Cold mass assembly at CERN

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12th HL-LHC Collaboration Meeting, Uppsala
https://indico.cern.ch/event/1161569/

22/09/2022

Outline

- CERN Cold masses charge for HL-LHC WP3
- New requirements for the MQXF magnets:
  - Purpose
  - Review for the MQXFB proposal
  - Implementations
- Welding quality improvements
- LMQXFB01 Assembly (First Q2)
- Status as of today
- Cold masses geometry and mass roll angle
- Summary

CERN Cold masses charge for HL-LHC WP3

Construction:

- LMQXFB (Q2) : 2*+10
- LMQXFBT (temp. cm to test MQXFB magnets): 7*
  assembly **and** disassembly
- LMBRD (D2): 1*+6
  Two cylinders butt welded
- LMCXF (CP): 1*+5
- LMQMT (Q10 with MS): 4

36

Finishing and preparation for cold tests:

- LMBXF (D1): 1*+6

* prototype

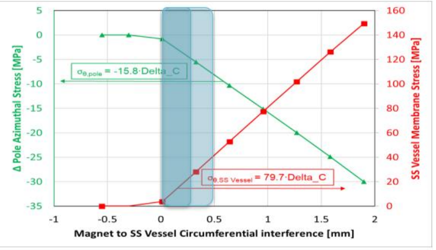
Developments on 11T are not considered in these numbers

New requirements for the MQXF magnets

- After the cold test of the first two prototypes, showing performance limitations, among the many steps taken to mitigate the risks of MQXFB, it has been decided to **reduce further the mechanical coupling between Al structure and SS shell**
- Two main effects:
  - Revision of the welding specification and the developed length of the SS shells
  - Design of the fixed point to withstand requirements in transport and in operation

INTERFERENCE BETWEEN MAGNET AND STAINLESS STEEL SHELL

- When welding the stainless steel shell around the Al structure of the magnet, we should minimize the mechanical coupling between the SS shell and the Al segmented shells
- Requirement:
  - The magnet to stainless steel vessel average circumferential interference shall be lower than 0.25 mm (Delta_C_Average ≥ -0.25 mm, where Delta_C is defined as the difference of the inner circumference of the stainless steel vessel and the outer circumference of the aluminium cylinder of the loaded magnet). This corresponds to a coil pre-load increase in the pole of 4 MPa and SS vessel membrane stress of 20 MPa. In short spots, for possible local recept, the circumferential interference can be up to 0.5 mm (Delta_C_Local ≥ -0.5 mm), which corresponds to a coil pre-load increase in the pole of 8 MPa and SS vessel membrane stress of 40 MPa



  - So the present target on the increase of stress in the coil at room temperature is 0^{+8} MPa
  - Before the test of MQXFBP1 and MQXFBP2, the requirement was less stringent, imposing a target of 8±8 MPa

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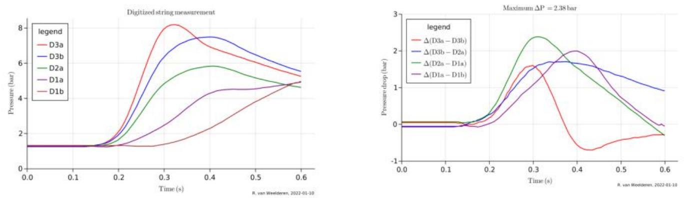
FIXED POINT

- Requirement due to transport (valid at room temperature): maximum acceleration of 0.5 g
  - Corresponds to a force of 55 kN
- Requirements due to operation at 1.9 K see EDMS 2675955
  - Two aspects:
    - The pressure wave that can be induced by the quench of D1 magnet
    - Pressure waves induced by operation



Pressure wave across LHC string1 [R. van Weelderen, et al.]

- This gives a requirement on the fixed point to be able to withstand 4 bar for the MQXFB magnet
  - Corresponds to a force of 96 kN

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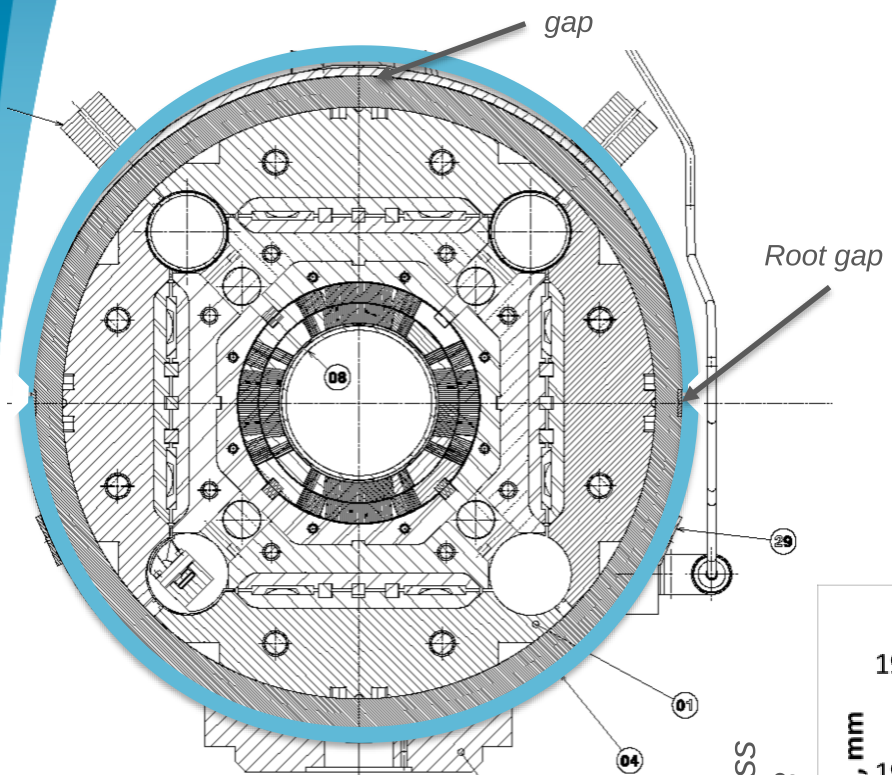
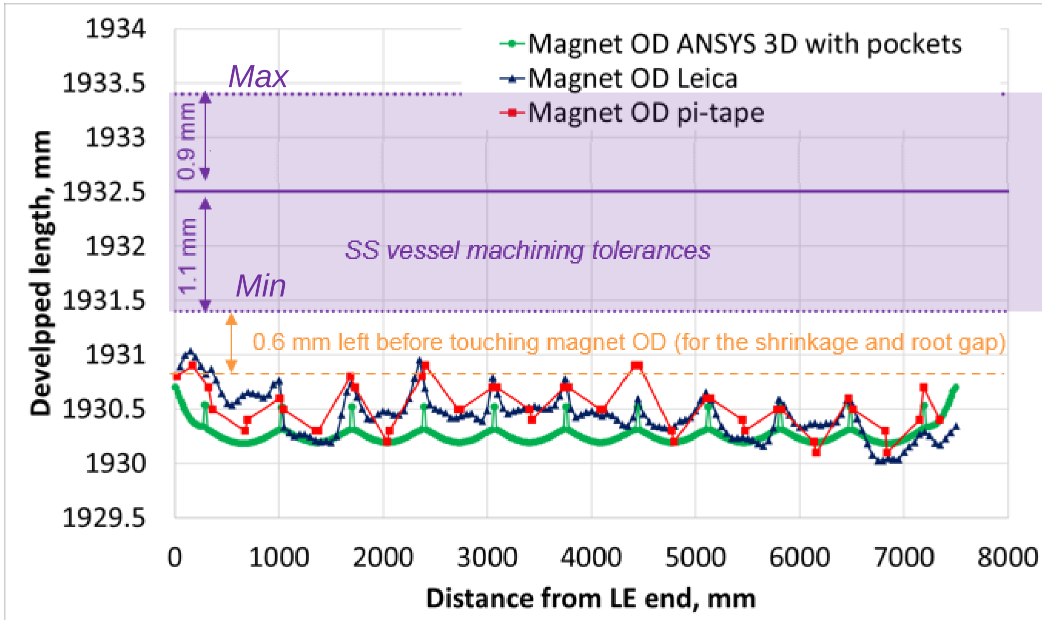
Mechanical coupling reduction
⇨ SS shell dev. length adjustment



≥ *1928.9mm* ⇨ ***1929mm***

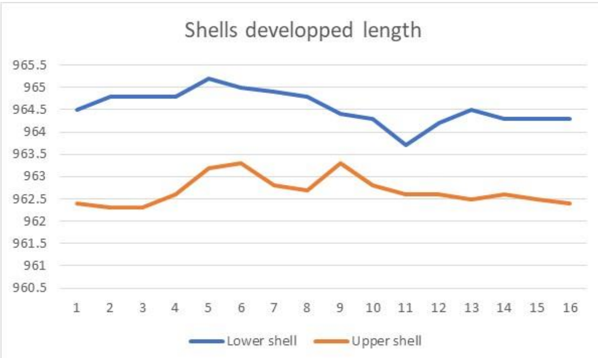
Ex: LMQXFBT04 cold mass with MQXFBP3

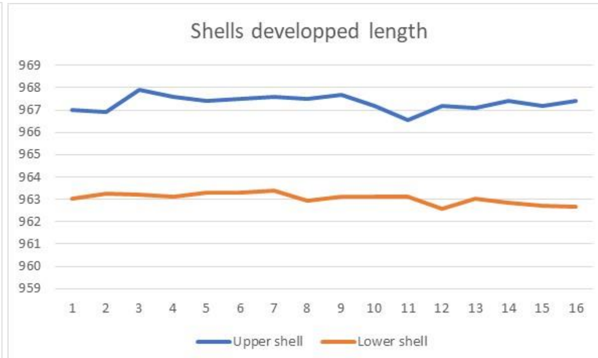


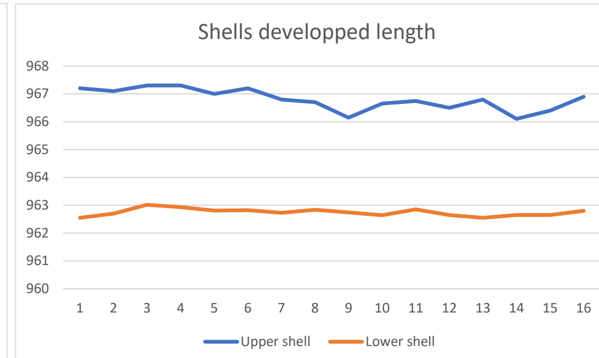
Magnet to Cold Mass Interference

LMQXFBT04 *(MQXFBP3)* | **LMQXFB01** *(MQXFBP2+MCBXFBP1)* | **LMQXFBT05** *(MQXFB02)*

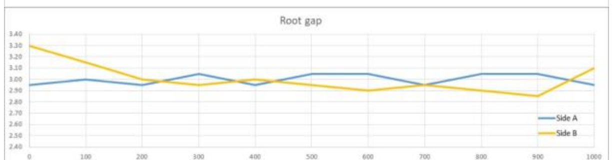
Shell dev length

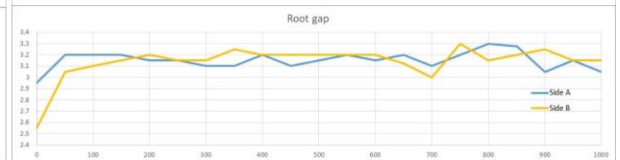


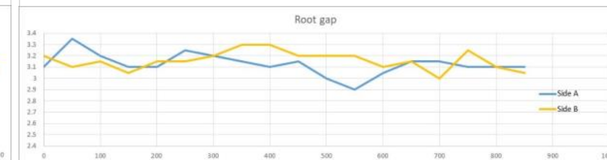




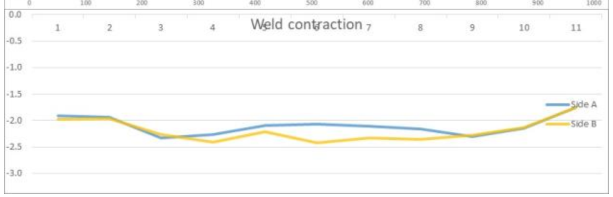
Root gap

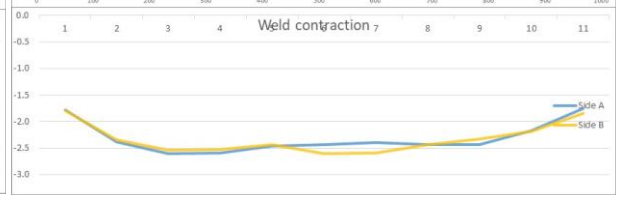






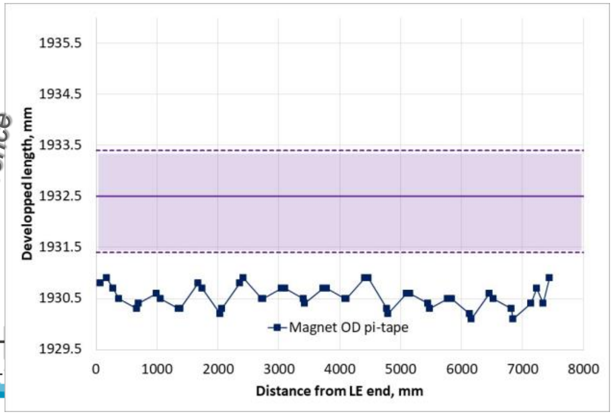
Weld contraction

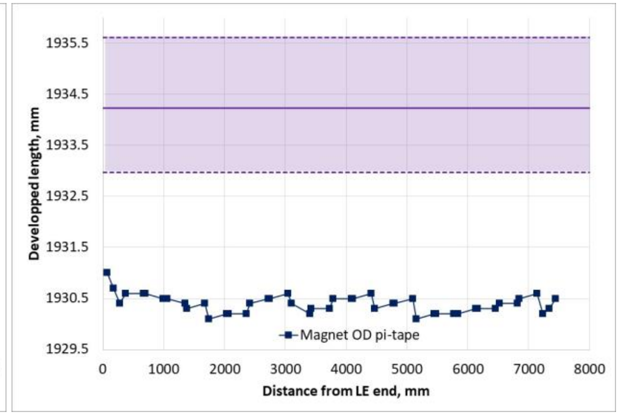


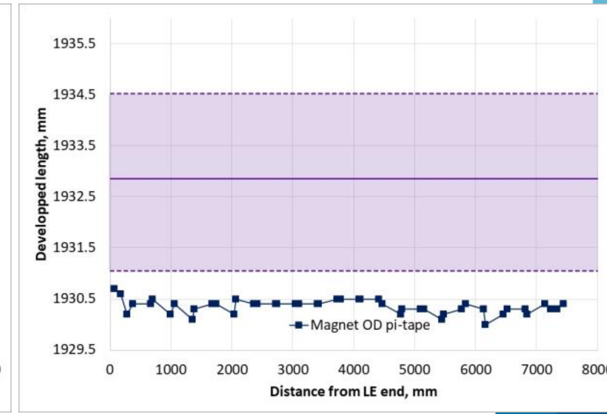


$$Ldev_{Cold\ mass} = Ldev_{Shells1} + Ldev_{Shells2} + Root\ gap_A + Root\ gap_B - Shrinkage_A - Shrinkage_B$$

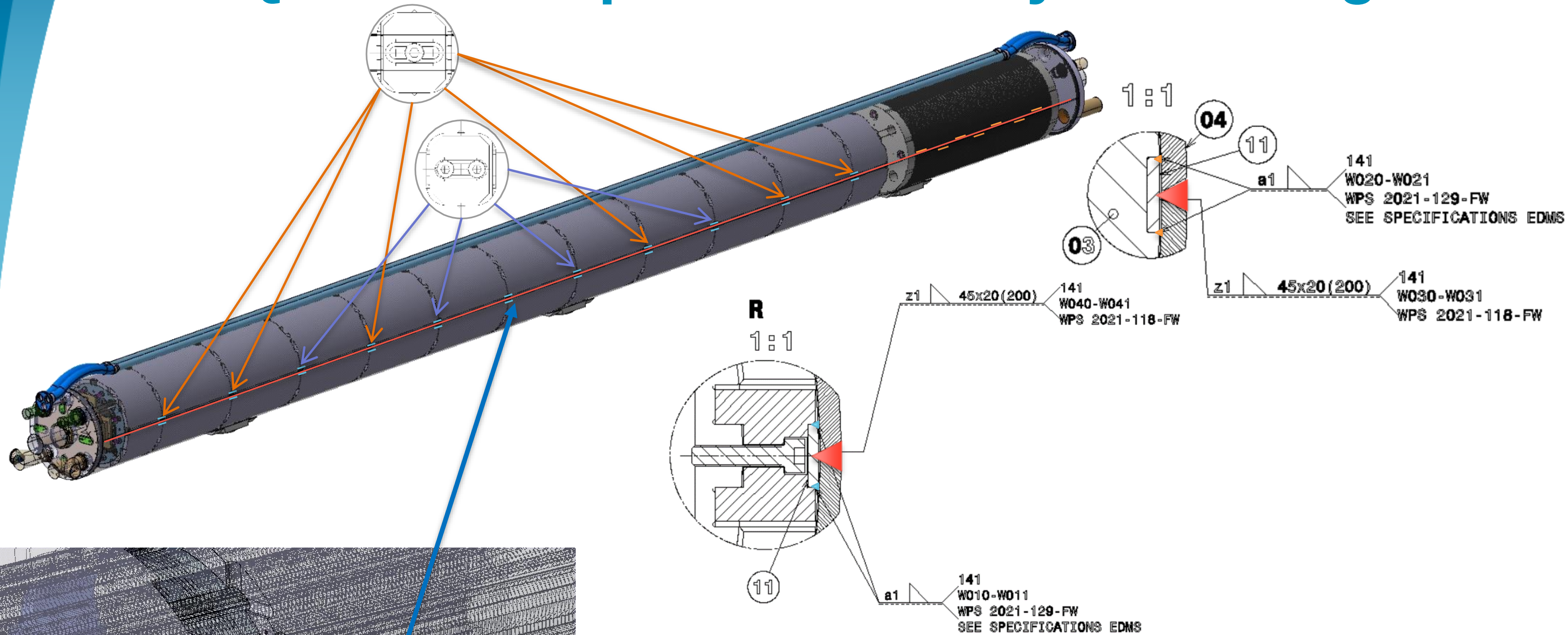
Magnet/Vessel Interference

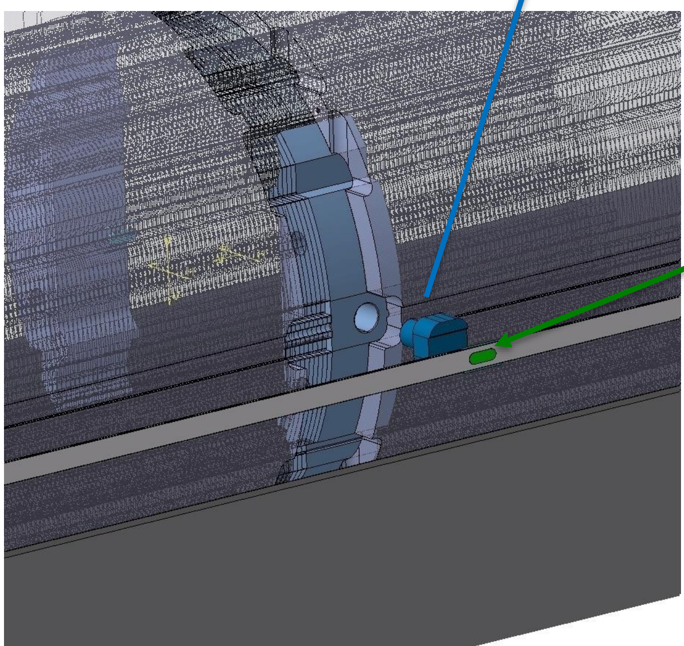




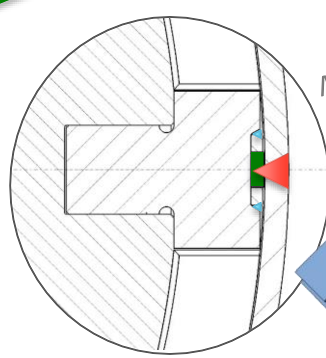


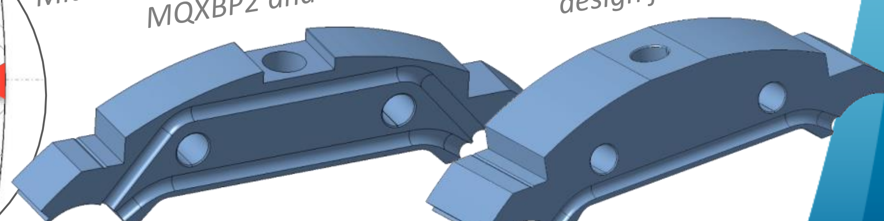
MQXFB fixed point necessity and design





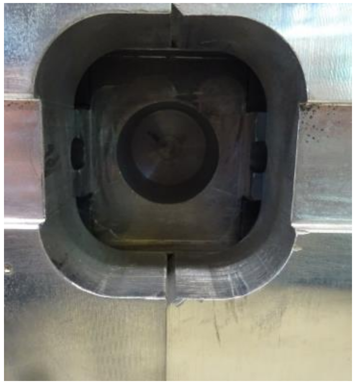
Plug weld according to EN 1993-1-8 : 2005(E)





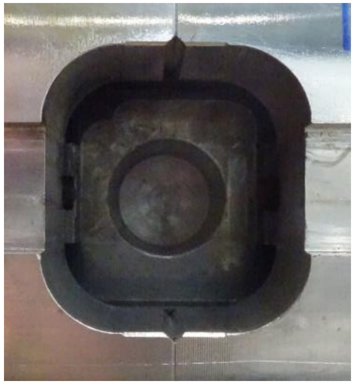
Fixed point implementation

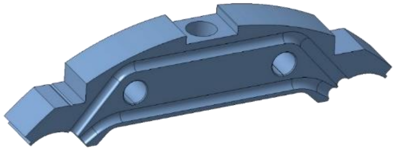
MQXFBP3
machined inside
LMQXFBT04



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

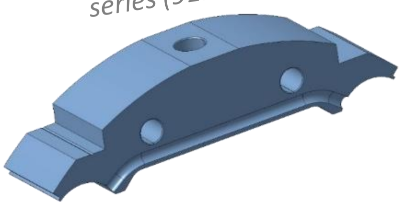
MQXFBP2
machined inside
LMQXFB01





MQXFB02
Assembled in
LMQXFBT05

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



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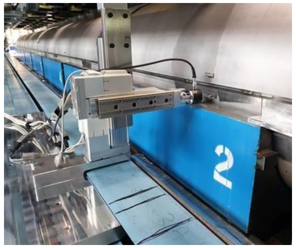
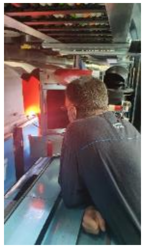
Welding quality improvements

Implemented

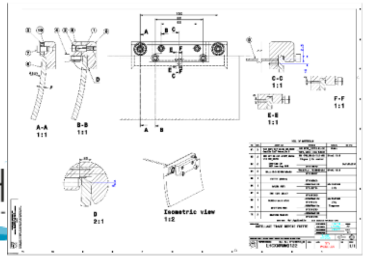
- Parameter refinements within the WPS range to improve weld profile and repeatability
- Tooling to eliminate the gap between the upper shell and the backing strip (0.5mm max)
- Pre-tack shims to maintain root gap consistency along the weld
- Modification of the program for the root pass to reduce the heat input and thus the weld contraction
- Trials conducted to validate tack up without filler material (to eliminate variables between technicians)
- Gaseous protection trailers serviced and gas flow optimized





Ongoing

- Measuring probe automation
- Protection boxes around the TIG welding torches for welders' safety, they will be replicated on the MIG torches
- Weldeye software to monitor continuously the welding parameters (Amperage, Voltage, heat input, estimated speed) implement on the MIG sources, TIG system integration to follow

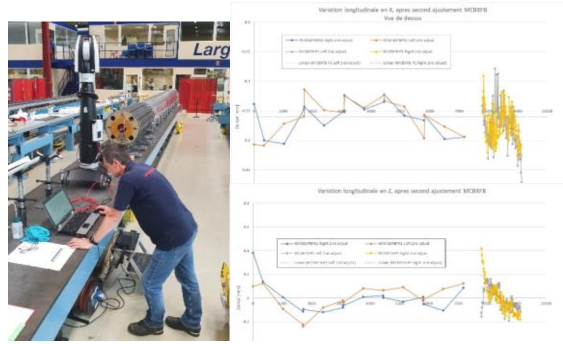


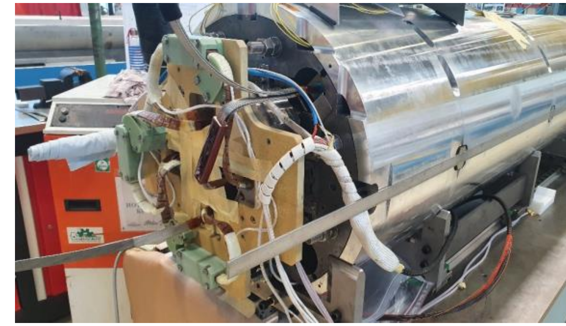
Proposed

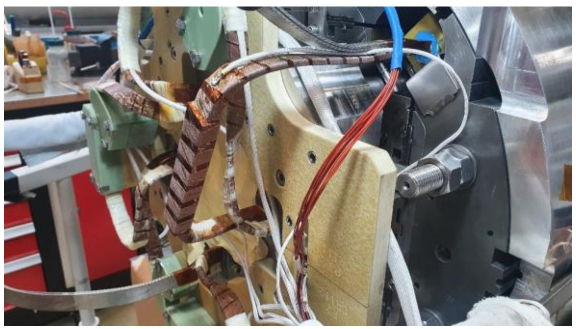
- System to mark the shells for torch and welding alignment

LMQXFB01 Assembly
The first Q2 cold mass (for the string)

Quad. and corr. Alignment on the assembly bench

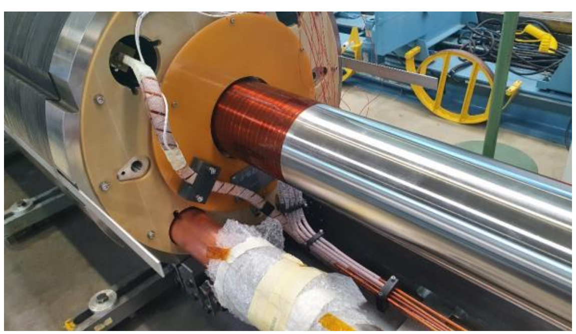

Magnet yoke measurements with the laser tracker


Backing strip installation and welding to the fixed points and alignment blocks


Busbars installation and splicing to the quad. lead


Corrector leads shaping and insulation


Cold bore and heat exchanger tubes installation


Busbars shaping in the extremities


Shell installation and alignment


Shell tack welding to the backing strips

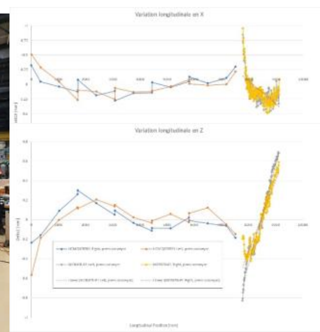
LMQXFB01 Assembly
The first Q2 cold mass (for the string)

2/2

Transfer to the rotation bench

Rotation upside down

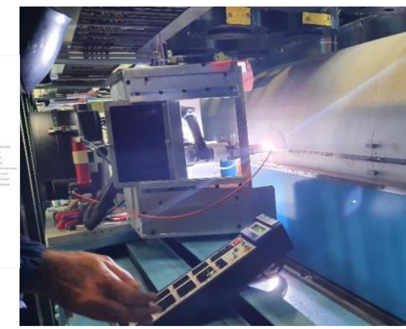
Transfer to the welding press conveyor



Magnet yoke measurements with the laser tracker

Thermometers installation

Upper shell alignment, tack welding to the backing strips. Welding shrinkage blocs measurements installation



Longitudinal welding: 1st pass TIG + 2 MIG filling passes

Mag. measurement to orient the field to gravity
Welding of the supports

Shell extremity cutting and welding preparation machining for the end covers

End covers alignment and welding

NEXT ACTIVIITIES:

- *Interfaces alignment in the extremities and welding*
- *FSI positioning*
- *N-lines assembly*
- *IFS capillary install. & forming*
- *CLIQ leads connection*
- *Final elect. tests, mag. meas.*
- *Pressure/leak tests*

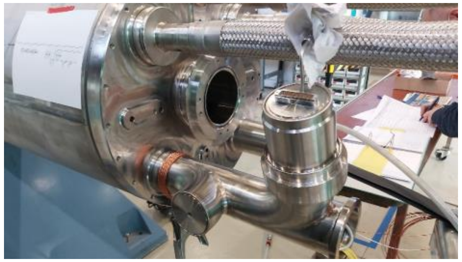
End of Oct. 22

Status as of today

LMQXFBT

LMQXFBT01 *(MQXFBP1)*
07/2019 →02/2020

LMQXFBT02 *(MQXFBP2)*
10/2020 →12/2020



LMQXFBT03 *(MQXFBP3)*
02/2021 →04/2021

LMQXFBT04 *(MQXFBP3)*
04/2022 →06/2022

LMQXFBT05 *(MQXFB02)*
08/2022 →10/2022

LMQXFB (Q2)

LMQXFB01
(MQXFBP2+MCBXFBP1)
06/2022 →10/2022

LMBRD (D2)

LMBRDP1
(MBRDP1+MCBRDP1b+MCBRDP2)
09/2021 →05/2022

LMCXF (CP)

LMCXF01 *(MCBXFAP1*
+MQXFS02+MCTXF2+MCTSXF1
+MCDXF01b+MCDXF02b+MCOXF03
+MCOXF04b+MCSXF01b+MCSXF02)

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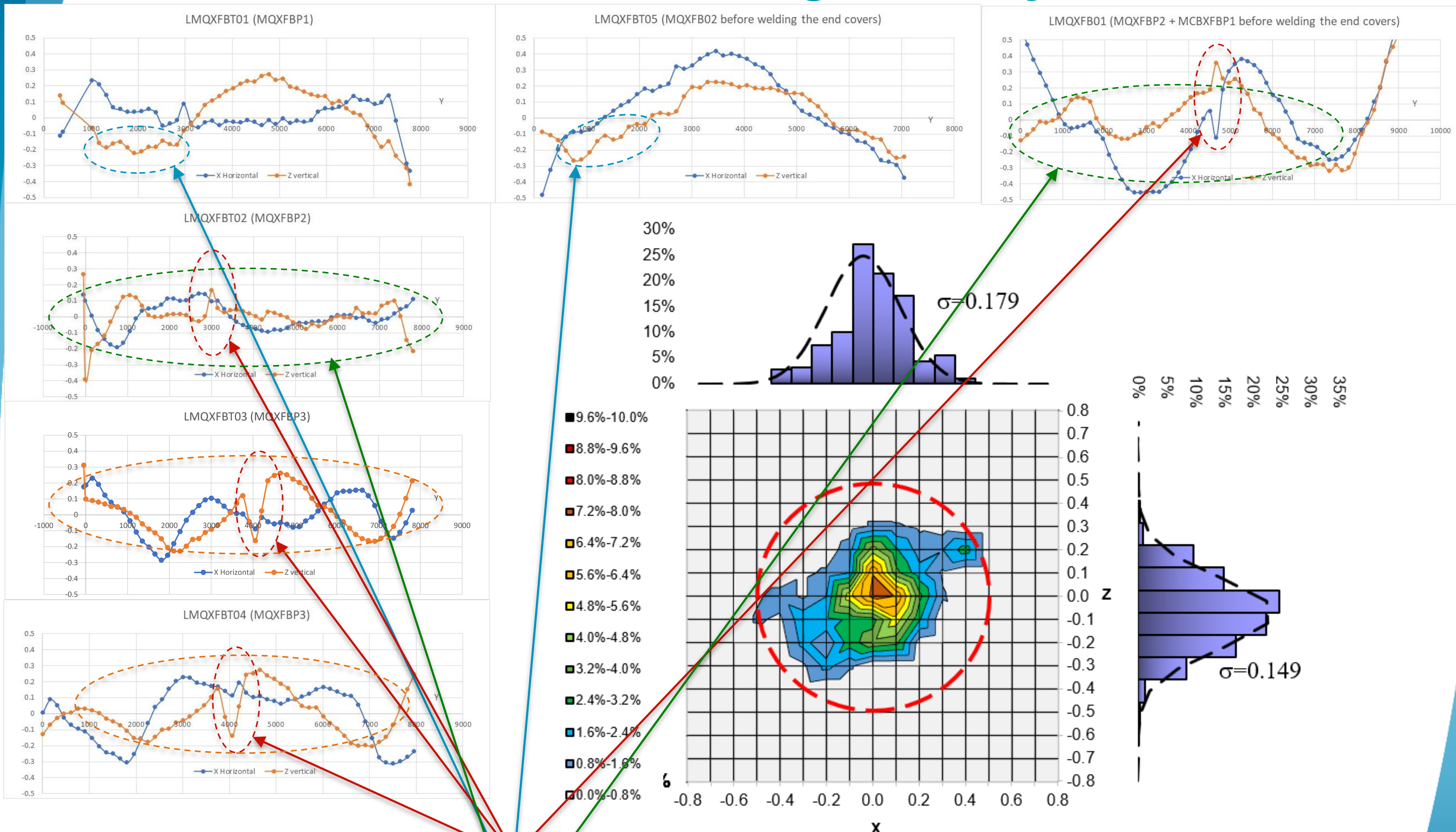
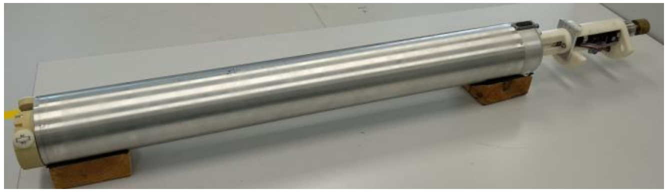
Cold masses geometry



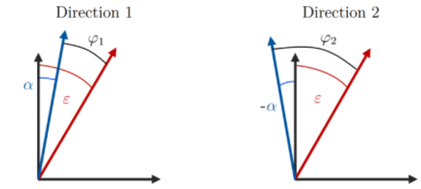
Machining defaults inside the cold bore tube are visible
Cold bore tube straightness plays a role in the geometry
But it is mainly dominated by the magnet shape which can change from one cold mass to another (MQXFBP2) or not (MQXFBP3)

Cold mass roll angle towards gravity

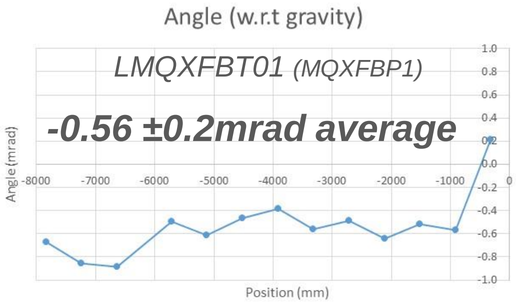
Courtesy of C. Petrone and P. Rogacki



- *Roll angle at ambient temperature by means of calibrated rotating-coil scanner.*
- *Calibration in-situ by measuring the magnet from both directions, and calculating the intrinsic offset of the scanner*



ε - probe offset (constant)
α - true field orientation (side dependent)
Φ_1, Φ_2 - measurement results.



-0.56 ±0.2mrad average

1.35 ±0.2mrad average

0.43 ±0.2mrad average

0.6 ±0.2mrad average

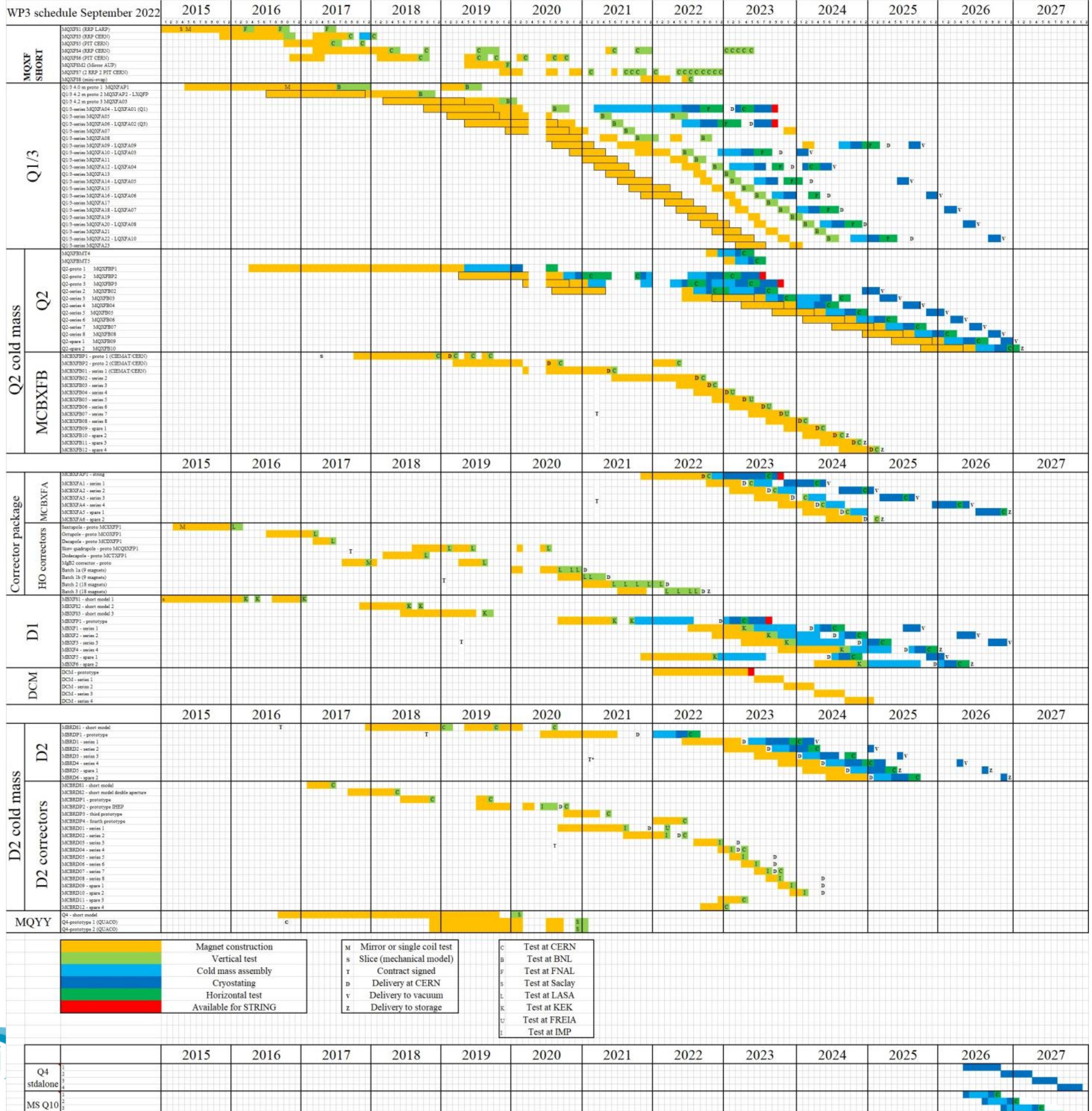
- *LMQXFB01 (first Q2): Roll angle at ambient temperature by means of stretched wire magnetic measurements method*

0.1 ±0.2mrad average

Summary

- Out of the 36 cold masses to be built 4 were completed, 2 will be finished by the end of October and the first CP is under construction.
- A great deal of knowledge was gained from the disassembled cold masses.
- The changes proposed during the review in March 2022 for the MQXFB magnets received very positive feedback from the review panel. They were successfully implemented on the last 3 cold masses. Applied changes to shell developed lengths alongside welding improvement have ensured no interference between the cold mass and the magnet assembly as requested.
- The first Q2 cold mass assembly is close to completion, procedures developed on the LMQXFBT cold masses are well defined and mastered. Activity durations are inline with the defined schedule.
- Cold bore tube alignment showed promising alignment measurements on cold masses with a single quadrupole magnet, to be confirmed once associated to the corrector.
- The first D2 prototype was completed on May 22, junction between the two cylinders will be enhanced for next cold masses.
- The first Corrector Package cold mass assembly will restart when the MCBXFA is delivered. HO corrector magnetic measurements showed good alignment results.
- No major showstopper on the components, tooling and assembly procedures identified. Issues with CBT insulation and HX installation are being treated.

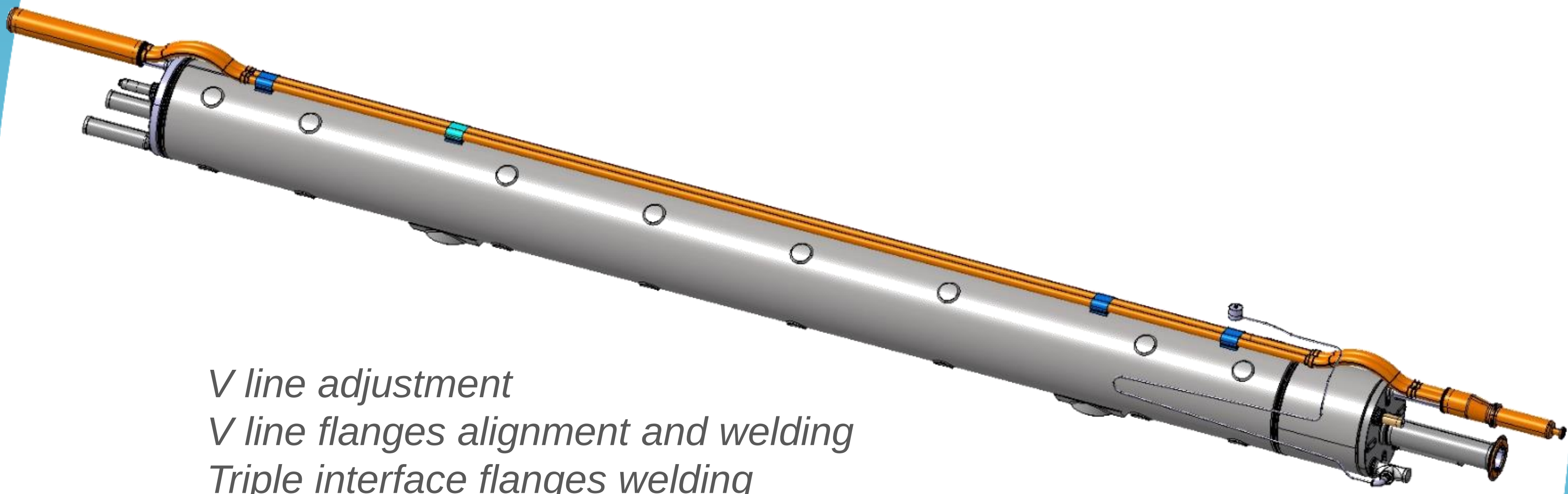
Spare Slides



WP3 schedule September 2022
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
MQXF SHORT
Q1/3
Q2 cold mass
Q2
MCBXFB
Corrector package
MCBXFA
HO correctors
D1
DCM
D2 cold mass
D2
D2 correctors
MQYY
Magnet construction
Vertical test
Cold mass assembly
Cryostating
Horizontal test
Available for STRING
M Mirror or single coil test
S Slice (mechanical model)
T Contract signed
D Delivery at CERN
V Delivery to vacuum
Z Delivery to storage
C Test at CERN
B Test at BNL
F Test at FNAL
S Test at Saclay
L Test at LASA
K Test at KEK
U Test at FREIA
I Test at IMP
Q4 stdalone
MS Q10

Work on the D1 cold mass at CERN

Finishing and preparation for cold tests

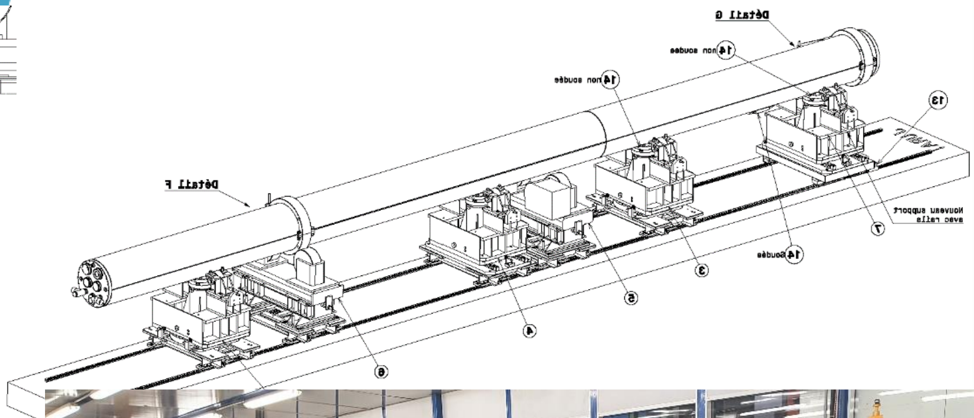


V line adjustment
V line flanges alignment and welding
Triple interface flanges welding
N lines installation and welding
Preparation for cold tests

Tooling for the two D2 cylinders welding

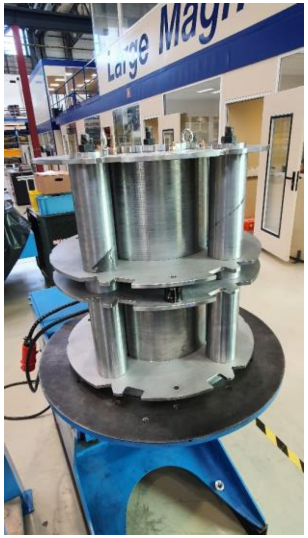
LHCLMBRDT0033

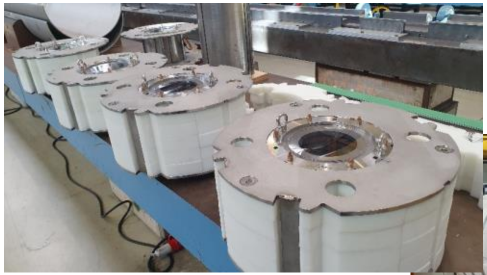
Positioning and alignment of cylinders

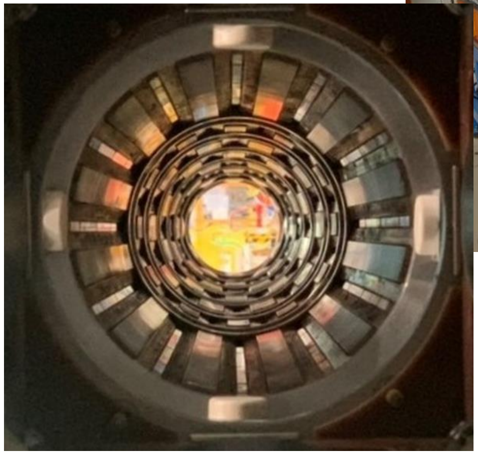


Orbital welding

The first CP cold mass assembly





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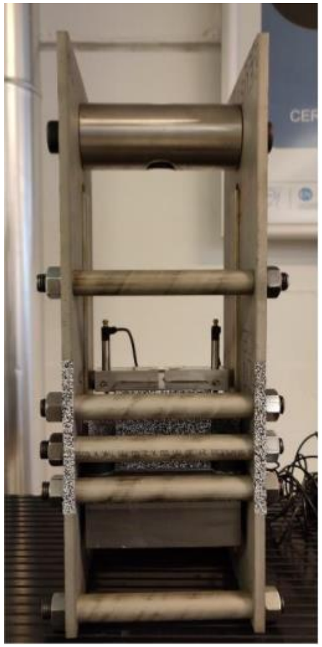
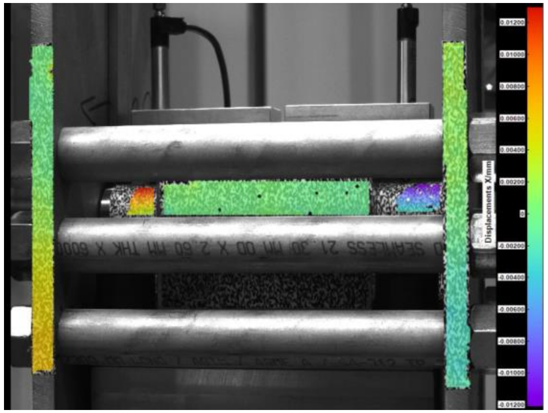
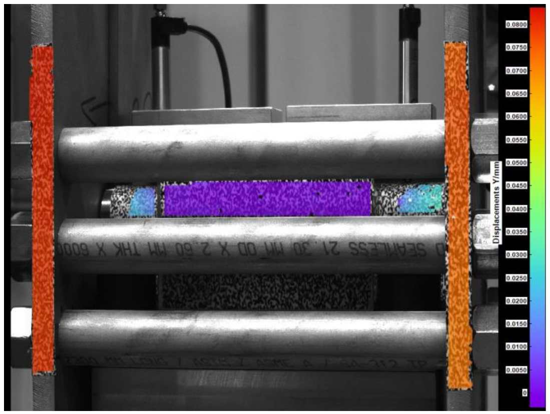
Fixed point tests at warm and 77K in the MME mechanical measurement lab

https://edms.cern.ch/document/2711705/
by O. Sacristan de Frutos





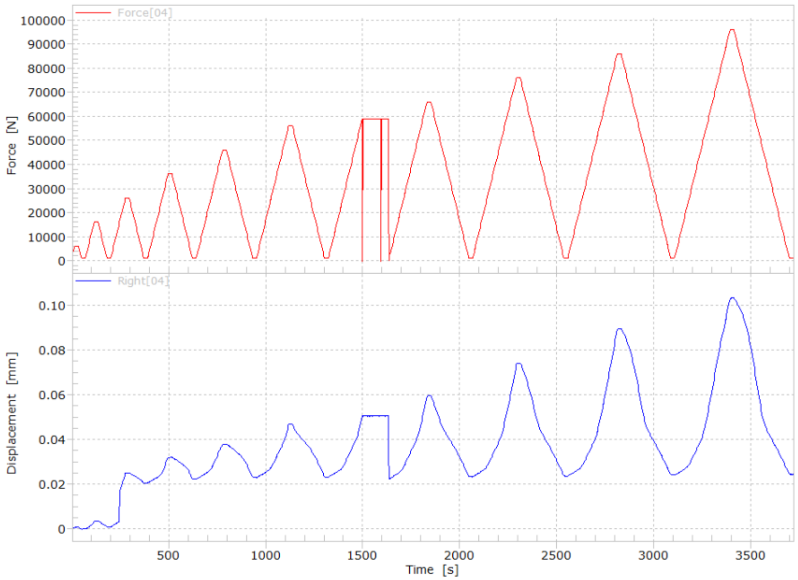
Horizontal displacement RBMR colormap at 55 kN.



Vertical displacement RBMR in the second ramp of test-protocol 2

Assembly #1 demonstrated an important flexibility of the lateral plates. This excessive flexibility was judged not representative of the actual mechanical behavior of the system in service.

Assembly #2 was produces as a modification of assembly #1. Stiffeners were included in the design. The tests performed both at room temperature and 77K depict small relative displacements consistent with local adjustment of the different parts, but ***no hints of permanent and significant deformation of the materials.***



load-unload cycles from 1 to 96 kN (load rate of 55 kN/min)

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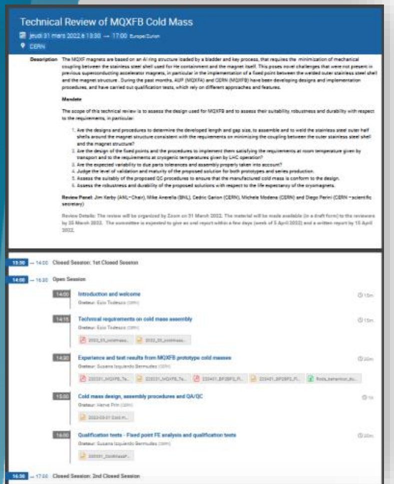
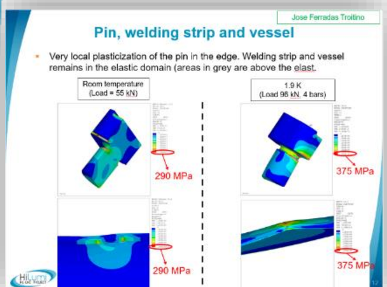
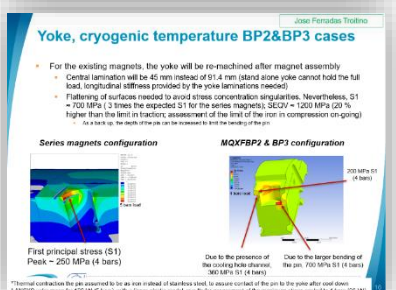
Outcome of Technical Review of MQXFB Cold Mass

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.

HiLumi HL-LHC PROJECT CERN

Shell production quality improvements

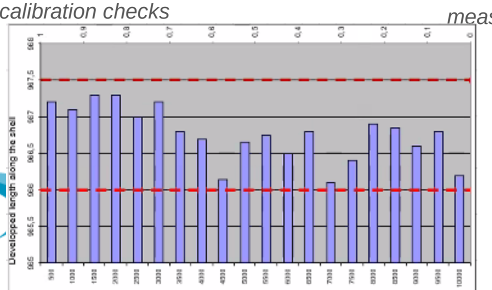
- Weekly meeting via Zoom since November 2021
- Visit in AP-Tela in June the 30th
  - Aim of the visit: review of the preformed shells in stock, review the measuring devices and techniques, assess the dimensional effect of the local ground marks on the shell profile after shaping and agree a production schedule.
  - Visit report: https://edms.cern.ch/document/2766233/
  - Agenda of the visit:
    - Review of the preformed shells in stock,
    - Review of tooling,
    - Review of the measuring devices and techniques,
    - Assessment of the dimensional effect of the local ground marks on the shell profile after shaping,
    - Agree a production schedule,

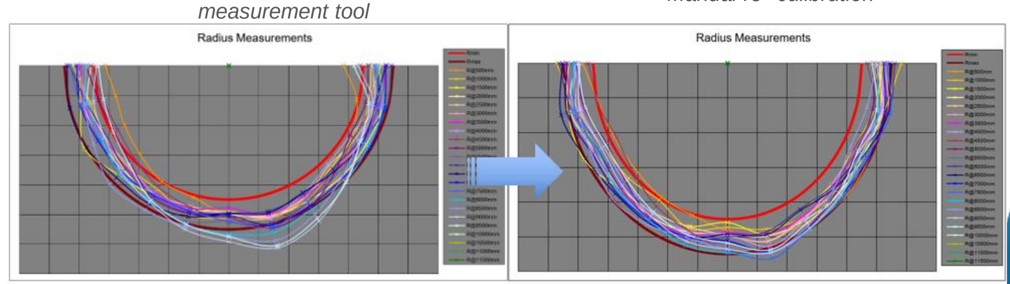
Developed length measurement tool and calibration checks

Shell developed length measurements

Shell shape template and measurement tool

Manual re-“calibration”





Welding shrinkage measurements on LMQXFBT05 side A