HiLumi
HL-LHC PROJECT

# Improvement in cold mass assembly


H. Prin

According to discussions and contributions from:

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Report on Ongoing Actions for MQXFB 29/04/2022

CERN

# Outline

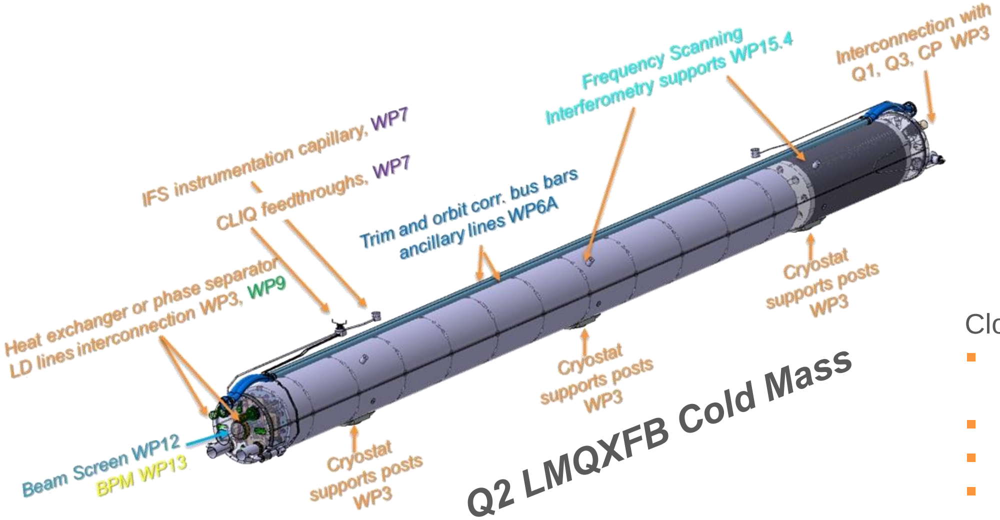
- Cold mass
  - HL-LHC cold masses
  - Link between the magnets and the envelope LHC vs HL-LHC
  - The LMQXFBT cold mass concept to test MQXFB magnets
  - Observations during disassembly of LMQXFBT01, 2 and 3
  - More information about  LMQXFBT01 to 03
- Requirements update after MQXFBP2 cold test
  - Determination of the shell developed length
  - Fixed point necessity and design
  - Outcome of Technical Review of MQXFB Cold Mass
- Additional QC and improvements for next cold masses
- Summary

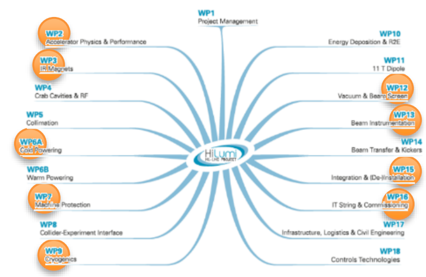
# HL-LHC Cold Masses

- ***Cold Mass:***

  ***<u>Leak tight envelope</u>*** *surrounding one or more superconducting magnets which acts as a* ***helium pressure vessel*** *and* ***provide the mechanical rigidity to align the magnetic element(s)****. It can be composed of two welded half-shells (main dipoles, insertion cold masses...) or by an "inertia tube" (arc SSS) closed by two end covers in the extremities.*

  https://espace.cern.ch/HiLumi/TCC/SiteAssets/LHC_Glossary_high_resolution.pdf




Close collaboration with many work packages:

- WP3: weekly meeting at CERN, regular meetings and exchanges with US and Japan
- WP6A, WP7: Magnet Circuit Forum (MCF) every other week
- WP9, WP12, WP13: meetings when necessary
- WP2, WP15: HL-LHC Integration meeting

CERN

- ***Q2 A or B (LMQXFB)***
- *D2 (LMBRD)*
- *CP (LMCXF)*

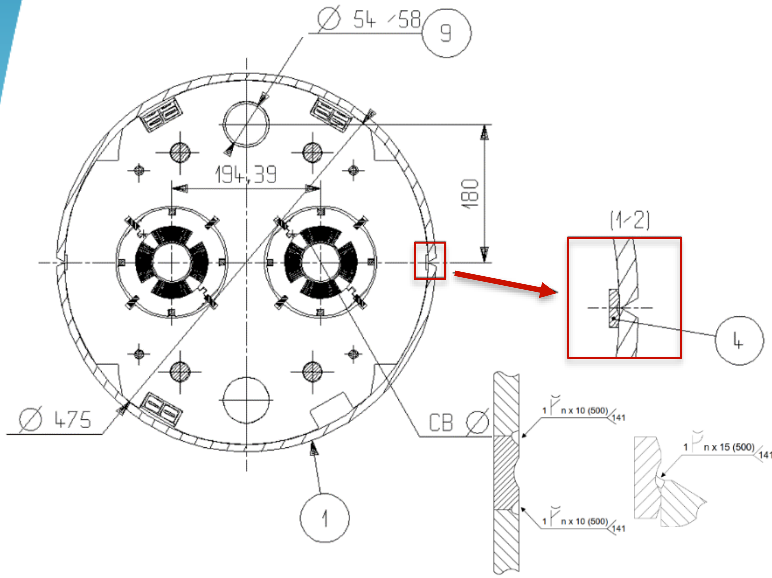
Standardisation of the components and procedures (assembly, welding, electrical testing, QA/QC…)

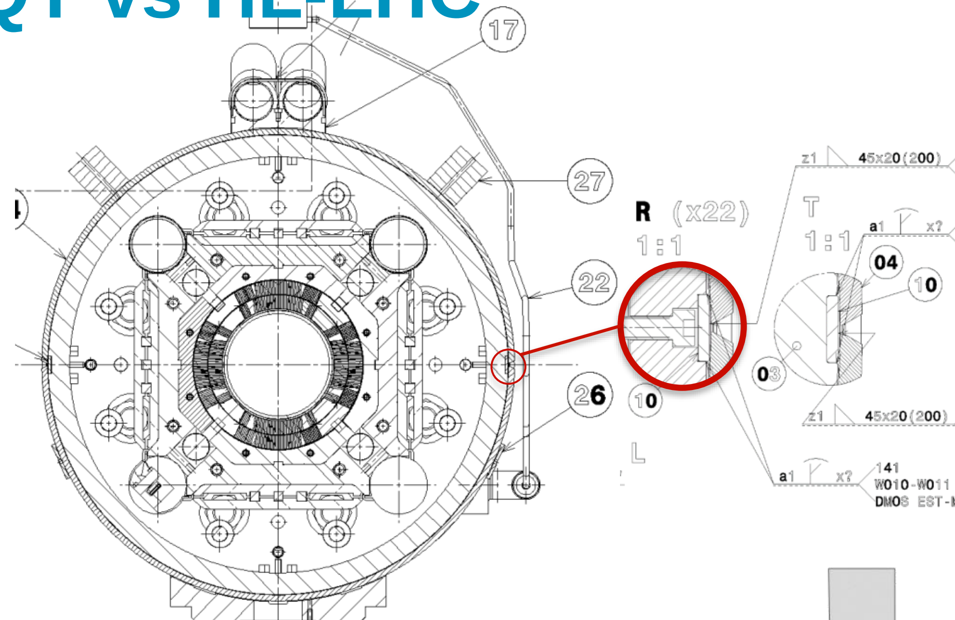
US HL-LHC AUP

- *Q1 and Q3 (LMQXFA)*
- *D1 (LMBXF)*

Standardisation of the components delivered by CERN
Regular discussions and exchanges concerning procedures

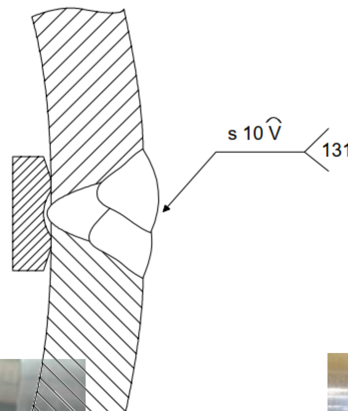
# Link between the magnets and the envelope LHC MQM/MQY vs HL-LHC




***3 MIG passes***

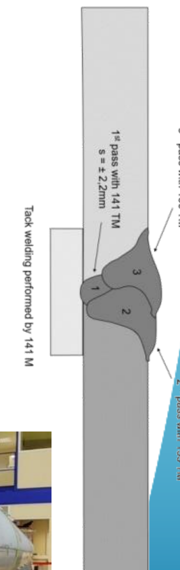
*Backing strip not part of the weld structure*



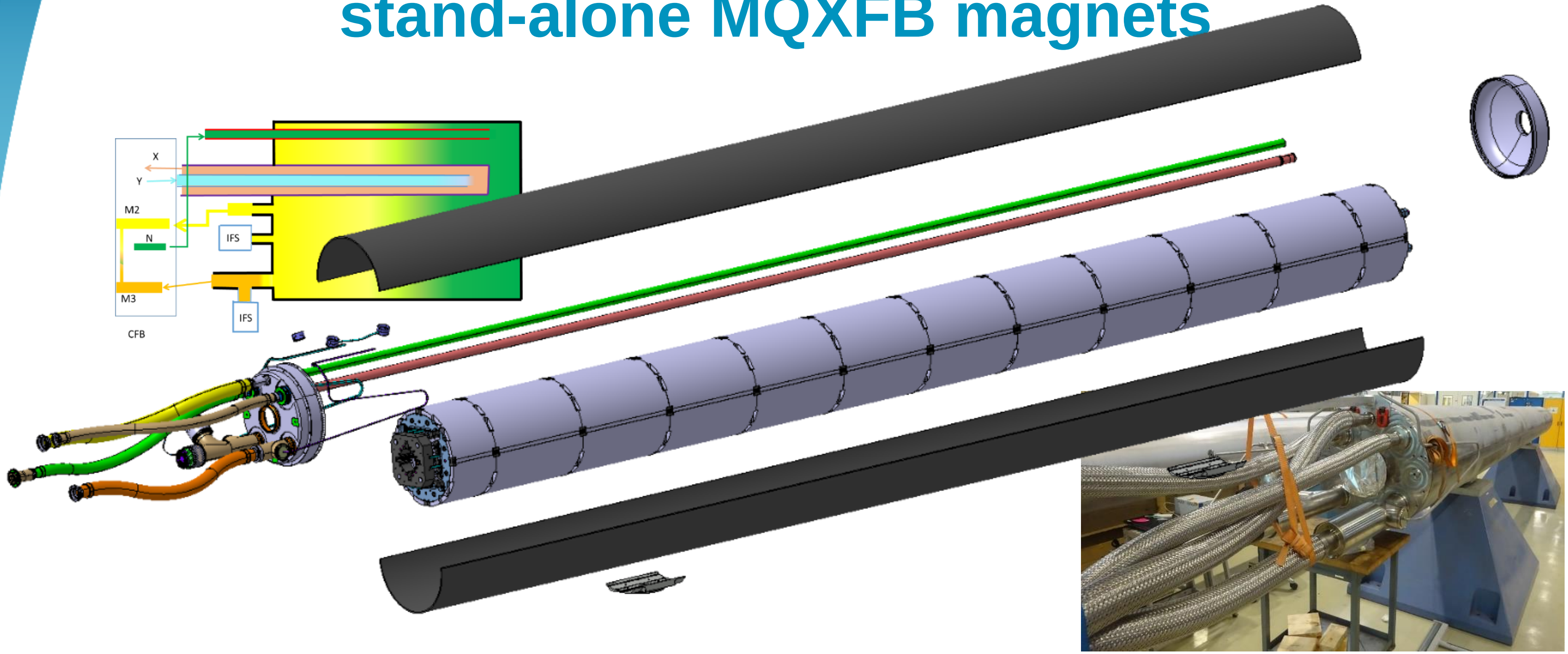

***Dual welding process***

*TIG root +2 MIG filling passes*

*Backing strip melted during the longitudinal welding to become part of the structure*

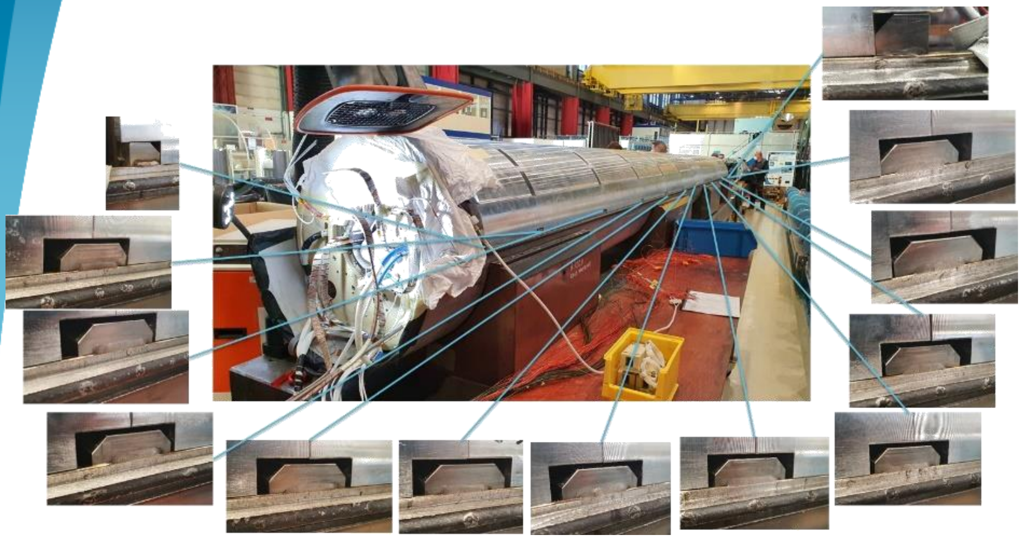



# The LMQXFBT cold mass to test stand-alone MQXFB magnets

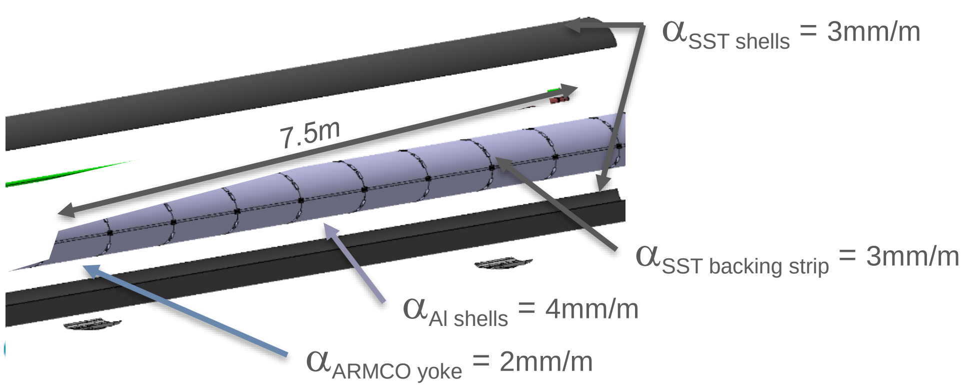



- Providing a leak tight envelope surrounding the MQXFB magnet to perform **cold test horizontally**,
- Providing **mechanical inertia**, rigidity and alignment in between aluminium shells,
- Fitting and integrating inside the **existing spare vacuum vessel** for the Q9
- Connecting to the **existing test bench in SM18**
- Enabling **magnetic measurements** at cold, eventually with the **beam screen** inserted,
- Housing **electrical protection and mechanical instrumentation** and providing interfaces to route the signals from 1.9K to RT,

# Observations during LMQXFBT01 disassembly



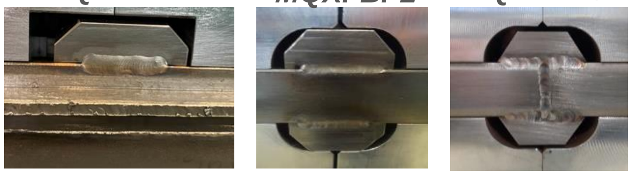
- *Longitudinal shrinkage along the cold mass axis was observed after cutting the half shells.*
- *All tacking blocks moved towards the magnet centre.*
- *Tack welds on the blocks in the extremities were broken.*




## *Procedures enhancement for future assemblies*

- Tack welding blocks centered in the aluminum shell pockets
- Design evolved to maximize the clearance

**MQXFBP1** **MQXFBP2** **MQXFBP3**



- Only one screw is installed per block, with a bias towards the centre to allow maximum movement

| REFERENCE | EDMS NO. | REV. | VALIDITY |
|---|---|---|---|
| LHC-MQXFB-FP-0020 | 2324061 | 6.1 | VALID |

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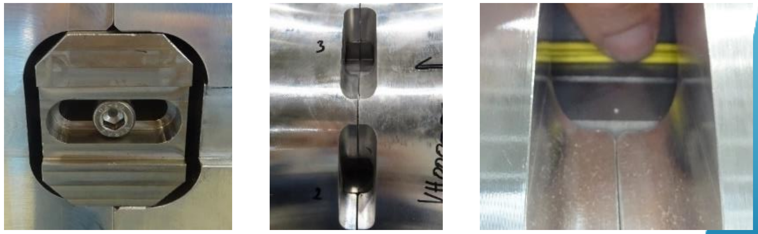
| | | |
|---|---|---|
| 13 | Vérifier que les blocs d'alignement centraux:<br>- Sont centrés,<br>- Ne dépassent pas de la gorge des shells aluminium,<br>- Sont fixés de manière à ce que la position de la vis permet un mouvement maximal vers le centre de l'aimant.<br><br>**PRENDRE DES PHOTOS DE TOUS LES BLOCS** | |

- Systematic measurements of gaps and relative positions of all elements



# Among observations during LMQXFBT02 & LMQXFBT03 disassembly

The longitudinal cut was performed in two steps. Initially the upper shell was dissociated from the backing strip. Then the lower one.

- Tack welding blocks positions before and after longitudinal cutting


*Measurements on LMQXFBT03 (very similar for LMQXFBT02)*

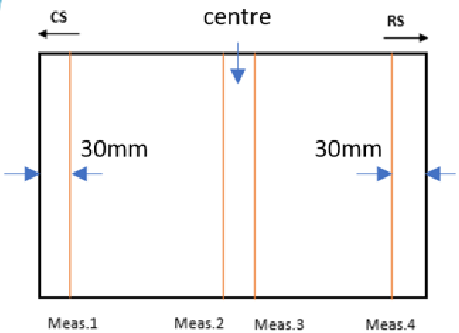
| P1-P4 side | Distance COC side (mm) after upper shell cut | Distance COC side (mm) after lower shell cut and transportation to 180 | Shift toward **the center (mm)** |
|---|---|---|---|
| Block 1 | 33.80 | 28.54 | 5.26 |
| Block 2 | 30.50 | 26.67 | 3.83 |
| Block 3 | 33.34 | 31.58 | 1.76 |
| Block 4 | 36.63 | 34.31 | 2.32 |
| Block 5 | 35.31 | 33.85 | 1.46 |
| Block 6 | 32.58 | 32.25 | 0.33 |
| Block 7 | 35.71 | 36.49 | 0.78 |
| Block 8 | 34.26 | 35.95 | 1.69 |
| Block 9 | 32.38 | 34.03 | 1.65 |
| Block 10 | 32.13 | 34.97 | 2.84 |
| Block 11 | 70.01 | 73.42 | 3.41 |

All blocks move towards the magnet centre after the second cut

Motion is due to stress accumulated during the longitudinal welding

# Among observations during LMQXFBT03 (not cold tested) disassembly

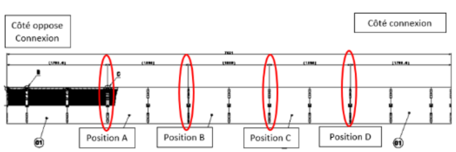
- Al shell developed lengths




| | Developed length (mm) | | |
|---|---|---|---|
| Shell No. | Before welding | After welding | Δ |
| 1 | 1931 | 1930.8 | -0.2 |
| 2 | 1930.5 | 1930.5 | 0 |
| 3 | 1930.4 | 1930.5 | 0.1 |
| 4 | 1930.5 | 1930.5 | 0 |
| 5 | 1930.6 | 1930.7 | 0.1 |
| 6 | 1930.6 | 1930.6 | 0 |
| 7 | 1930.7 | 1930.7 | 0 |
| 8 | 1930.7 | 1930.5 | -0.2 |
| 9 | 1930.5 | 1930.5 | 0 |
| 10 | 1930.6 | 1930.4 | -0.2 |
| 11 | 1930.5 | 1930.3 | -0.2 |
| 12 | 1930.7 | 1930.7 | 0 |

Differences between -0.1 and 0.2mm within Pi tape measurement accuracy

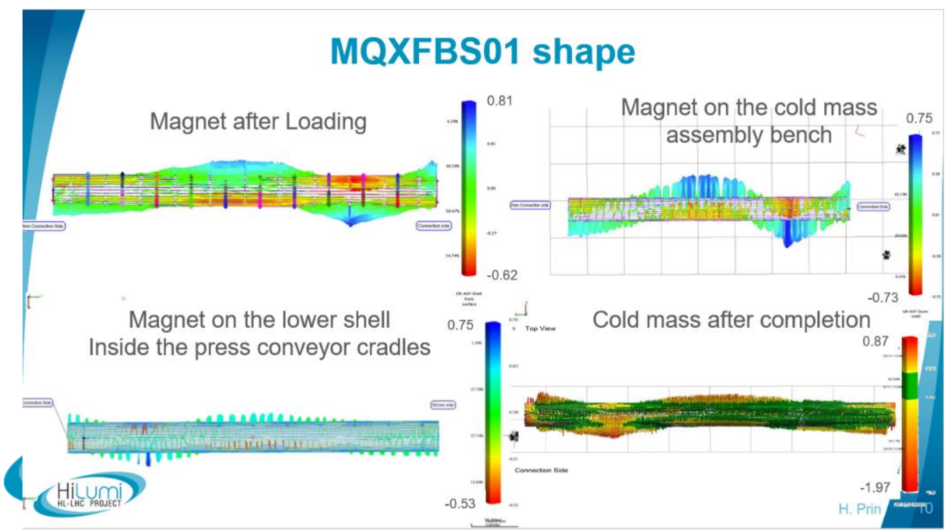
- Gaps between Al shells

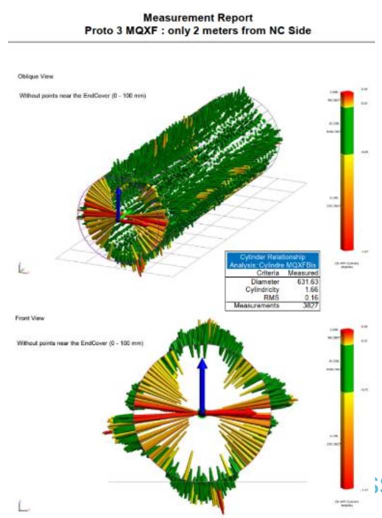



| | Gap between aluminium shells, mm | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Position A | | Position B | | Position C | | Position D | |
| Step | P3 | P4 | P3 | P4 | P3 | P4 | P3 | P4 |
| After loading | 1.2 | 0.65 | 1.45 | 1.70 | 1.10 | 1.25 | 1.95 | 1.80 |
| After half shells removal | 1.65 | 1.75 | 1.19 | 1.03 | 1.58 | 1.38 | 0.54 | 1.02 |

Differences up to 1.4mm that are not uniform on both sides of the magnet

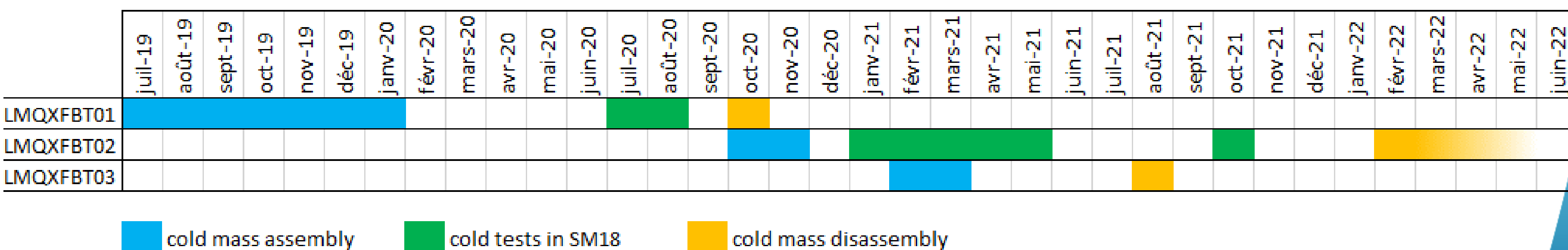
Any realignment after the magnet was welded inside its envelope?




# More information about LMQXFBT01 to 03 cold masses

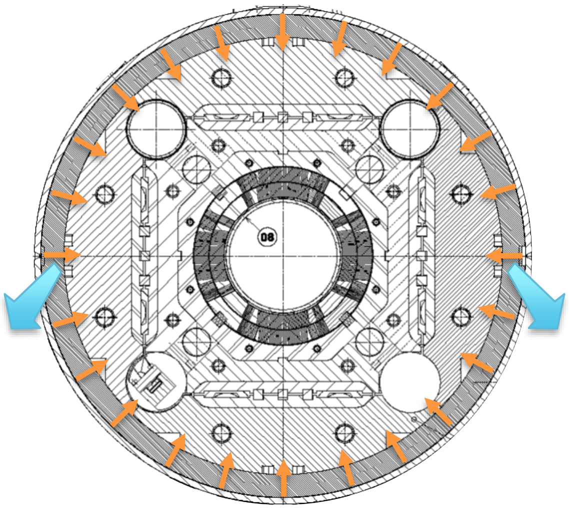
- **LMQXFBT01:**
  - MIP — EDMS 23096431 including all links to inspection reports, pictures and procedures
  - Disassembly report — EDMS 2422353
  - MTF — HCLMQXFBT01-CR000001
- **LMQXFBT02:**
  - MIP — EDMS 2524279
  - Disassembly report — EDMS 2719687 (ongoing)
  - MTF — HCLMQXFBT01-CR000002
- **LMQXFBT03:**
  - MIP — EDMS 2524279
  - Disassembly report — EDMS 2620240
  - MTF — HCLMQXFBT01-CR000003



# Requirements update after MQXFBP2 cold test

## *Coupling between magnet and stainless steel shell*

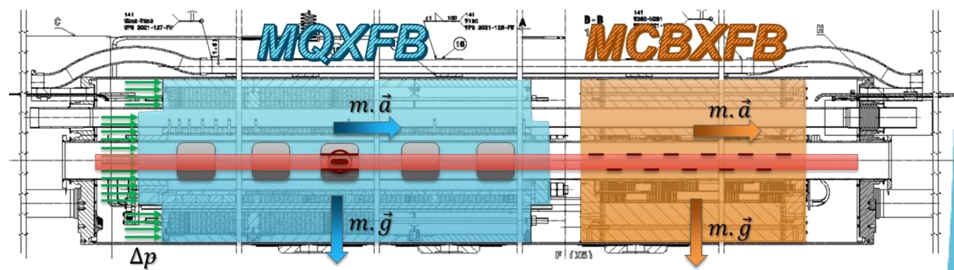
*The design should minimize the mechanical coupling between the Stainless-Steel shell and the Aluminum segmented shells.*



*Target on the **increase of stress in the coil** at room temperature after welding has been decreased from 8±8 MPa to **0+8 MPa***

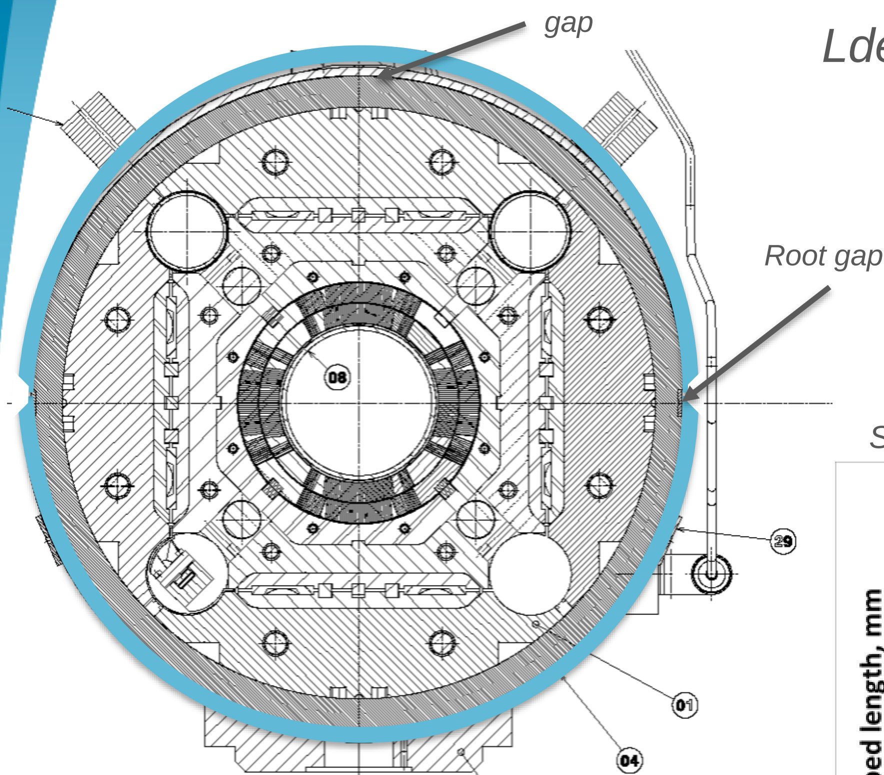
## *Magnets longitudinal fixed point*

*The fixed point (and the magnet components in contact) must withstand the loads appearing:*

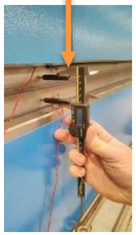



- *During **transport**, the maximum load that shall be carried by the fixed point is **0.5 g** resulting in a load of **55 kN** for the MQXFB.*
- *During **operation** of the **cryogenic system,** the MQXFB magnet inside the cold mass shall withstand **4 bar differential pressure between its ends** (induced by cryogenic operation or by quench of other magnets) resulting in a load of **96 kN**.*

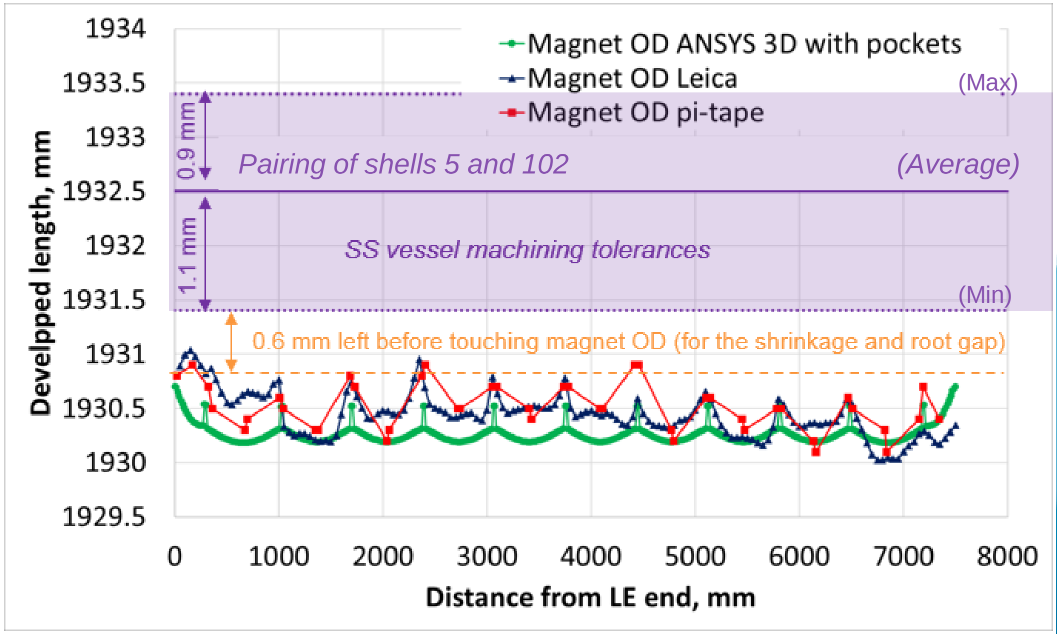
# Determination of the shell developed length



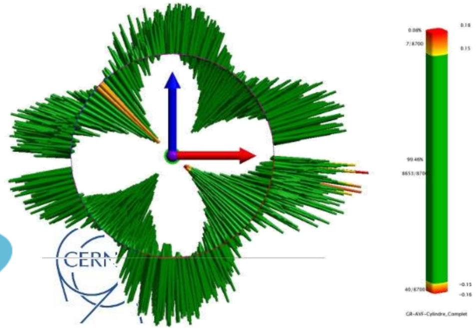

$$Ldev_{Shells} = Ldev_{Mag_{max}} + 2x\ shrinkage - 2x\ root\ gap$$



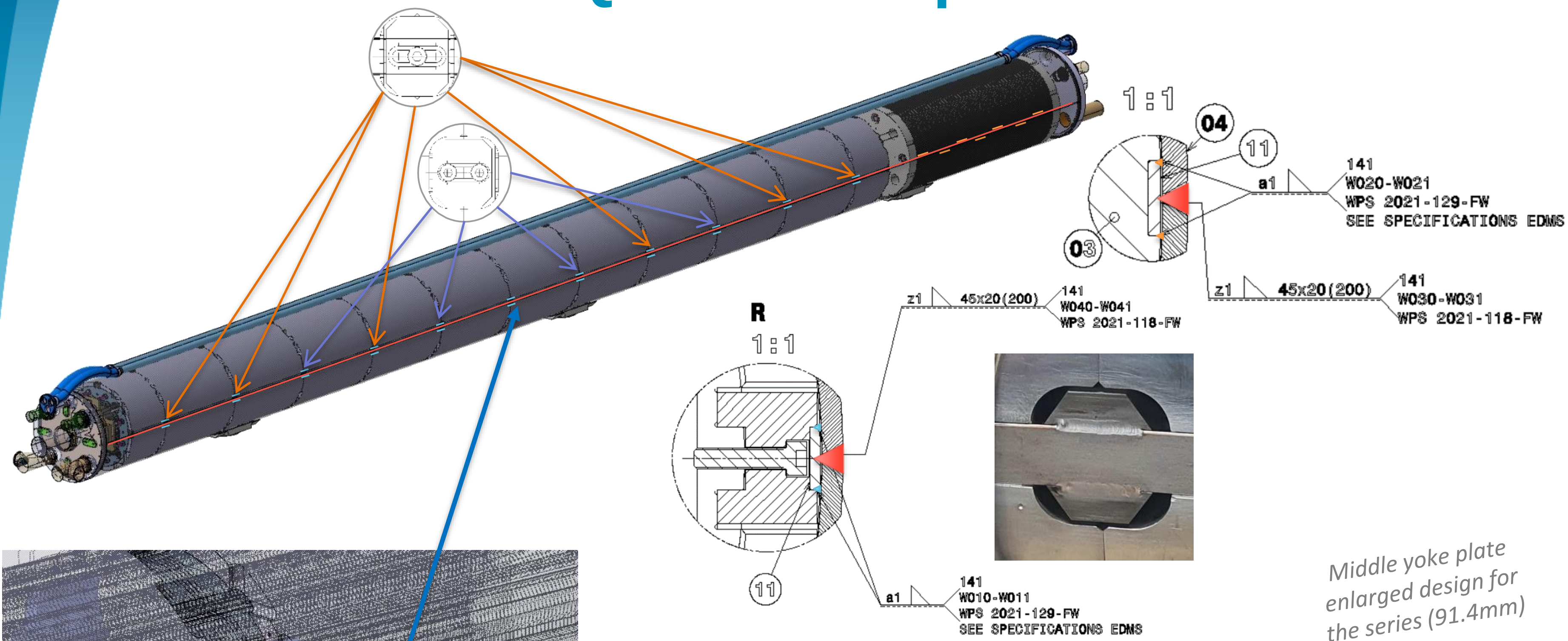
*Shell pairing for LMQXFBT04, the second cold mass with MQXFBP3:*

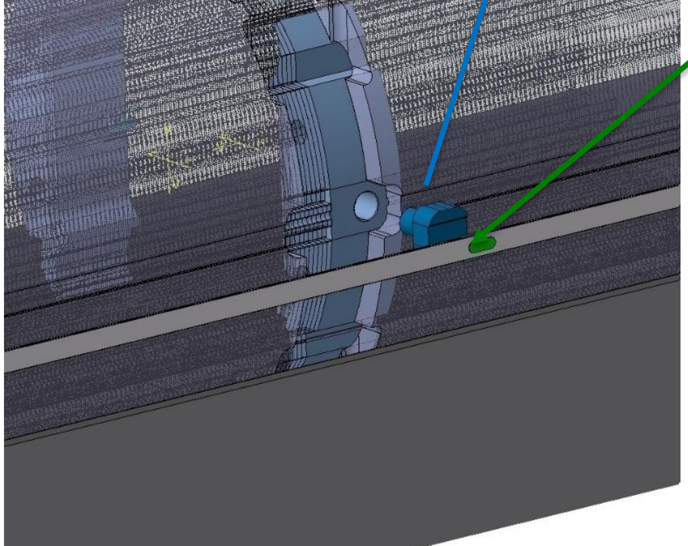



*Courtesy of Susana*

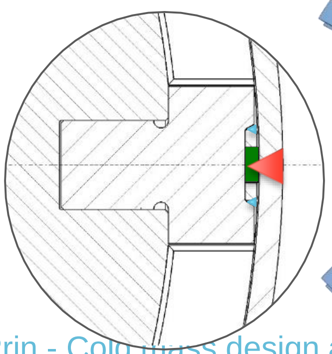


# MQXFB fixed-point



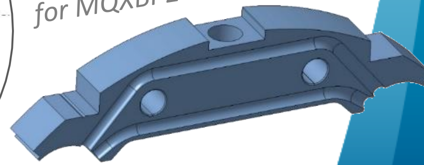



*Plug weld according to EN 1993-1-8 : 2005(E)*



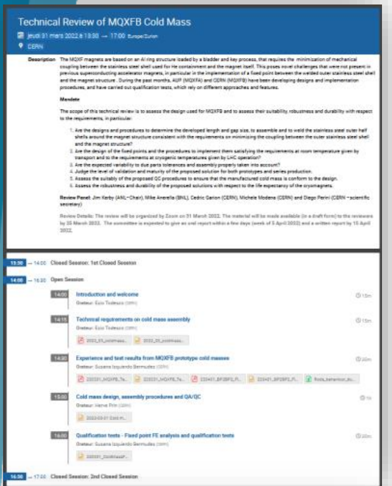
*Middle yoke plate enlarged design for the series (91.4mm)*

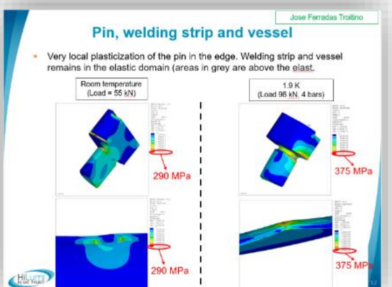
*Middle yoke plate machined for MQXBP2 and 3 (45mm)*

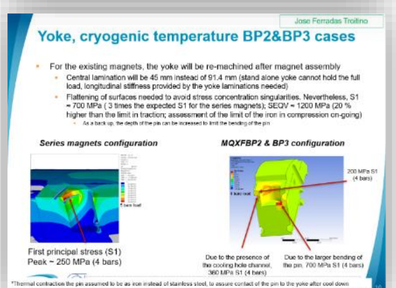


# Outcome of Technical Review of MQXFB Cold Mass

https://indico.cern.ch/event/1142636/




**1.Are the designs and procedures to determine the developed length and gap size, to assemble and to weld the stainless-steel outer half shells around the magnet structure consistent with the requirements of minimizing the coupling between the outer stainless-steel shell and the magnet structure?**

**Yes**, assuming the vendor can meet the strict shell manufacturing tolerances proposed. A complete set of procedures has been developed and is implemented (or is under implementation) both at the shell supplier premises and at CERN. As a general comment, the proposed loose stainless-steel shell, requires a careful assembly and control sequence. It can be done since these are small series of quadrupoles to be manufactured in very controlled conditions.

**2.Are the design of the fixed points and the procedures to implement them satisfying the requirements at room temperature given by transport and the requirements at cryogenic temperatures given by LHC operation?**

**Yes**, in the case of the quadrupoles that will be manufactured starting from new modified components.

In the case of the existing prototypes already assembled, the proposed solution is quite at the limit and there are risks associated to their operation. These magnets will be used in the string and not in LHC machine. For this reason, the proposed configuration is not ideal but seems acceptable providing a risk analysis in case of fixed point failure is carried out and, in case of need, mitigation measures are defined.

The committee discussed if four fixed points (instead of two), machined on place, on the same plane could help in the case of BP2 and BP3. For This might help in cases where stress re-distribution occurs after local deformations.

**Recommendation N1:** We suggest carrying out a risk analysis to clarify the consequences of the failure of the fixed point components; both for the string cryomagnets and for the series.

**Recommendation N2:** For the prototype magnet, we recommend investigating any improvements that may significantly reduce the stress level in the Armco central plate. We understand that increasing the depth of the rod could slightly improve the stresses in the brittle Armco support. We recommend checking this possibility and implementing it in case the simulations confirm the stress decrease. We recommend as well to introduce a chamfer or a rounded shape at the bottom of the rod cavity.

**Recommendation N3:** The life cycle of the quadrupoles was not given in the presentations. It is most likely not an issue during transport: low stress and high ductility of the material. At cold, a minimum number of expected quenches and life cycle requirement should be specified. It is important to assess the resistance of the parts for more than one single quench event. We recommend performing several cyclic tests, consistent with expected lifetime, at cryogenic temperature to check the resistance to crack propagation.

**3.Is the expected variability due to parts tolerances and assembly properly considered?**

**Yes**.

**4.Judge the level of validation and maturity of the proposed solution for both prototypes and series production.**

**Extensive FEM computations and engineering considerations have been carried out and presented**. For the series production the situation is **well understood**, and the solution is **feasible**. As said before, the prototypes are at the limit and the presented analysis seems not fully conservative (laminations accounted as solid block, no stress redistribution for the fracture analysis). Recommendations 1, 2 and 3 applies particularly to this case.

**5.Assess the suitably of the proposed QC procedures to ensure that the manufactured cold mass is conform to the design.**

**QC procedures are well defined**.

**6.Assess the robustness and durability of the proposed solutions with respect to the life expectancy of the cryomagnets.**

**Solution proposed for the series production is fine**. The solution for the prototypes, considering their limited use in the string, is acceptable providing the recommendations 1 to 3 are applied.

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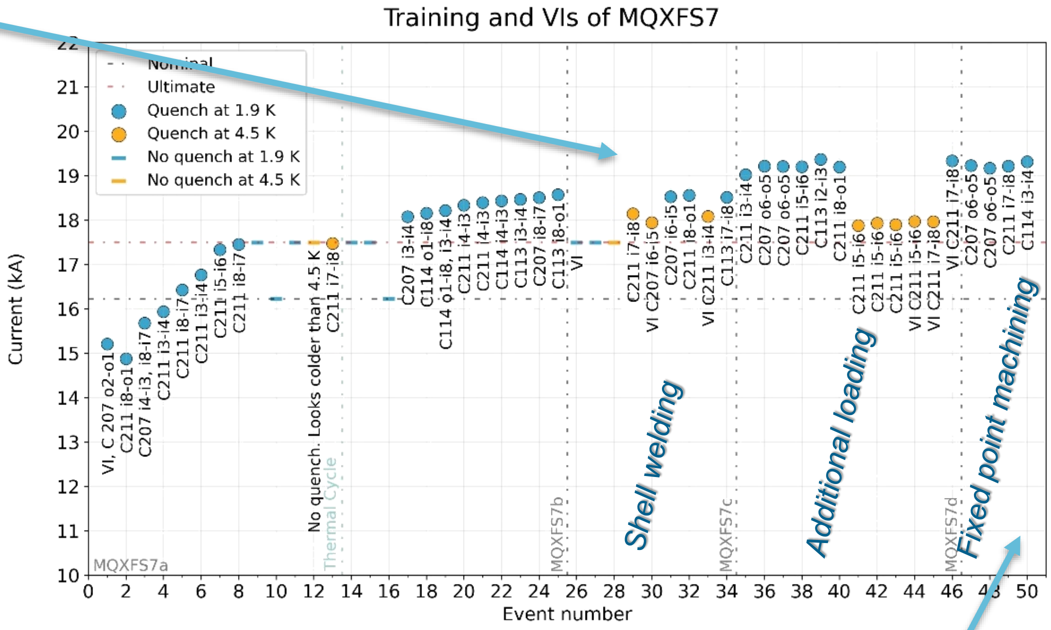
# Implementations on MQXFS7

*Shell welding*

*Shell Cutting*

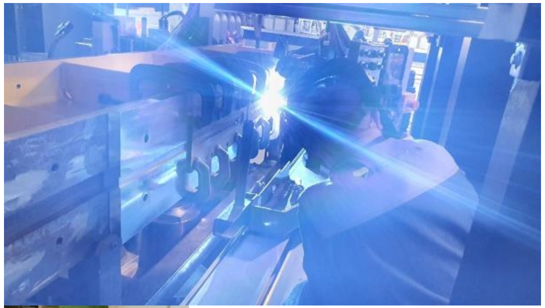
*Fixed point Machining*

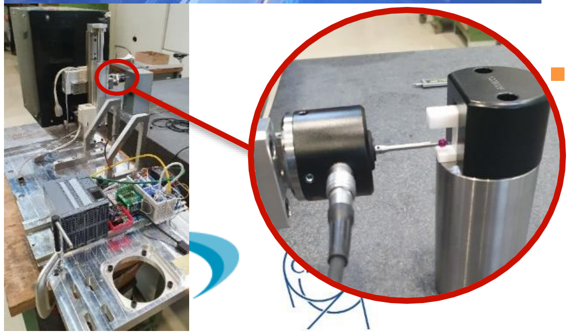



*Shell welding, then cutting and bore machining in the model yoke does not affect its performance*

# Additional QC and improvements for next cold masses

- Weekly meeting with the half shell manufacturer for a close follow-up.
- Magnet developed length measurements (+shape) using different technics (like pi tape, dedicated tooling or laser tracker).





- Shell re-measurements during reception at CERN, ultimate adjustment envisaged either by pairing or machining using a portable machine developed in house
- Possible adjustment of the developed length thanks to a portable milling machine developed in house.
- Systematic root gap checks and measurements after tack welding
- Welding power sources upgraded in 2021, improved repeatability by requalification with amended parameters.
  - ✓ Shim and shell tack-up procedure defined
  - ✓ TIG pass fixed parameters
  - ✓ Defined values to fine tune the WPS range according to given welding preparation geometry (wire speed automatically adjusting current and voltage, voltage trim minor adjustment)
- Welding shrinkage measurement improvement in terms of accuracy and automation developed in house using a probe like the ones used in the CMM.

# Summary

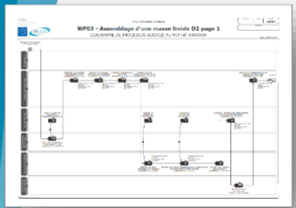
- *After MQXFBP2 cold test, the target of mechanical coupling magnet to cold mass shells was reviewed.*
- *Coupling minimisation between the stainless steel and aluminium shells obtained by:*
  - *SST shell developed length increase and tolerancing review,*
  - *Welding developments to define and control parameters,*
  - *Welding shrinkage characterisation and root gap control with calibrated shims.*
- *Minimised coupling between magnets and their envelope generated a need to fix the magnets inside the cold mass to cope with acceleration during transport and against pressure waves.*
- *The fixed-point proposed design was presented during a technical review the 31st of March, it received very positive conclusions. All recommendations are being implemented.*
- *The proposed design was, or will be, also implemented on:*
  - *MQXFS07, bores drilled inside the yoke without any effect on the model performance,*
  - *LMBRDP2, the D2 prototype cold mass, cylinders welded with new nominal developed lengths*
  - *LMQXFBT04, 4th cold mass to test the 3rd MQXFB prototype, presently being assembled*
  - *LMQXFB01, first Q2 cold mass with MQXFBP2 2nd prototype magnet, staring in May*
- *Procedures are being refined and additional tooling being developed to cope with the effects and impacts of the proposed changes.*

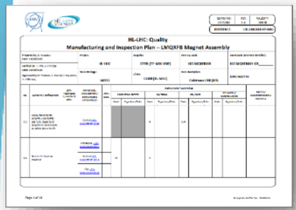
# LMQXFBT04 with MQXFBP3

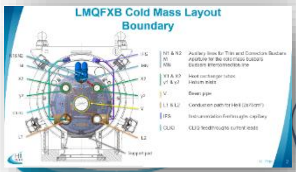

*First TIG pass of the longitudinal welding will start on Tuesday the 3rd*

# *Spares slides*

# Applicable Documents for HL-LHC cold masses



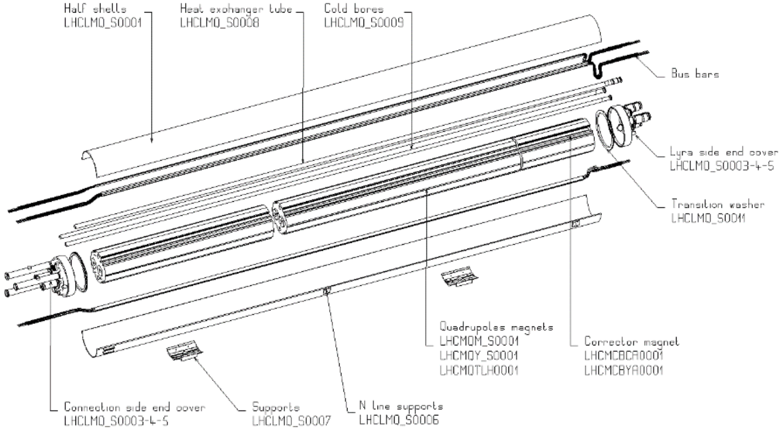





- **Flowcharts:** cold mass assembly process from the magnets delivery up to its acceptation by the WPE
  - Q2 flowchart: LHC-LMQXFB-FP-0002 2366861
  - D2 flowchart: LHC-LMBRD-FP-0002 2263493 v0.2
  - CP flowchart: LHC-LMCXF-FP-0008 2711593 V0.1 (draft)
- **MIPs:** cold mass Manufacturing and Inspection Plan
  - Q2 MIP: LHC-LMQXFB-FP-0001 2315780
  - D2 MIP: LHC-LMBRDP-FR-0013 2716556 v1.0 (ongoing)
  - CP MIP: LHC-LMCXF-FP-0009 2711595 V0.1 (ongoing)
- **Production report:**
  - D2 production report :
    - Prototype cold mass LHC-LMBRDP-FR-0015 2679760
    - D2 prototype cylinder LHC-LMBRDP-FR-0021 2706834
  - CP production report: LHC-LMCXF-FR-0019 2682730
- **Triplet interface specification:** 2131281

# LHC CERN IR cold mass assembly principle
## (MQM and MQY types)

LHC Project Report 713




**Two half-shells:**

- serve for positioning of the various magnetic elements (quad. and dipole orbit corr.)
- provide the rigidity for their alignment
- serve as a helium pressure vessel closed with two end covers

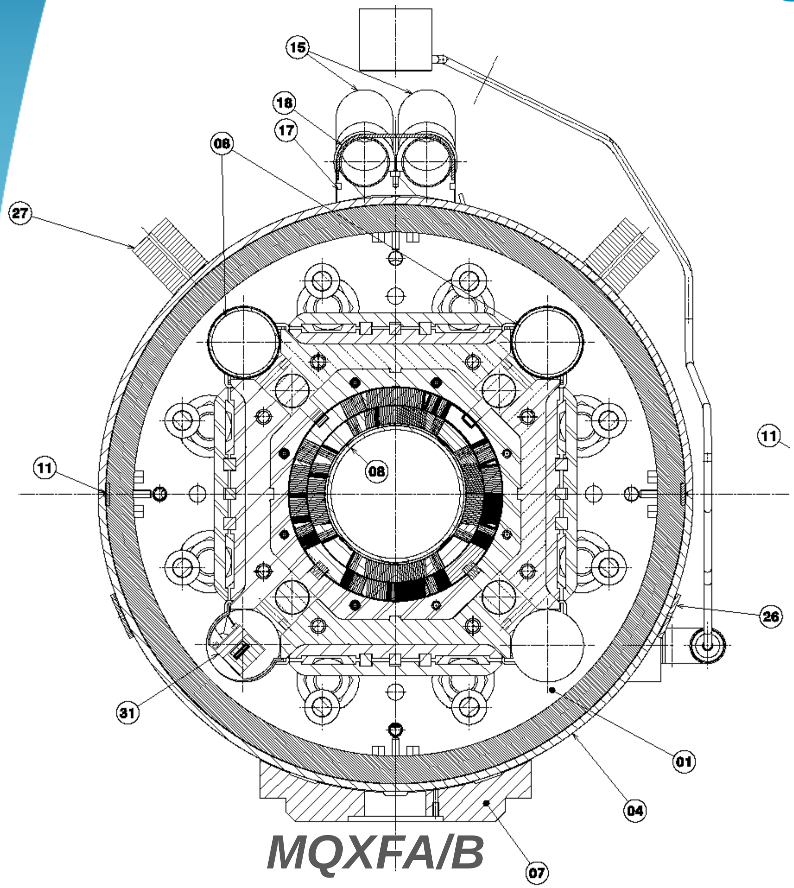




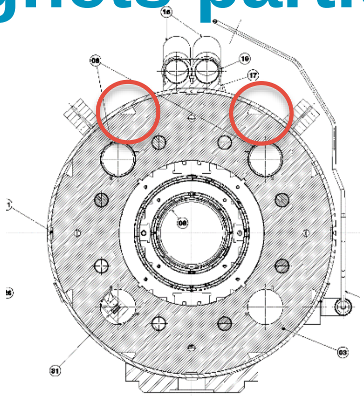
**Magnets Alignment:**

1. Align the magnet yokes individually using precision alignment cradles
2. Tack welding the alignment keys to the laminations under compression.
3. Aligned magnets are placed in the half-shell.
4. Align magnets relative to each other using the cradles.
5. Tack weld the alignment keys to the chamfer of the half-shell.

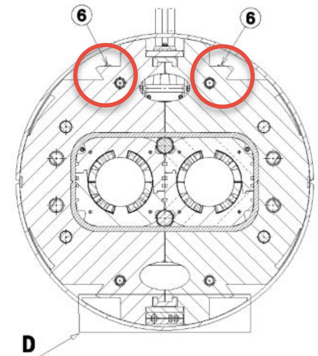
# HL-LHC magnets particularities



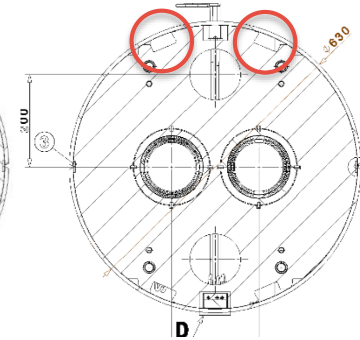

MQXFA/B



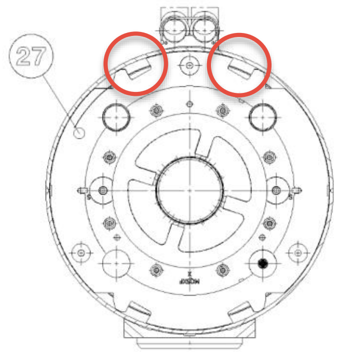
MCBXFA/B



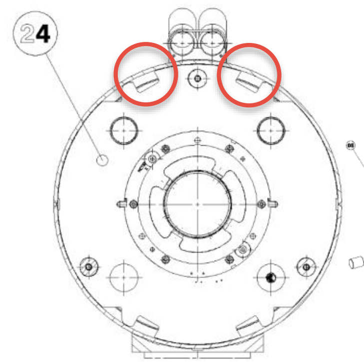

MBRD (D2)



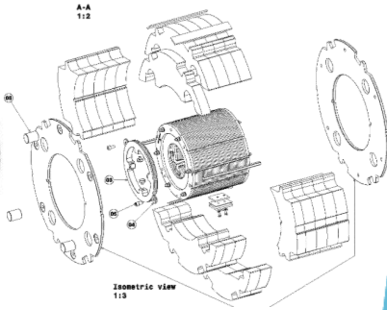

MCBRD (CCT)




MQXSF




HO corr. n≥6

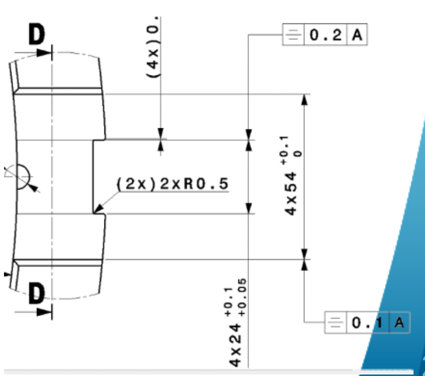



***__MQXF__ dictates parameters for other magnets on one side:***

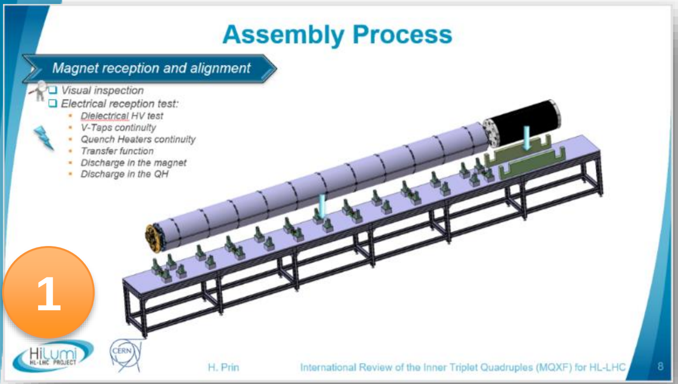
- *Øext = 614mm*
- *Backing strip: 4 x $24^{-0.1}_{-0.2}$*

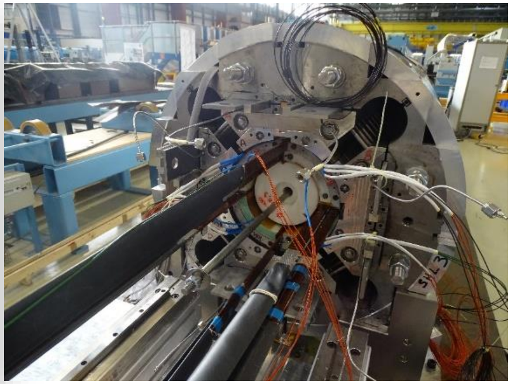
***__Vacuum vessel__ installation constraints fix the cold mass dimensions:***

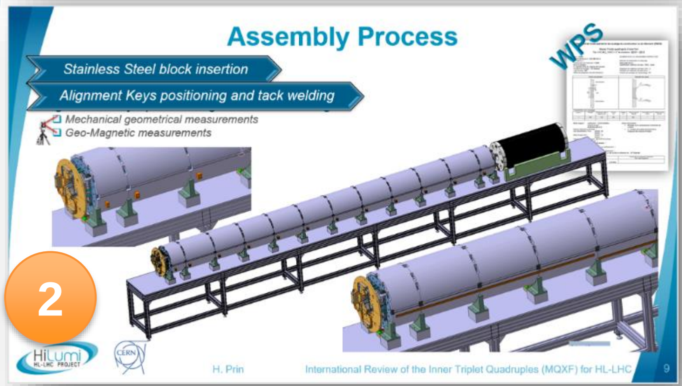
- *Lmax ≤ 15160mm from the main dipole*
- *Øext ≤ 630mm ⇨ shell thickness ≤ 8mm*

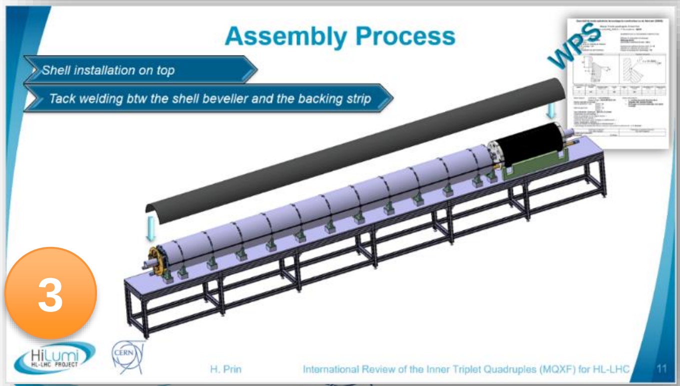


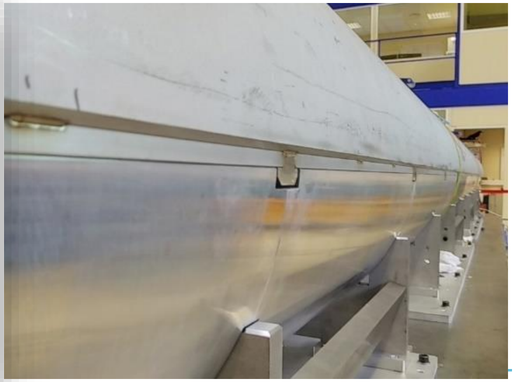
# Assembly procedure 1/2



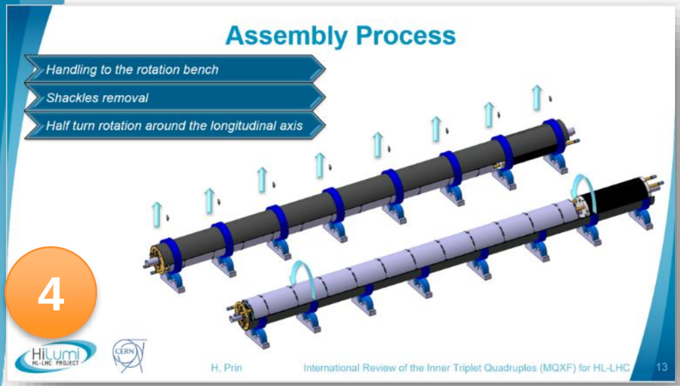



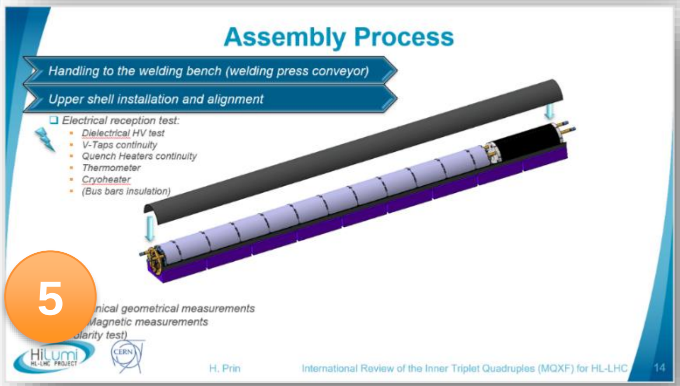


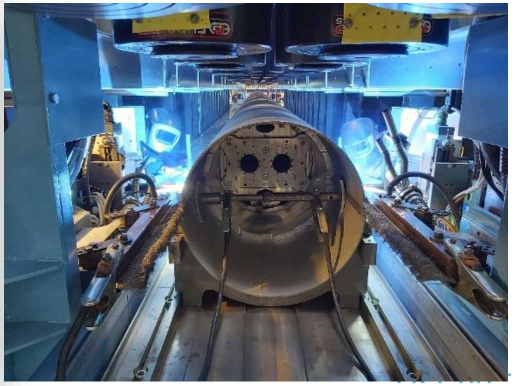



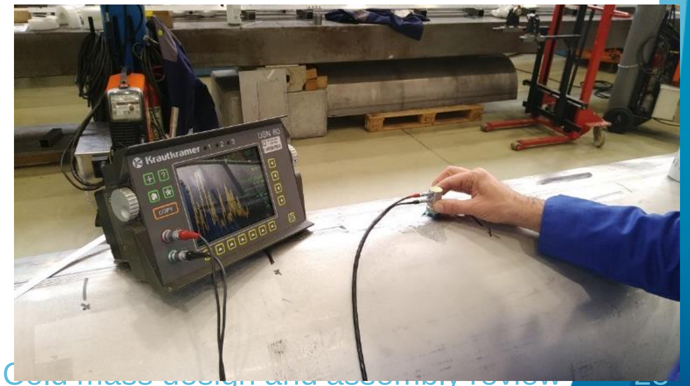
# Assembly procedure 2/2



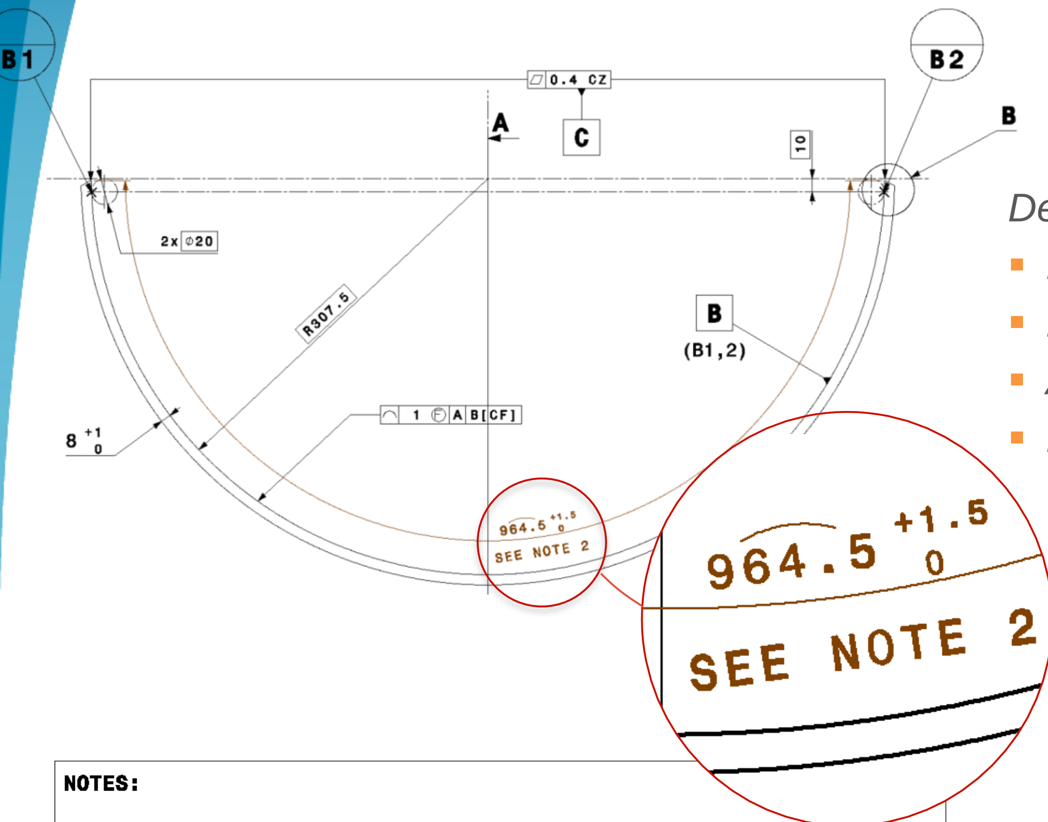







# Shell design




NOTES:

1- SHELL AND RAW MATERIAL REQUIREMENTS AS PER TECHNICAL SPECIFICATION: TECHNICAL SHEET n° 700-Ed.1 EDMS 1531078
2- INNER 1/2 CIRCUMFERENCE, DIMENSION TO BE HELD REGARDLESS OF TOLERANCE ON THE INSIDE RADIUS.
3- TOLERANCE TO BE HELD ON EACH ROOT FACE THE SHELL IS CONSTRAINED IN THE MACHINING JIG. TO BE CONSIDERED AS 0.3mm/m IN RELEASED STATE.
4- MARKING ON THE OUTSIDE ONLY

*Developed length history (LHCLMQXF_S0001):*

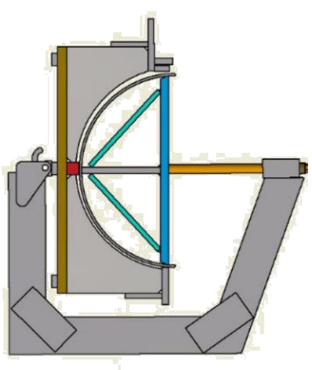
- *Mar 2017: 966.04 -0.25/+0.5*
- *Nov 2018: 964.47 -0.25/+0.5 ⇦ Coil 8 MPa [±8]*
- *Aug 2019: 963.04 -0.25/+0.5 ⇦ Dual WP*
- *Now: 964.5 -0/+1.5 ⇦ 0 MPa [+8]*

***It is agreed with the manufacturer that shells could be combined to reach the defined 1929mm length for the pair***

# Shell production improvements

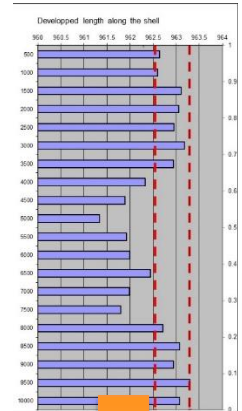
- *12m press, 3'000 tons capacity, fully revised in March 21 to improve the quality of the forming*

- *Forming process in three steps rather than two used previously to improve shaping accuracy.*

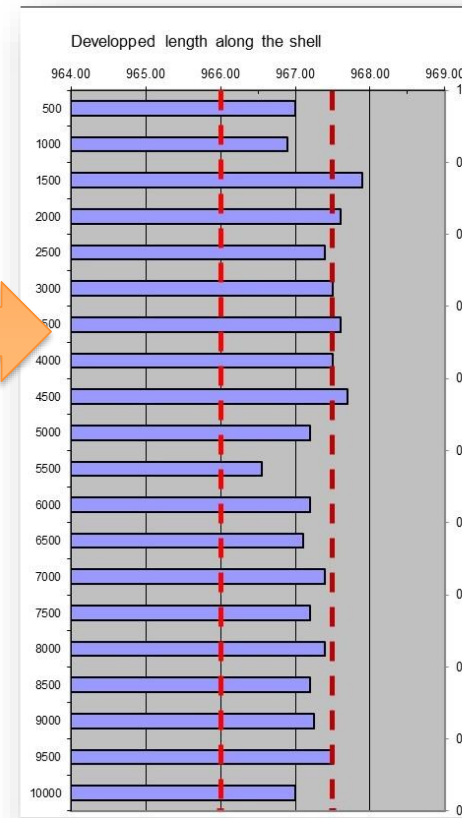


- *Machining jig modified to insert two compressing C clamps in the shell centre.*
- *Estimation of the compressive force is about 2 tons.*
- *Additional screws added to fix the shell extremities and prevent movements.*

*<u>Before enhancements</u>*

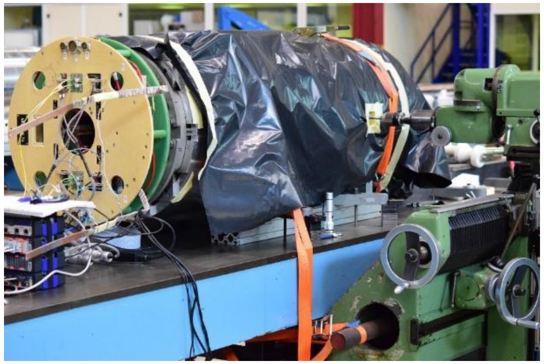



*<u>After proposed improvements:</u>*
*Last shell #6-2 to be paired with shell #6 machined after process improvement. Target developed length was the maximum value*



# Fixed point machining procedure

## (To be used only on already assembled magnets MQXFBP2 and 3)



*Tested on MQXFS7*

- Check parallelism magnet / y axis of the machine
- Centering in the existing thread with a 6.8mm drill

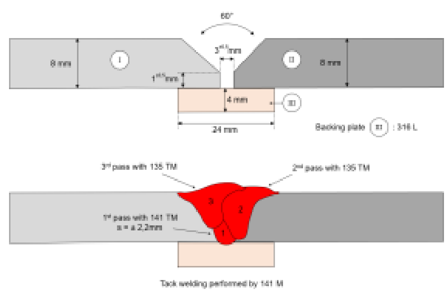
| STEP 1 | STEP 2 | STEP 3 | STEP 4 | STEP 5 |
|---|---|---|---|---|
| ***Tool:***<br>Drill ø16<br>***Cutting speed:***<br>200 rpm on 10mm then 400 rpm<br>***Depth:***<br>36.5 mm | ***Tool:***<br>Milling cutter ø16 with central cut<br>***Cutting speed:***<br>250 rpm<br>***Depth:***<br>37 mm | ***Tool:***<br>Counterbore ø29 with centering ø16 and 35mm length<br>***Cutting speed:***<br>250 rpm<br>***Depth:***<br>33mm, then remove centering and go to 37mm | ***Tool:***<br>Reamer ø30H7<br>***Cutting speed:***<br>80 rpm<br>***Depth:***<br>max | ***Tool:***<br>Counterbore ø45 with centering ø30<br>***Cutting speed:***<br>200 rpm<br>***Depth:***<br>0.5mm |


| WELDING PROCEDURE SPECIFICATION (WPS) | WPS No.: 2021-130-FW<br>Ref.: HL - LHC<br>Date: 30.03.22 Rev: 1 |
|---|---|

| | | | | | |
|---|---|---|---|---|---|
| Prod. by: | A. CROCHEMORE | Client: | H. PRIN | Ref. stand: | ISO 15614-1 |
| Project: | LMQXFB Q2A-B COLDMASS | Ref. spec.: | | Exam. body: | APAVE |
| Location: | Building 180 | Ref. WPQR: | FR-22-0168-V1 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Welding process | 1 | 141 M (Pointage) | 2 | 141 TM | 3 | 135 TM |
| Shielding gas type | | I1-Ar | | I1-Ar | | M12-ArC-2.5 |
| Weaving (yes/no) | | NO max: mm | | NO max: mm | | NO max: mm |

| | |
|---|---|
| Purging gas type | l/min |
| Welding positions | Tack: PA PC |
| Joint type | Butt weld |
| Joint preparation | Plates (tôles) |
| Cleaning method | |
| Backing | mb (with backing) |
| Single/Double | single side |
| Back gouging | |
| Flux designation | |
| Flux handling | |
| Tungsten electrode | TACK:WCe-Ø2.4 / WELD:WCe-Ø4 mm |
| Torch angle | 90 ° |
| Stand off distance | 141TM:13mm/135:unmeasurabl mm |
| Nozzle diameter(s) | TACK:12.7mm - WELD:19mm mm |
| Tack welding proc. | Manual Rev: |




**Identification of parent metal** I: CE max: C max: PCM max: II: CE max: C max: PCM max:

| Part | Name/Grade | Standard | Group | Delivery cond. | Thickness range [mm] | Diameter range [mm] |
|---|---|---|---|---|---|---|
| I | EN 1.4429 (316LN) | | 8.1 | Plate | 8,00 - | - |
| II | EN 1.4429 (316LN) | | 8.1 | Plate | 8,00 - | - |

**Identification of filler metal**

| Index | Trade name | Classification | Group | Filler handling |
|---|---|---|---|---|
| 1 | BÖHLER ASN 5-IG | WZ 18 16 5 Mn NL (ER317L mod.) | FM5 | |
| 2 | BÖHLER ASN 5-IG (Si) | GZ 18 16 5 NL (ER317L mod.) | FM5 | |
| 3 | BÖHLER ASN 5-IG (Si) | GZ 18 16 5 Mn NL (ER317L mod.) | FM5 | |

**Welding Parameters** Equipment: MFHX56-504

| Pass no. | Index | Dia. [mm] | Welding process | Wire feed speed [m/min] | Current [A] | Voltage [V] | Current / Polarity | Welding speed [mm/min] | Run Out Length [mm] | Gas [l/min] | Heat input [kJ/mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TACK | 1 | 1,60 | 141 M | . | 100 . 12 | 11,3. 13,8 | DCEN | . | | 5-7 | . |
| 1 | 2 | 1,00 | 141 TM | 0,72 . 0,88 | 180 . 245 | 10,0. 10,4 | PULSE | 92,0 . 112 | | 19-21 | 1,0 . 1,1 |
| 2 | 3 | 1,20 | 135 TM | 6,30 . 7,70 | 185 . 227 | 20,5. 25,0 | PULSE | 225 . 275 | | 17-19 | 0,8 . 1,4 |
| 3 | 3 | 1,20 | 135 TM | 5,40 . 6,60 | 148 . 181 | 19,2. 23,6 | PULSE | 225 . 275 | | 17-19 | 0,5 . 0,8 |
| | | | | . | . | . | | . | | | . |
| | | | | . | . | . | | . | | | . |
| | | | | . | . | . | | . | | | . |
| | | | | . | . | . | | . | | | . |
| | | | | . | . | . | | . | | | . |

**Heat treatment** Method:

Preheat min: °C Interpass temp. max: 60 °C Heat treatment proc.: Temp. control:

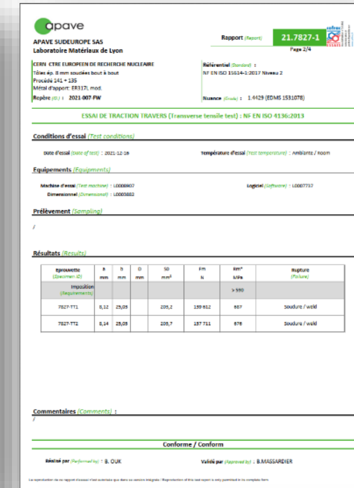
PWHT min: °C max: °C Soaking: min/mm min Heating rate: °C/h Cooling rate: °C/h

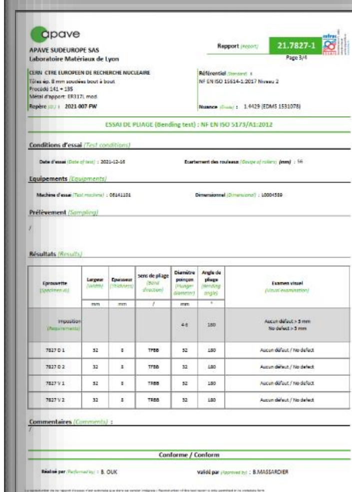
Remarks:
LONG MASTER TIG KEMPPI 2300 AC/DC
FIRST PASS 141TM : PC 600-3 PROGRAMM 11 ROOT ATTACHED (PULSE)
2-3 PASSES 135TM : KEMPPI X8 - Trainard I1-Ar @ 30L/min
LONGITUDINAL MQXF - COLD MASS, done on MFHX56-504 (PRESSE)
DRAWING: LHCLMQXFB0004

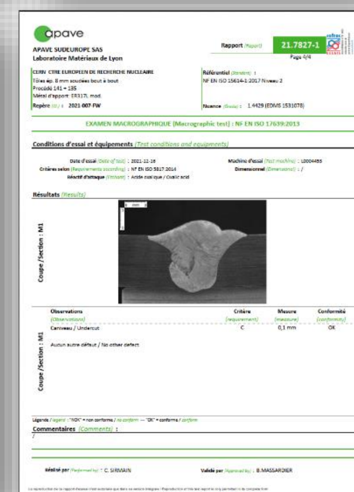
Additional info enclosed (Yes/No): YES

Date/Signature: 30.03.22 AC
Antoine CROCHEMORE

Index no. 1001423166 Page 1 of 1 Produced by WeldEye®

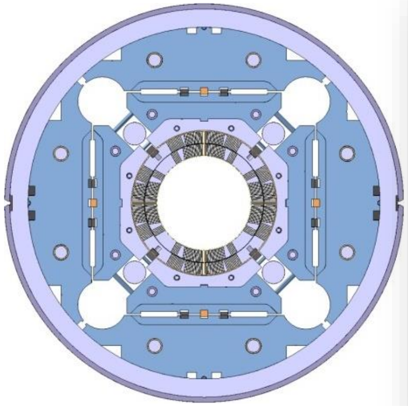
# Welding over aluminium: a potential issue?

*Welding trials using existing procedure qualification records have be performed using a **stainless steel backing strip** and a **longitudinal groove** for gaseous protection machined in the aluminium support.*

***X-rays show no inacceptable defect on both samples.***

*<u>Further developments in collaboration with EN-MME (Welding, Material and NDT):</u>*

- ***Monitoring of the temperature** during welding on several locations*
- ***Metallographic section** and **EDS analysis** (Energy Dispersive X Rays Spectrometer) to determine the presence of Aluminium, Manganese or other gaseous deposition on the weld or shell surfaces*
- ***Tensile tests** to confirm no mechanical degradation.*
- ***Leak tests** on the root pass*



# Radiographic Testing Report over the first sample (EDMS 1460432)

**CERN**
CH1211 Geneva 23
Switzerland

| EDMS NO. | REV. | VALIDITY |
|---|---|---|
| 1460432 | 0.0 | approved |

REFERENCE
Inner Triplet Upgrade MQXF / H. Prin TE/MSC

Date of control: 05.12.2014

## 2. Control parameters

| Weld n° | Image n° | SFD (mm) | f (mm) | kV | mA | Time (s) | Wire | Film size (cm) | Defects | Conformity |
|---|---|---|---|---|---|---|---|---|---|---|
| S1 weld with Al backing strip | 1 | 600 | 589 | 140 | 10 | 90 | W15 | 10 x 40 | 2011 ; 2015 | A |
| S2 weld with SS backing strip | 1 | 600 | 589 | 140 | 10 | 90 | W15 | 10 x 40 | 2011 | A |

Conformity: A = Acceptable, NA = Not Acceptable following ISO 5817, level B

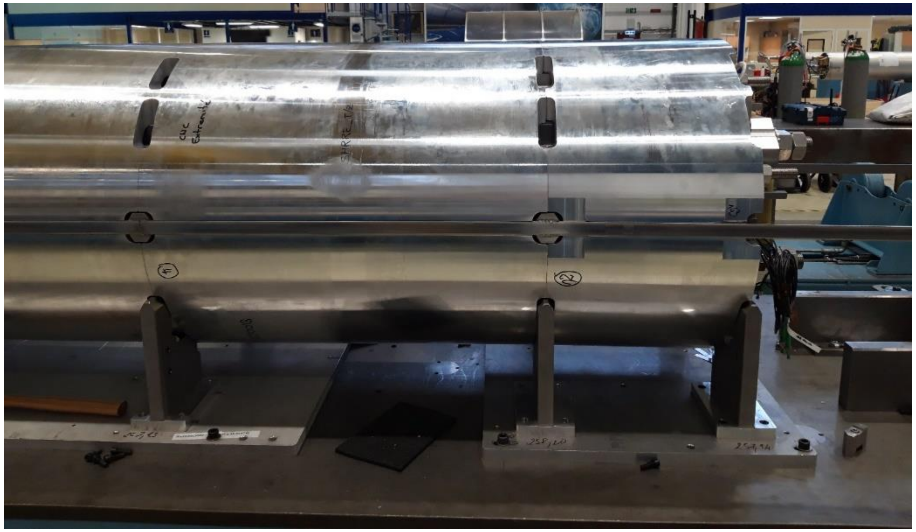
ISO 6520-1 reference for identified defects (imperfection designation): 2011 (gas pore) and 2015 (elongated cavity).

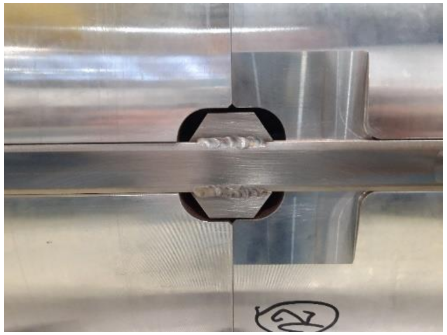
## 3. Conclusion

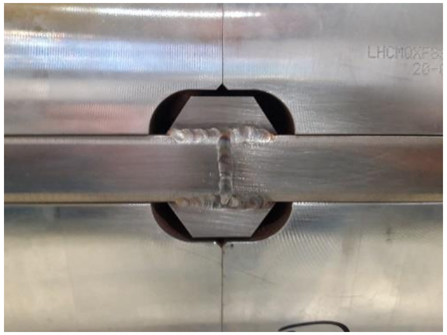
The welds are conform with the standard ISO 5817, level B.

*Remark: the radiographic interpretation has to be performed on a HD screen.*

# Tack blocks and backing strips installation







- LHC-MQXFB-FP-0020 – Controls before assembly

REFERENCE LHC-MQXFB-FP-0020 | EDMS NO. 2324061 | REV. 6.1 | VALIDITY VALID

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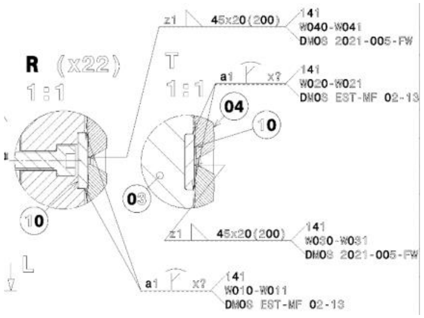
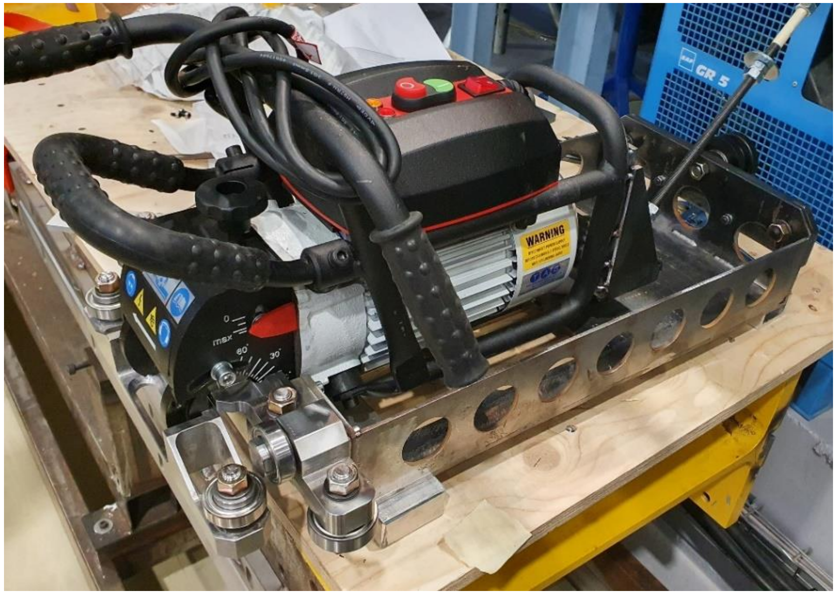
| | | |
|---|---|---|
| 13 | Vérifier que les blocs d'alignement centraux:<br>- Sont centrés,<br>- Ne dépassent pas de la gorge des shells aluminium,<br>- Sont fixés de manière à ce que la position de la vis permet un mouvement maximal vers le centre de l'aimant.<br>**PRENDRE DES PHOTOS DE TOUS LES BLOCS** | |
| 14 | A l'aide d'un pointeau, marquer la position de la culasse par rapport aux jointure des shells aluminium.<br>Remarque : Au cas où les shells aluminium ne soient pas jointives, pointer le centre de l'espace entre<br>**PRENDRE DES PHOTOS DE TOUS LES BLOCS**<br>**Remplissez l'opération K.10 du MIP [3].** | |

  - Tack blocks should be centered inside the aluminum shell pockets.
  - Dot marking on the tack blocks and the magnet yoke in line with the aluminum cylinders junctions.
  - Screws are installed on the magnet with a bias towards the center to allow maximum movement.
  - All blocks are photographed in position before placing the backing bars.

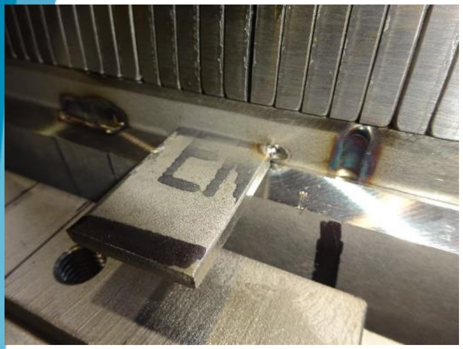



- Tack blocks are welded in position using filler material.
- Excess is removed so the shell can locate correctly.

# Shell adjustment milling machine




# New dev. lengths implemented on LMBRDP02
## (D2 prototype)



Lower shell #4 and shims tack welding to the baking strips

Upper shell #101 dev length machining

$\widehat{L_4} = 967.2^{+0.8}_{-0.7}$

$\widehat{L_{101}} = 961.8^{+1}_{-0.8}$

$\widehat{L_4} + \widehat{L_{101}} = 1928.96^{+1.3}_{-1.2}$

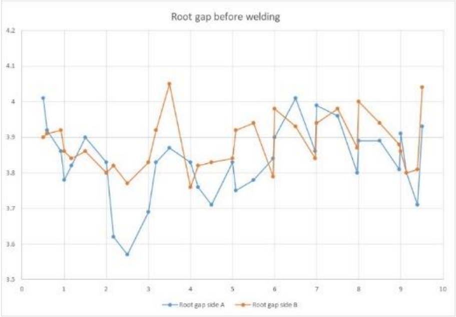
Slide 11

Upper shell installation on top of the magnet

Upper shell sitting on top of the shims surface

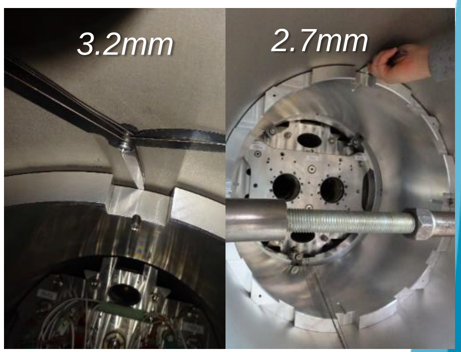
Upper shell tight adjustment to the magnet yoke and backing strip

Upper shell #101 and shims tack welding to the baking strips




Root gap measurements after tack welding and shims removal

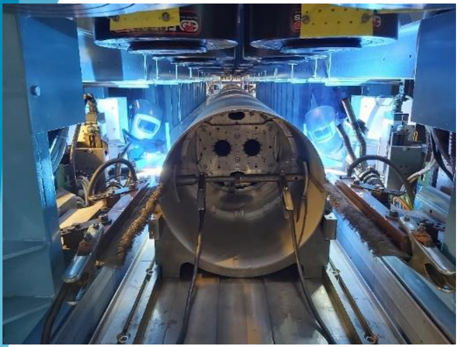
- Side A 3.8mm [3.6, 4]
- Side B 3.9mm [3.8, 4.1]



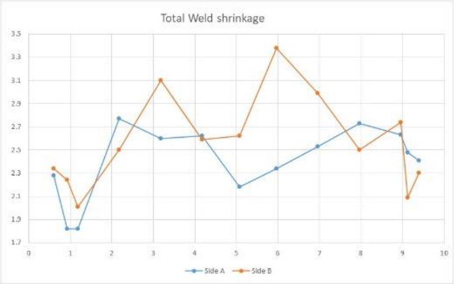

Upper shell/retrains gap measurements in the extremities:

- CS 3.2mm
- RS 2.7mm

# New dev. lengths implemented on LMBRDP02
## (D2 prototype)

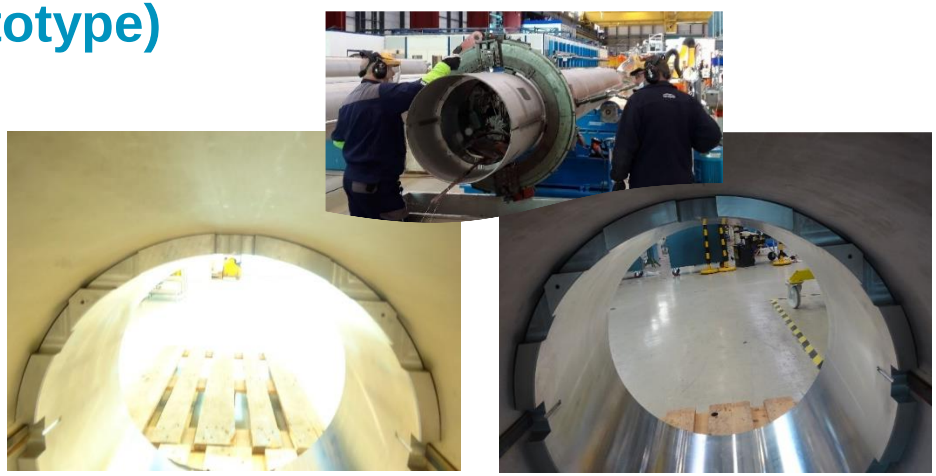


*Dual welding process:*
*Root pass TIG*
*2 filling passes MIG*

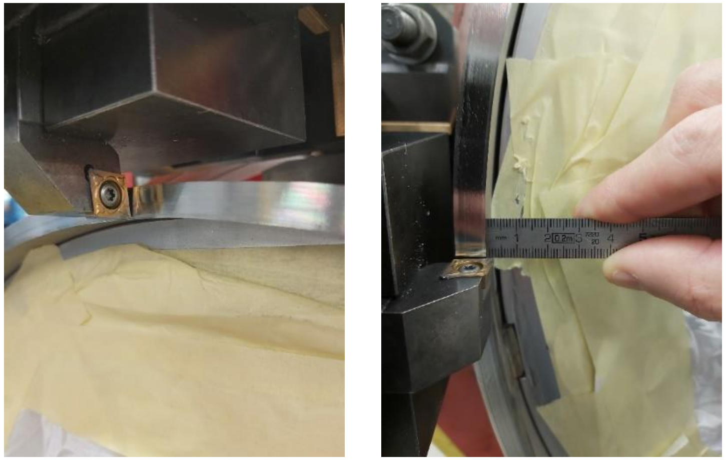



*Welding shrinkage after the 3 passes:*

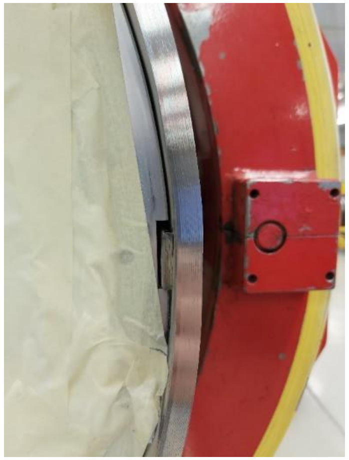
- *Side A = 2.4mm [1.82, 2.77]*
- *Side B = 2.57mm [2, 3.38]*



*Shell extremities after orbital cutting.*
*Gap measurements between 0.5mm on top and 0.95mm at 2 and 10 o'clock*
*No gaps on the lower shell*



*Shells elliptical shape in the extremities*



*Rotational movement noted on the backing strip in the extremities*

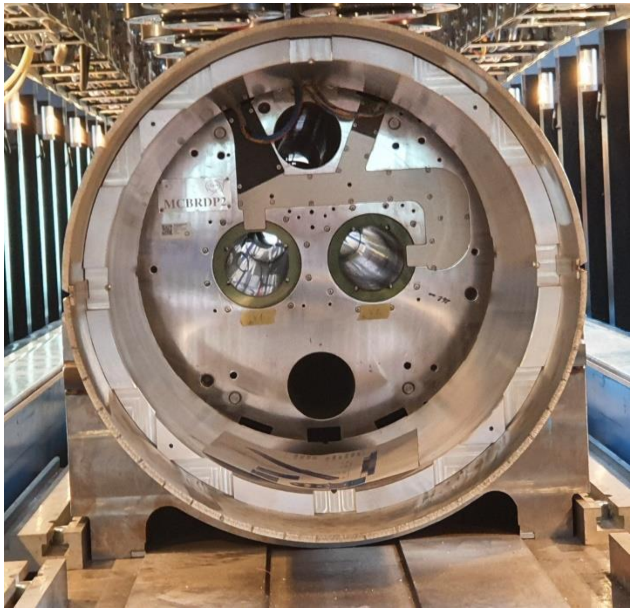
*Stainless steel shape re-rounding using a jack in the extremities*

# Welding shrinkage determination

## *MQXFS7*

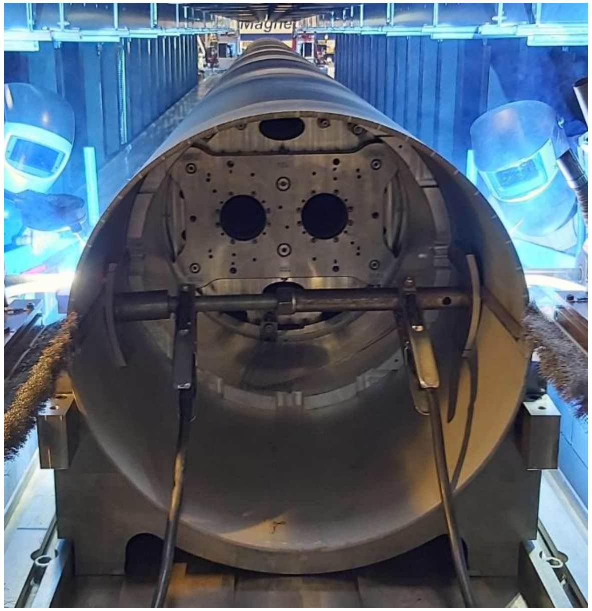
- *Side A = 2.2mm [1.9, 2.6]*
- *Side B = 2.7mm [2.6, 2.8]*

## *MBRDP03*



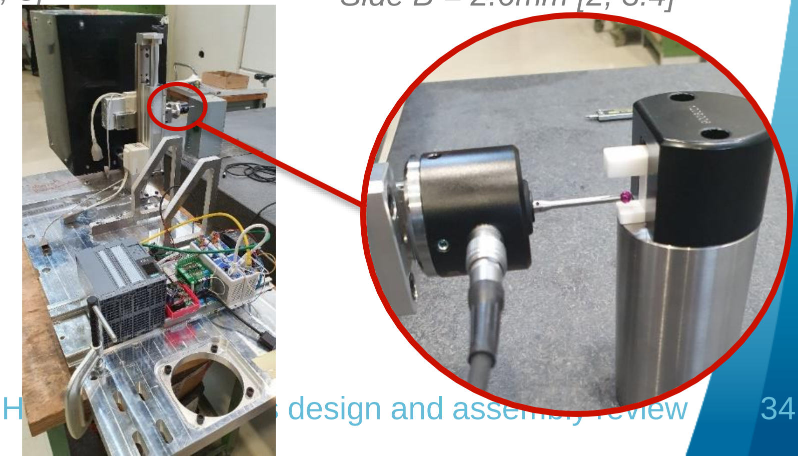

- *Side A = 2.1mm [1.9, 2.3]*
- *Side B = 2.4mm [2, 3]*

## *MBRDP02*



- *Side A = 2.4mm [1.8, 2.8]*
- *Side B = 2.6mm [2, 3.4]*

*New automated system to be mounted on the welding press to increase the measurement accuracy of the welding shrinkage (available for next cold mass)*



# Fixed point traction tests

*Initial test beginning of March 2022*

*Second setup to be tested in week 18*