Status of D1

Tatsushi NAKAMOTO, KEK

On behalf of CERN-KEK Collaboration for D1 Construction for HL-LHC

12th HL-LHC Collaboration Meeting, Uppsala Univ., Sept. 19, 2022

Acknowledgement

- KEK (in particular)

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- Fusac Technologies

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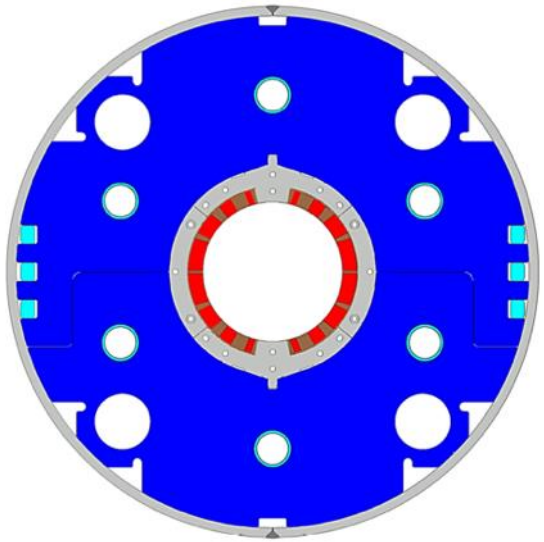
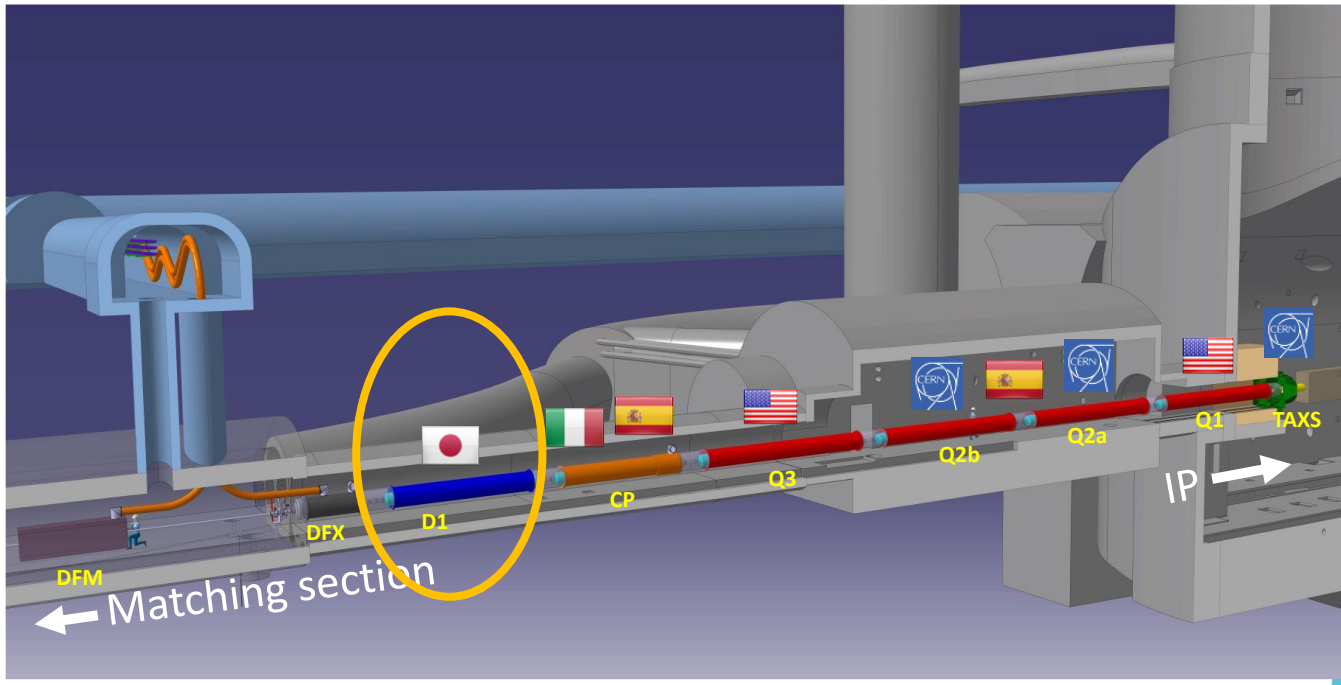
Japanese Contribution to HL-LHC: D1 magnets



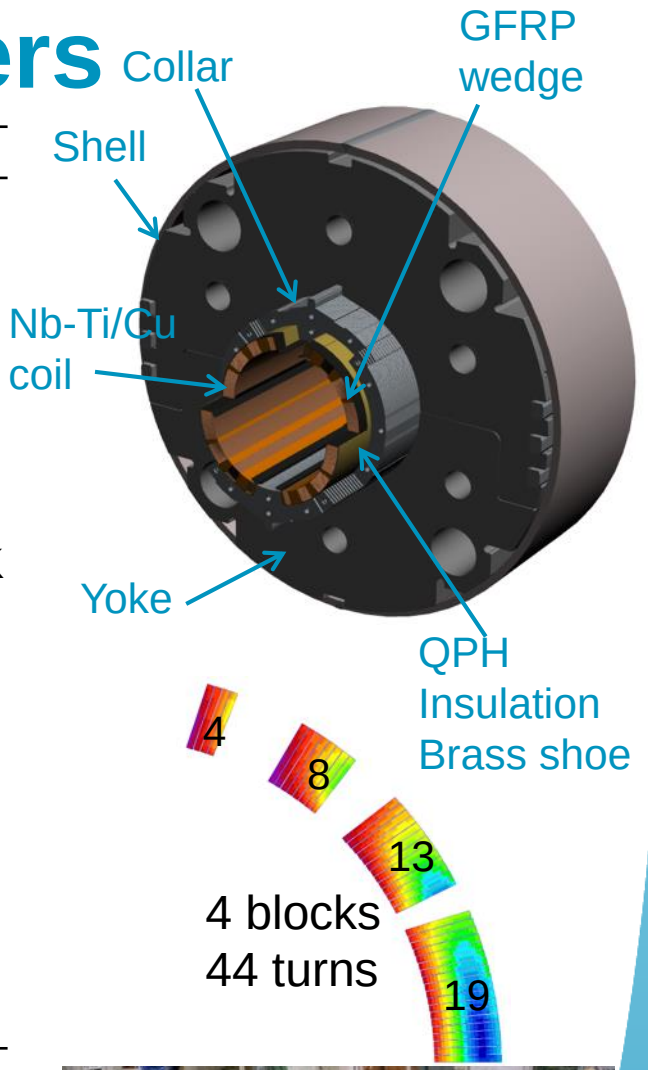


- Beam separation dipole (D1) by KEK
  - Design study of D1 for HL-LHC within the framework of the CERN-KEK collaboration since 2011.
  - 150 mm single aperture, 35 Tm (5.6 T x 6.3 m), Nb-Ti technology.
  - Development 2-m long model magnets (3 units) at KEK
- Deliverables for HL-LHC
  - *1 full-scale prototype cold mass (LMBXFP)*
  - *6 series cold masses (LMBXF1-6)*

7 units x 7-m long cold masses

Design parameters

	prototype, series production (7m)
Coil aperture	**150 mm**
Field integral	**35 T m**
Field (3D)	Nominal: 5.60 T, Ultimate: 6.04 T
Peak field (3D)	Nominal: 6.58 T, Ultimate: 7.14 T
Current	Nominal : 12.11 kA, Ultimate 13.23 kA
Operating temperature	1.9 K
Field quality	<10^{-4} w.r.t B_1 (R_{ref}=50 mm)
Load line ratio (3D)	Nominal: 76.5%, Ultimate: 83.1% at 1.9 K
Differential inductance	Nominal: 4.0 mH/m
Conductor	Nb-Ti: LHC-MB outer cable
Stored energy	Nominal: 340 kJ/m
Magnetic length	6.26 m
Coil mech. length	6.58 m
Magnet mech. length	6.73 m 12 ton
Heat load	**135 W (Magnet total)** **2 mW/cm^3 (Coil peak)**
Radiation dose	**> 25 MGy**



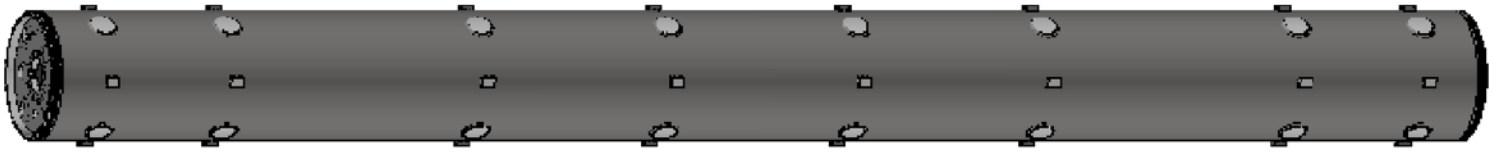
Large-aperture single layer coil →
Mechanical support of a coil is challenging

Three 2 m model magnets were developed at KEK.

D1 Prototype Cold Mass: MBXFP1

Full-scale D1 Prototype

- Magnet technology developed through 2m-long model magnet program (2011-2019) by KEK has been transferred to Hitachi.
- **Objective:** *Validation of design, manufacturing procedure and performance of a full-scale magnet constructed by Hitachi.*
- Cold test of the D1 prototype magnet at 1.9 K at the 9-m deep vertical cryostat at KEK was carried out in June to Sep. 2021.

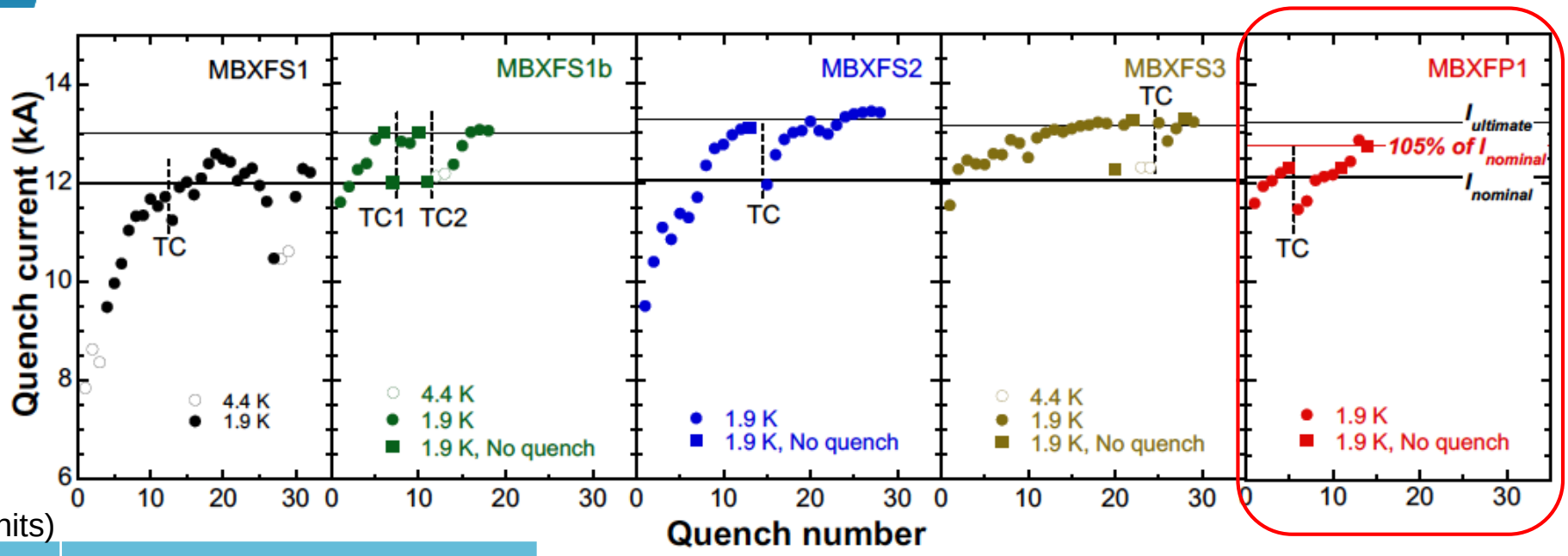


D1 magnet for vertical cold test (Yoked magnet w/ shell, end-ring)

D1 cold mass to be delivered to CERN

Vertical Cold Test Results

Prototype



(units)

	Field Integral at 12.1 kA		
	Calculation		Meas.
	CERN H-Cryo.	**KEK V-Cryo.**	**KEK V-Cryo.**
b_3	-0.5	**-6.5**	**-12.7**
b_5	4.9	**4.8**	**6.5**
b_7	0.3	**0.3**	**0.5**
b_9	0.5	**0.5**	**0.8**
b_{11}	-0.2	**-0.2**	**-0.2**
b_{13}	-0.8	**-0.8**	**-1.0**
b_{15}	-1.3	**-1.3**	**-1.4**

Training behavior

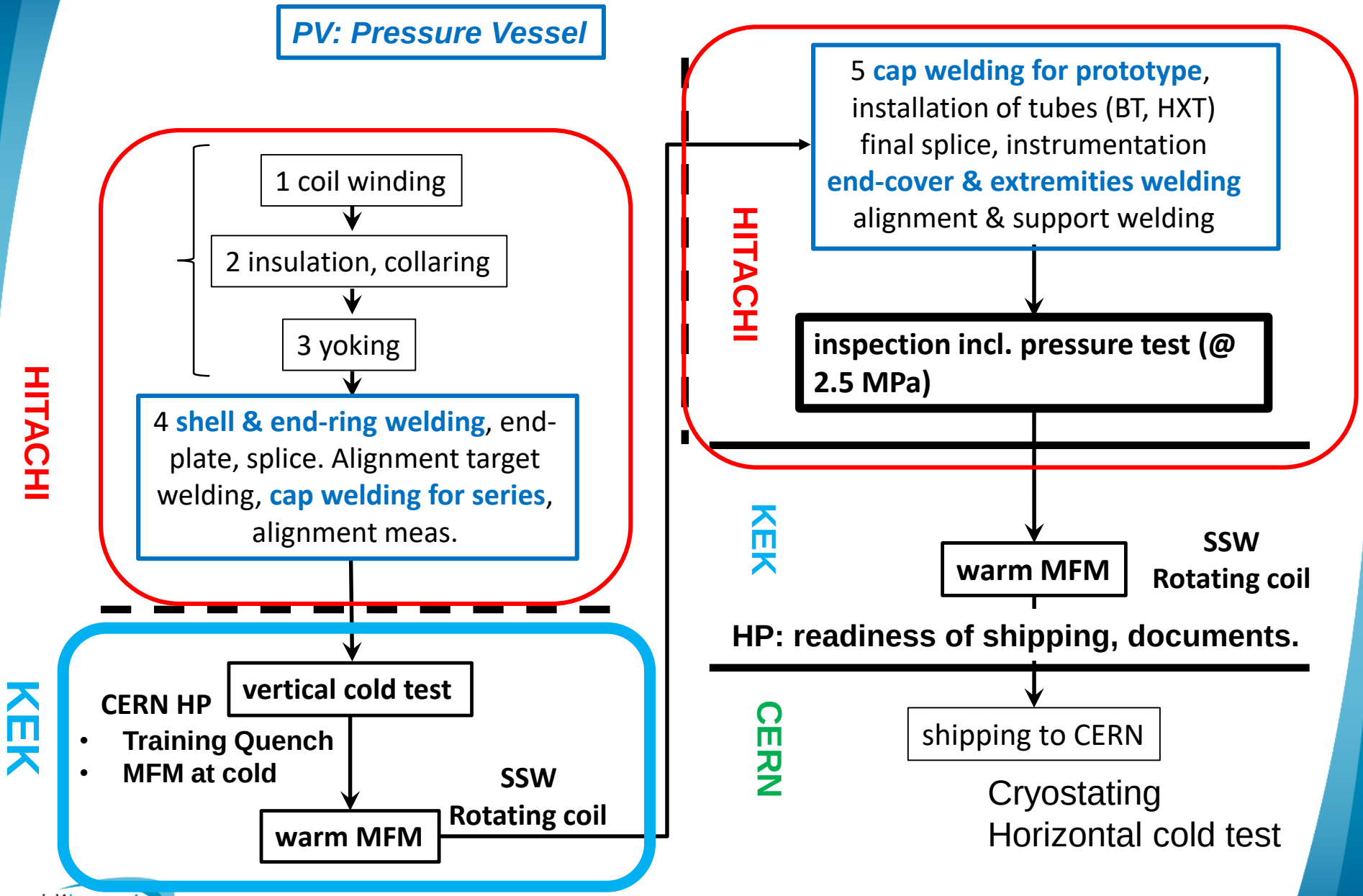
- The maximum current was 12.87 kA which was limited by allowable terminal voltage of DCCB.
- Good performance was confirmed while the ultimate was not demonstrated.

Field quality

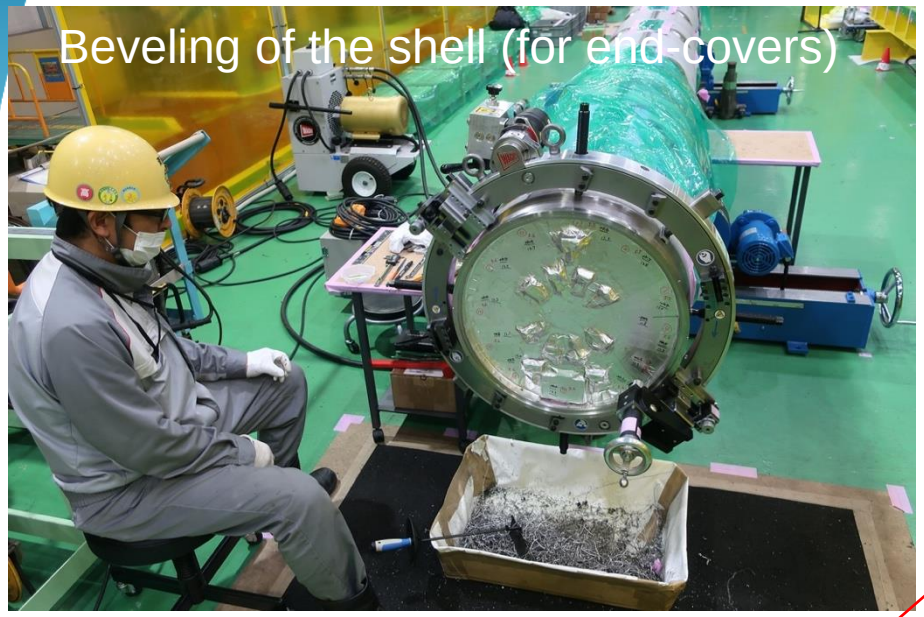
- Some discrepancies observed in b_3 and b_5.
  - Larger discrepancy observed in b_3 integral comes from the coil ends.
- A fine tuning of the coil cross section for series production magnets.

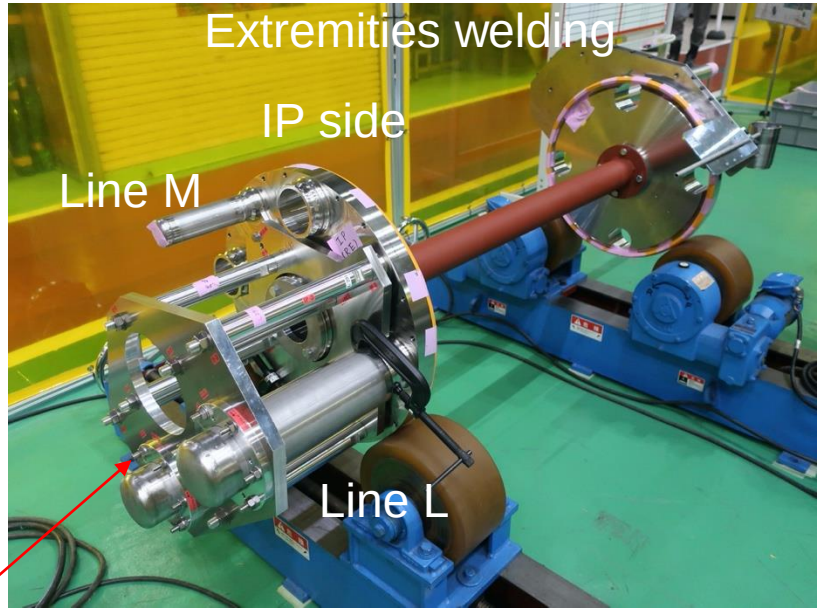
Flow of D1 Cold Mass Production

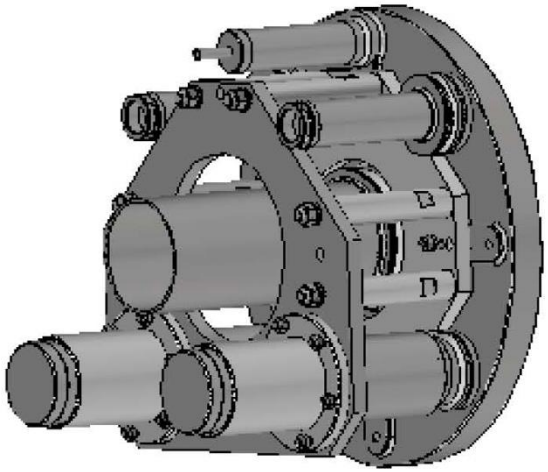
PV: Pressure Vessel

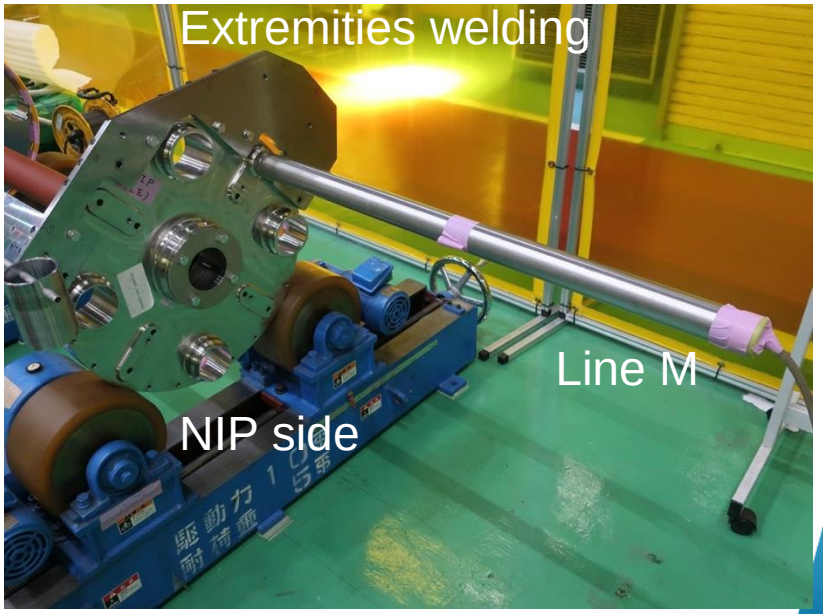


Extremities Welding





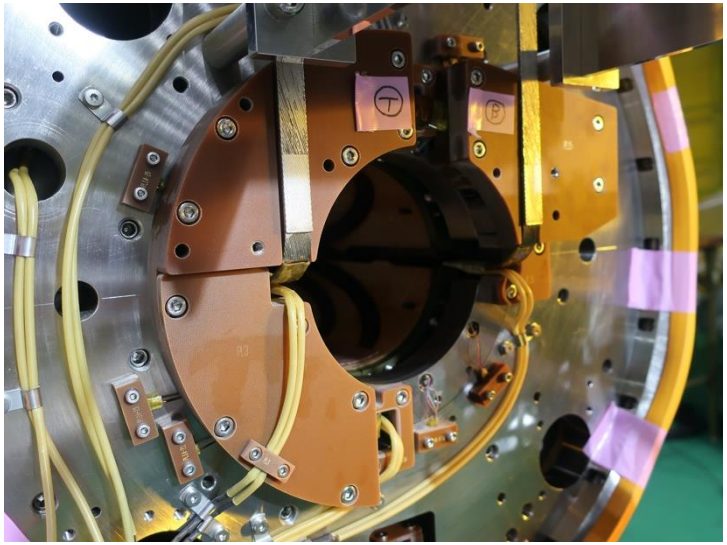


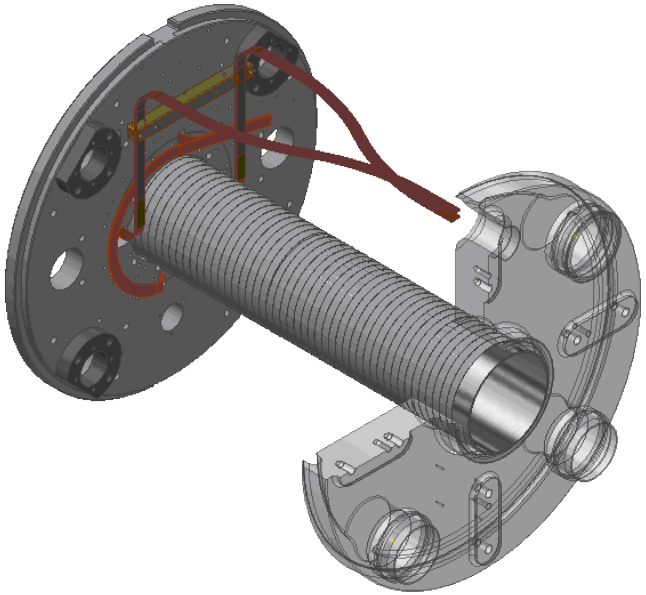


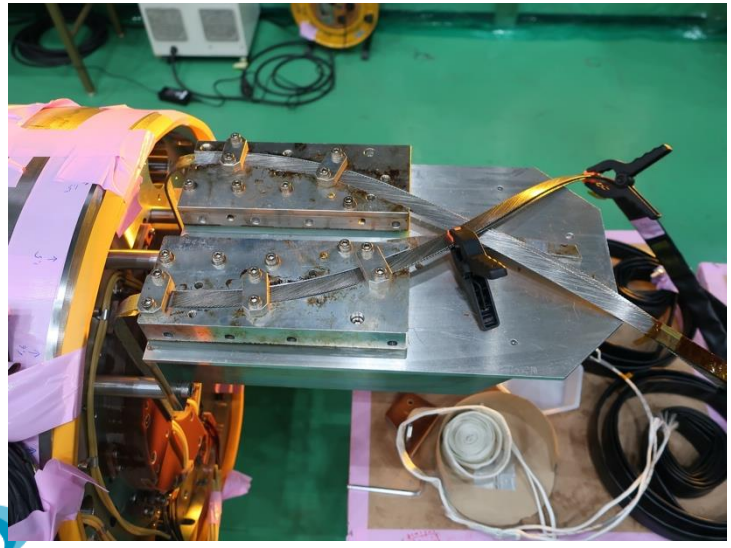
Extremities Position Adjustment Tooling
(Lines M, L, X, V for NIP and IP sides)

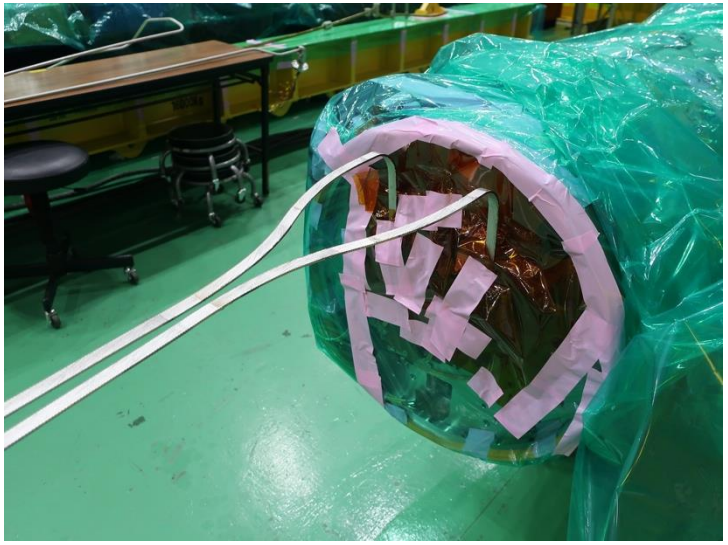
SC Bus Leads and “Spider”

- SC bus leads and “Spider”: thanks to Herve and Rosario.
- Vtap installation and wire routing.

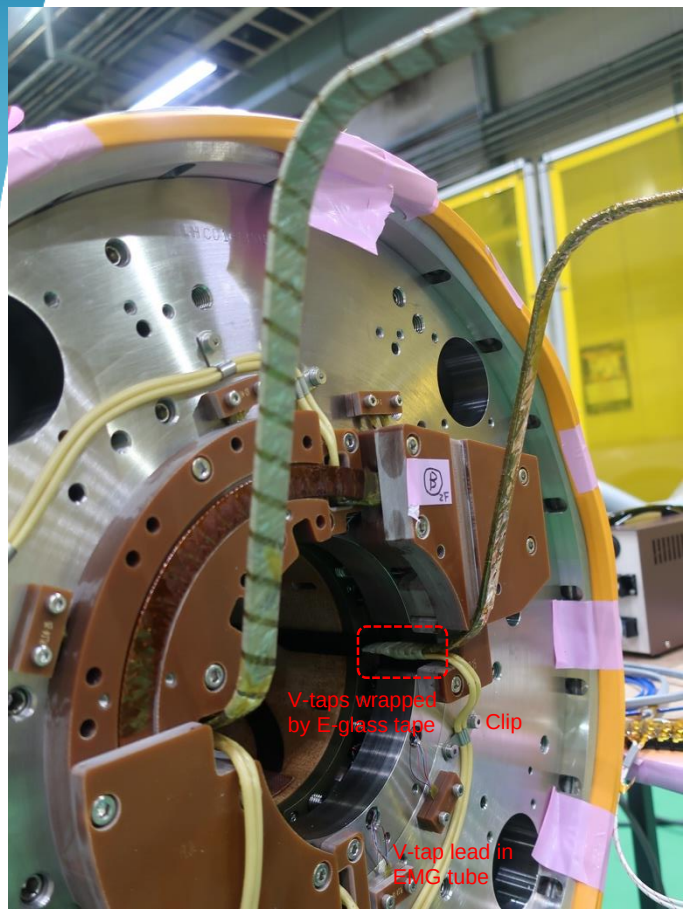


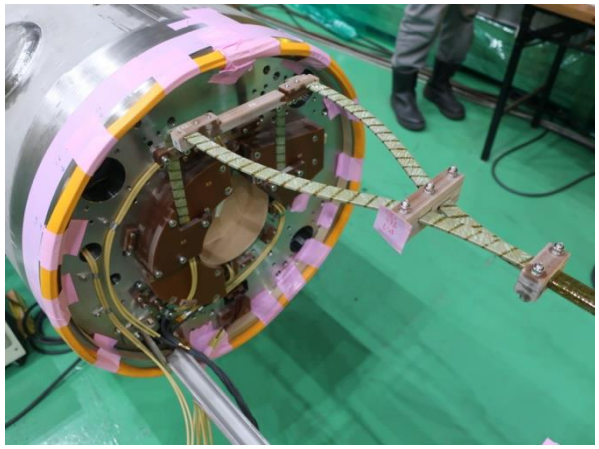


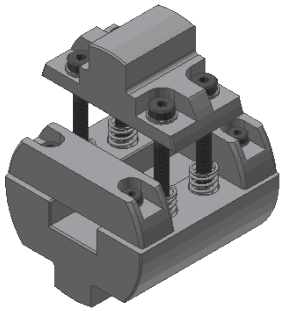


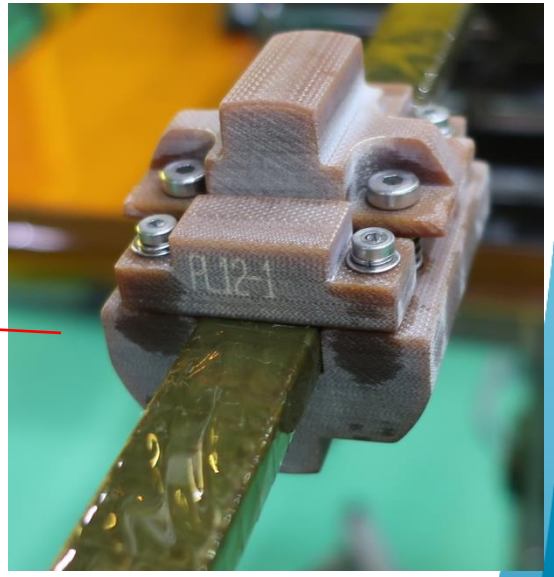


SC Bus Leads and “Spider”

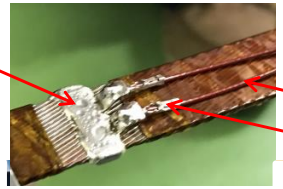






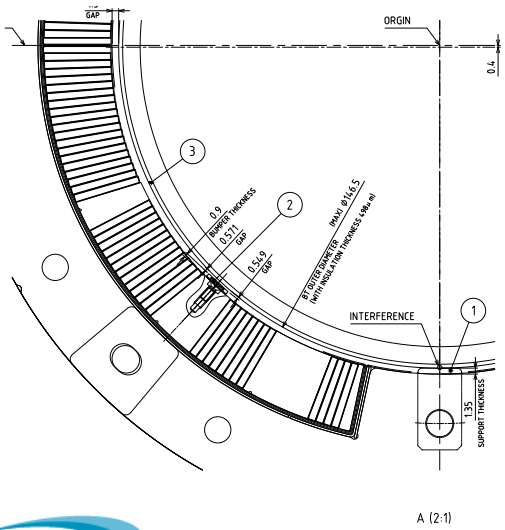


Spider for centering the bus-leads in Line M

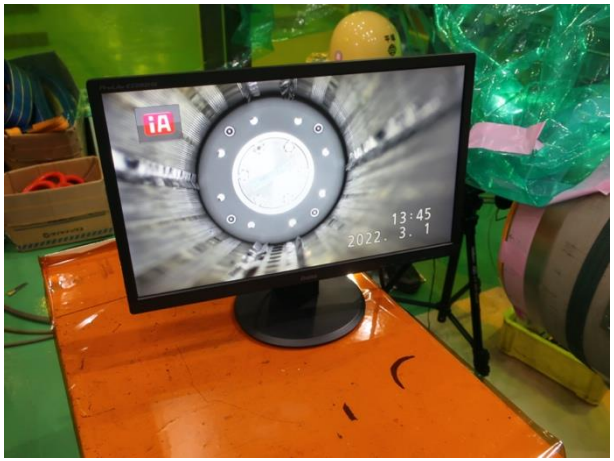


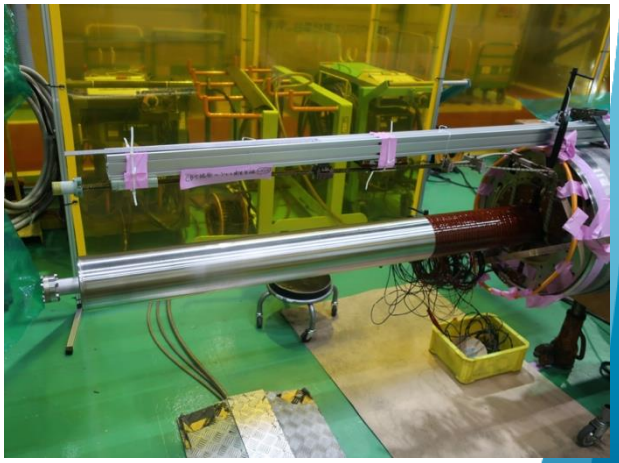
Insertion of CBT

- The allowed gap between CBT and inner surface of the coil structure is approximately ~1 mm.
- Insertion was very smooth and applied load was consistent with prediction (weight of CBT, friction of pinion): impedance induced in the bore was negligible.
- Hipot test at 2 kV was successfully passed.

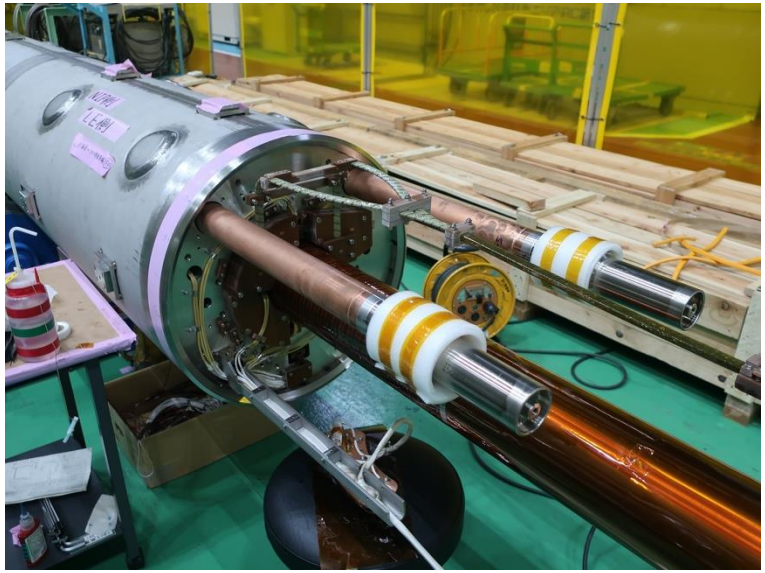


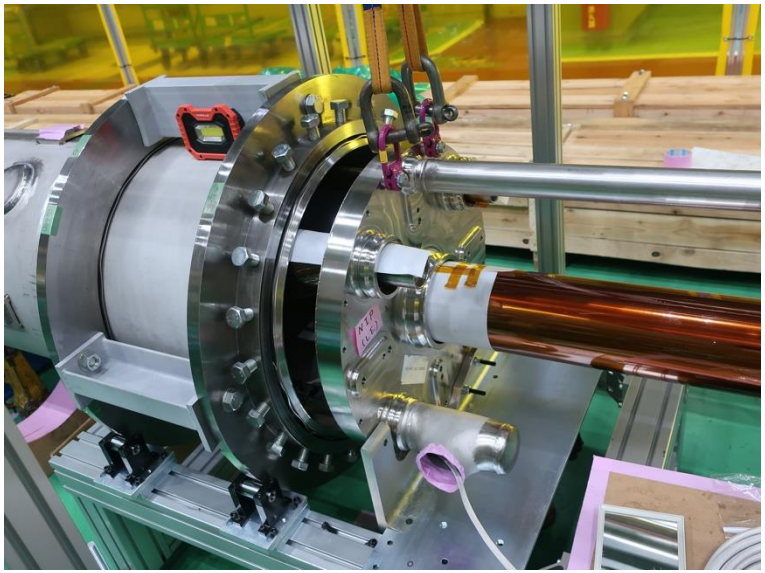
A (2:1)





End-dome, End-cover

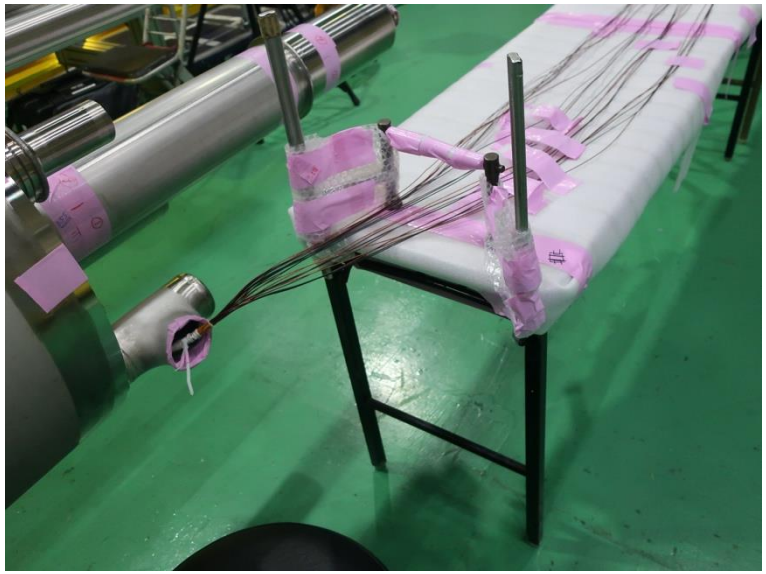




- Outer-rings to correct the formed and longitudinally-welded end-dome.
- Position of the end-cover was precisely aligned with respect to the mechanical fiducial of the magnet defined by the 32 alignment markers using the laser tracker.

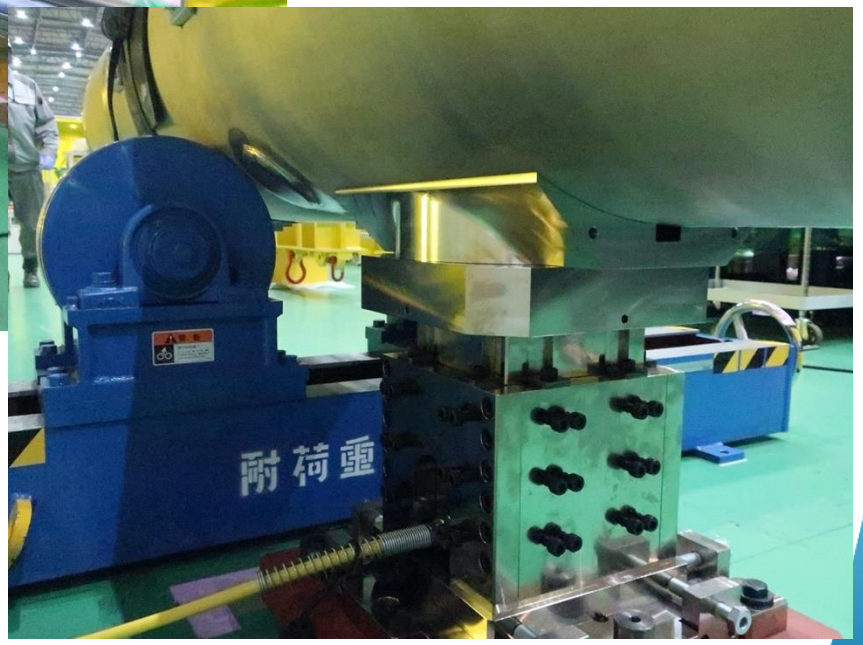
IFS Line

Instrumentation wires, routing



- Hipot test at 3.1 kV between IFS tube and wires was passed.

Saddle

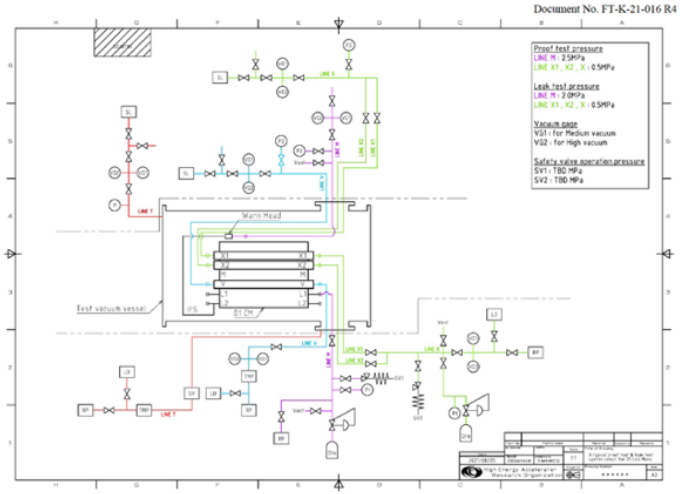


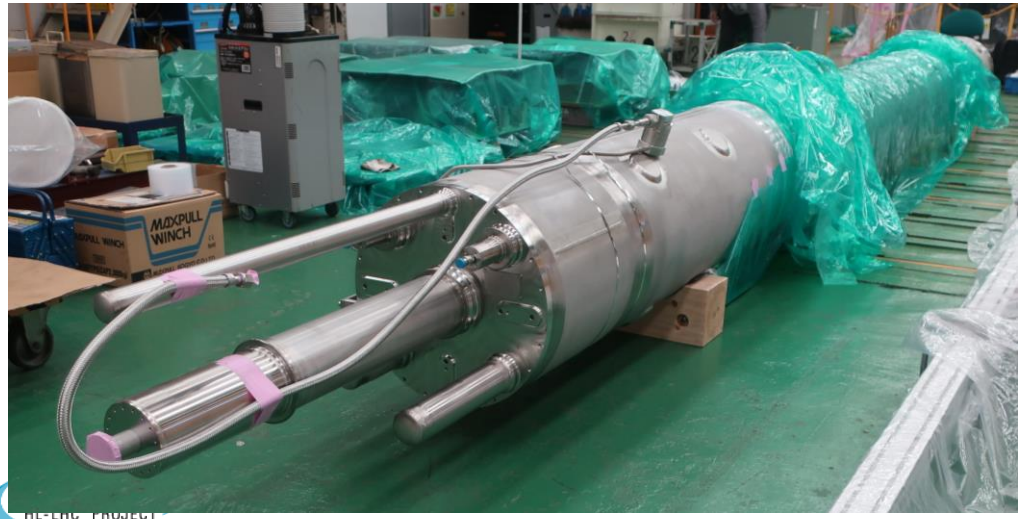
- Position of the support saddles was precisely aligned with respect to the mechanical fiducial of the magnet defined by the 32 alignment markers using the laser tracker.

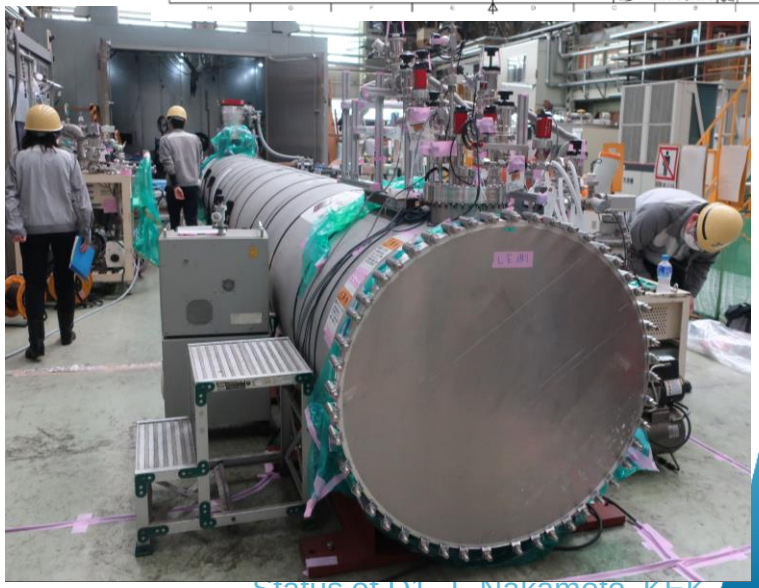
Pressure Proof Test and Leak Test of the D1 Prototype

- A dedicated SS vacuum chamber (10 m long, ID 1000mm) was prepared for the pressure proof test (PPT) and leak test (LT) at Hitachi.
- "Guideline of Proof Test and Helium Leak Test for D1 Cold Masses": EDMS 2681049.
- Test condition and criteria:
  - PPT at 2.5 MPa_{Abs} for cold mass,
  - LT at 2.0 MPa_{Abs}
    - ✓ Vacuum chamber: < 1 e-10 Pam^3/sec
    - ✓ Cold bore tube: < 1 e-11 Pam^3/sec
    - ✓ HX tubes : < 1 e-6 Pam^3/sec

All passed.





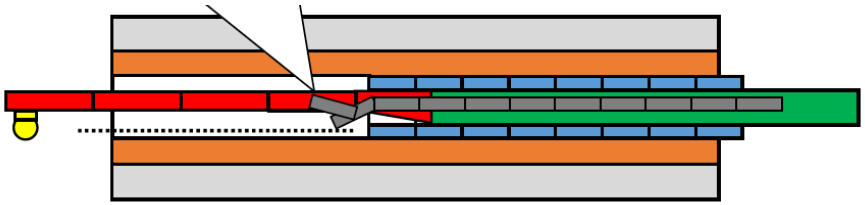


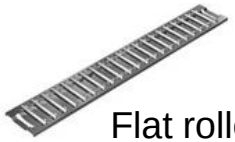
1st Series Production: MBXF5

Manufacturing of MBXF5

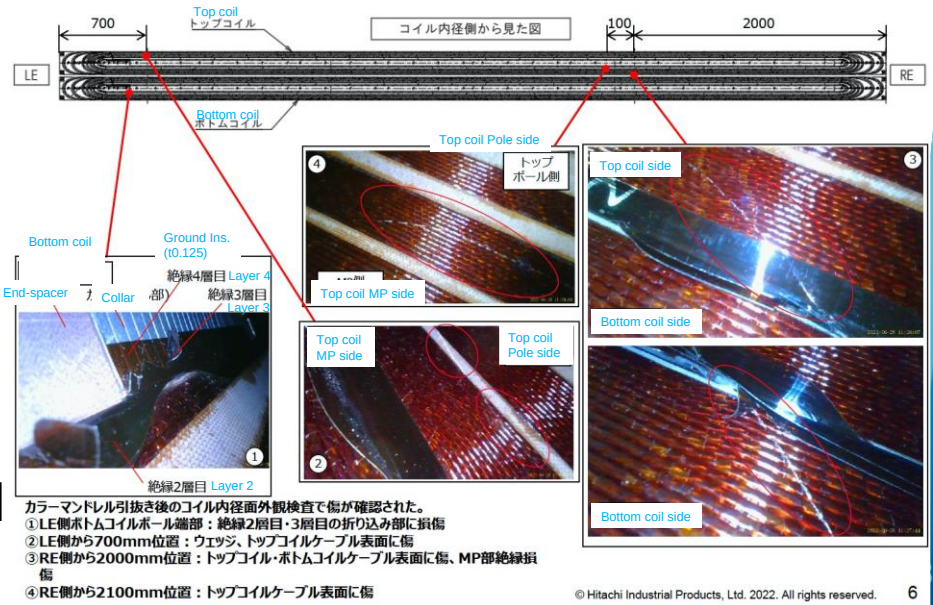
- LT-1 and LB-1 coils for MBXF5 were completed.
  - Estimated coil pre-stress: Good.
    - LB-1: L120.7 (L) & 122.9 (R), LT-1: 121.7 (L) & 122.2 (R) (unit: MPa).
    - EDMS 2724784
- All components for the magnet were already fabricated.
- Collaring and yoking processes were successfully done in June 2022.
- NC: potential coil insulation damage was found after removal of the collaring-mandrel. EDMS 2753776.
  - Disassembly was started in Sep. for further inspection.

Spacers more than plan were removed from the RE side and the coil were exposed to the flat-rollers…





Flat rollers



MFM of MBXF5 after yoking

- Experimental check of **new coil cross section for the series magnets.**
  - Fine tuning of b_3 and b_5 with respect to the MBXFP1.
- Warm field measurement at Hitachi Rinkai-work.

R_{ref}=50 mm

Measurement

Calculation

n	Data						Roxie2D					
	MBXFP		MBXF5		MBXF5-MBXFP		MBXFP (v11.D)		MBXF5 (v13.A)		MBXF5-MBXFP	
	an	bn	an	bn	an	bn	an	bn	an	bn	an	bn
2	-1.4	0.8	-1.7	-0.3	-0.3	-1.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	-4.9	-0.6	-0.1	-0.6	4.8	0.0	-7.3	0.0	-2.7	0.0	4.6
4	0.1	0.4	0.0	0.0	-0.1	-0.4	0.0	0.0	0.0	0.0	0.0	0.0
5	-0.1	2.9	0.0	-2.8	0.1	-5.7	0.0	2.7	0.0	-2.8	0.0	-5.5
6	0.3	0.1	0.1	0.2	-0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	1.0	0.1	0.0	0.1	-1.0	0.0	1.1	0.0	0.1	0.0	-1.0
8	0.4	0.1	0.1	0.0	-0.2	-0.1	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.6	0.1	0.1	0.1	-0.5	0.0	0.6	0.0	0.0	0.0	-0.6
10	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0
12	-0.2	-0.1	0.0	0.1	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	-0.6	0.0	-0.5	0.0	0.0	0.0	-0.6	0.0	-0.6	0.0	0.0
14	-0.5	-0.3	0.1	0.0	0.5	0.3	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	-1.0	0.1	-1.0	0.2	0.0	0.0	-1.2	0.0	-1.0	0.0	0.1
16	-0.3	-0.2	-0.1	-0.1	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0
17	0.1	-0.6	0.0	-0.5	-0.1	0.1	0.0	-0.7	0.0	-0.7	0.0	0.0
18	0.3	0.1	0.1	0.1	-0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.3	-0.1	0.1	0.0	-0.2	0.0	0.4	0.0	0.4	0.0	0.0
20	0.0	0.0	-0.1	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0

- ✓ Tuning of Multipoles: Consistent with the 2D model
- ✓ KEK proposes to give Hitachi a green-light to resume fabrication of the wedges of MBXF2.

Production Schedule

Plan by Hitachi in June 2022

- MBXFP1: Delivery to KEK Sep. 26th. SSW meas. Delivery to CERN planned in Dec. 22.
- MBXF5: Being disassembled due to the coil surface damage (EDMS 2753776).
- MBXF1: Two coils are ready for the collaring.
- MBXF2: Coil winding with new wedges will be started in December.