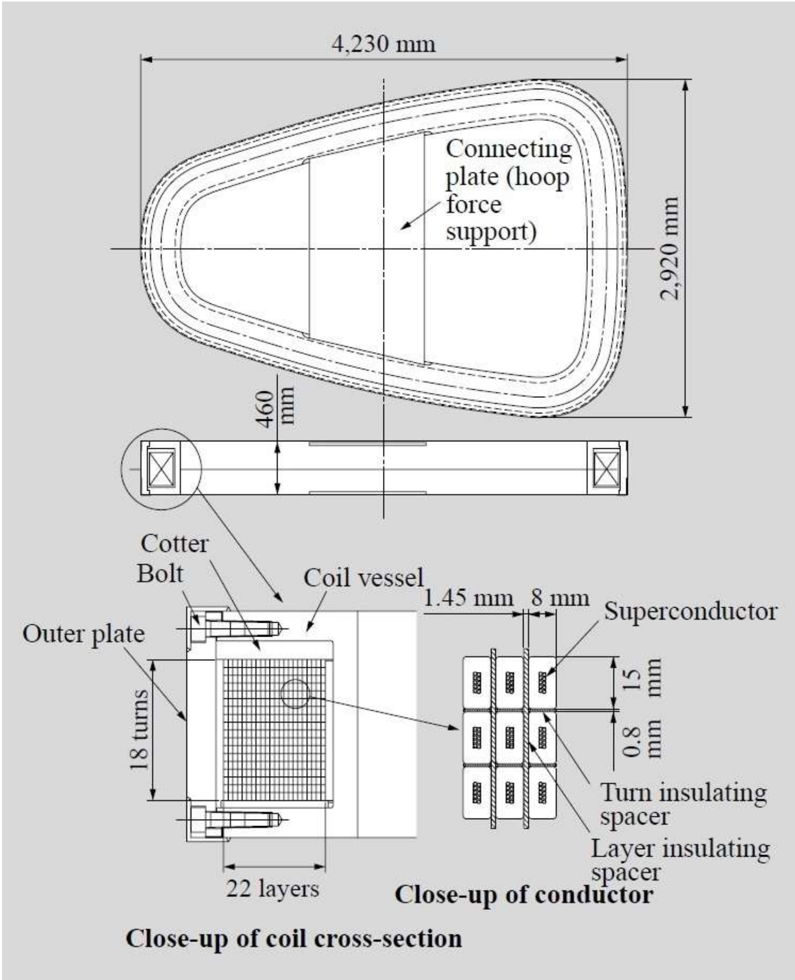
Number of Sectors	6
Maximum Sector Field	3.8T
Maximum Stored Energy	235 MJ
Material of Shield	Pure Iron
Size	Diameter 19m, Height 8m
Total Weight	8300 tons

3-5 SRC (Superconducting Ring Cyclotron) Sector Magnets

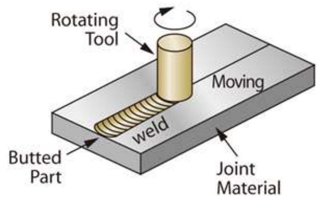
HITACHI
Inspire the Next

Main coil specification

Rated current	5000 A
Cooling scheme	LHe pool boiling
Superconductor	Al stabilized NbTi stranded cable
Magnetomotive force	4 MA/sector
Central Magnetic Field	3.8T
Stored Magnetic Energy	240 MJ/total



Ni-doped Al stabilized conductor:
Sufficient mechanical strength, low electrical resistance, and low cost are achieved.

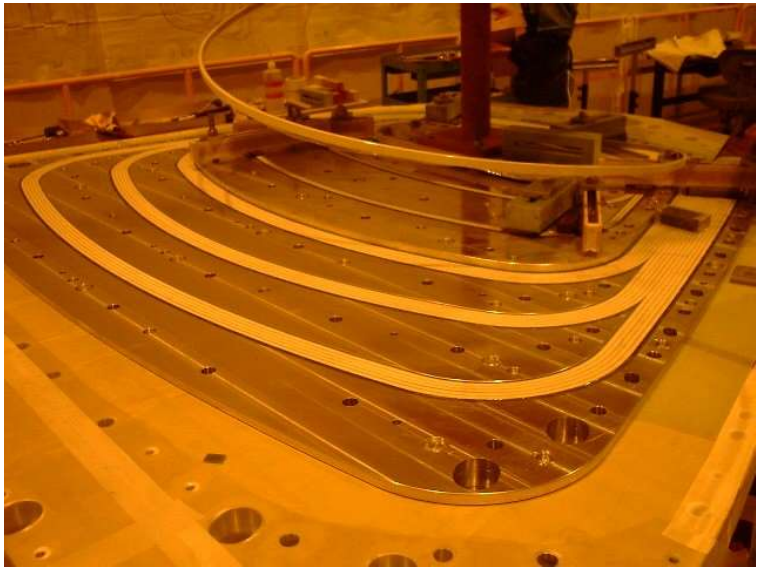


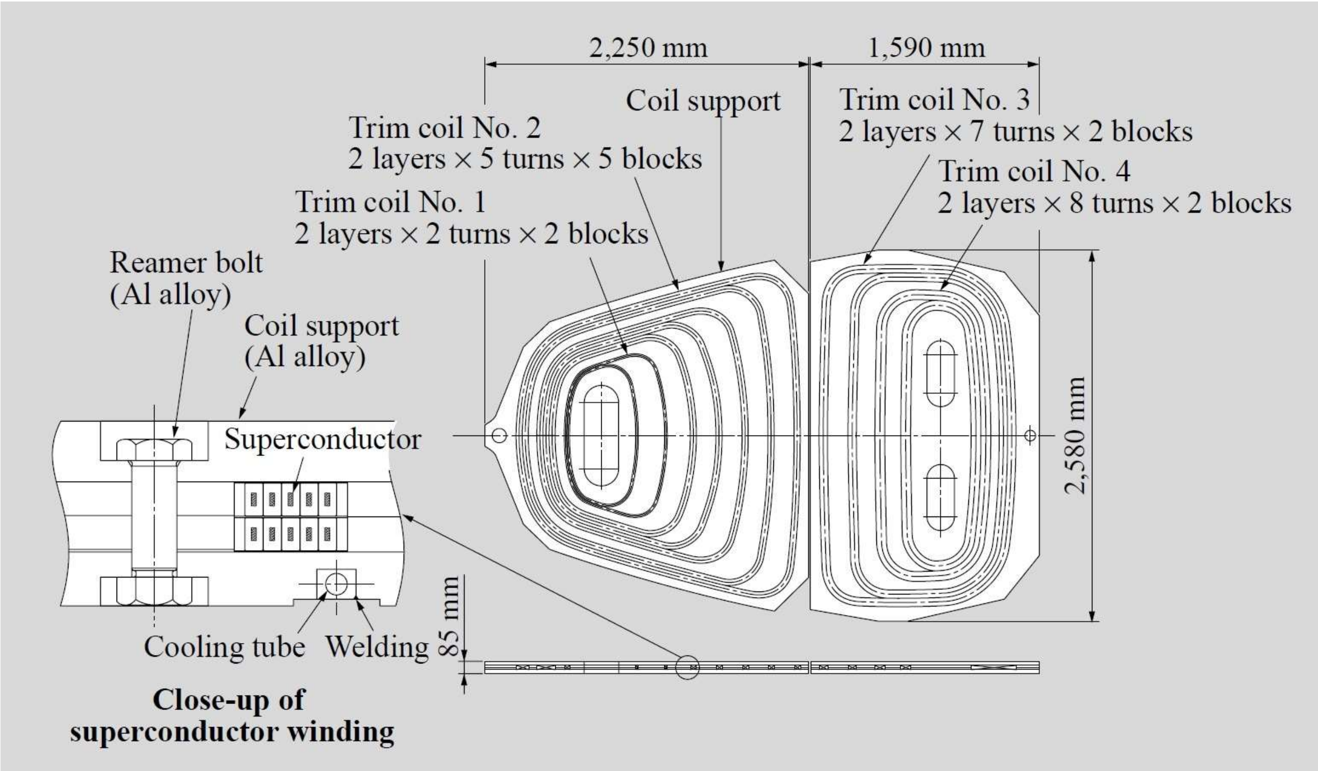
Friction Stir Welding

FSW is used for the conductor connection. Mechanical strength and low electrical resistance are achieved.

3-5 SRC (Superconducting Ring Cyclotron) Sector Magnets

HITACHI
Inspire the Next





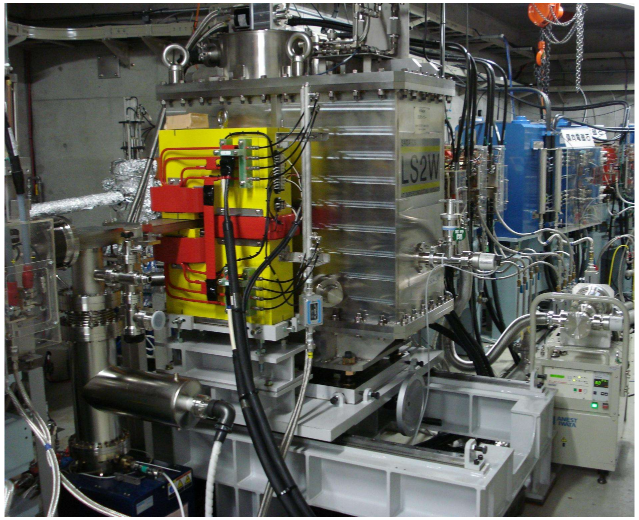
Trim coil specification

Rated current	3000 A
Cooling scheme	Two-phase He flow conduction cooling
Superconductor	Al stabilized NbTi stranded cable

- Double pancake winding coils are sandwiched between two Al-alloy plates with epoxy resin, pressurized and heated, and bonded together.
- Cooling pipes are welded to Al-alloy plates.

4. From Recent Products to the Future

4-1 Superconducting Magnets with GM Refrigerator Cooling



Superconducting Wiggler for 1.4GeV synchrotron radiation facility SAGA-LS

Configuration	Super/Normal Hybrid
Cooling Method	GM Ref. Conduction Cooling
Conductor	NbTi/Cu
Rated Current	172 A
Magnetic Field	4 T
Warm Gap	35 mm
Magnetic Energy	0.05MJ

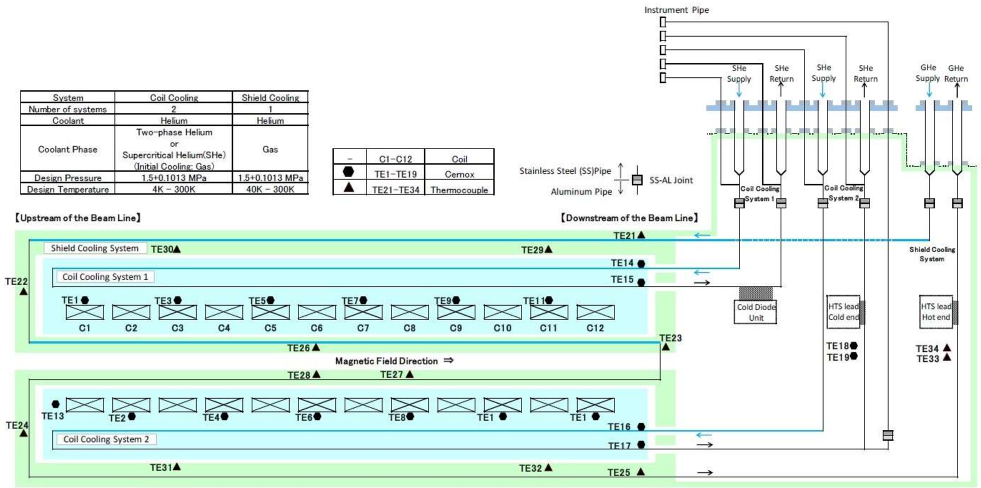
Magnetic Field Measurement @ Factory

Large Bore Superconducting Solenoid for J-PARC Muon Transport Beam Line

Cooling Method	GM Ref. Conduction Cooling
Conductor	NbTi/Cu
Rated Current	180 A
Magnetic Field	0.5 T
Solenoid Length	1.5 m
Warm Bore Diameter	0.6 m
Magnetic Energy	0.6 MJ

4-2 Long Solenoid with SHe Conduction Cooling

HITACHI
Inspire the Next



Cooling He Flow Diagram


Completion of each coil


Completion of Superconducting Solenoid

Superconducting Solenoid for J-PARC Muon Transport Beam Line

Cooling Method	SHe Conduction Cooling
Conductor	NbTi/Cu
Reted Current	415 A
Central Magnetic Field	3.5 T
Length of Solenoid	6 m
Warm Bore Diameter	0.2 m
Magnetic Energy	2.2 MJ
Bobbin Material	Al Alloy
Quench Protection	Cold Diode and Quenchback Heater

4-3 HL-LHC Beam Separation Dipole (D1) Magnets

Coil Winding

Preparation of Yoking

Yoked Magnet

Shell Welding completed

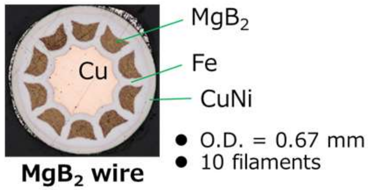
Design Parameters

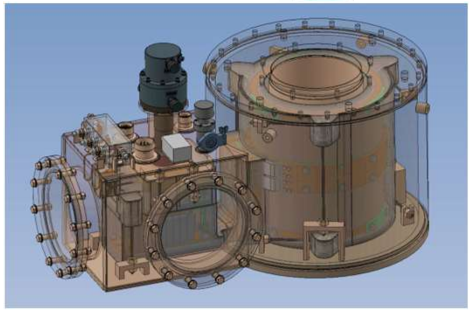
Coil aperture	150 mm
Field integral	35 T m
Field	5.60 T
Current	12.1 kA
Operating Temp.	1.9 K
Conductor	NbTi/Cu
Stored Energy	340 kJ/m
Magnetic Length	6.26 m

4-4 Maintain and Improve Technology for the Future

HITACHI
Inspire the Next

-- New Product Development --



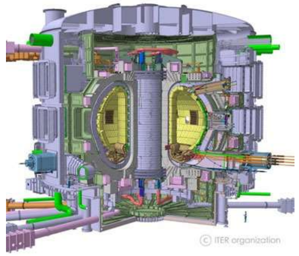


MgB2 Solenoid for X-band Klystron

Central Field	0.8 T
Max. Field in the winding	1.06 T
Stored Energy	11.8 kJ
Operation Current	57.1 A
Warm Bore	Φ 256 mm

-- Maintaining technical capabilities --

▪Manufacture of equipment
for Nuclear fusion experiment



▪Production of equipment
for medical applications

ex. SC magnet for Open MRI
Accelerator equipment for PBT

5. Summary

5-1 Past to Present

(1) Technologies developed (partly based on tech. transfer from Institutes)

Tension winding, Dimension control, Resin impregnation, Heat treatment, Shrink fitting, Conductor EBW, NC winding, Laser measurement, Conductor soldering, FSW, Resin coating, Pressurization and Heating, Heat treatment of superconducting materials (Nb_3Sn, Nb_3Al, MgB_2) , Electrical insulation work, Collaring, Yoking, Precision machining, Precision assembly, Welding control, Regulatory compliance, Electrical test methods, Helium leak test methods, Pressure tightness test methods, etc.

X Co-extrusion of Al Stabilized conductor ----- (Our wire rod business no longer exists)

(2) Technologies required for fabrication of SC Detector Magnets

Part of (1) above plus “Inner winding”. Depends on each magnet specification.
Assuming conductors can be procured !

(3) Things to keep in mind

a. If the product does not continue, the technology is lost.
b. Companies do not invest in themselves for uncertain future orders.
(Unless some synergy can be expected with the direction of the business)

5-2 Future Prospects

HITACHI
Inspire the Next

(1) What companies should work on

a. Maintain manufacturing technology with ongoing efforts in other fields (ex. nuclear fusion, medical applications), even if it is not a superconducting device.

b. Actively adopt technologies that have the potential to be used in other fields

c. Continuously searching for new applications for our technologies

(2) What we expect from this community

a. Accumulation of knowledge and technology needed in the future
When the time comes, transfer them to manufacturers

b. Ensure sufficient budget and processes for prototyping and production
To be able to respond to unforeseen events in a timely manner

c. Technology development with an eye to expanding into other fields
Development as a possibility to open up the future

Photos and Data : Courtesy of KEK, Tsukuba Univ., NIFS, Riken, SAGA-LS, CERN, QST, and others

HITACHI
Inspire the Next

END

Development of Superconducting Magnets for Accelerators in Hitachi

- Toward Future Magnets for Detectors -

Sept. 13, 2022

Tomoyuki Semba

Hitachi, Ltd.

Hitachi Social Innovation is
POWERING GOOD