HiLumi HL-LHC PROJECT

MQXS inner layer quench heaters

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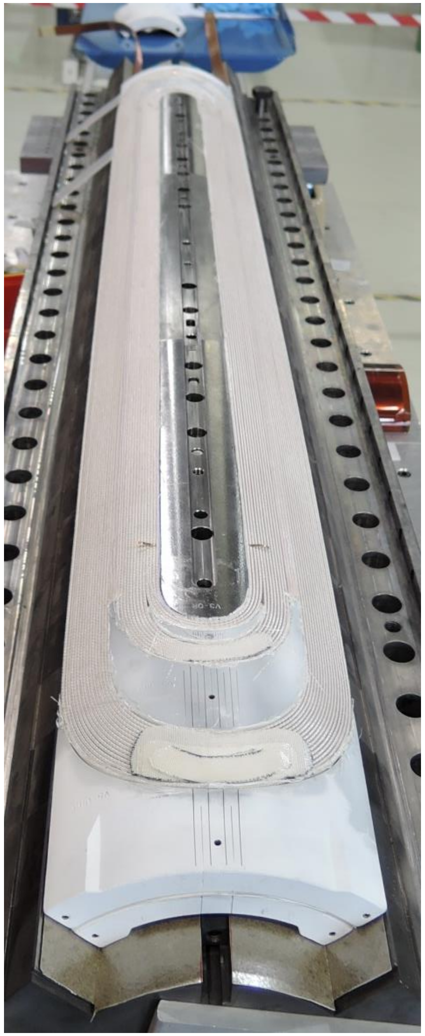
CERN LARP

Basic definitions (1)

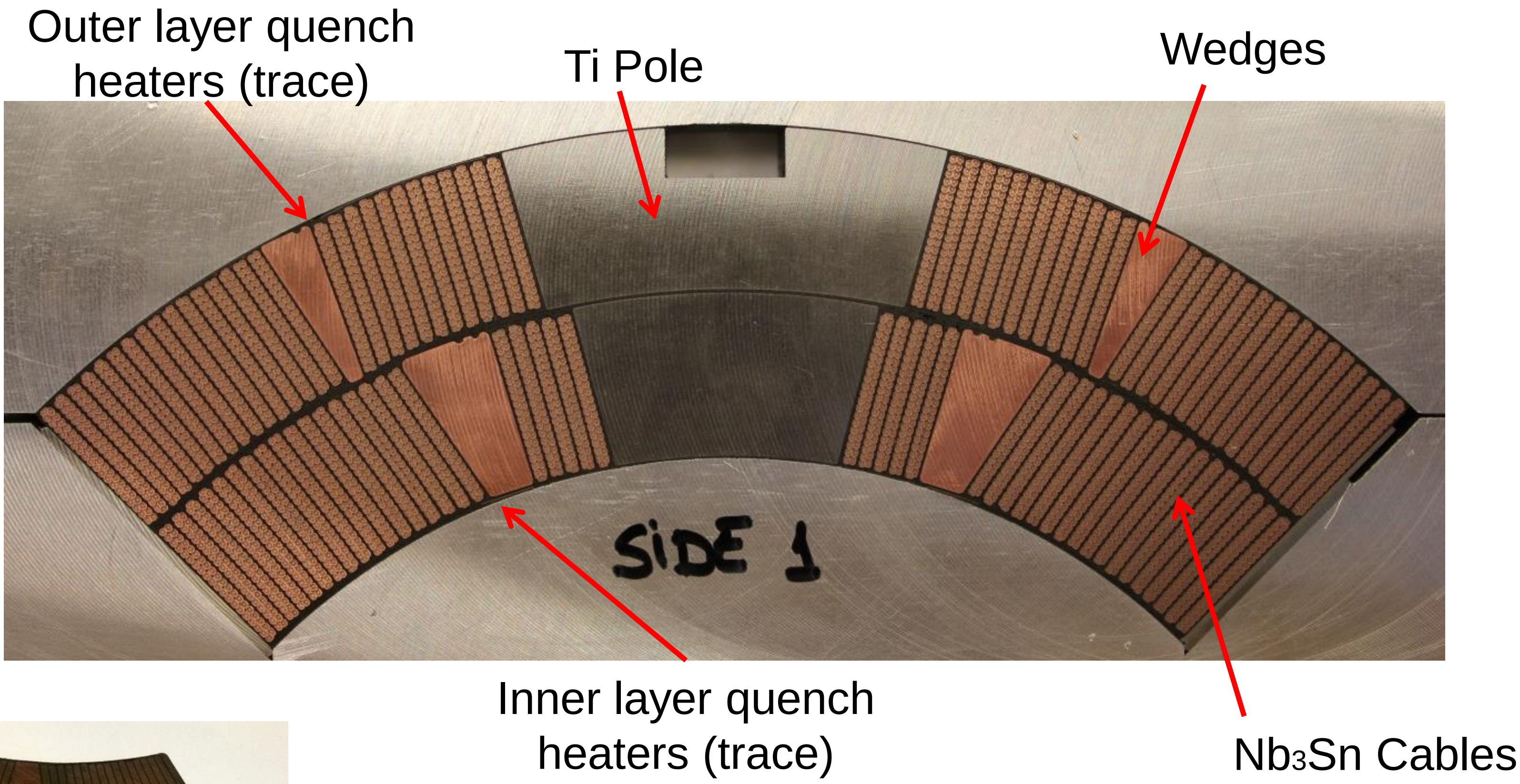
Coil after curing

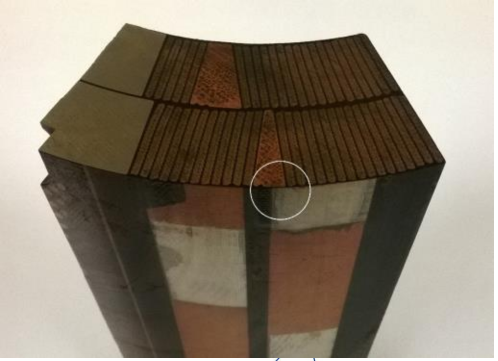


Coil after reaction

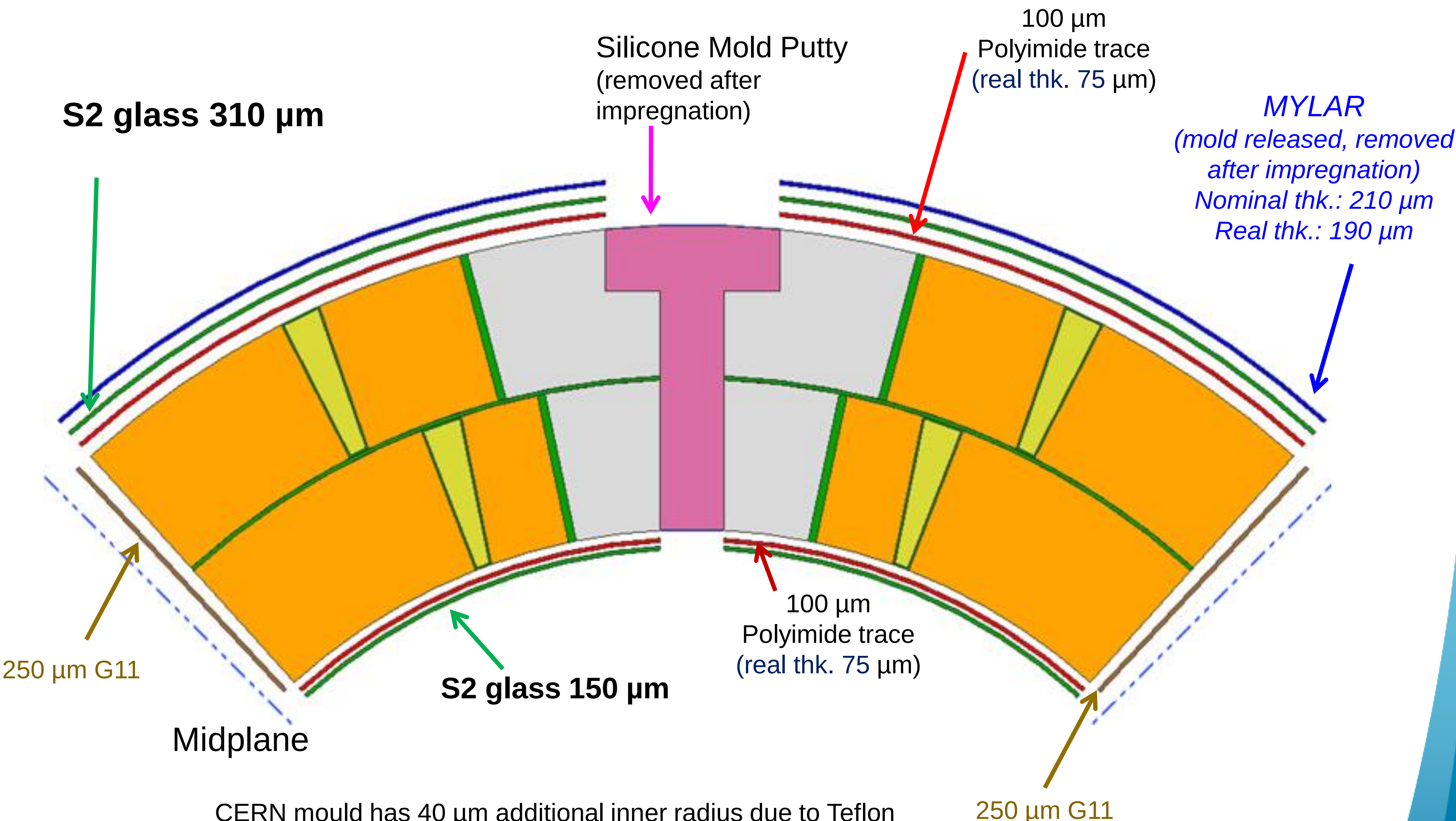
Coil after imprgnation

Basic definitions (2)



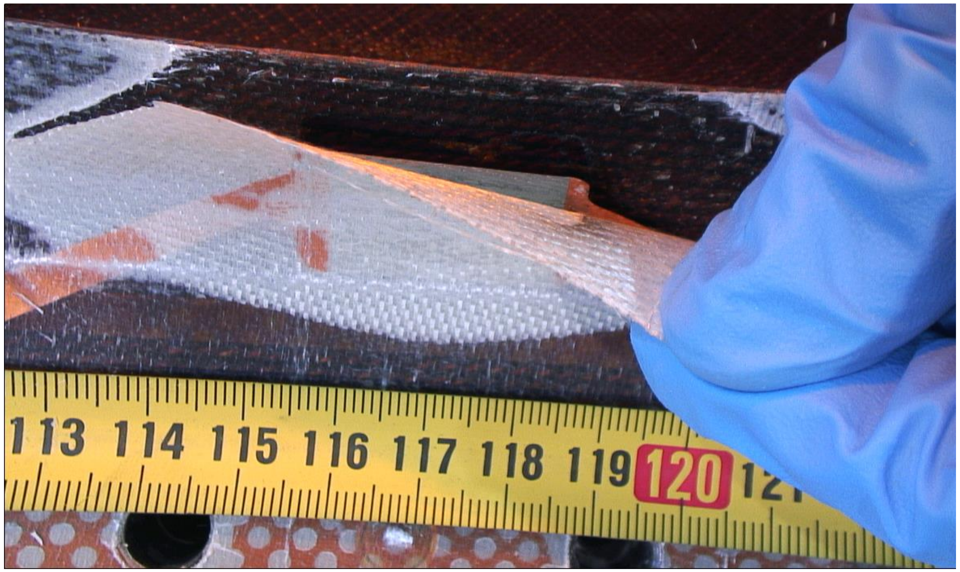


Basic definitions (3)

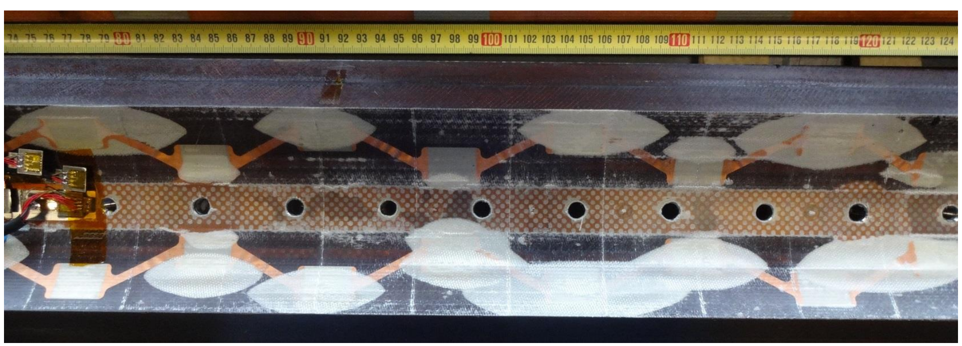


CERN mould has 40 µm additional inner radius due to Teflon coating

Our problem – MQXFS3

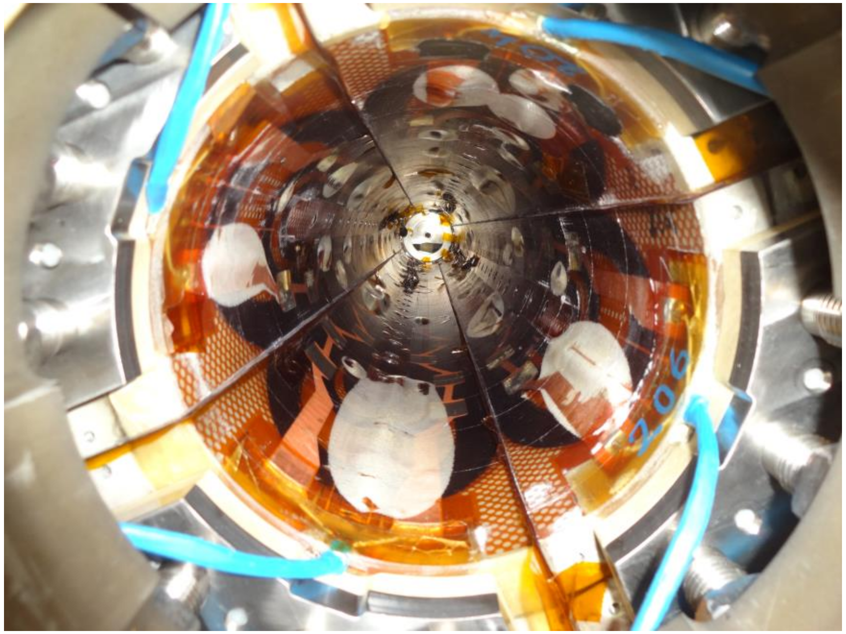


- After cold magnet test (inner layer heaters were powered), de-laminations observed in the coil inner diameter.
- The bubbles issue is a problem of adherence glass to stainless steel (or copper).



Our problem - MQXFS5a

- Inner layer heaters were not powered during the first and second thermal cycle, to study the heater degradation due to cool down and magnet powering.
- Large bubbles observed even if heaters were never powered!
  - The source of the problem is the magnet quench and not the heater powering.



Similar issues also in “recent” 11 T coils

Coil 115

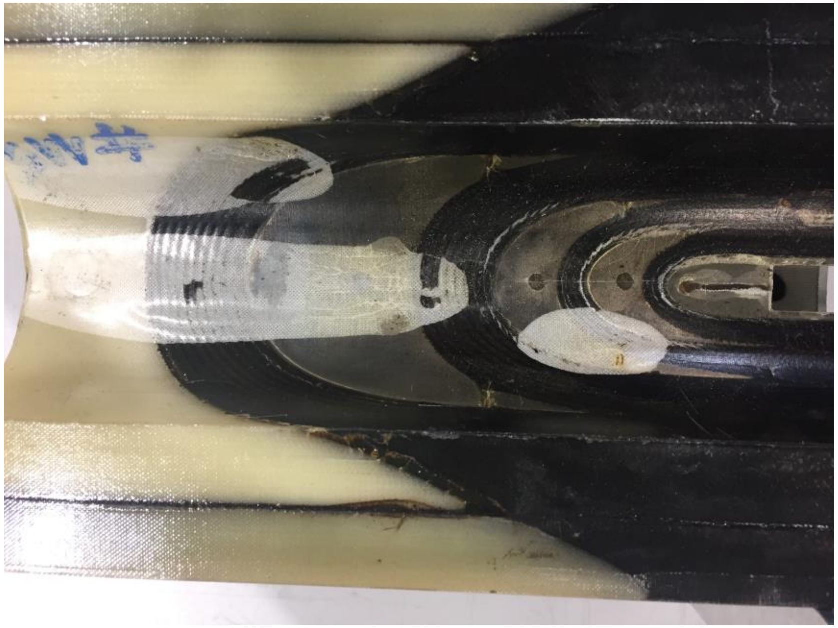
Assembled in MBHSP105 and MBHSP105b*

0 quenches on the IL lead end

Coil 115

Assembled in MBHSP105 and MBHSP105b*

1 quench on the IL return end



* Cold powering test not done yet

Action plan

- Problem characterization
  - Coil visual inspections
  - Electrical integrity tests on tested magnet
  - Peel off test for the glass-epoxy to trace
- Finding a solution
  - Encapsulated trace
  - Improve epoxy to metal adherence
  - Actions on the coil insulation layout out

- Problem characterization
  - Coil visual inspections [1]
    - Delamination mainly between heater and glass.
    - The highest risk is the damage of the coil insulation.
    - Heater also can be damage following a delamination.
    - Heater to polyamide delamination also observed in few locations.
    - Delamination also present on the coil ends.
  - Electrical integrity tests on tested magnet
    - MQXFS3 (IL heaters fired)
      - 3 out of 8 failed during heater powering (open circuit)
      - 7 out of 8 IL-QH did not pass the 3 kV insulation test after cold test
    - MQXFS5 (IL heaters not fired)
      - 8 out of 8 IL-QH did not pass the 3 kV insulation test after cold test(failure > 2.5 kV)
      - When re-tested at 1 kV, leakage current in 3 heaters > 4m A at 200 V. The rest, OK.
  - Peel off test for the glass-epoxy to trace [2]
    - Glass epoxy to metal close to 0 N (the same of JPS 26781 and HEXCEL 4522)
    - Glass epoxy to polyamide > 20 N (polyamide breaks)

[1] https://indico.fnal.gov/conferenceDisplay.py?confId=15146
[2] EDMS 1842073 v.1. Sarah Gayot; Sandra Tavares

- Finding a solution
  - Encapsulated trace
    - Peel off on trace sample [3]
    - What is the best configuration for the encapsulated trace? (PCB lab)
    - MDT to modify hole pattern to avoid holes in the polyamide in the regions in contact with metal
  - Improve epoxy to metal adherence
    - Primer (Sandra Tavares/TE/MSC/Polymer lab)
    - Enhanced cleaning and/or surface treatment on stainless steel (B.Teissandierl/TE/VSC)
  - Actions on the coil insulation layout out

[3] Mickael Meyer EDMS 1840661 v.1

- Finding a solution
  - Encapsulated trace
    - Peel off on trace samples `[3]
      - GTS (standard material, after process) — around 3 N to the metal
      - GTS (standard material, raw material) — around 3 N to the metal
      - GTS (encapsulated) — Around 10 N to the metal and polyamide
      - UBE (Technomech supply, after process) — around 20 N to the metal
      - UBE (Cern supply, raw material) — around 3 N to the metal
    - What is the best configuration for the encapsulated trace?
    - MDT to modify hole pattern to avoid holes in the polyamide in the regions in contact with metal

[3] Mickael Meyer EDMS 1840661 v.1

- Finding a solution
  - Improve epoxy to metal adherence
    - Primer (Sandra Tavares/TE/MSC/Polymer lab)
    - Enhanced cleaning and/or surface treatment on stainless steel (B.Teissandierl/TE/VSC)
      - MDT to provide detailed technical procedure for trace production and representative polyamide + stainless steel raw material/processed material
      - VSC to study cleanliness of the surface, propose and test alternative cleaning/surface treatments.

Finding a solution

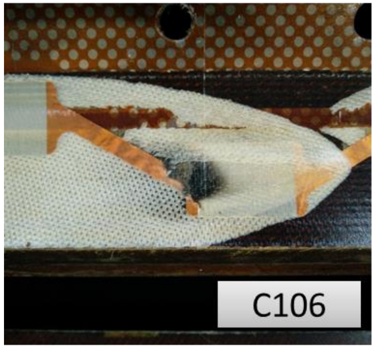
Actions on the coil insulation layout out

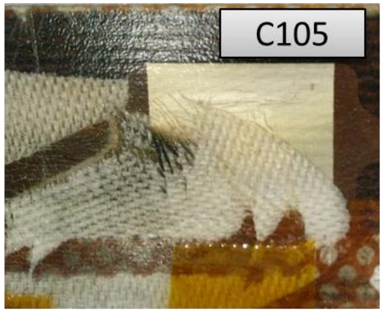
- From coil 207, coils produced using Hexcel 4522 instead of Tisstech 493
- Coil 207, no inner layer heaters
- Coil 108, S2-glass heat-cleaned
- Coil 109, traced produced with UBE raw material
- More open fiber to facilitate helium flow? The test from Sarah on two different fibers show the same result, not promising.
- Holes on the fiber to leave the helium go through? Concerns on coil electrical integrity

Additional slides

MQXFS3 heater failures during cold powering

- 2 out of 8 IL strips were lost during MQXFS3a training:
  - Inner layer strip of coil 105, right, failed after the second training quench during a trip at 4 kA (a.002)
  - Inner layer strip of coil 106, left, failed after the fourth training quench during a trip at 6 kA (a.018)
- In MQXFS3b, one additional heater strip was lost:
  - Inner layer strip of coil 106, right, failed after OL+IL quench integral study at nominal current (hh051)
- These are the only locations where burnt areas were found during coil inspection
- Several voltage taps on the inner layer of coil 105 and 106 we also lost.





Giorgio Vallone
https://indico.fnal.gov/conferenceDisplay.py?confId=13725

MQXFS3c: Status of the inner layer quench heaters before assembly

	General	Resistance	Insulation (Test value = 3 kV)
105	1 out of 2 failed during powering	1 high 1 normal	2 in short with the coil
106	2 out of 2 failed during powering	2 high	2 in short with the coil
107	No failure at cold	2 normal	1 in short with the coil Short coil to pole (already there before powering)
LP8	Not tested at cold	2 normal	All OK

- All outer layer heaters are OK
- We lost 3-4 voltages taps per coil during cold powering test.

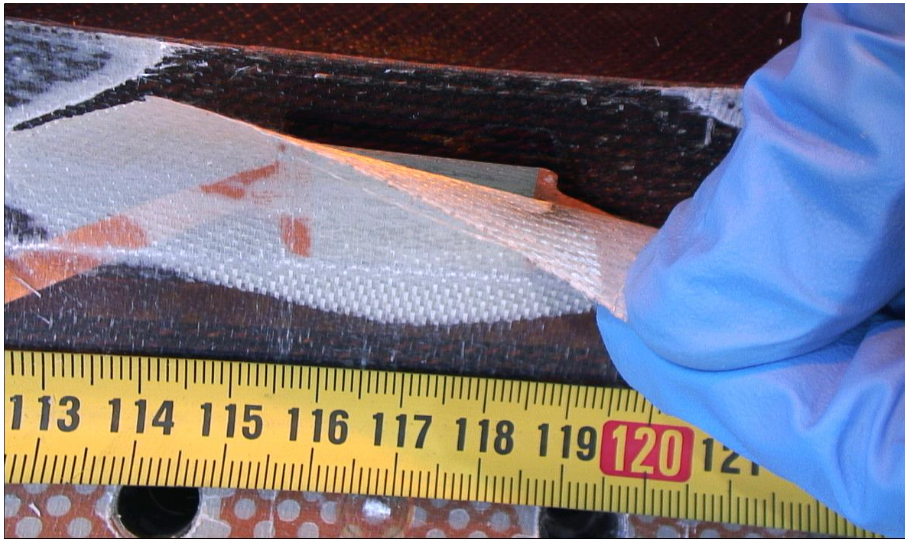
MQXFS5a: Electrical integrity

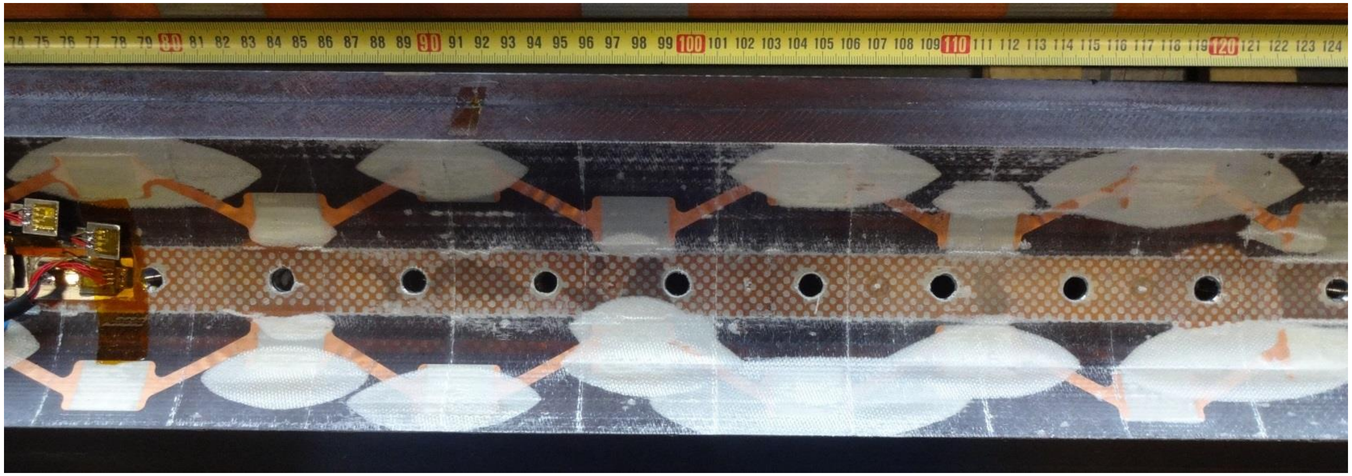
- Non of the heaters pass the 3 kV insulation test, and during the test, three heaters were degraded!
- Insulation on OL heaters not tested
- 7 voltage taps were lost
  - C203 I5, O5, O6; C206 I7, I3; C205 I7;C204 I5)

<table>
<tr><th></th><th>Insulation test 1
(before cold powering)
(Test value = 3 kV)</th><th>Insulation test 2
(after cold powering)
(Test value = 3 kV)</th><th>Insulation test 3
(after cold powering)
(Test value = 1 kV)</th></tr>
<tr><td>203</td><td rowspan="4">All OK</td><td rowspan="4">All failed in the
2.5 kV-3kV range
(value not registered!)</td><td>Right: OK
Left: I > 4mA @ 200 V</td></tr>
<tr><td>204</td><td>Right:: I > 4mA @ 200 V
Left: OK</td></tr>
<tr><td>205</td><td>Right:: I > 4mA @ 200 V
Left: OK</td></tr>
<tr><td>206</td><td>Right: OK
Left: OK</td></tr>
</table>

Destructive inspection results from LP07 coil

- The bubbles issue is a problem of adherence glass to stainless steel (or copper).
- It was verified and confirmed through peel off test in specific samples with different types of fibers.
  - No significant difference found in between JPS 26781 and HEXCEL 4522.





Peel off tests

EDMS 1842073 v.1. Sarah Gayot; Sandra Tavares

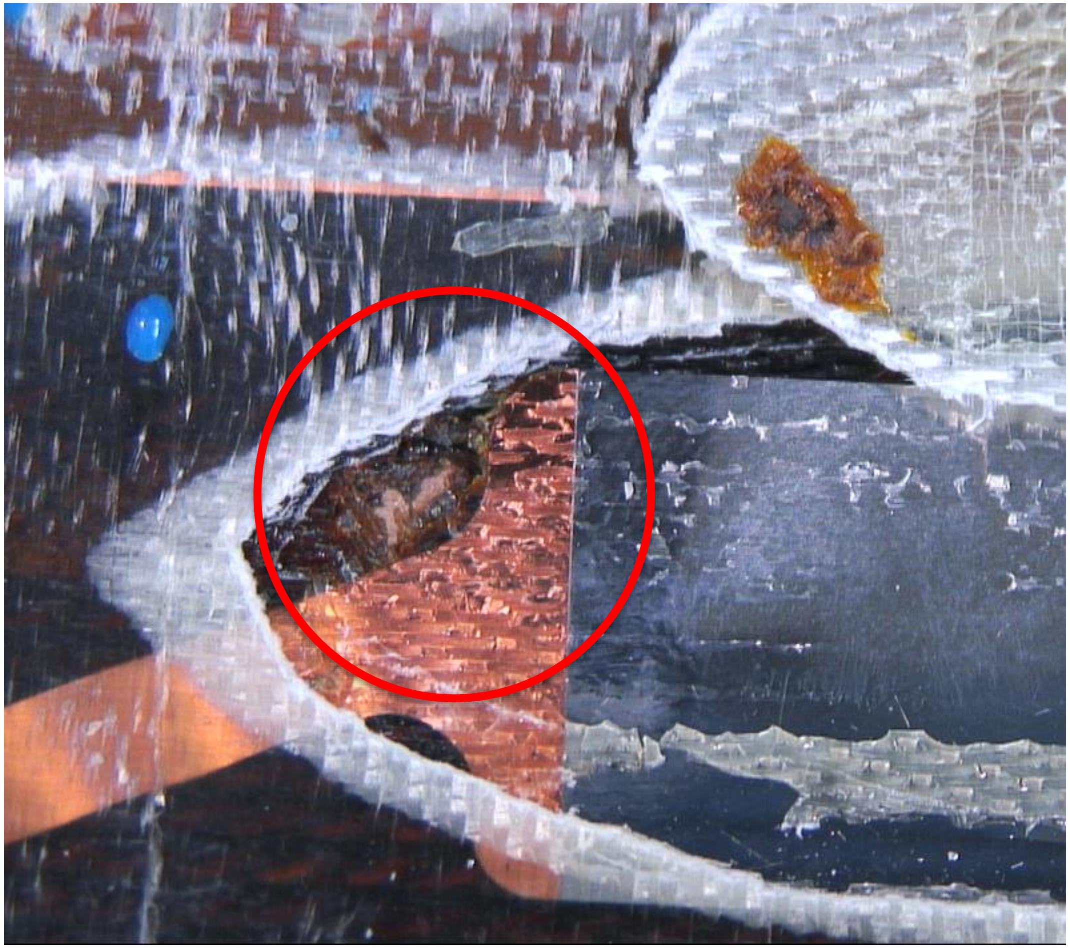
SAMPLE TYPE	TEST	LOAD (N)	ASPECT AFTER TEST	COMMENT
Metal/ impregnated fibre	90°	~ **0**		**NO ADHESION** between metal from trace (copper or inox) and impregnated Hexcel fibre
Polyimide/ impregnated fibre	90°	>20 Polyimide broke		**VERY GOOD ADHESION** between polyimide from trace and impregnated Hexcel fibre → Polyimide ripped before being peeled off !

Destructive inspection results from LP07 coil

- Only in 3 out of the 38 heater stations we observed stainless steel to polyamide delamination.

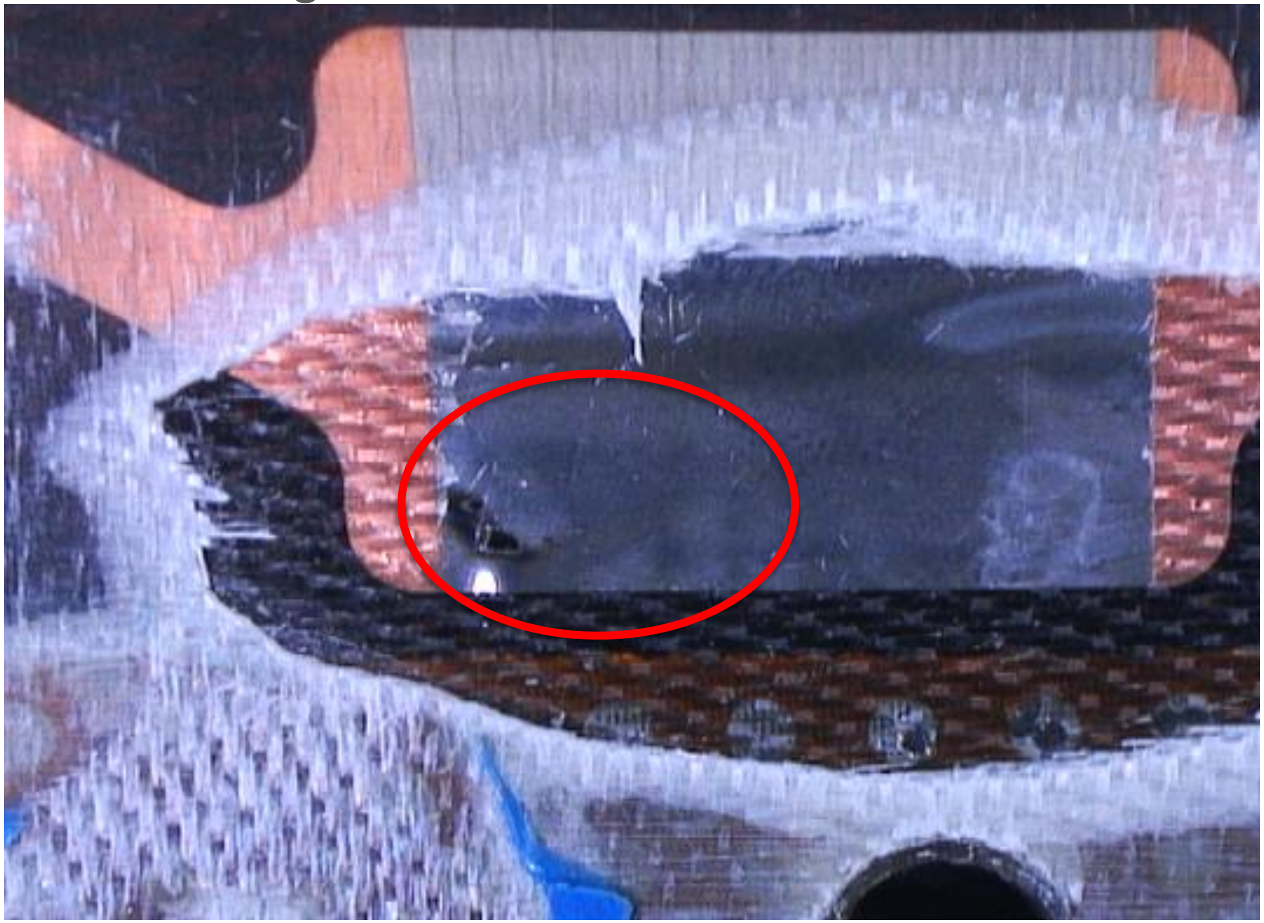
Destructive inspection results from LP07 coil

- The bubbles are dangerous, since they can remove the conductor and wedge insulation



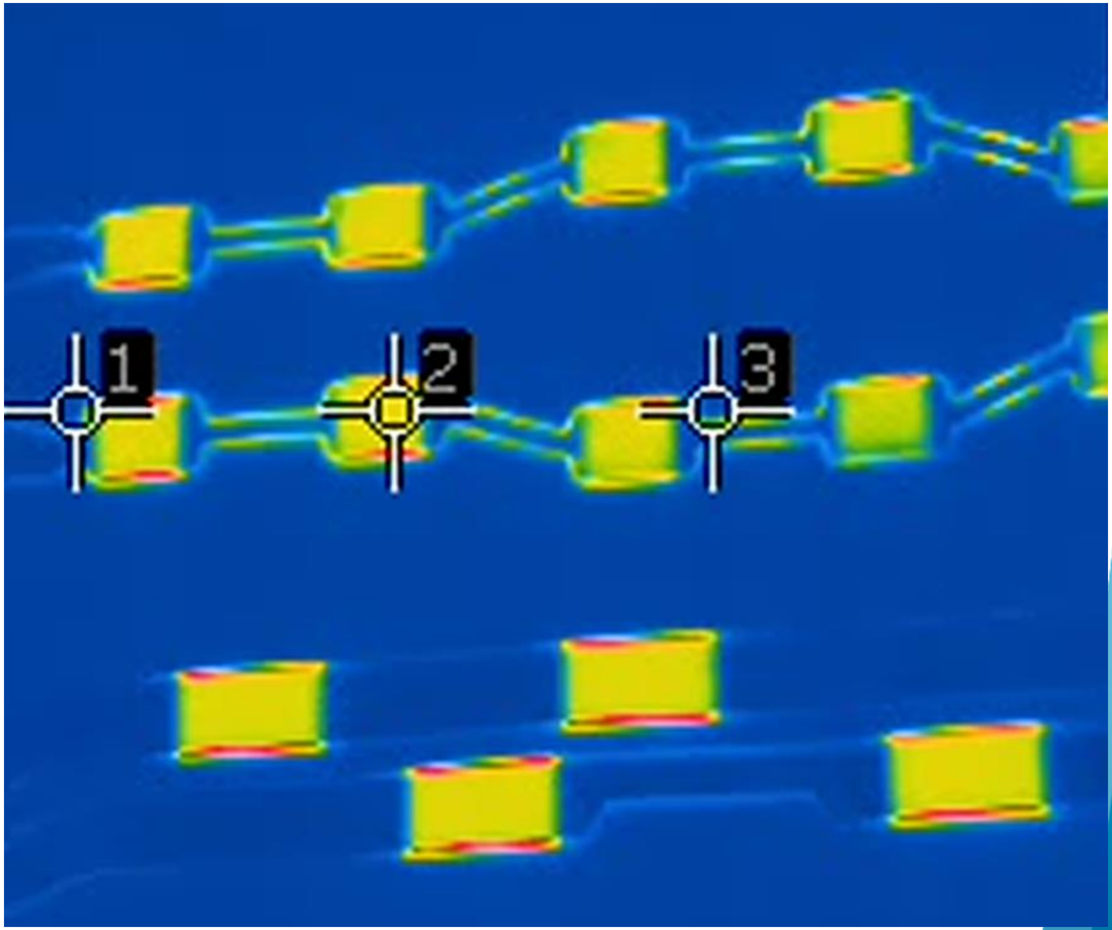
Destructive inspection results from LP07 coil

- Heater was locally burnt in one spot.
  - When did it happened? The defect was there from manufacturing or it was a bubble-related issue



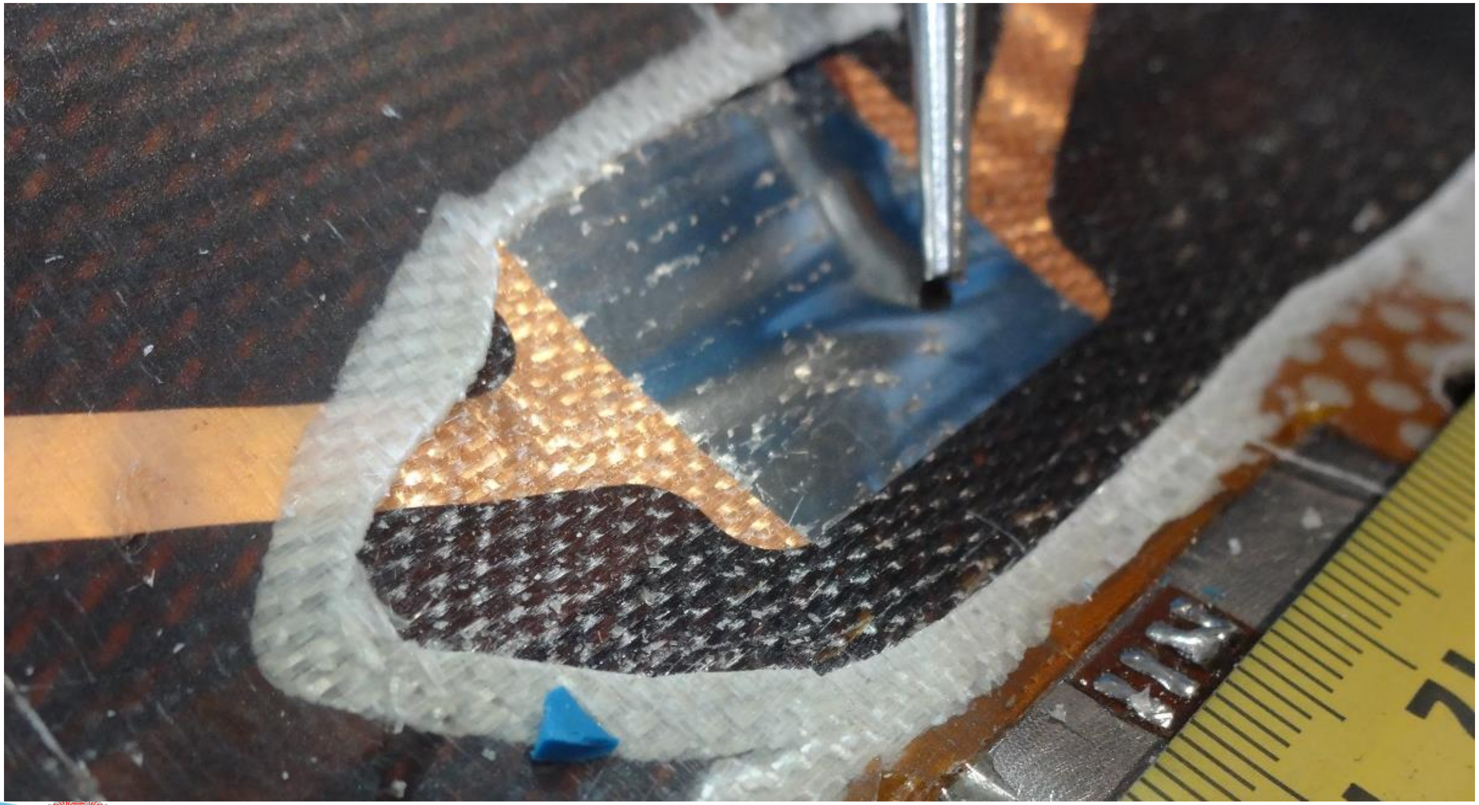
Test on old trace

- We tried to burn one old set of heaters, applying 80 A/380 V/500 J, to verify if the copper platting was behaving as expected
  - Behavior OK, not over-heating in the copper-stainless transition.



Destructive inspection results from LP07 coil

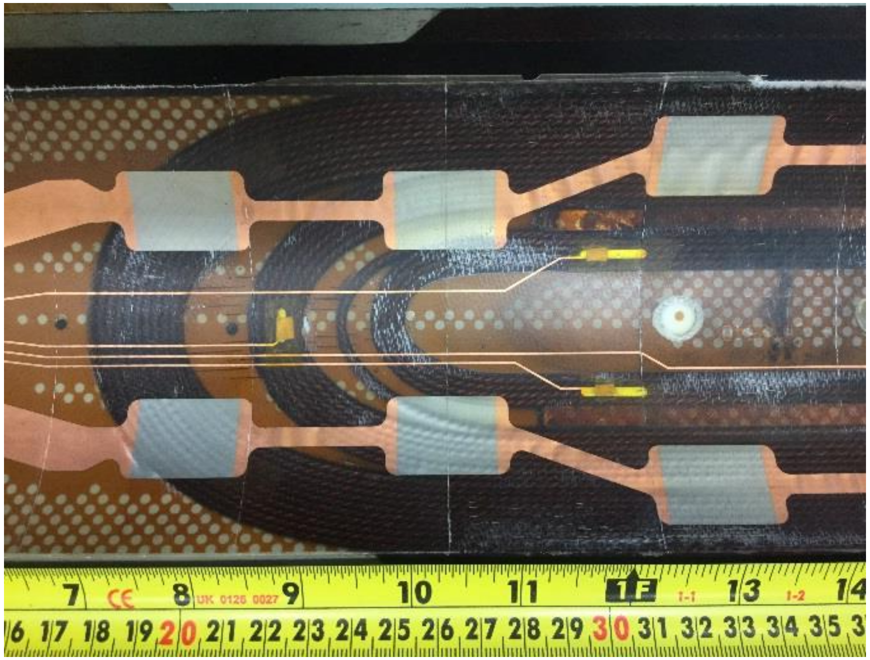
- In some locations, heaters al folded (gas bellow)
  - Second order problem



Destructive inspection results from LP07 coil

- Even if we remove the heaters, we will still have an issue of adherence to the pole and the end spacers.

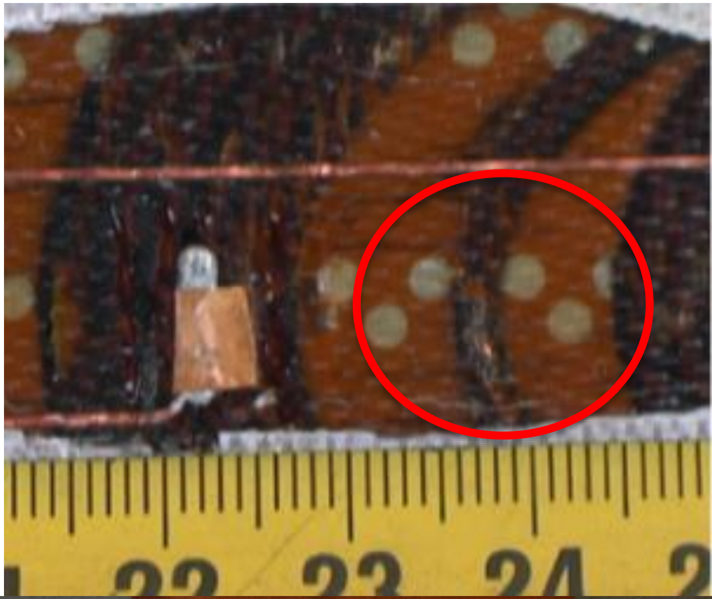
- LP 7 before cold test

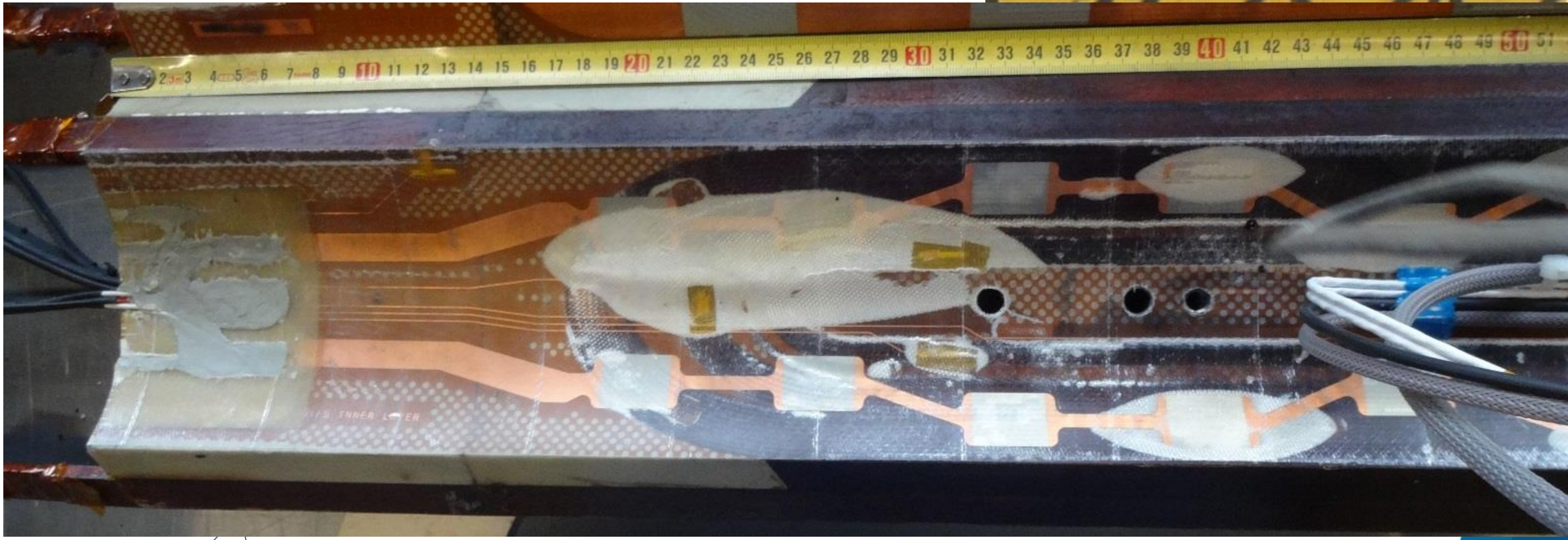


- LP 7 after cold test

Destructive inspection results from LP07 coil

- The bubble in the lead end was able to remove the conductor insulation.
- Discharge test up to 4.5 kV did not show any weakness.
- This coil quenched a lot in that region, so the situation is probably a bit less dramatic.



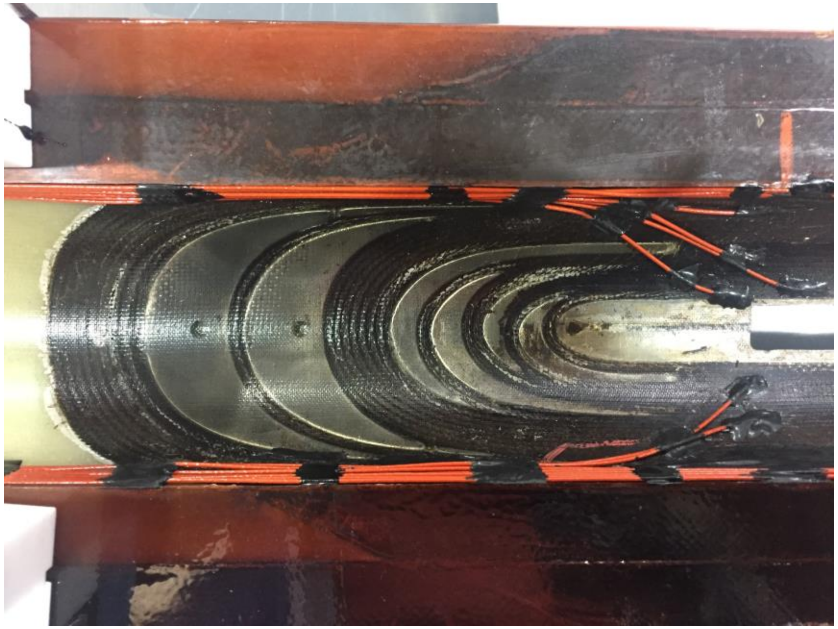


11 T – status of the inner coil after powering

Coil 109

Assembled in MBHSP103 and MBHSP104b*

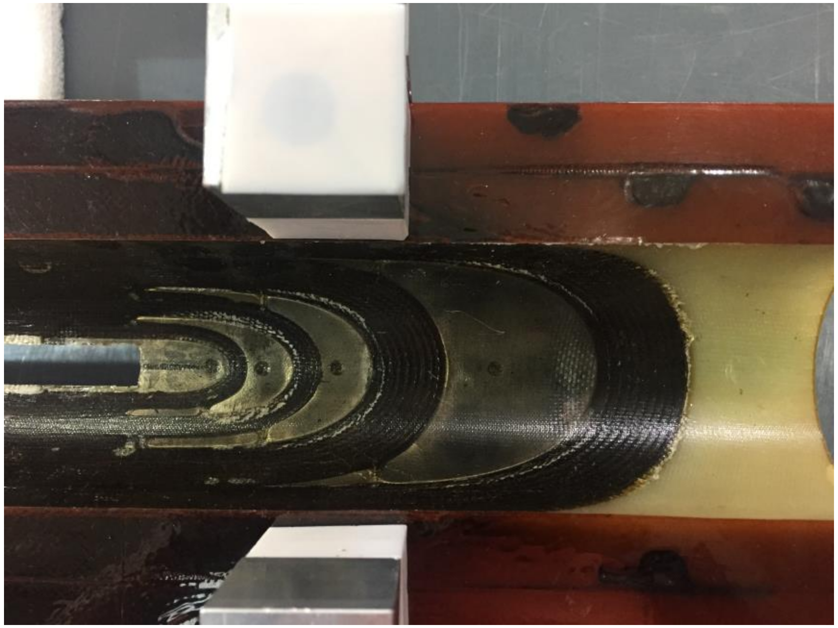
0 quenches on the IL lead end



Coil 109

Assembled in MBHSP103 and MBHSP104b*

1 quenches on the IL return end



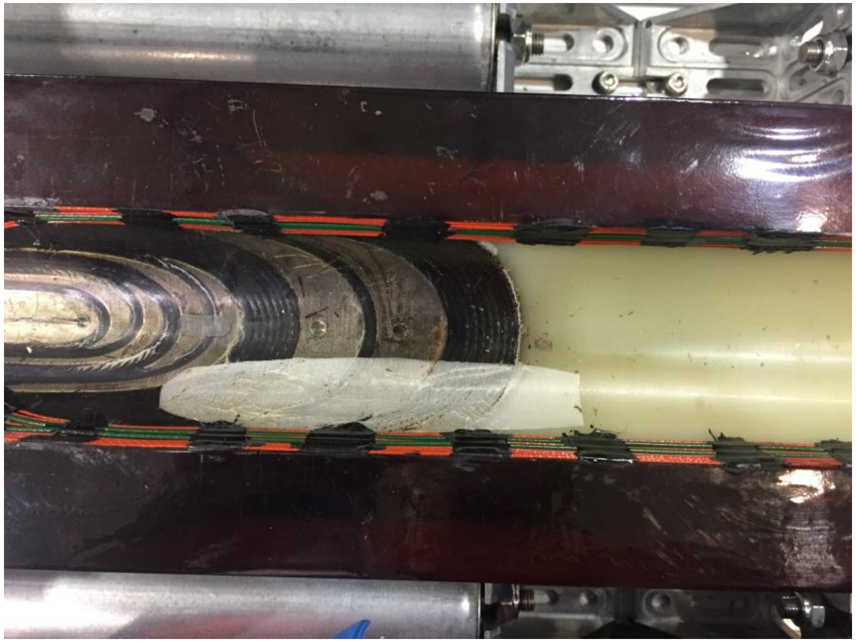
* MBHSP104b Cold powering test not done yet

11 T – status of the inner coil after powering

Coil 112

Assembled in MBHSP104 and MBHSP104b*

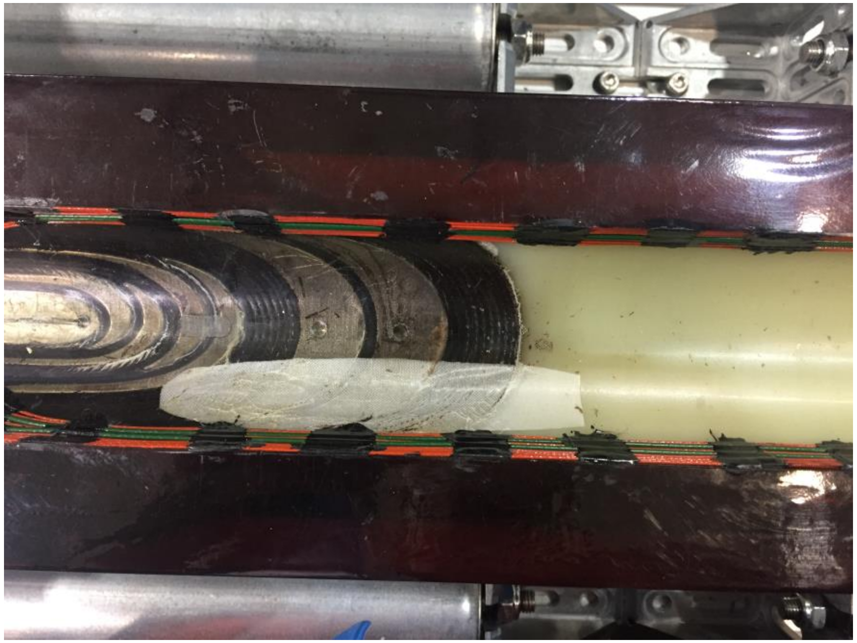
1 quenches on the IL lead end



Coil 112

Assembled in MBHSP104 and MBHSP104b*

0 quenches on the IL return end

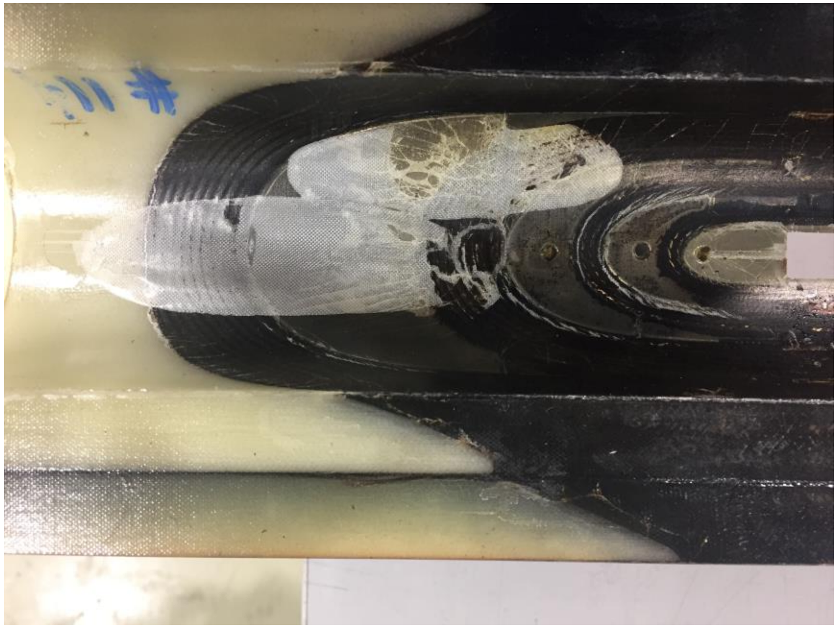


* Cold powering test not done yet

11 T – status of the inner coil after powering

Coil 114
Assembled in MBHSP105 and MBHSP105b*
0 quenches on the IL lead end

Coil 114
Assembled in MBHSP105 and MBHSP105b*
0 quenches on the IL return end



* Cold powering test not done yet

11 T – status of the inner coil after powering

Coil 115
Assembled in MBHSP105 and MBHSP105b*
0 quenches on the IL lead end

Coil 115
Assembled in MBHSP105 and MBHSP105b*
1 quench on the IL return end

* Cold powering test not done yet

Possible actions

- MQXFS5:
  - Next thermal cycle (3th), protection studies with CLIQ and outer layer heaters.
  - 4th thermal cycle required to test the bore tube insertion. Inner layer heater powering only after that.
- Close future:
  - We produced some coils where we change different parameters on the trace-glass layout (see next slide).
  - If the results are not successful, and we remove inner layer heaters but we still have delamination in the end spacers or pole region:
    - Avoid holes in the regions of the polyamide that are in contact with the metal parts.
    - Remove the inner layer S2 glass layer.
      - This represents quite a “big” change with respect to our standard way of doing things.
      - We did it twice in 11 T coils, no particular issue to point out.

Lay-out for the coming coils

	S2 glass type	S2 heat cleaned?	Trace base material
CERN “standard”	1xTisstech 493	No	GTS
207	2xHexcel 4522	No	No IL heaters
208	1xHexcel 4522	No	GTS
209	1xHexcel 4522	No	GTS
108	1xHexcel 4522	Yes	GTS
109	1xHexcel 4522	No	UPISEL-C[1]
110	?	No	GTS encapsulated[2]

1. Produced by Ube Exymo, Japan. Better adherence stainless steel to polyamide.
2. Polyamide on the two sides of the stainless steel, to avoid the resin to metal interface in the coil. Not decided/installed yet.

MQXFS3 inner layer quench heaters after powering

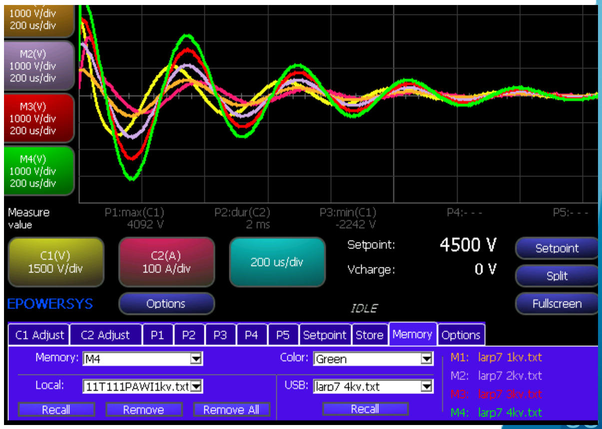
- Summary on electrical tests
- MQXFS3a FINAL before cold test :
  - 64/64 Vtaps are Ok
  - 3 clic leads
  - 24/24 QH are OK
  - Insulation Ok:
  - QH discharge OK
  - Coil discharge Ok
  - MQXFSa1 before cold test :

Insulation resistance	U[test] [V]	time [s]	measured [GΩ]
All coils + all QHs ---> ground	3000	30	15.00
All coils ---> all QHs	3000	30	6.4
All coils ---> ground	3000	30	34.5

- Push test to the limit on LP07 before destruction
  - Insulation :

Coil-CP Brd @ 2kV
QH-coil Brd
Coil – Endshoe CS Brd @ 4kV
Coil – Endshoe NCS Brd @ 2.5kV
QHs-Endshoe CS Brd @ 4.5kV
QHs-Endshoe NCS Brd @ 3kV

  - Coil discharge test : Pb @ 4.5kV



MQXFS3 inner layer quench heaters after powering

- Summary on electrical tests
- MQXFS3c, coils standalone before assembly:
  - Coil 105 :

    14/16 Vtaps Ok, 5/6 QHs Ok (inner pb), short 2 inner QHs-Coil, Discharge coil and QH Ok
  - Coil 106 :

    13/16 Vtaps Ok, 4/6 QHs Ok (2 inner pb), short 2 inner QHs-Coil, Discharge coil and QH Ok
  - Coil 107 :

    13/16 Vtaps Ok, 6/6 QHs Ok, short 1 inner QH-Coil, short CP-coil, Discharge coil and QH Ok
  - Coil LP08 :

    16/16 Vtaps Ok, 6/6 QHs Ok, Insulation Ok, Discharge coil and QH Ok

Quench heater fabrication

Les Bobines - Quench Heater
•Nickel de Wood – Température ambient (Ta)
•1er passage sans courant
•2eme passage sous courant 150A
•Cuivre électrolytique brillant – Température ambient
2 passages complets pour une feuille à 120A
•Transfert image
•Lamination 2 passage à 100 deg C
•Développement 1 passage à 30 deg C (carbonate de soude)
•Gravure 1 passage à 30 deg C (perchlo + acide chloridrique)
•Stripage Température ambient (alcool)
•Lamination 1 passage 100 deg C
•Développement 1 passage à 30 deg C (carbonate de soude)
•Gravure Cu et Ni Température ambient (50% acide nitrique + 50% eau)
•Stripage Température ambient (alcool)
•Pressage
1 heure a 170 deg C, pression 30kg/cm2

Processus	Température	Chimie	Passage
Nickel de Wood	Ta	Nickel de Wood	2
Cuivre électrolytique brillant	Ta	Cuivre électrolytique brillant	2
Lamination	100	-	3
Développement	30	Carbonate de soude	2
Gravure Cu	30	Perchlo + acide chloridrique	1 vitesse min
Stripage	Ta	Alcool	2
Gravure Cu et Ni	Ta	50% acide nitrique + 50% eau	1
Pressage	170 (pression 30kg/cm2)		1

PRINCIPLE OF PEELING TESTS

Sarah Gayot

Single-cavity mould (cavity depth = h)
+
Shim (h – 250 µm)

1 layer spare QXF trace, laser-cut

Teflon paper strips on both ends

1 layer glass fibre, laser-cut

Shim
+
mould lid

Impregnation with CTD 101K + curing

15-mm strips

Metal/impregnated fibre

Polyimide/impregnated fibre

Peel-off tests 90 & 180°

UTS tensile machine

1KN load, 7mm/min

Coil 207

The coil has been impregnated.

The quench heaters of IL have not been installed: i.e. the trace has been cut, and only the parts containing the circuits of vtaps have been installed.

S2 glass inner layer: 2 layers Hexcel 4522 (1 layer in correspondence of the vtaps)