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HL-LHC WP3

Status of activities on resistive magnets

P.A. Thonet

Points 1 and 5

Points 1 and 5: Removal of 24 MBXW magnets

- Activity being organized with colleagues from other groups (EN-HE, EN-CV, TE-VSC, TE-MPE, BE-SU, EN-EL,…)

- Request for a storage space in view to keep these magnets in stock for potential use in other machines/projects (~50 m^2 as these magnets can be stacked by 3 or 4 units).

Points 3 and 7

Points 3 and 7

Given high integrated dose expected on MQW and MBW magnets in points 3 and 7 a study and test campaign was performed to:

- Evaluate and keep (in collaboration with SY-STI) the expected integrated dose until the end of HL-LHC up-to-date.
- Evaluate the resistance to radiation of critical magnet components:

Material	Dose corresponding to the beginning of damage (no bubbles, limited variation in properties) [MGy]	Dose corresponding moderate damage (bubbles formation and beginning of properties reduction) [MGy]	Dose corresponding to the failure on component (extensive bubbles, properties loss) [MGy]
MQW Coils	10-50	50-75	>75
MBW Coils	50-75	75-90	>90
MQW Spacers	5-10	10-15	>15

- Find some ways to mitigate the dose and implement the solution.
- Evaluate and implement possible corrective actions in case of failure.

Installation of radiation shielding completed

CERN CH-1211 Geneva 23 Switzerland

LHC

EDMS NO.	REV.	VALIDITY
1321044	1.0	RELEASED

REFERENCE
LHC-MW-EC-0001

Date: 2013-12-10

ENGINEERING CHANGE REQUEST

Radiation Shielding Installation for the MBW and MQW Magnets in IR 3 and 7 of the LHC.

First phase during LS1

BRIEF DESCRIPTION OF THE PROPOSED CHANGE(S):

The present document describes a program to reduce the absorbed dose on the MBW and MQW magnets installed in the LSS of point 3 and 7 in order to reduce the risk of failure before LS3 and, if possible, extend the magnet lifetime in HL-LHC era.

This document describes actions to be implemented in LS1. It provides the general background that is the basis of the modification. The program shall be completed by action in LS2 and LS3 described in LHC-MW-EC-0002.

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DISTRIBUTION LIST: LSC MEMBERS

SUMMARY OF ACTIONS TO BE UNDERTAKEN AND APPROVED WITH THIS DOCUMENT:

LS1:

- Installation of shielding on 4 MBW (2R+2L) and 4 MQW (2R+2L) magnets in IR 7
- Installation of high dose dosimeters on each MQW and MBW magnet of IR 3 and IR7 (no technical solution proposed yet)

Note: When approved, an Engineering Change Request becomes an Engineering Change Order.
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LHC

EDMS NO.	REV.	VALIDITY
1321045	2.0	RELEASED

REFERENCE
LHC-MW-EC-0002

Date: 2018-08-03

ENGINEERING CHANGE REQUEST

Radiation Shielding Installation and Possible Optics Change for the MBW and MQW Magnets in IR 3 and 7 of the LHC.

Second phase LS2, LS3 and HL-LHC

BRIEF DESCRIPTION OF THE PROPOSED CHANGE(S):

The present document describes a program to reduce the absorbed dose on the MBW and MQW magnets installed in the LSS of point 3 and 7 in order to reduce the risk of failure before LS3 and, if possible, extend the magnet lifetime in HL-LHC era.
This document describes actions to be implemented in LS2, LS3 and HL-LHC era. It complements the actions taken following document LHC-MW-EC-0001 and it should be read together with the above mentioned document.

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DOCUMENT SENT FOR INFORMATION TO:

LSC Members, ATS groups leaders.

SUMMARY OF THE ACTIONS TO BE UNDERTAKEN:

LS2: (actions in function of results of the reading of the previously installed dosimeters)

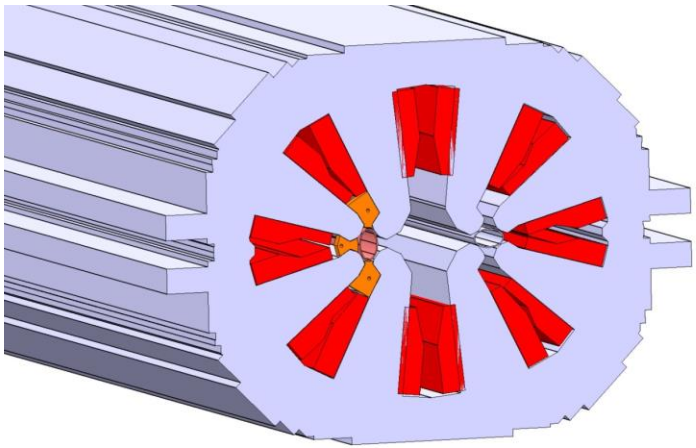
- Completion of the shielding installation program IR3 and IR7
- Modification of optics IR7 and installation of one absorber per side
- It has been decided that no new magnet will be built, but tooling to refurbish existing units will be developed.

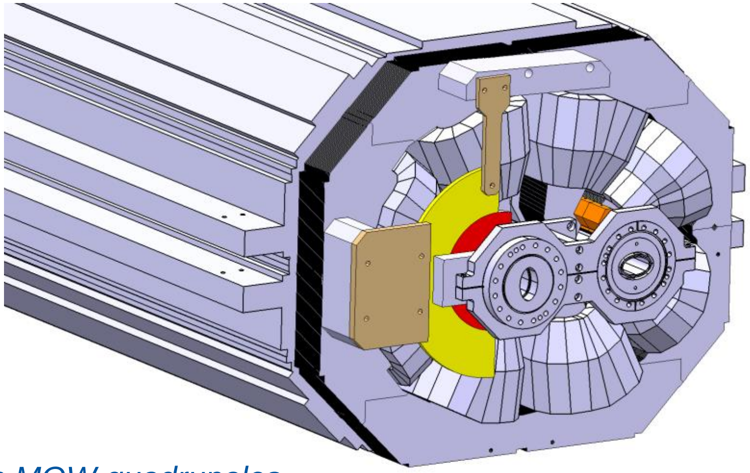
LS3: It has been decided not to install any new magnets.

Note: When approved, an Engineering Change Request becomes an Engineering Change Order.
This document is uncontrolled when printed. Check the EDMS to verify that this is the correct version before use.

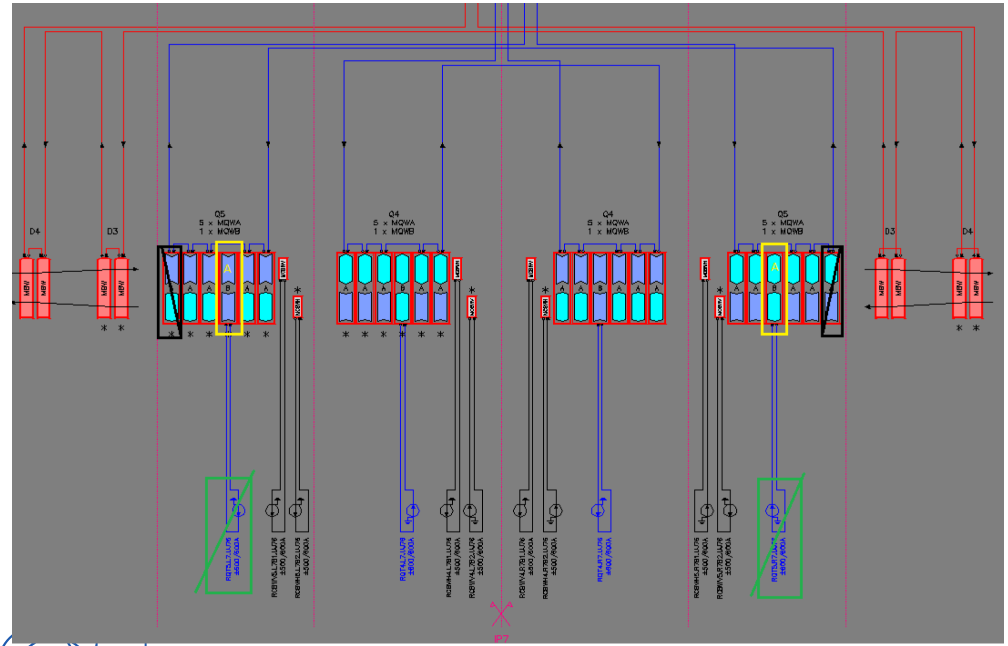
Courtesy P. FESSIA

Installation of radiation shielding completed





Pictured: Shielding on MQW quadrupoles



Pictured: MQW optic change in point 7 and installation of an absorber

Pictured: Shielding on MBW dipoles

Expected dose in point 3 (from 2018 study)

Table 5 — Magnet coil doses with W screen in IR3.

IR3	Dose [MGy] for integrated luminosity 150 fb^{-1} (LS2)	Dose [MGy] for integrated luminosity 350 fb^{-1} (LS3)	Dose [MGy] for integrated luminosity 3000 fb^{-1} (LS6)	Dose [Mgy] for integrated luminosity 4000 fb^{-1} (End of HL-LHC)
MQWA.A4	0.04	0.09	0.3	0.3
MQWA.B4	0.04	0.09	0.3	0.3
MQWB.4	0.04	0.06	0.1	0.1
MQWA.C4	0.04	0.06	0.1	0.1
MQWA.D4	0.04	0.06	0.1	0.1
MQWA.E4	0.68	**1.72**	**4.8**	**5.6**
MQWA.A5	0.23	**0.35**	**0.7**	**0.8**
MQWA.B5	0.29	**0.43**	**0.9**	**1**
MQWB.5	0.78	**1.17**	**2.4**	**2.7**
MQWA.C5	0.84	**1.27**	**2.6**	**2.9**
MQWA.D5	0.41	**0.62**	**1.2**	**1.4**
MQWA.E5	1.48	**3.74**	**10.5***	**12.2***
MBW.A6	0.74	**1.86**	**5.2**	**6.1**
MBW.B6	0.66	**1.66**	**4.7**	**5.4**
MBW.C6	0.43	**1.08**	**3.0**	**3.5**

Table 6 — MQW spacer doses with W screen in IR3

IR3	Dose [MGy] for integrated luminosity 150 fb^{-1} (LS2)	Dose [MGy] for integrated luminosity 350 fb^{-1} (LS3)	Dose [MGy] for integrated luminosity 3000 fb^{-1} (LS6)	Dose [Mgy] for integrated luminosity 4000 fb^{-1} (End of HL-LHC)
MQWA.A4	0.01	0.04	0.11	0.12
MQWA.B4	0.02	0.04	0.11	0.13
MQWB.4	0.02	0.02	0.05	0.05
MQWA.C4	0.02	0.02	0.05	0.05
MQWA.D4	0.02	0.02	0.05	0.05
MQWA.E4	0.28	**0.72**	**2.01**	**2.34**
MQWA.A5	0.10	**0.14**	**0.29**	**0.33**
MQWA.B5	0.12	**0.18**	**0.36**	**0.41**
MQWB.5	0.32	**0.49**	**0.98**	**1.11**
MQWA.C5	0.35	**0.53**	**1.06**	**1.19**
MQWA.D5	0.17	**0.26**	**0.52**	**0.59**
MQWA.E5	0.61	**1.55**	**4.38**	**5.08***

- All work listed in ECR 1321044 and 1321045 was completed during LS2 (few minor exceptions for front-face shields on MQW due to space constraints)
- It includes the installation of shielding on MQW and MBW
- Expected integrated doses on magnet components mostly below limits which start to degrade insulation and shimming materials
- Study on going to update the integrated dose with latest RPLs measurements, taking into account the magnets where front-face shields were not installed

Expected dose in point 7 (from 2018 study)

Table 7 — Coil doses with W screen in IR7.

IR7	Dose [MGy] for integrated luminosity 150 fb^{-1} (LS2)	Dose [MGy] for integrated luminosity 350 fb^{-1} (LS3)	Dose [MGy] for integrated luminosity 3000 fb^{-1} (LS6)	Dose [MGy] for integrated luminosity 4000 fb-1 (End of HL-LHC)
MQWA.A4	0.22	0.55	1.5	1.8
MQWA.B4	0.32	0.82	2.3	2.7
MQWB.4	0.63	**0.95**	**1.9**	**2.2**
MQWA.C4	0.93	**1.40**	**2.8**	**3.2**
MQWA.D4	0.19	**0.28**	**0.6**	**0.7**
MQWA.E4	**0.53**	**1.34**	**3.8**	**4.4**
MQWA.A5	1.04	**1.57**	**3.2**	**3.6**
MQWA.B5	1.04	**1.57**	**3.2**	**3.6**
MQWB.5	1.04	**1.57**	**3.2**	**3.6**
MQWA.C5	1.04	**1.57**	**3.2**	**3.6**
MQWA.D5	0.83	**1.26**	**2.5**	**2.9**
MQWA.E5	**0.65**	**Removed**	**Removed**	**Removed**
MBW.A6	**1.24**	**3.15**	**8.9**	**10.3**
MBW.B6	**1.88**	**4.75**	**13.4**	**15.5**

Table 8 — MQW spacer doses with W screen in IR7

IR7	Dose [MGy] forintegrated luminosity 150 fb^{-1} (LS2)	Dose [MGy] for integrated luminosity 350 fb^{-1} (LS3)	Dose [MGy] for integrated luminosity 3000 fb^{-1} (LS6)	Dose [MGy] for integrated luminosity 4000 fb^{-1} (End of HL-LHC)
MQWA.A4	0.09	0.23	0.64	0.74
MQWA.B4	0.13	0.34	0.95	1.11
MQWB.4	0.26	**0.39**	**0.79**	**0.89**
MQWA.C4	0.52	**0.79**	**1.59**	**1.78**
MQWA.D4	0.22	**0.33**	**0.66**	**0.74**
MQWA.E4	**0.26**	**0.67**	**1.89**	**2.19**
MQWA.A5	0.43	**0.65**	**1.3**	**1.47**
MQWA.B5	0.43	**0.65**	**1.3**	**1.47**
MQWB.5	0.43	**0.65**	**1.3**	**1.47**
MQWA.C5	0.43	**0.65**	**1.3**	**1.47**
MQWA.D5	0.26	**0.39**	**0.79**	**0.89**
MQWA.E5	**0.45**	**Removed**	**Removed**	**Removed**

- All work listed in ECR 1321044 and 1321045 was completed during LS2
- It includes the installation of shielding on MQW and MBW and removal of the 2 MQWA.E5 (reconfiguration of MQWB.5 in MQWA) and installation of an absorber
- No further work to be done
- Expected integrated doses on magnet components below limits which start to degrade insulation and shimming materials

Expected dose in point 7 (updated 2024)

IR7: latest HL dose predictions for warm magnets

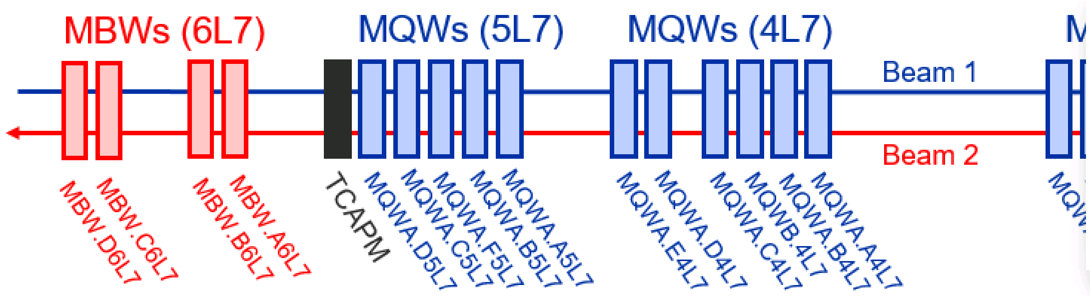


Table 4 — New material radiation limits.

Material	Dose corresponding to the beginning of damage (no bubbles, limited variation in properties) [MGy]	Dose corresponding moderate damage (bubbles formation and beginning of properties reduction) [MGy]	Dose corresponding to the failure on component (extensive bubbles, properties loss) [MGy]
MQW Coils	10-50	50-75	>75
MBW Coils	50-75	75-90	>90
MQW Spacers	5-10	10-15	>15

Dose values in most exposed magnets, scaled to **1.8x10^{17} protons lost in HL era** (=1.5x10^{16} protons lost per year, for 12 years)

Loss scaling was established in Run 2 (2015-2018), and confirmed with 2022+2023 BLM data.

Note that the dose values in the ECRs are outdated since the loss scaling was refined

	Coils	Spacers
MBW.B6L7/R7	16 MGy	N/A
MBW.A6L7/R7	13 MGy	N/A
MQWA.D5L7/R7	1.3 MGy	1.1 MGy
MQWA.C5L7/R7	0.9 MGy	0.5 MGy
MQWA.E4L7/R7	2 MGy	1.8 MGy
MQWA.D4L7/R7	<0.7 MGy	<0.7 MGy
MQWA.C4L7/R7	<1 MGy	<1 MGy

Scaled from the FLUKA results presented by Bahamonde (ColUSM #104) and E. Skordis (CWG #237)

LHC resistive magnets spare status

- All spare magnets were certified, and vacuum chambers installed in 2023-2024. For each type, some spares are available and ready to be installed (excepting MSI due to different vacuum chamber configurations in points 2 and 8).

- Depending on magnet type and location a magnet exchange would take 1 to 2 weeks. Original installation documentation exists, and handling equipment is still available.

LHC RESISTIVE MAGNETS

Name	Magnet type	Number of installed magnets	Magnet location	Number of spare magnets	Number of spare magnets ready to be installed (with vacuum chamber)	Remarks
MQW	QUADRUPOLE	46	Points 3 and 7	6	**5**	5 magnets out of 6 equipped with vacuum chamber
MBXWS	HORIZONTAL DIPOLE	2	Point 8	1	**1**	
MBXWT	VERTICAL DIPOLE	2	Point 2	1	**1**	
MBW	HORIZONTAL DIPOLE	20	Points 3 and 7	4	**2**	2 magnets equipped with vacuum chambers supports of each type
MBXW	HORIZONTAL DIPOLE	24	Points 1 and 5	4	**3**	
MBXWH	HORIZONTAL DIPOLE	1	Point 8			
MCBWV	VERTICAL DIPOLE	8	Points 3 and 7	2	**1**	
MCBWH	HORIZONTAL DIPOLE	8	Points 3 and 7	2	**1**	
MBWMD	VERTICAL DIPOLE	1	Point 2	1	**1**	
MSIA	SEPTA MAGNET	4	TI2 and TI8	2	**0**	Vacuum chambers available but different configuration for points 2 and 8
MSIB	SEPTA MAGNET	6	TI2 and TI8	3	**0**	Vacuum chambers available but different configuration for points 2 and 8
MSDA	SEPTA MAGNET	10	Point 6	5	**5**	
MSDB	SEPTA MAGNET	10	Point 6	5	**5**	
MSDC	SEPTA MAGNET	10	Point 6	5	**5**	

Regular inspections and tests

- All Magnets are inspected every year. No noticeable color change of the coil resin observed so far.

- Dosimeters are exchanged and measured every year (EDMS 2881444 for 2022, EDMS 3027410 for 2023).

- Heat run at nominal current is done every year. No problem detected so far.

- High voltage test and heat run with thermal inspection is done during long stops. No problem detected so far.

In case of MBW failure and replacement

- Bolted yoke construction
- Coil replacement would fall in standard procedure for coil replacement and shimming, using existing equipment.

=> No further work to be done

In case of MQW failure and replacement

- Non-standard procedure and equipment to refurbish these magnets

- A procedure explaining manufacturing and assembly, taken from Alstom exists and is relatively well detailed, including pictures.

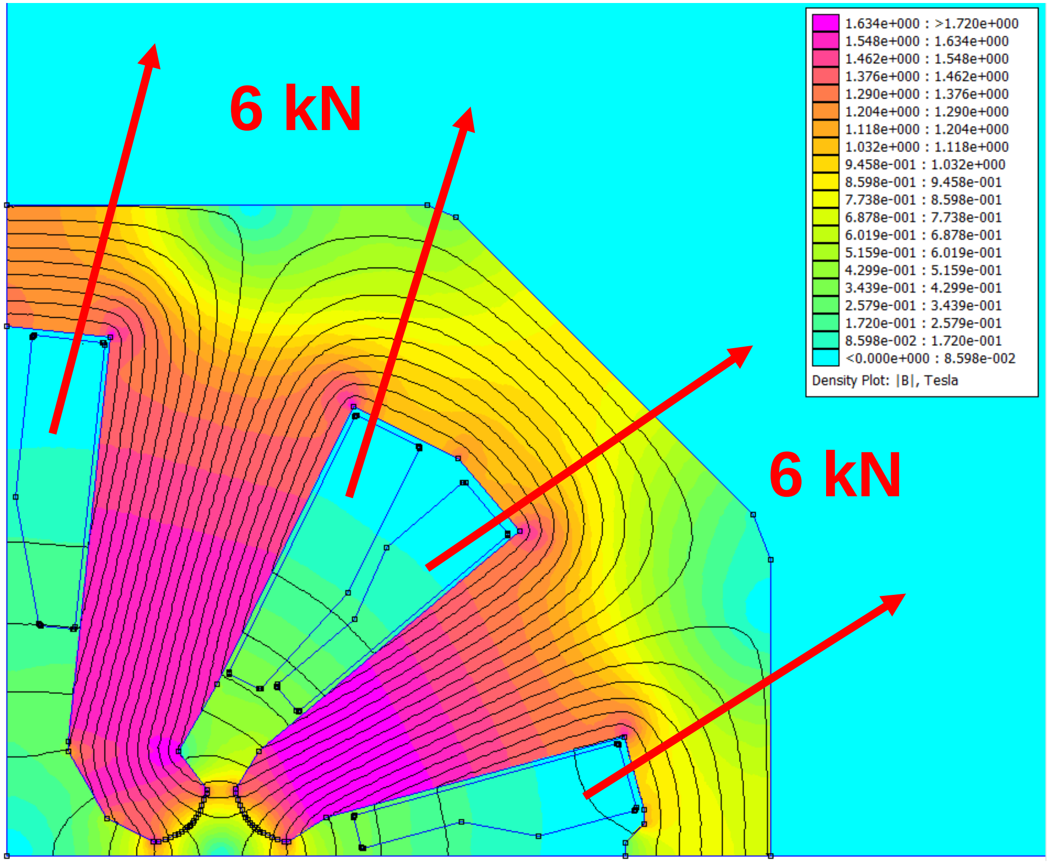
- A tooling inventory was done and there are not many equipment that were found and can be re-used (or it is in bad condition).

- Most of the assembly tooling will have to be re-designed (based on existing drawings).

- In case of failure of an MQWA, it was proposed some years ago to convert a MQWB into an MQWA to continue the run (eventually in slightly degraded mode), as it was done for circuit RQ5.LR7 in point 7.

How MQW coils are stressed

- Maximum of 450 Volts for ground insulation
- Maximum of few Volts between turns
- Maximum forces on coil of 6 kN over the 3.1 m length
- Relatively low water velocity and pressure
- Operation in DC (with slow ramp)



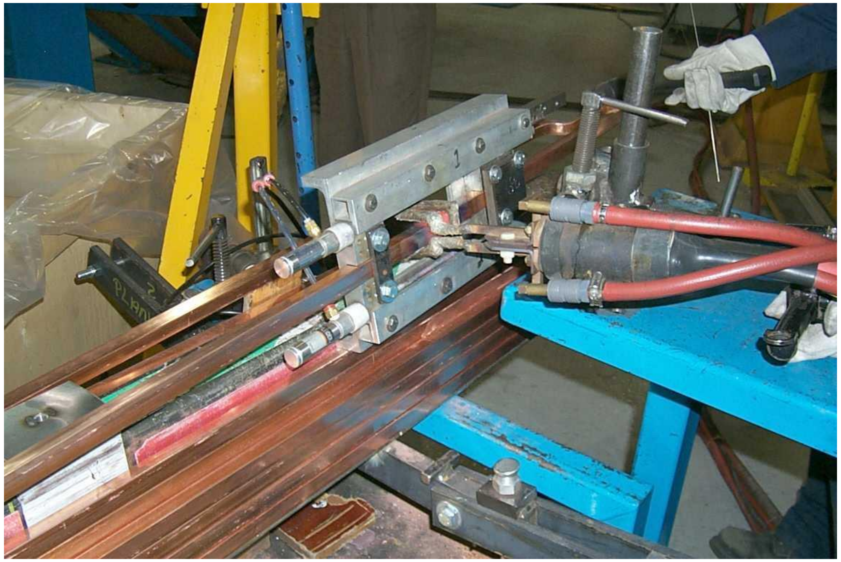
=> Not heavily stressed

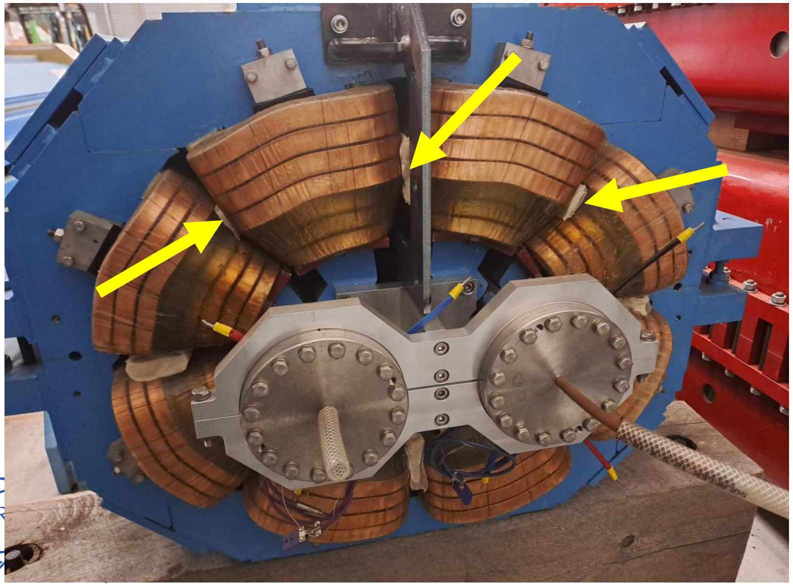
MQW potential weaknesses

- Internal brazing are present (as in many over LHC or CERN complex resistive magnets). Risk on internal short circuit in case of leak.

- Potential degradation of resin performance due to integrated radiation doses.

- Shimming between coil made of charged epoxy resin injected in pockets. It is more subject to radiation damage than coils. Mainly coils on upper half yoke are concerned.

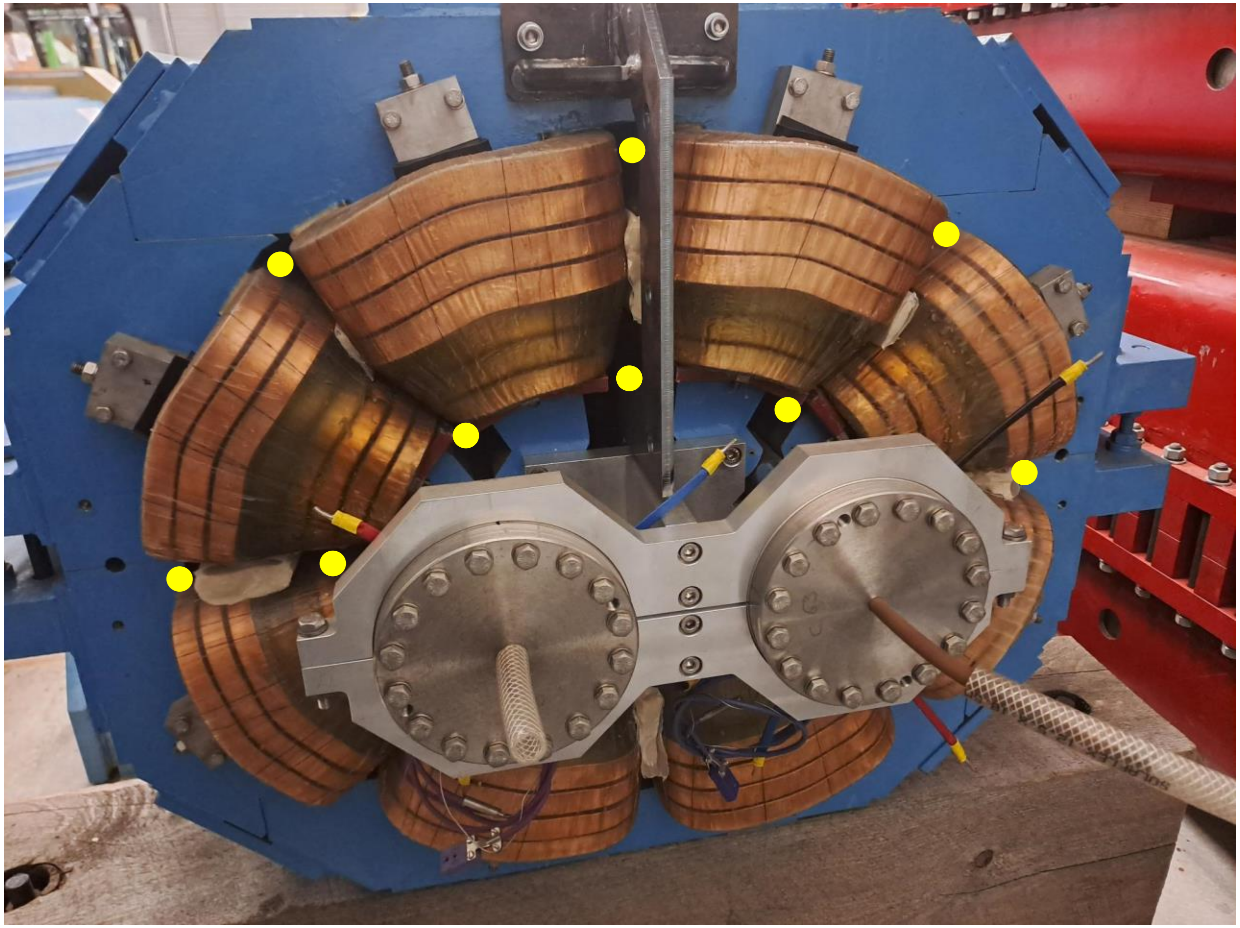




A possibility to repair coil shimming

- In case of shimming degradation, It may be possible to inject new pockets on the outside and inside of the coils.

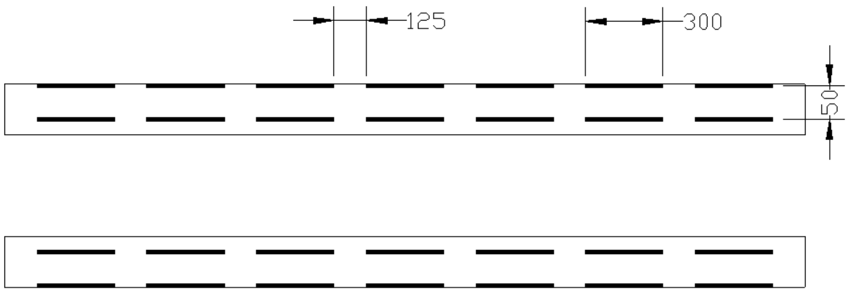
- For the inside ones, the installed shielding would help to constraint the pockets in any directions.

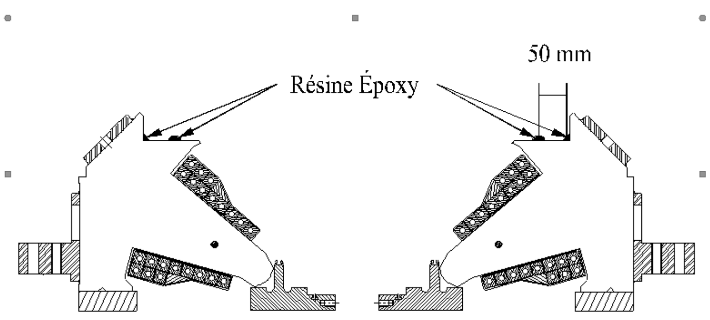


Potential difficulty to open an MQW

- It was recently found that the quadrants were glued together with epoxy before being welded.

- The glue is used to fill the space and has no structural purpose but if it performs well, it may be tricky to separate the quadrants.





Mélanger 150 g de résine et 20 g de durcisseur.

Source Alstom

MQW future actions

- Development of a solution and process to re-shim coils with injected pockets in case of coil shimming repair and in case of opening and closing operation.
- Monitoring of coils potential movements when cycling (YETS 24-25).
- Endoscopy of cooling channels to identify potential brazing problems or degradation of brazed joints (connexions pieces and internal brazing if possible). Test to be done in 2024 on 2 magnets taken out from point 7.
- Request for demineralized water analysis (network and MQW outlet) and comparison with SPS and PSB (YETS 24-25).
- Design of opening/closing tool was started with EN-MME but put on hold since LS2. It is at early stage and would still require a lot of work (opening of the magnet, machining, handling of the quadrants, alignment and closing). It is proposed to document what is already done and restart this design only if one of the MQW fails in the machine.

CONCLUSION

- For any of the LHC resistive magnet types (excepting MSI septa), spare magnets are ready to be installed.

- Regular inspection and tests are done to identify any condition changes or damages. No visible damage identified so far.

- All work planned (minor few exceptions due to space constraints) in ECR 1321044 and 1321045 was completed during LS2.

- Continue dose monitoring and update the integrated dose previsions to keep up-to-date the risk of degradation of coils insulation and shimming material due to radiation (to be decided until when we do this and if it will be acceptable for people to take such radiation dose for RPLs exchange during HL-LHC).

- For MQW magnets:
  - Given current situation (expected radiation dose minored, no degradation), it appears safe to rely on available spare magnets until the end of HL-LHC.
  - Measurement campaign to be done (2024 and YETS 24/25) to detect any coil movement or brazed joints degradation.
  - Tooling and process to re-shim coils to be set in 2024-2025.
  - Opening and closing tooling design would restart only if a MQW magnet fails.

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