# Highlights on status of activities in Hitachi


**Tatsushi NAKAMOTO, KEK**

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



12th HL-LHC Collaboration Meeting, Uppsala Univ., Sept. 21, 2022

# Flow of D1 Cold Mass Production

HITACHI

3 yoking

4 **shell & end-ring welding**, end-plate, splice. Alignment target welding, **cap welding for series**, alignment meas.

KEK

**vertical cold test**

**CERN HP**

- **Training Quench**
- **MFM at cold**

**warm MFM**

**SSW**
**Rotating coil**

HITACHI

5 **cap welding for prototype**, installation of tubes (BT, HXT) final splice, instrumentation **end-cover & extremities welding** alignment & support welding

**inspection incl. pressure test (@ 2.5 MPa)**

KEK

**warm MFM**

**SSW**
~~**Rotating coil**~~

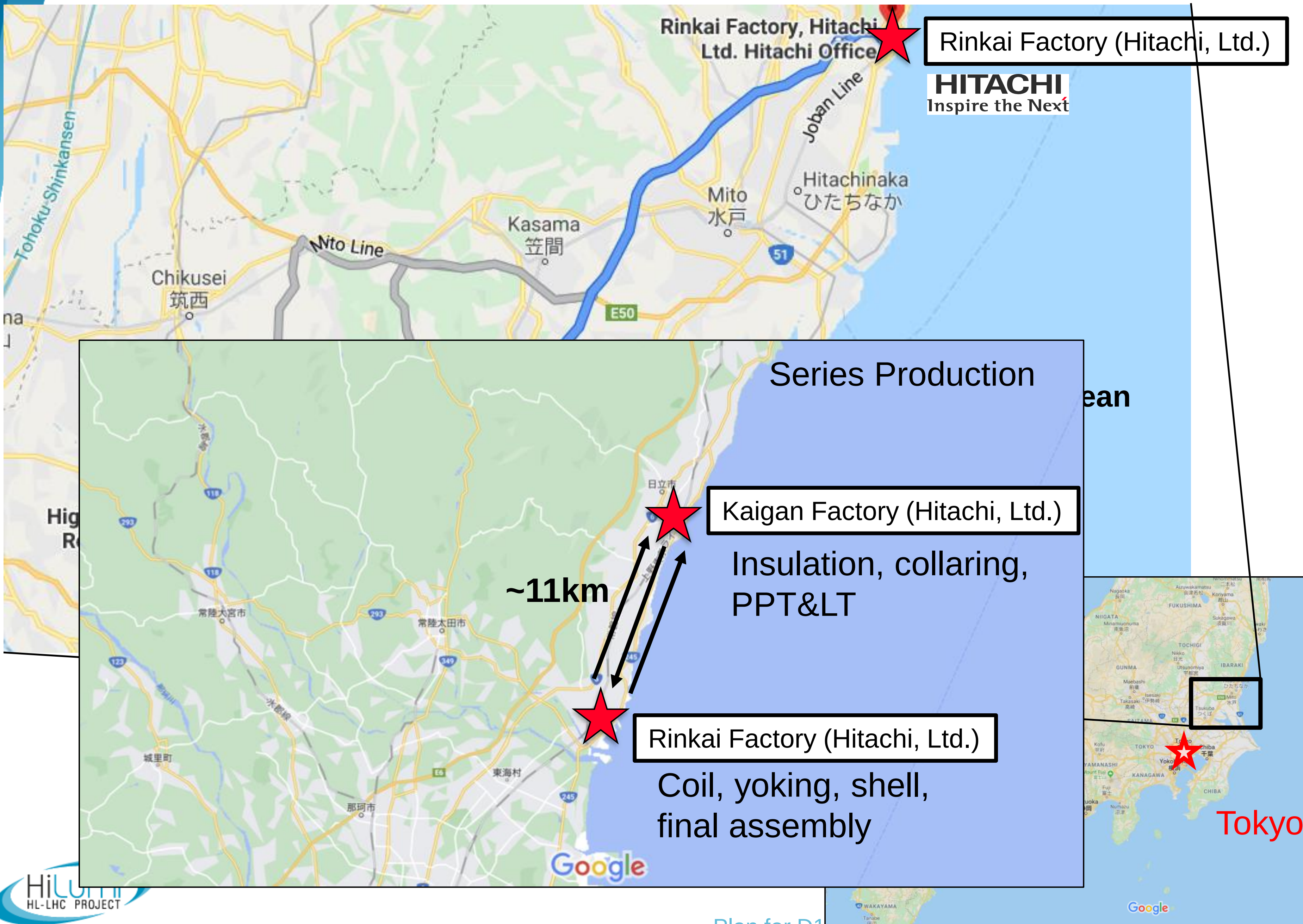
**HP: readiness of shipping, documents.**

CERN

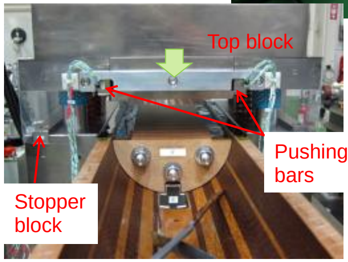
shipping to CERN

Cryostatting
Horizontal cold test

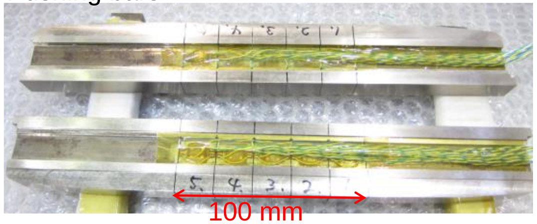
# Hitachi Workshop and KEK Tsukuba

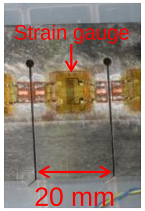


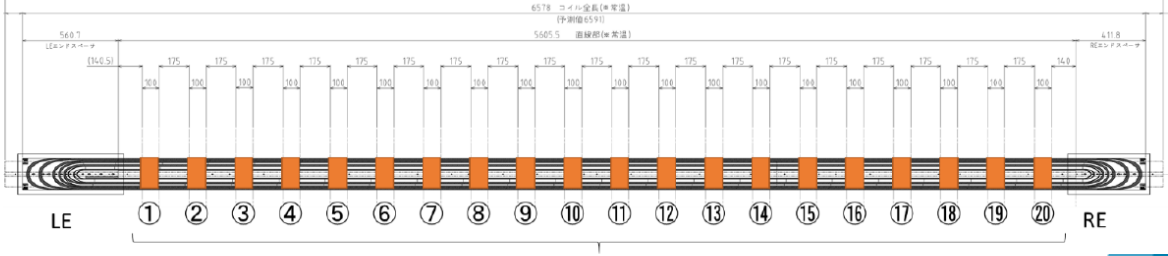
# Manufacturing of D1 Prototype


Pushing bars



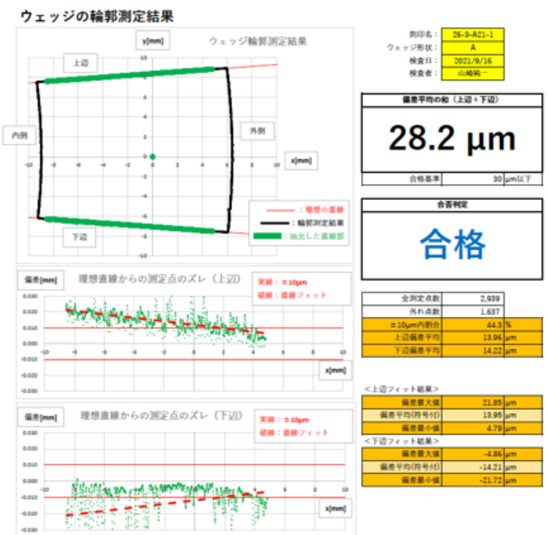




Control of the coil size is crucial for the D1
- to attain the sufficient preload for the training performance, and
- not to exceed the mechanical limit of insulation.

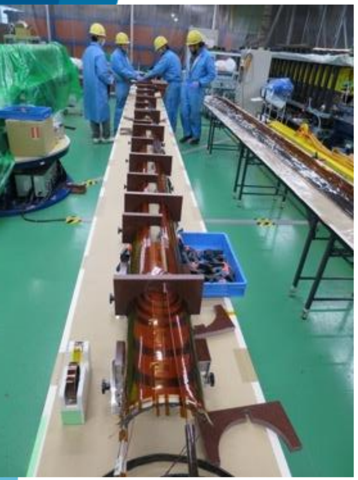
# Summary of results of coil size measurement

| Magnet | Coil | Total average (MPa) | Max value (MPa) | Min value (MPa) | Standard deviation (MPa) | Cable thickness (44 stack) wrt S2-4 cable (mm)* |
|---|---|---|---|---|---|---|
| MBXFP1 | LPT-1 | 112 | 116 | 106 | 2.0 | 0.262 |
| | LPB-1 | 110 | 113 | 108 | 1.4 | 0.256 |
| MBXF5 | LT-1 | 122 | 125 | 119 | 1.5 | 0.418 |
| | LB-1 | 122 | 125 | 118 | 1.8 | 0.422 |
| MBXF1 | LT-2 | 117 | 120 | 114 | 1.3 | 0.397 |
| | LB-2 | 125 | 128 | 112 | 1.6 | 0.403 |

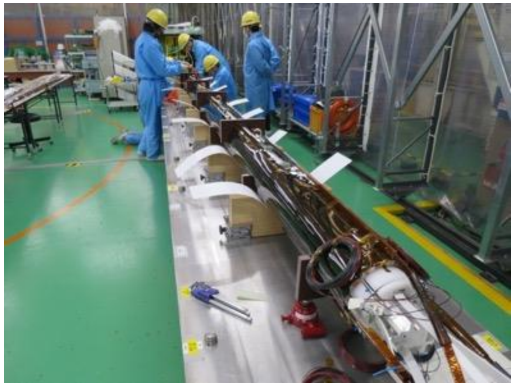
- **Target range of the total average: 115±10 MPa.**
- Thickness of the insulated SC cables from 19 spools was determined by the "10-stack measurement" before the coil winding.
- Dimension control of the wedge thickness: <30 μm
- All the prestresses are within the target range.
  - ➢ Check for the LB-2 coil with higher value is underway.



# Manufacturing of D1 prototype



QPH, ground insulation wrapping

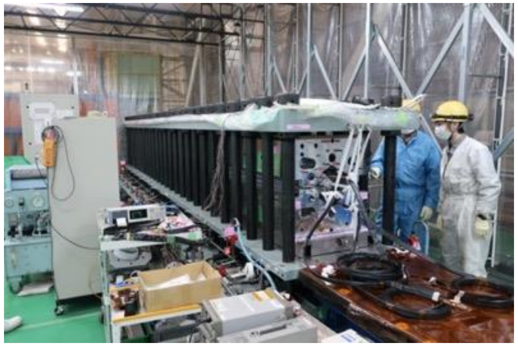


Top/bottom coil assembly

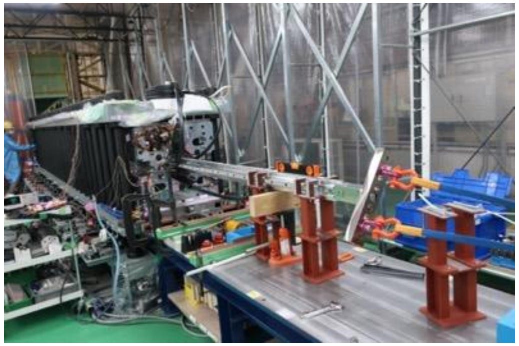
Brass shoe assembly

Collaring

Collared coil on bottom yoke



Yoking



Removal of collaring mandrel

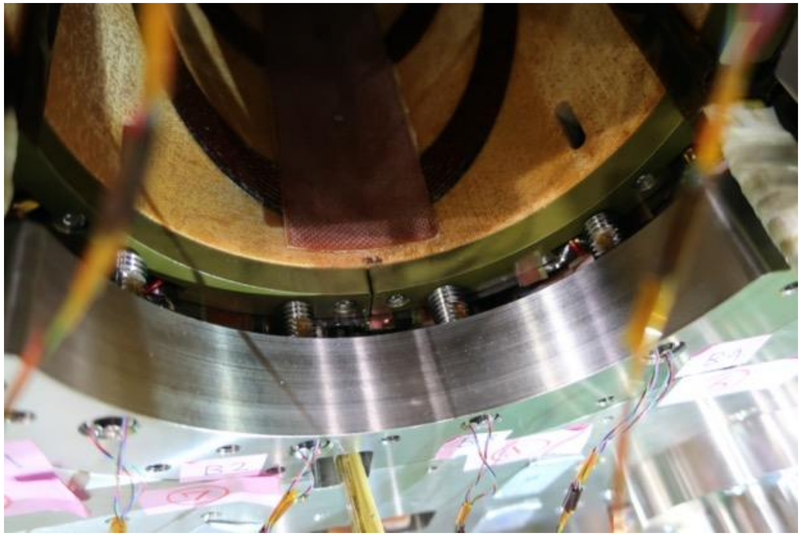
Shell welding

Welding of alignment markers

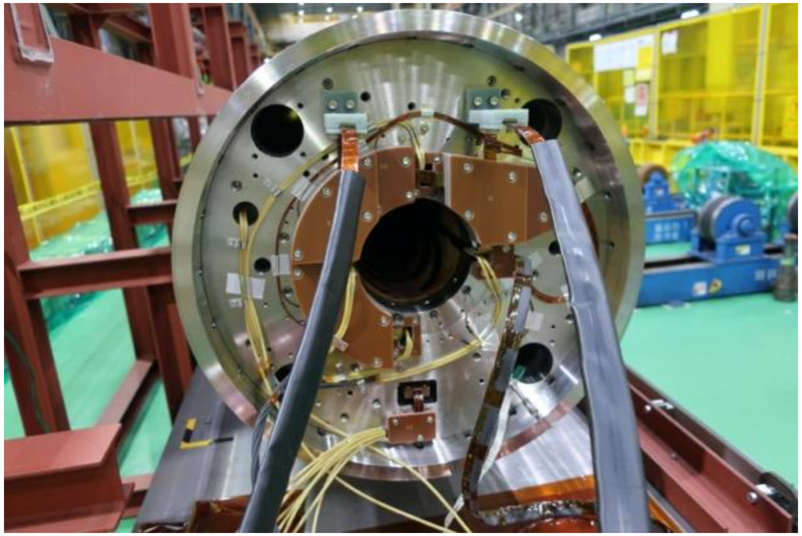
End ring welding

# Manufacturing of D1 Prototype

- Axial compression on SC coils



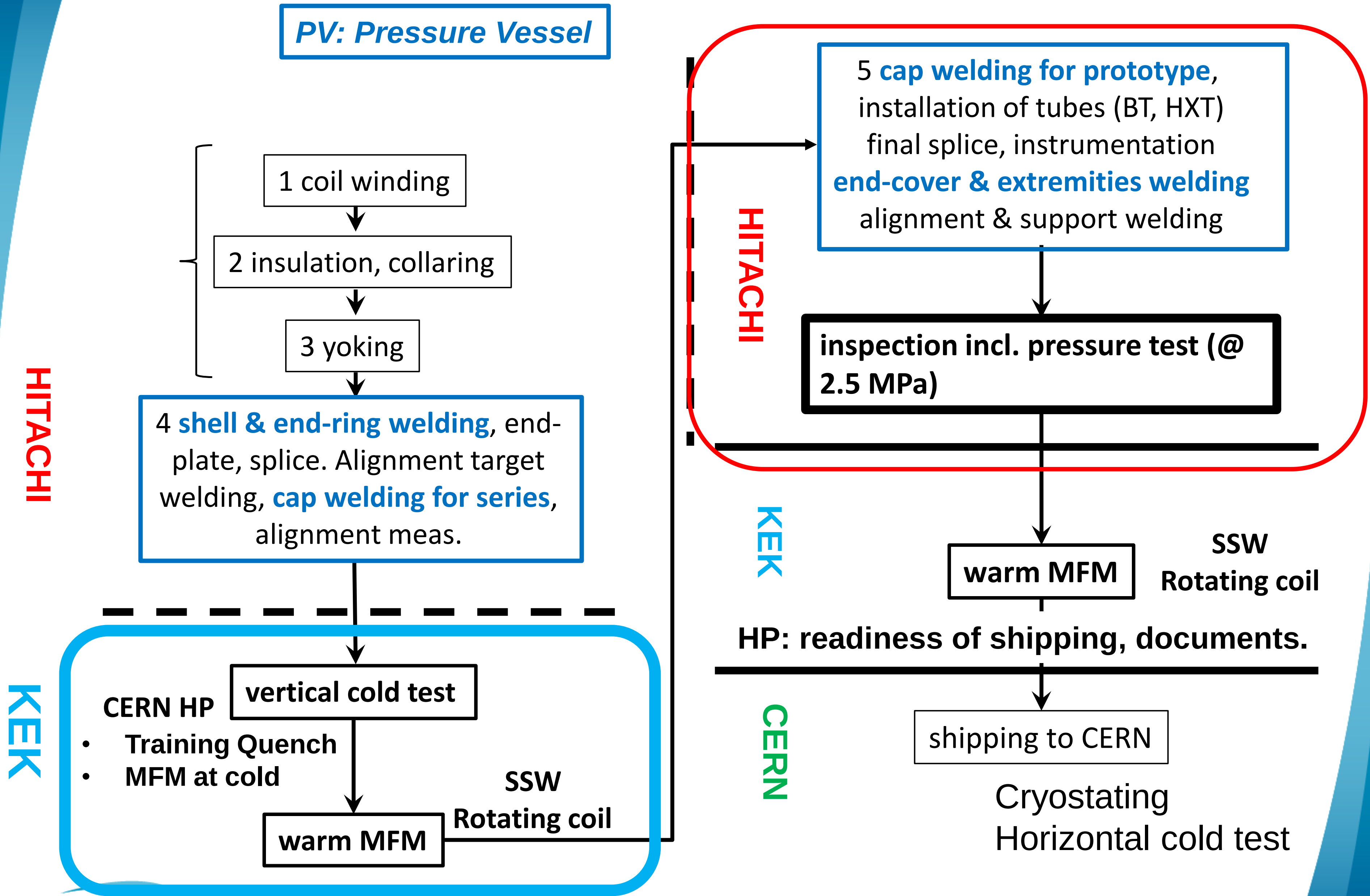
- Splice work and bus-leads



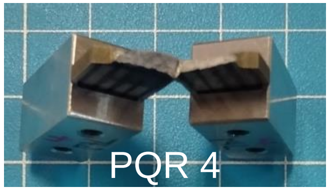
# Manufacturing of D1 Prototype

- Completed D1 prototype magnet

# Flow of D1 Cold Mass Production

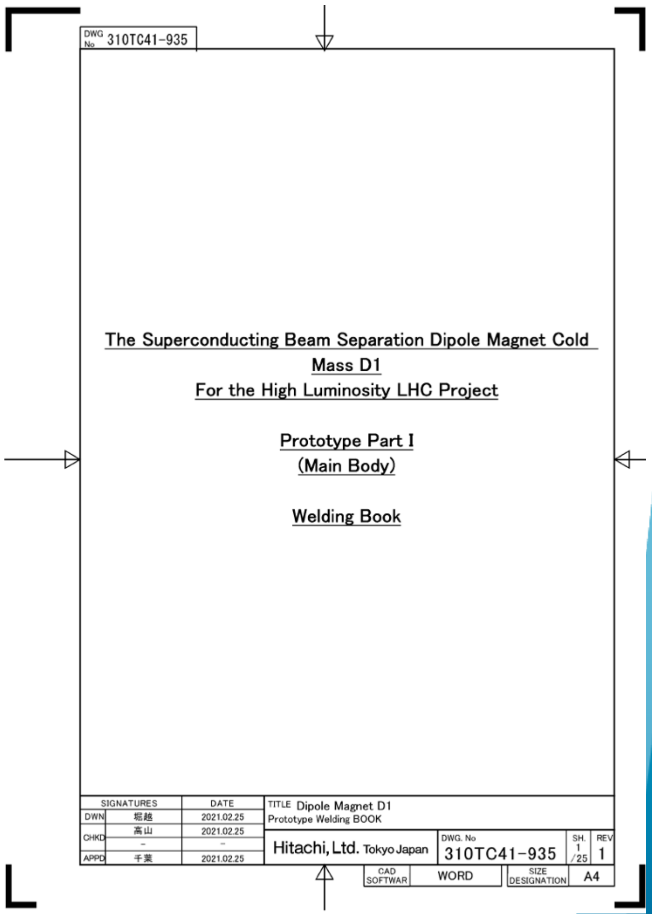


# Welding Qualification for Manufacturing the D1 Pressure Vessel





- Welding Book Part. 1 for Main body: **EDMS 2492330 Released.**
  - Welding for the magnet (shell, end-ring).
  - PQR 1, 2 for t=10mm: Completed.
- Welding qualification for the “final assembly of the cold mass”.
  - Welding for End-cover, CBT, HX and the extremities.
  - PQR 4, 5 for t=1 to 3 mm: Charpy V notch test required in EDMS 1891856 Rev. 4.31, but not-appropriate for shin plates. Quite a long time for establishing qualification regulation…
    - Charpy Test for PQR 4 (t=2 mm) was completed on Jan. 11.
    - Charpy Test for PQR 5 (t=1 mm) was finally completed on Feb. 1, 2022.
  - PQR 6, 7, 8: Lip weld joints, not specified in ASME or EN. Special agreement with CERN for welding qualification.
    - PQRs were completed including the burst-test.


DWG No 310TC41-935

The Superconducting Beam Separation Dipole Magnet Cold Mass D1
For the High Luminosity LHC Project

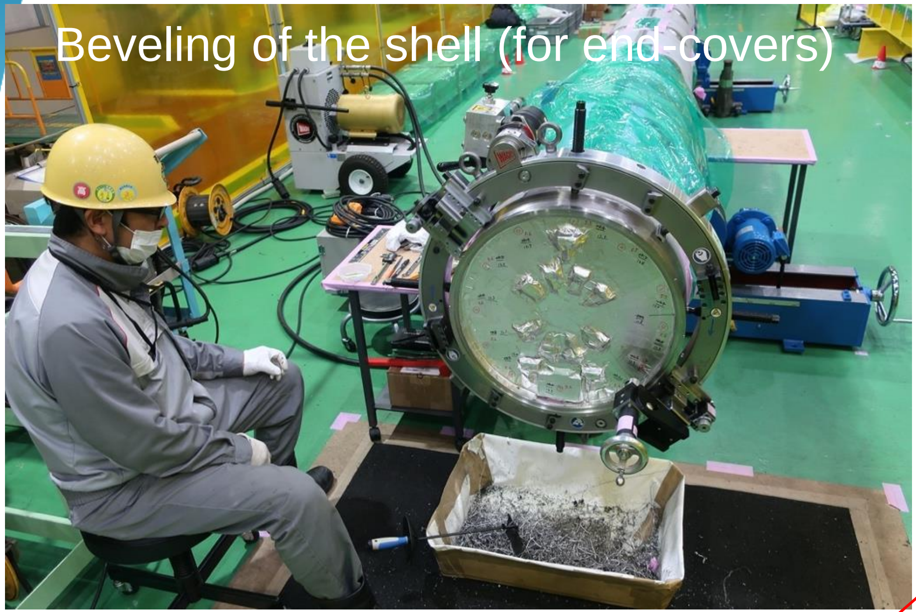
Prototype Part I
(Main Body)

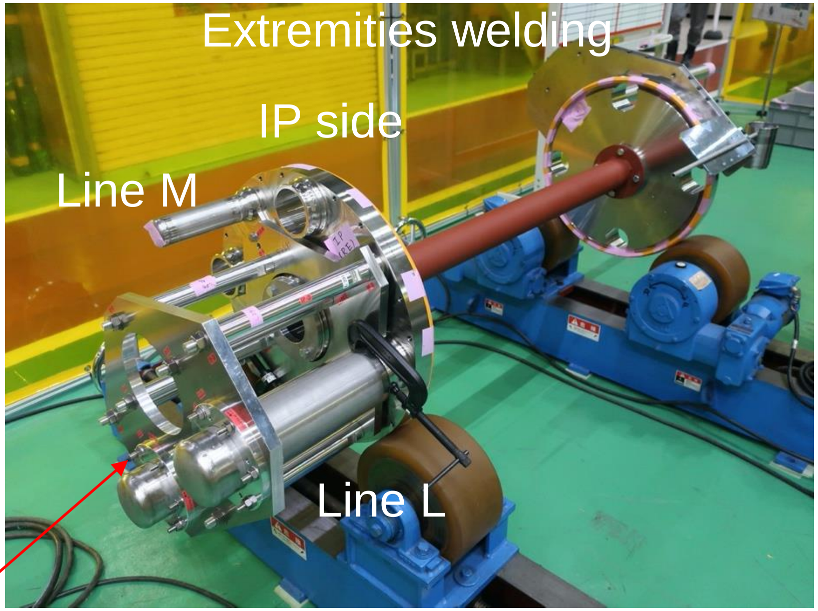
Welding Book

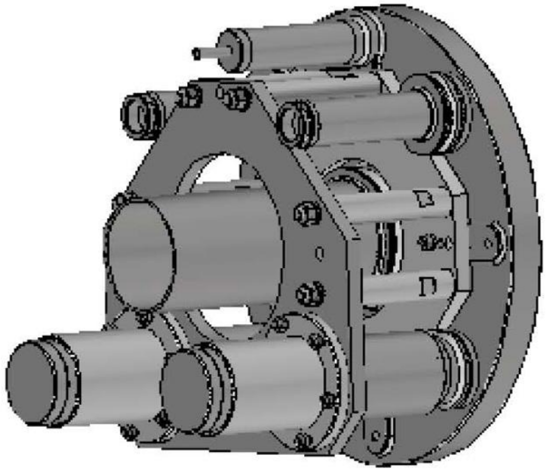
| SIGNATURES | | DATE | TITLE Dipole Magnet D1 Prototype Welding BOOK | | | |
|---|---|---|---|---|---|---|
| DWN | 堀越 | 2021.02.25 | | | | |
| CHKD | 高山 | 2021.02.25 | Hitachi, Ltd. Tokyo Japan | DWG. No 310TC41-935 | SH. 1 /25 | REV 1 |
| | - | - | | | | |
| APPD | 千葉 | 2021.02.25 | | | | |

| CAD SOFTWAR | WORD | SIZE DESIGNATION | A4 |
|---|---|---|---|

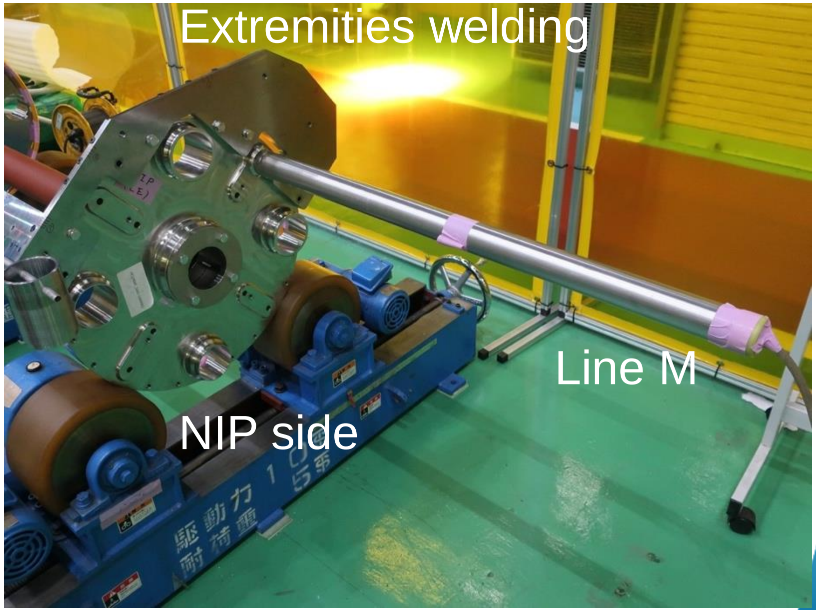
# Extremities Welding



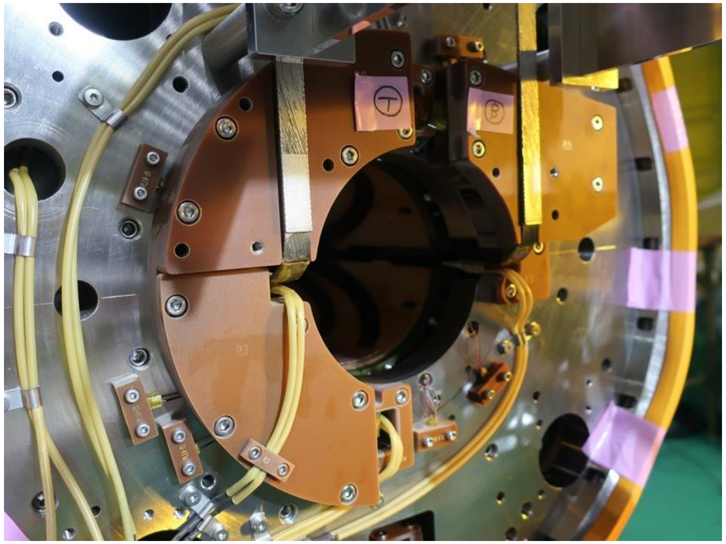



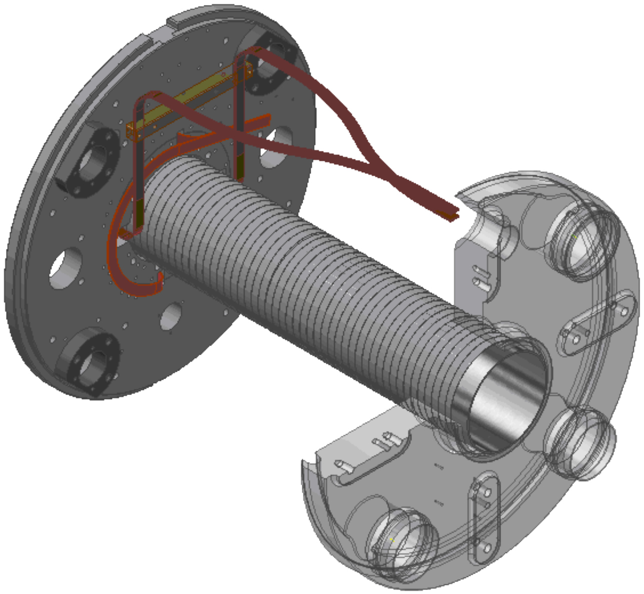
Extremities Position Adjustment Tooling
(Lines M, L, X, V for NIP and IP sides)

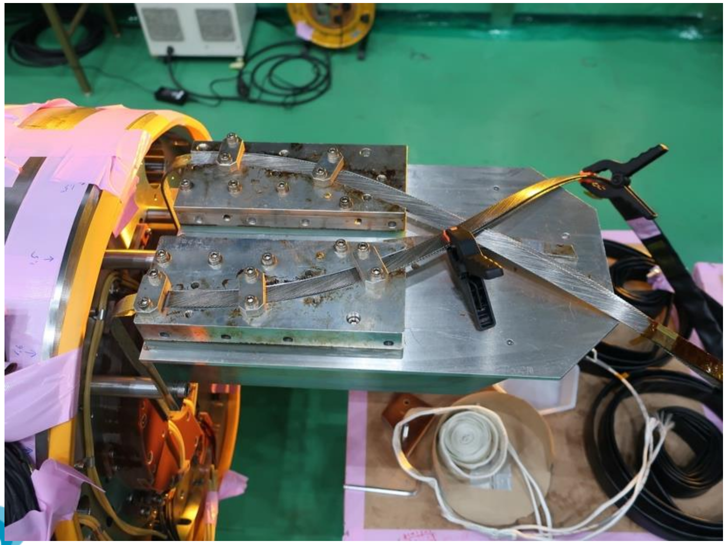


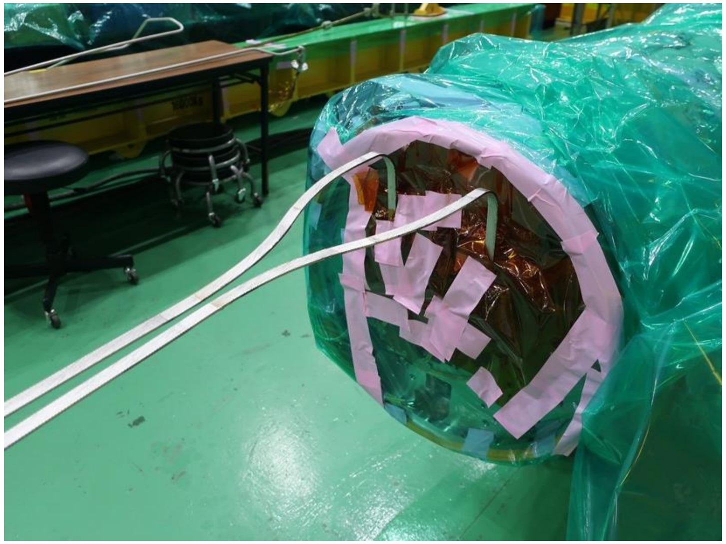
# SC Bus Leads and “Spider”

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

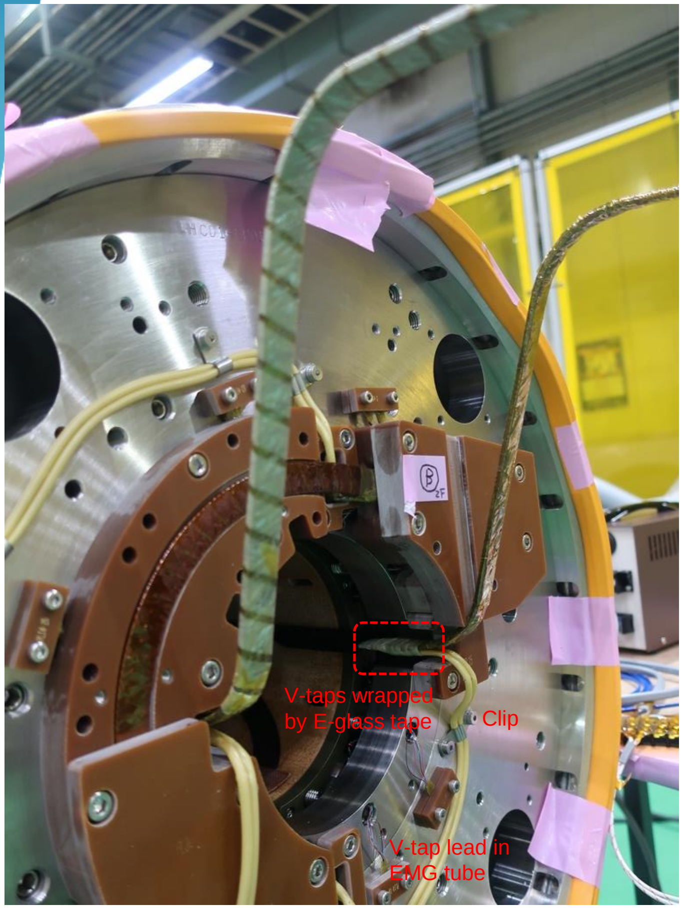


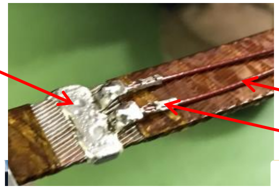


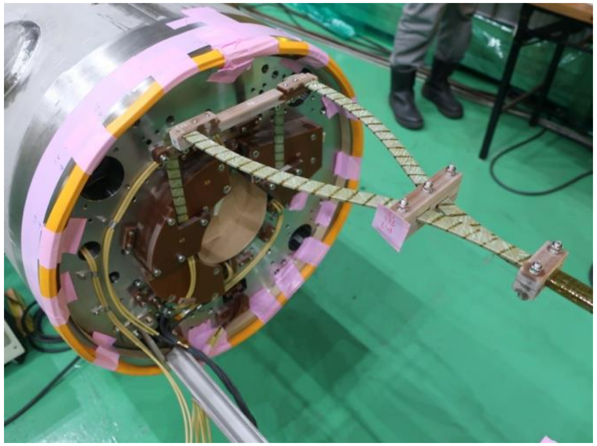


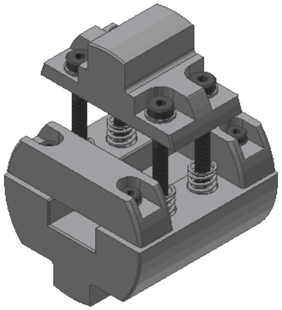


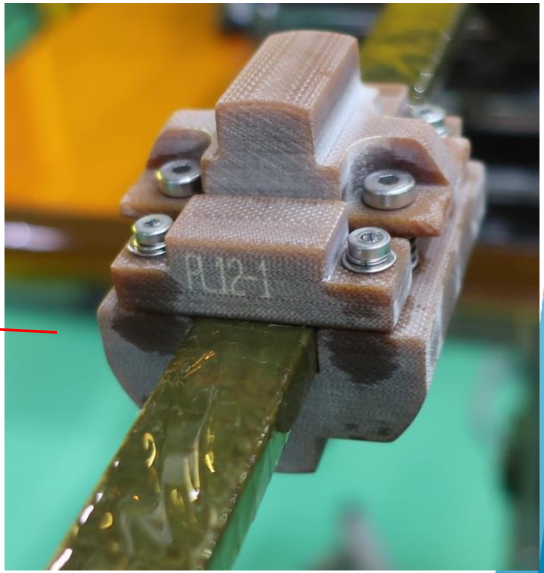
# SC Bus Leads and "Spider"



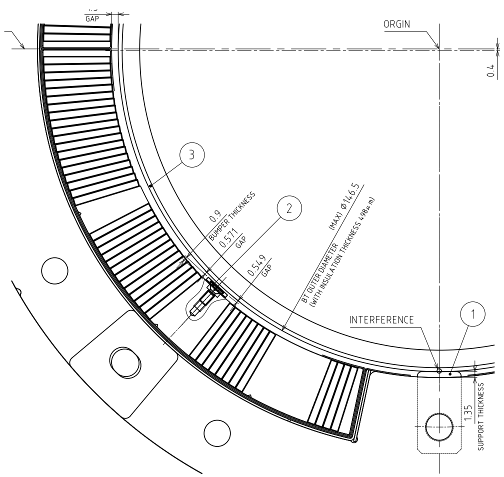




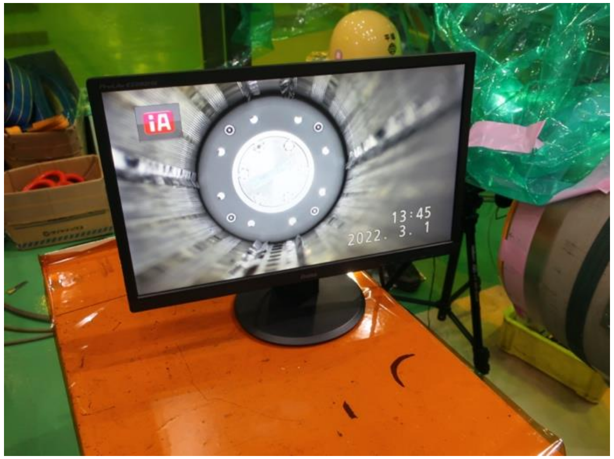
Spider for centering the bus-leads in Line M

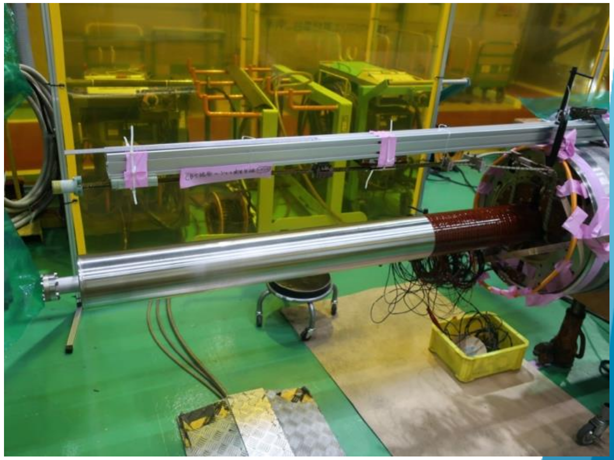
# Insertion of CBT

- 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.

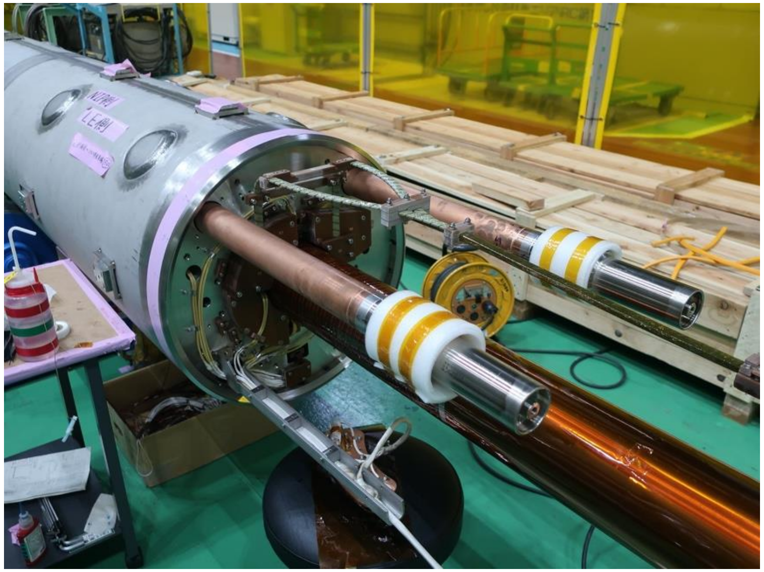



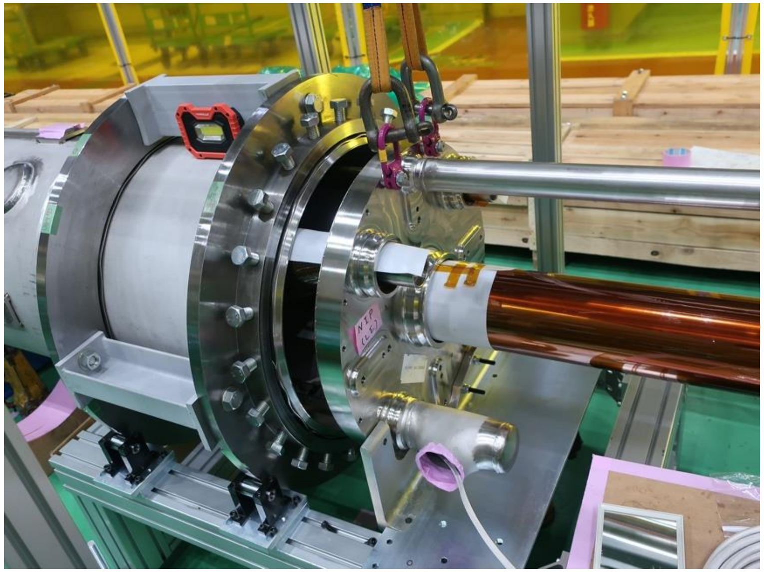

A (2:1)



# End-dome, End-cover



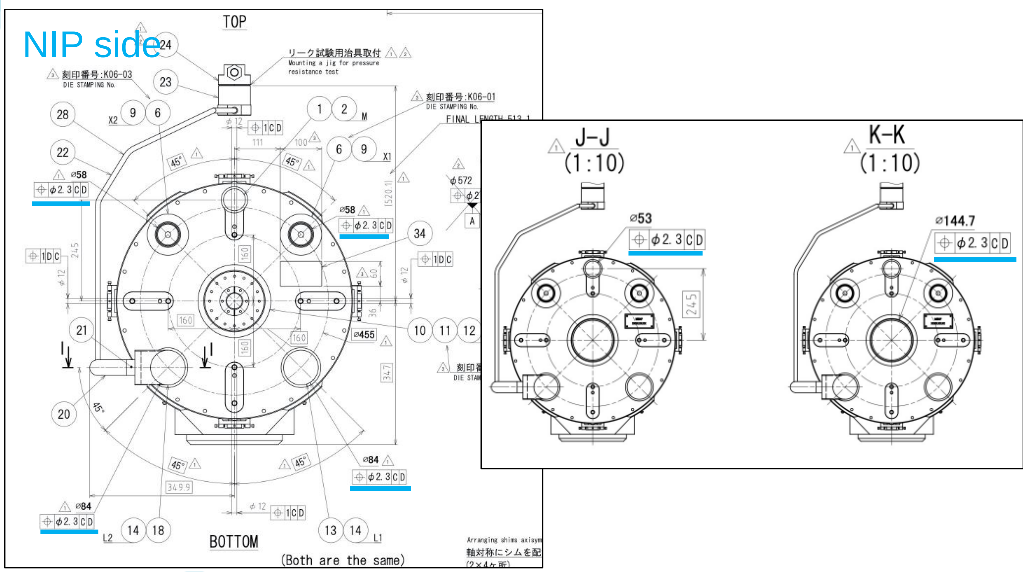


- Outer-rings to correct the formed and longitudinally-welded end-dome.
- Position of the end-cover was precisely aligned with respect to the mechanical fiducial of the magnet defined by the 32 alignment markers using the laser tracker.

# Position of Extremity Pipes

Pipe | Reference | Measurement | Deviation in X, Y | Δr

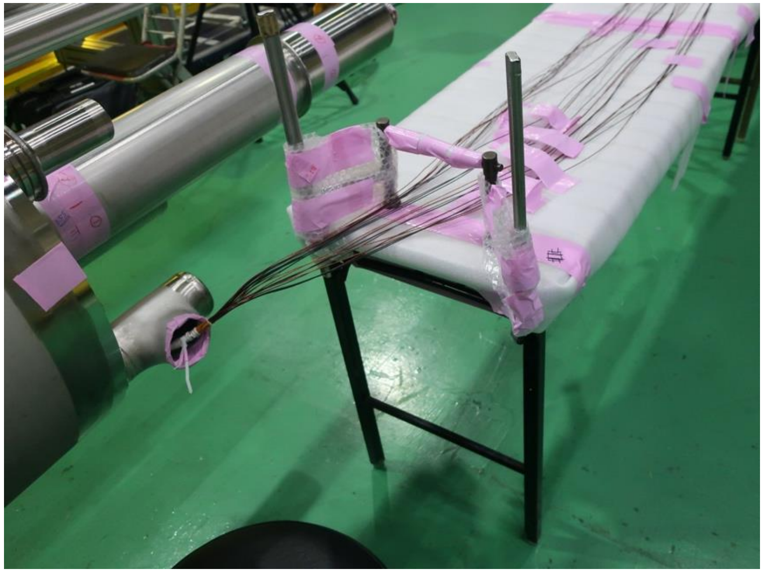
| 配管名称 | 側 | 判定基準 [mm] | | center位置座標 [mm] | | | 基準座標からの偏差 [mm] | | 基準座標からの距離 [mm] | 合否 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | X | Y | X | Y | Z | dx | dy | L (L<=1.15) tolerance | |
| X1 | LE | 160.87 | 160.87 | 161.19 | 160.12 | 152.47 | 0.32 | -0.75 | 0.82 | Conformed |
| | RE | 160.87 | 160.87 | 160.02 | 160.85 | -7578.95 | -0.85 | -0.02 | 0.85 | Conformed |
| X2 | LE | -160.87 | 160.87 | -159.83 | 160.85 | 153.10 | 1.04 | -0.03 | 1.04 | Conformed |
| | RE | -160.87 | 160.87 | -161.32 | 162.65 | -7577.45 | -0.45 | 1.78 | 1.84 | Non-Conformed |
| L1 | LE | 160.87 | -160.87 | 161.33 | -161.05 | -0.03 | 0.46 | -0.18 | 0.49 | Conformed |
| | RE | 160.87 | -160.87 | 160.86 | -161.13 | -7367.02 | -0.01 | -0.26 | 0.26 | Conformed |
| L2 | LE | -160.87 | -160.87 | -160.71 | -160.47 | 0.16 | 0.16 | 0.40 | 0.43 | Conformed |
| | RE | -160.87 | -160.87 | -160.73 | -160.45 | -7366.90 | 0.14 | 0.42 | 0.44 | Conformed |
| M | LE | 0 | 245 | 1.03 | 245.74 | 499.91 | 1.03 | 0.74 | 1.27 | Non-Conformed |
| V | LE | 0 | 0 | -0.08 | 0.86 | 681.00 | -0.08 | 0.86 | 0.86 | Conformed |
| | RE | 0 | 0 | -0.34 | 0.03 | -7426.06 | -0.34 | 0.03 | 0.34 | Conformed |




- Determined by the laser tracker system (AT403).
- Thanks to the alignment tooling and performance of the welders at Hitachi, the lateral positions of the extremity pipes were well controlled except 2 NC cases.
  - 2 NC case are also acceptable for the cryostat work at CERN.
- CERN will revise the position tolerances for the series production based on the experience of the prototype.

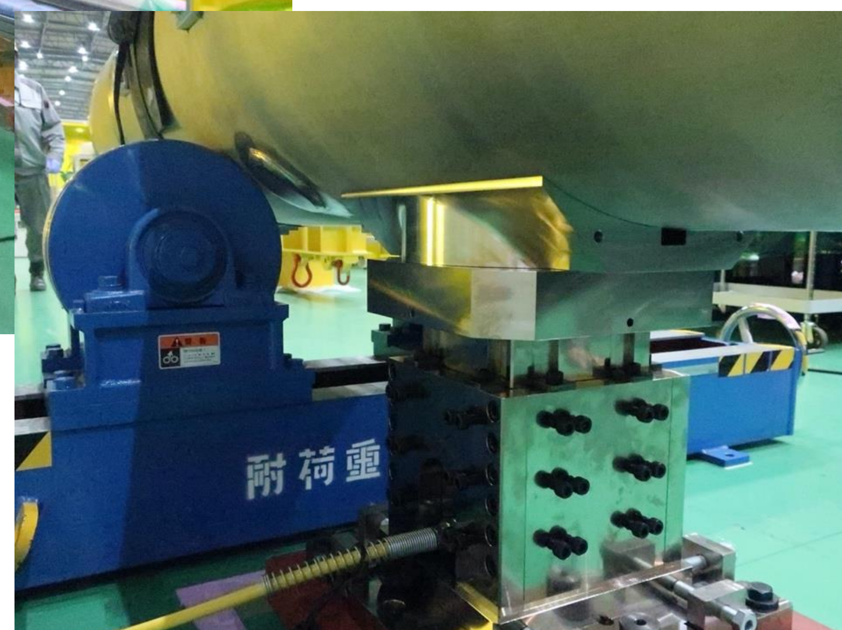
# IFS Line

Instrumentation wires, routing



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

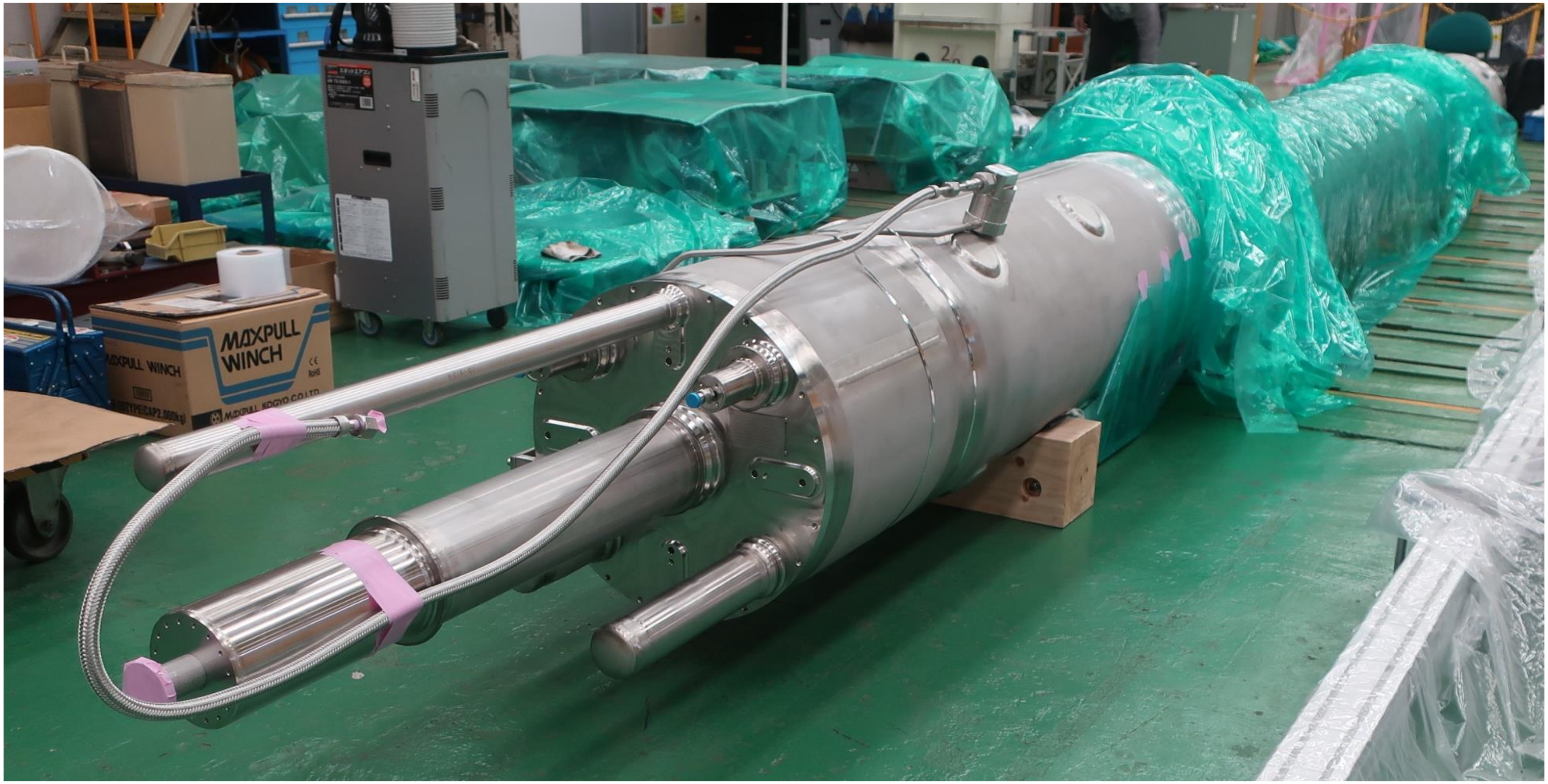
# Saddle




- 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.

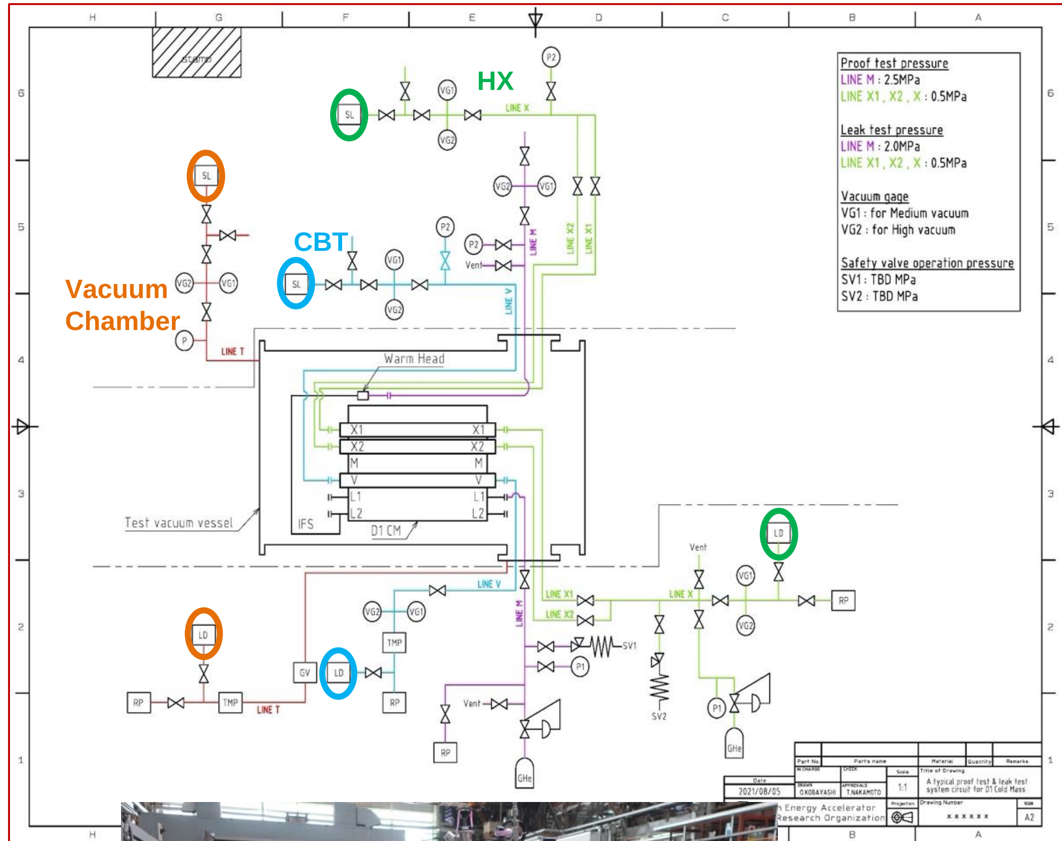
# Manufacturing of D1 Prototype

- Completed D1 prototype cold mass



# Pressure Proof Test and Leak Test of the D1 Prototype

- The criteria of the LT for the D1 cold mass given by CERN (1x10$^{-10}$ Pam$^3$/sec for vacuum chamber, 1x10$^{-11}$ Pam$^3$/sec for CBT) are NOT so easy to achieve.
  - In particular, the LT in the industry's workshop, where the maximum temperature exceeds more than 30 degC in summer and another cold test using the helium gas is performed nearby, is really challenge.
- Choice of the joints (i.e. VCR, helicoflex, etc.) is not trivial. Flexible tube to fulfill the test condition (>2.5MPa, <1x10$^{-11}$ Pam$^3$/sec) is not available in the market.
  - The leak was found in the 1st gas displacement at 1.25 MPa. The leak localization took about 1 month and the leak was eventually localized in the flexible tube.
- The LT of the MBXFP1 was really a good lesson for Hitachi and KEK. Improvement to avoid the leaks along the pressurization lines will be made for the LT of the series production cold masses.




# Non-Conformities

Closed
In work

- Welding Qualification
  - EDMS 2469433: Invalid Qualification Result of Fatigue Pre-cracking Requirement for 4 K Fracture Toughness Test of PQR2 HAZ Specimen for the D1 Cold Mass Manufacturing, **C2**
- MBXFP1
  - EDMS 2426526: Deformation of SC cable due to over-tension, **C3**
  - EDMS 2437654: Small crack at GFRP ramp-box of LPT-1 Coil, **C1**
  - EDMS 2443118: Insulation Damage after Curing of D1 Prototype Bottom Coil, **C3**
  - EDMS 2464985: Partial Damage of Ground Insulation, **C1**
  - EDMS 2581587: Weld Defect of the D1 Cold Mass Prototype (end-cover), **C2**
  - EDMS 2595209: Crane Incident at KEK, **C3**
  - EDMS 2731453: Partial peeling of surface insulation of cryo-heater wire for MBXFP1, **C1**
  - EDMS 2753741: Partial peeling of surface insulation of QPH wire for MBXFP1, **C1**
  - EDMS 2753742: Weld Defect of Joint G-2 of MBXFP1, **C2**
  - EDMS 2753743: Weld Defects of Joints I-L2 and I-R2 of MBXFP1, **C2**
  - EDMS 2753744: Weld Defect of Joint D of MBXFP1, **C2**
  - EDMS 2753745: Out of Tolerance of the Length of the D1 Cold Mass Prototype
  - EDMS 2753746 Out of Tolerance of the Transversal Positions of the Extremity Pipes of the D1 Cold Mass Prototype
  - EDMS ID is TBD: Unadministered thickness measurement of the pressure vessel part of the D1 Cold Mass Prototype
- MBXF5
  - EDMS2753776: Insulation damage of inner surface of MBXF5 coils, **C4**

Coil

Welding

Wiring in F.A.

Welding

Removal of collaring mandrel

# NCR: Insulation Damage after Curing of D1 Prototype Bottom Coil (EDMS 2443118)

| EDMS NO. | REV. | VALIDITY |
|---|---|---|
| 2443118 | 1.0 | VALID |

**REFERENCE** : LHC-MBXFP-QN-0001

An investigation of the root cause is underway. But results of the inspection can be summarized in the following.

The damage of the 20th turn looked severest: the cable insulation was partially peeled off and a scratch on a surface of a strand was clearly confirmed. However, the damage was limited within one strand and current transport capability seemed to be fine because the scratch was not so deep and we could see a glossy copper matrix. Regarding the 19th and the 21st turns, a level of the damage was obviously lower with respect to the 20th turn. The outer layer insulation was damaged but we could not judge if the inner layer insulation was also damaged or not.


Fig. 3: Macrograph of insulation damage.

The visual inspection was also performed for the protection sheet to judge if the insulation was damaged during the curing process or not. We confirmed that the surface of the corresponding location was still normal and not damaged at all. As mentioned above, the scratch of the copper of the 20th turn was glossy (no resin). For these reasons, we concluded that the insulation was not damaged during the curing, but was damaged during the coil handling after the curing.

According to the measurement results of the coil resistance and the inductance, the values were normal and within the acceptance range. It should be noted that the ringing (impulse) test and the hipot test will not be performed until the repair be completed.

| ***Documents used as reference*** | ***Date of Issue*** |
|---|---|
| 310PB71-358 Rev. 0 (LHCMBXFC0181 v.AA), R79H011-60801, R79H011-60802, KS1SCM14-410001, KS1SCM14-410002, ES20-HL-LHC0120 | 2020-11-26 |

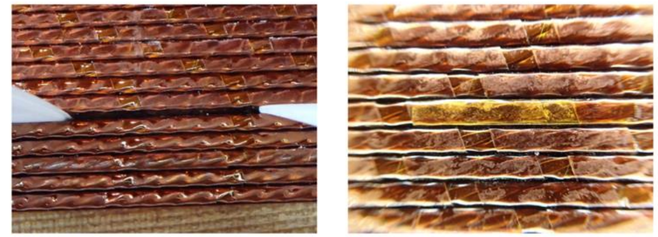
**NC Evaluation**

Further investigation with macrography instrument and deepness instrument devices shown that the scratch is 0.1 mm deep in the deepest part, and 0.6 mm large (Fig. 4).

Page 2 of 5 Template EDMS No.: 1501109

| EDMS NO. | REV. | VALIDITY |
|---|---|---|
| 2443118 | 1.0 | VALID |

**REFERENCE** : LHC-MBXFP-QN-0001



Figg. 7 and 8: Repair test with dedicated tools and final result

***Documents used as reference***

K200010

***Evaluation team:*** T. Nakamoto, M. Sugano, Y. Ikemoto, A. Horikoshi, T. Chiba, Y. Daigo, K. Shiga, A. Musso

**Decision**

Considering the damage of the cable and the insulation, the following procedure shall be applied:

- To remove the damaged insulation part very carefully from turns 19, 20 and 21, in order to avoid extra-thickness after repair.
- To adopt the test procedure, using the dedicated tools and inserting polyimide insulation as shown in Fig. 9.

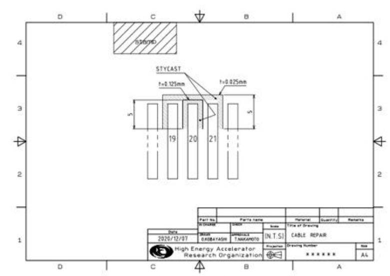
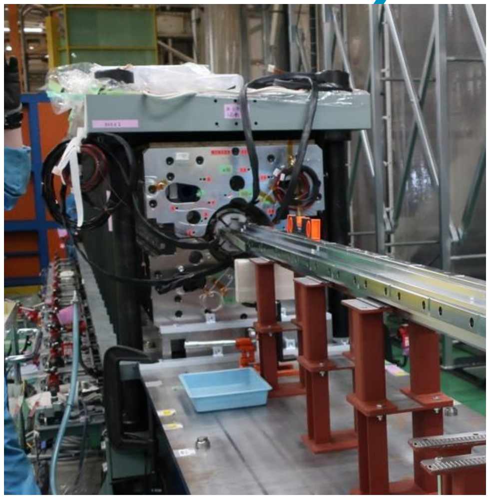


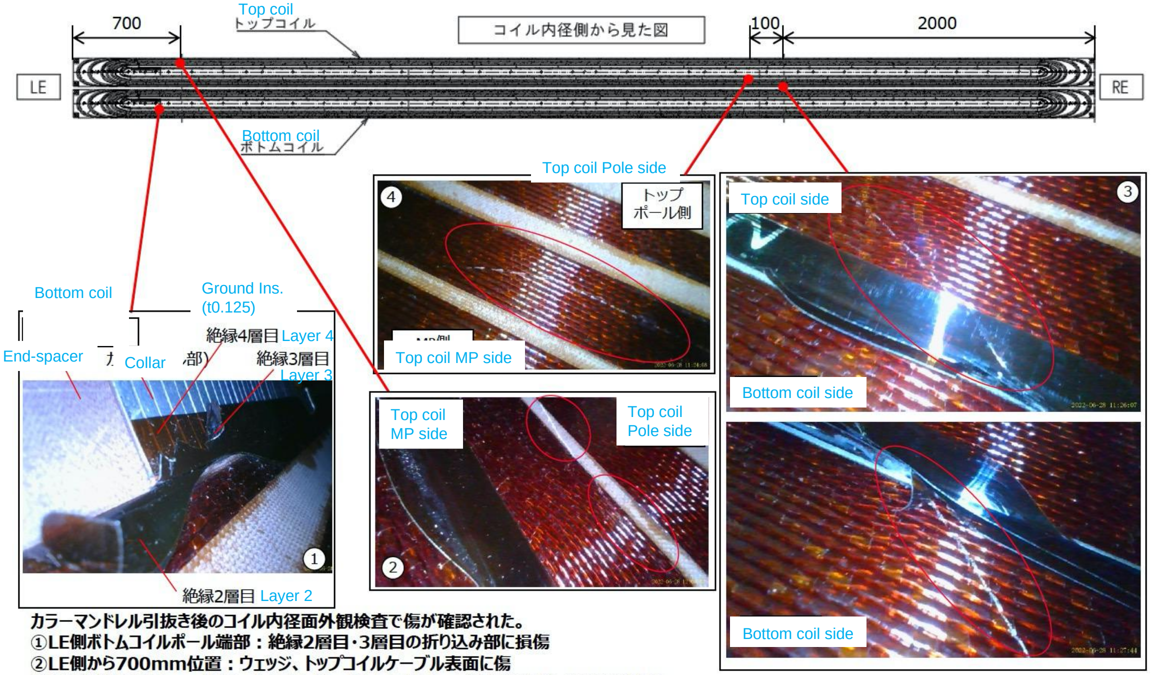

Fig. 9 – Repair drawing

Page 4 of 5 Template EDMS No.: 1501109

**The coil was successfully repaired..**

# NCR: Insulation damage of inner surface of MBXF5 coils (EDMS2753776) 1/2





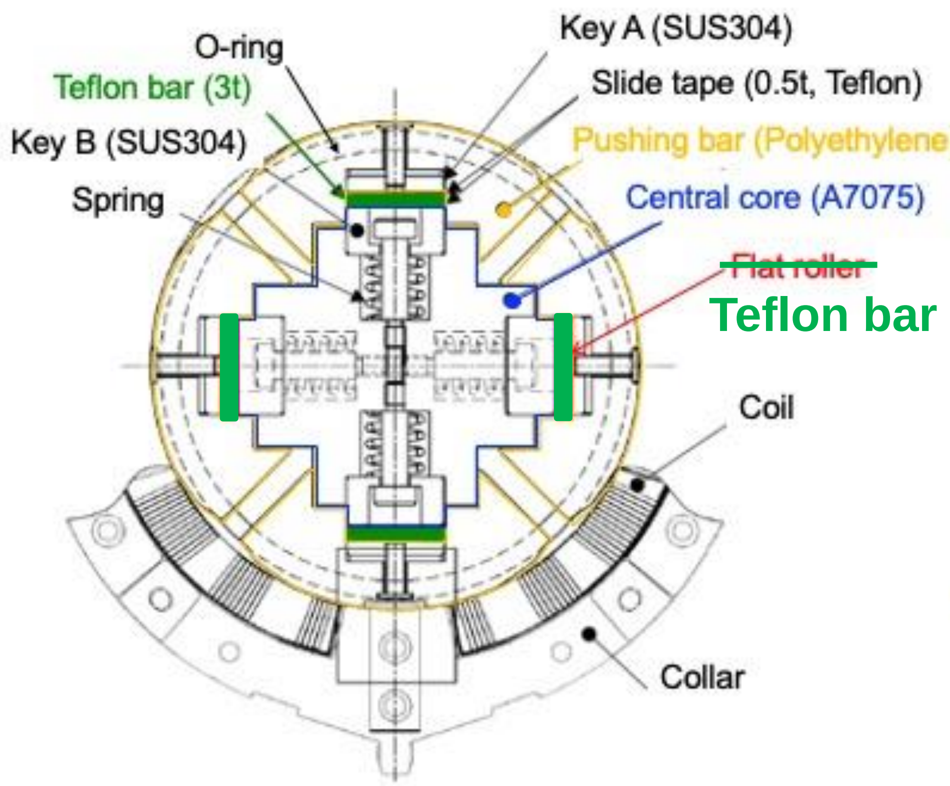

カラーマンドレル引抜き後のコイル内径面外観検査で傷が確認された。
①LE側ボトムコイルポール端部：絶縁2層目·3層目の折り込み部に損傷
②LE側から700mm位置：ウェッジ、トップコイルケーブル表面に傷
③RE側から2000mm位置：トップコイル·ボトムコイルケーブル表面に傷、MP部絶縁損傷
④RE側から2100mm位置：トップコイルケーブル表面に傷

 6

Flat rollers

# NCR: Insulation damage of inner surface of MBXF5 coils (EDMS2753776) 2/2

## Collaring-Mandrel for MBXF5




- **Collaring-mandrel for 2 m model magnets (KEK)**
  Flat rollers were used to smoothly pull out the collaring mandrel. Successfully worked.
- **Collaring-mandrel for MBXFP1 (Hitachi)**
  Instead of flat rollers, Teflon bars were used for both vertical and horizontal pushing bars. The central core could be pulled out, but the pulling load was higher than our expectation (~20 kN). In particular, friction at horizontal pushing bars were relatively high. A gap opened at joint part of the central core, suggesting that mechanical strength of central core was not enough.
- **Collaring-mandrel for MBXF5 (Hitachi)**
  In order to reduce the friction, flat rollers were introduced instead of Teflon bars only for the horizontal pushing bars, while Teflon bars were still used for the vertical pushing bars.

Preventive Plan: EDMS 2773481

- Instead of flat rollers, teflon bars will be revived in the same way of MBXFP1.
- New collaring mandrel will be adopted for MBXF1.

# Summary

- Through the manufacturing experience of the D1 cold mass prototype (MBXFP1), the manufacturing and inspection process have been established.
  - There were many good lessons and sufferings…
- Collaboration with Hitachi has become pretty well.
- Control of the coil parts (wedges, shims, end-spacers) is very crucial for the good training performance.
  - Fabrication of the coil parts has been carefully caried out with thorough dimensional inspection.
- Performance of the welders at Hitachi is excellent.
- There were several NCs in the prototype manufacturing and some of them were caused by the careless mistakes. But the NC rate for the series production seems to be decreased unless the NC (C4) at the collaring mandrel removal process of MBXF5.
- Manufacturing records and the inspection test reports have to be circulated in Hitachi for having approval and a significant delay of the delivery to KEK has been observed. Pace of documentation has to be improved in the series production.