HL-LHC Magnet Circuits Internal Review

Closed session # 2

Additional information

FRM, 24th March 2017

Content

1. 11T Dipole
2. Matching Section
3. Inner Triplet

Input from TE/EPC

- The power converter is not designed to withstand the 2.1 kV. Therefore, we could foresee a circuit separator at the output of the PC since the cables are air cooled. The present TE-EPC design doesn't withstand more than 1.2 kV.
  - ElQA implications to be considered
- The impact of the 11T trim PC on the QDS of the neighboring magnets should be studied in SM18 by connecting two magnets in series and simulation of (close to) machine conditions

11T Dipole Trim

- A set of 4, 120A current leads could be integrated to avoid the design of a new, gas-cooled lead for 250A
- Paralleling of 2 leads per polarity seems feasible from the powering point of view
- The issue is whether or not this design of leads is compatible with the qualification voltage level of 3.4 kV coil-to-ground in nominal conditions (5 kV at warm)

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Follow-up of issues

- Re-Use of DSL
    - Communication from TE-CRG on the need for dismantling DSL during the modification of the QRL – see next
- Decision on series connection of MCBY in Q4/Q5

Summary for Cryogenics (by Serge Claudet)

Introduction:

- As part of the cost to performance exercise conducted mid 2016 for the HL-LHC project, it was considered that existing components could be re-used such as DFBL's and DSL's at P1/P5.
- At this stage, we considered that these items could be re-used "as-is", without any modification.
- If this is the case for the DFBL's, it was not clear if the DSL's could be kept in place for the dismantling of the QRL and installation of HiLumi components, in particular the QXL.
- A brief but efficient study has been performed by P. Fessia & S. Maridor.

Statement for Cryogenics:

- Based on this study, the cryo team would arrive to the following conclusion for the existing DSL:
- the DSL integrity would need to be touched at the level of compensation boxes to allow dismantling the existing QRL. For the time being and considering the extremely delicate work required, we cannot commit that this would be possible without accident for the 4 units concerned.
- **Therefore, we conclude that it is not possible to keep the present DSL in place for LS3 activities (touching only the splices at extremities).**

Complements:

- However, we are confident that the present DSL could be kept in place from its extremity at DFBL to the proximity of the junction to Q6. With time and appropriate resources (CRG-MSC), it should be possible to study the integration of a junction cylinder (with splices) from this proximity of Q6 to the required interface for new Q6-Q5-Q4 positions via a new DSL termination part. Making use of the dismounted elements of the DSL and having spare superconducting cable should be part of the study if the approach would be validated.
- Besides, the study does not identify potential issues for the junction of the QXL to the QRL or for the connection of the DFBL to the QXL. This is conform to our present plans.

Content

1. 11T Dipole
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New calculations

- update conservative scenario with ultimate currents
- analysis of implications of large scattering in terms of RRR, Cu/non-Cu ratio, etc. for both "standard" and conservative scenarios
- implications of the bus bar quench and/or link quench in terms of voltages (and currents) – in progress
- consider reduced volume heating (inner layers) – in progress

Standard (non conservative) scenario

Table 1. Simulated peak currents in the circuit elements (see Figure 1) after a quench at ultimate current, in units of kA

Configuration	Lead A	Lead B	Lead C	Lead D	Lead E	Crowbar TS1	Crowbar TS2	Crowbar TS3
Case A – $I_{Q1}=I_{Q2a}=I_{Q2b}=I_{Q3}$=17.80 kA								
O-QH + CLIQ, Reference	17.8	0.7	0	0.7	17.8	0.1	0.7	0.1
Case B – $I_{Q1}=I_{Q3}$=15.80 kA, I_{Q2a}=17.68 kA, I_{Q2b}=17.80 kA								
O-QH + CLIQ, Reference	15.8	2	0.2	2.2	15.8	2.2	0.2	2.2
O-QH + CLIQ, 1 ms delay of 1 CLIQ protecting Q3								
O-QH + CLIQ, 5 ms delay of 1 CLIQ protecting Q3								
O-QH + CLIQ, misfiring of 1 CLIQ unit protecting Q3								
O-QH + CLIQ, RRR of Q1/Q3 300, RRR of Q2a/Q2b 100								
O-QH + CLIQ, RRR of Q1/Q2a/Q3 300, RRR of Q2b 100	15.8	2.2	1.5	3.5	15.8	3.5	1.5	3.5
Case C – I_{Q1}=17.80 kA, I_{Q2a}=15.68 kA, $I_{Q2b}=I_{Q3}$=15.80 kA								
O-QH + CLIQ, Reference								
O-QH + CLIQ, 1 ms delay of 1 CLIQ protecting Q2a								
O-QH + CLIQ, 5 ms delay of 1 CLIQ protecting Q2a								
O-QH + CLIQ, misfiring of 1 CLIQ unit protecting Q2a								
O-QH + CLIQ, RRR of Q1/Q3 100, RRR of Q2a/Q2b 300								

Table 2. Simulated peak current rate changes in the circuit elements (see Figure 1) after a quench at ultimate current, in units of kA/s

Configuration	Lead A	Lead B	Lead C	Lead D	Lead E	Crowbar TS1	Crowbar TS2	Crowbar TS3
Case A – $I_{Q1}=I_{Q2a}=I_{Q2b}=I_{Q3}$=17.80 kA								
O-QH + CLIQ, Reference	175	51	5	52	197	30	52	30
Case B – $I_{Q1}=I_{Q3}$=15.80 kA, I_{Q2a}=17.68 kA, I_{Q2b}=17.80 kA								
O-QH + CLIQ, Reference	173	83	28	89	195	89	28	89
O-QH + CLIQ, 1 ms delay of 1 CLIQ protecting Q3								
O-QH + CLIQ, 5 ms delay of 1 CLIQ protecting Q3								
O-QH + CLIQ, misfiring of 1 CLIQ unit protecting Q3								
O-QH + CLIQ, RRR of Q1/Q3 300, RRR of Q2a/Q2b 100								
O-QH + CLIQ, RRR of Q1/Q2a/Q3 300, RRR of Q2b 100	172	84	35	108	194	108	35	108
Case C – I_{Q1}=17.80 kA, I_{Q2a}=15.68 kA, $I_{Q2b}=I_{Q3}$=15.80 kA								
O-QH + CLIQ, Reference								
O-QH + CLIQ, 1 ms delay of 1 CLIQ protecting Q2a								
O-QH + CLIQ, 5 ms delay of 1 CLIQ protecting Q2a								
O-QH + CLIQ, misfiring of 1 CLIQ unit protecting Q2a								
O-QH + CLIQ, RRR of Q1/Q3 100, RRR of Q2a/Q2b 300								

Table 3. Simulated thermal load in the circuit elements (see Figure 1) after a quench at ultimate current, in units of MAAs

Configuration	Lead A	Lead B	Lead C	Lead D	Lead E	Crowbar TS1	Crowbar TS2	Crowbar TS3
Case A – $I_{Q1}=I_{Q2a}=I_{Q2b}=I_{Q3}$=17.80 kA								
O-QH + CLIQ, Reference	26.4	0.1	0	0.1	26.3	0	0.1	0
Case B – $I_{Q1}=I_{Q3}$=15.80 kA, I_{Q2a}=17.68 kA, I_{Q2b}=17.80 kA								
O-QH + CLIQ, Reference	25.4	0.5	0	0.6	25.3	0.6	0	0.6
O-QH + CLIQ, 1 ms delay of 1 CLIQ protecting Q3								
O-QH + CLIQ, 5 ms delay of 1 CLIQ protecting Q3								
O-QH + CLIQ, misfiring of 1 CLIQ unit protecting Q3								
O-QH + CLIQ, RRR of Q1/Q3 300, RRR of Q2a/Q2b 100								
O-QH + CLIQ, RRR of Q1/Q2a/Q3 300, RRR of Q2b 100	27.3	0.6	0.2	1.4	27.2	1.4	0.2	1.4
Case C – I_{Q1}=17.80 kA, I_{Q2a}=15.68 kA, $I_{Q2b}=I_{Q3}$=15.80 kA								
O-QH + CLIQ, Reference								
O-QH + CLIQ, 1 ms delay of 1 CLIQ protecting Q2a								
O-QH + CLIQ, 5 ms delay of 1 CLIQ protecting Q2a								
O-QH + CLIQ, misfiring of 1 CLIQ unit protecting Q2a								
O-QH + CLIQ, RRR of Q1/Q3 100, RRR of Q2a/Q2b 300								

Conservative scenario

Table 1. Simulated peak currents in the circuit elements (see Figure 1) after a quench at ultimate current, in units of kA

Configuration	Magnet suddenly quenched	Lead A	Lead B	Lead C	Lead D	Lead E	Crowbar TS1	Crowbar TS2	Crowbar TS3
Case A – $I_{Q1}=I_{Q2a}=I_{Q2b}=I_{Q3}=17.80$ kA	None	17.8	0.7	0	0.7	17.8	0.1	0.7	0.1
Case A – $I_{Q1}=I_{Q2a}=I_{Q2b}=I_{Q3}=17.80$ kA	Q1								
Case A – $I_{Q1}=I_{Q2a}=I_{Q2b}=I_{Q3}=17.80$ kA	Q2b	17.8	0.7	3.5	3.7	17.8	3.7	3.5	3.7
Case A – $I_{Q1}=I_{Q2a}=I_{Q2b}=I_{Q3}=17.80$ kA	Q3								
Case B – $I_{Q1}=I_{Q3}=15.80$ kA, $I_{Q2a}=17.68$ kA, $I_{Q2b}=17.80$ kA	None	15.8	2	0.2	2.2	15.8	2.2	0.2	2.2
Case B – $I_{Q1}=I_{Q3}=15.80$ kA, $I_{Q2a}=17.68$ kA, $I_{Q2b}=17.80$ kA	Q1								
Case B – $I_{Q1}=I_{Q3}=15.80$ kA, $I_{Q2a}=17.68$ kA, $I_{Q2b}=17.80$ kA	Q2b	15.8	2	3.6	4.8	15.8	4.8	3.6	4.8
Case B – $I_{Q1}=I_{Q3}=15.80$ kA, $I_{Q2a}=17.68$ kA, $I_{Q2b}=17.80$ kA	Q3								
Case C – $I_{Q1}=17.80$ kA, $I_{Q2a}=15.68$ kA, $I_{Q2b}=I_{Q3}=15.80$ kA	None								
Case C – $I_{Q1}=17.80$ kA, $I_{Q2a}=15.68$ kA, $I_{Q2b}=I_{Q3}=15.80$ kA	Q1								
Case C – $I_{Q1}=17.80$ kA, $I_{Q2a}=15.68$ kA, $I_{Q2b}=I_{Q3}=15.80$ kA	Q2b								
Case C – $I_{Q1}=17.80$ kA, $I_{Q2a}=15.68$ kA, $I_{Q2b}=I_{Q3}=15.80$ kA	Q3								

Table 2. Simulated peak current rate changes in the circuit elements (see Figure 1) after a quench at ultimate current, in units of kA/s

Configuration	Magnet suddenly quenched	Lead A	Lead B	Lead C	Lead D	Lead E	Crowbar TS1	Crowbar TS2	Crowbar TS3
Case A – $I_{Q1}=I_{Q2a}=I_{Q2b}=I_{Q3}=17.80$ kA	None	175	51	5	52	197	30	52	30
Case A – $I_{Q1}=I_{Q2a}=I_{Q2b}=I_{Q3}=17.80$ kA	Q1								
Case A – $I_{Q1}=I_{Q2a}=I_{Q2b}=I_{Q3}=17.80$ kA	Q2b	173	55	70	95	196	95	70	95
Case A – $I_{Q1}=I_{Q2a}=I_{Q2b}=I_{Q3}=17.80$ kA	Q3								
Case B – $I_{Q1}=I_{Q3}=15.80$ kA, $I_{Q2a}=17.68$ kA, $I_{Q2b}=17.80$ kA	None	173	83	28	89	195	89	28	89
Case B – $I_{Q1}=I_{Q3}=15.80$ kA, $I_{Q2a}=17.68$ kA, $I_{Q2b}=17.80$ kA	Q1								
Case B – $I_{Q1}=I_{Q3}=15.80$ kA, $I_{Q2a}=17.68$ kA, $I_{Q2b}=17.80$ kA	Q2b	172	83	74	97	194	97	74	97
Case B – $I_{Q1}=I_{Q3}=15.80$ kA, $I_{Q2a}=17.68$ kA, $I_{Q2b}=17.80$ kA	Q3								
Case C – $I_{Q1}=17.80$ kA, $I_{Q2a}=15.68$ kA, $I_{Q2b}=I_{Q3}=15.80$ kA	None								
Case C – $I_{Q1}=17.80$ kA, $I_{Q2a}=15.68$ kA, $I_{Q2b}=I_{Q3}=15.80$ kA	Q1								
Case C – $I_{Q1}=17.80$ kA, $I_{Q2a}=15.68$ kA, $I_{Q2b}=I_{Q3}=15.80$ kA	Q2b								
Case C – $I_{Q1}=17.80$ kA, $I_{Q2a}=15.68$ kA, $I_{Q2b}=I_{Q3}=15.80$ kA	Q3								

Table 3. Simulated thermal load in the circuit elements (see Figure 1) after a quench at ultimate current, in units of MAAs

Configuration	Magnet suddenly quenched	Lead A	Lead B	Lead C	Lead D	Lead E	Crowbar TS1	Crowbar TS2	Crowbar TS3
Case A – $I_{Q1}=I_{Q2a}=I_{Q2b}=I_{Q3}=17.80$ kA	None	26.4	0.1	0	0.1	26.3	0	0.1	0
Case A – $I_{Q1}=I_{Q2a}=I_{Q2b}=I_{Q3}=17.80$ kA	Q1								
Case A – $I_{Q1}=I_{Q2a}=I_{Q2b}=I_{Q3}=17.80$ kA	Q2b	25.7	0.1	1	1.2	25.6	1.2	1	1.2
Case A – $I_{Q1}=I_{Q2a}=I_{Q2b}=I_{Q3}=17.80$ kA	Q3								
Case B – $I_{Q1}=I_{Q3}=15.80$ kA, $I_{Q2a}=17.68$ kA, $I_{Q2b}=17.80$ kA	None	25.4	0.5	0	0.6	25.3	0.6	0	0.6
Case B – $I_{Q1}=I_{Q3}=15.80$ kA, $I_{Q2a}=17.68$ kA, $I_{Q2b}=17.80$ kA	Q1								
Case B – $I_{Q1}=I_{Q3}=15.80$ kA, $I_{Q2a}=17.68$ kA, $I_{Q2b}=17.80$ kA	Q2b	25.4	0.5	1	2.2	25.3	2.2	1	2.2
Case B – $I_{Q1}=I_{Q3}=15.80$ kA, $I_{Q2a}=17.68$ kA, $I_{Q2b}=17.80$ kA	Q3								
Case C – $I_{Q1}=17.80$ kA, $I_{Q2a}=15.68$ kA, $I_{Q2b}=I_{Q3}=15.80$ kA	None								
Case C – $I_{Q1}=17.80$ kA, $I_{Q2a}=15.68$ kA, $I_{Q2b}=I_{Q3}=15.80$ kA	Q1								
Case C – $I_{Q1}=17.80$ kA, $I_{Q2a}=15.68$ kA, $I_{Q2b}=I_{Q3}=15.80$ kA	Q2b								
Case C – $I_{Q1}=17.80$ kA, $I_{Q2a}=15.68$ kA, $I_{Q2b}=I_{Q3}=15.80$ kA	Q3								

Table 1. Simulated peak currents in the circuit elements (see Figure 1) after a quench at ultimate current, in units of kA

Configuration	Lead A	Lead B	Lead C	Lead D	Lead E	Crowbar TS1	Crowbar TS2	Crowbar TS3
Case B – $I_{Q1}=I_{Q3}$=15.80 kA, I_{Q2a}=17.68 kA, I_{Q2b}=17.80 kA								
O-QH + CLIQ, Reference	15.8	2	0.2	2.2	15.8	2.2	0.2	2.2
Case B – $I_{Q1}=I_{Q3}$=15.80 kA, I_{Q2a}=17.68 kA, I_{Q2b}=17.80 kA, sudden quench of the entire magnet Q2b								
O-QH + CLIQ, Reference	15.8	2	3.6	4.8	15.8	4.8	3.6	4.8
O-QH + CLIQ, quench detection+validation in 15 ms, RRR of Q1/Q2a/Q3 300, RRR of Q2b 100	15.8	3.4	2.4	5.1	15.8	5.1	2.4	5.1
O-QH + CLIQ, quench detection+validation in 15 ms, RRR of Q1/Q2a/Q3 300, RRR of Q2b 100, Cu/noCu ratio of Q1/Q2a/Q3 1.3, Cu/noCu of Q2b 1.1	15.8	4	1.4	4.5	15.8	4.5	1.5	4.5

Table 2. Simulated peak current rate changes in the circuit elements (see Figure 1) after a quench at ultimate current, in units of kA/s

Configuration	Lead A	Lead B	Lead C	Lead D	Lead E	Crowbar TS1	Crowbar TS2	Crowbar TS3
Case B – $I_{Q1}=I_{Q3}$=15.80 kA, I_{Q2a}=17.68 kA, I_{Q2b}=17.80 kA								
O-QH + CLIQ, Reference	173	83	28	89	195	89	28	89
Case B – $I_{Q1}=I_{Q3}$=15.80 kA, I_{Q2a}=17.68 kA, I_{Q2b}=17.80 kA, sudden quench of the entire magnet Q2b								
O-QH + CLIQ, Reference	172	83	74	97	194	97	74	97
O-QH + CLIQ, quench detection+validation in 15 ms, RRR of Q1/Q2a/Q3 300, RRR of Q2b 100	172	104	47	106	194	106	47	106
O-QH + CLIQ, quench detection+validation in 15 ms, RRR of Q1/Q2a/Q3 300, RRR of Q2b 100, Cu/noCu ratio of Q1/Q2a/Q3 1.3, Cu/noCu of Q2b 1.1	172	110	52	99	194	99	52	99

Table 3. Simulated thermal load in the circuit elements (see Figure 1) after a quench at ultimate current, in units of MAAs

Configuration	Lead A	Lead B	Lead C	Lead D	Lead E	Crowbar TS1	Crowbar TS2	Crowbar TS3
Case B – $I_{Q1}=I_{Q3}$=15.80 kA, I_{Q2a}=17.68 kA, I_{Q2b}=17.80 kA								
O-QH + CLIQ, Reference	25.4	0.5	0	0.6	25.3	0.6	0	0.6
Case B – $I_{Q1}=I_{Q3}$=15.80 kA, I_{Q2a}=17.68 kA, I_{Q2b}=17.80 kA, sudden quench of the entire magnet Q2b								
O-QH + CLIQ, Reference								
O-QH + CLIQ, quench detection+validation in 15 ms, RRR of Q1/Q2a/Q3 300, RRR of Q2b 100	28.1	1.3	0.5	2.7	28	2.7	0.5	2.7
O-QH + CLIQ, quench detection+validation in 15 ms, RRR of Q1/Q2a/Q3 300, RRR of Q2b 100, Cu/noCu ratio of Q1/Q2a/Q3 1.3, Cu/noCu of Q2b 1.1	28.4	1.9	0.1	2.2	28.3	2.2	0.1	2.2

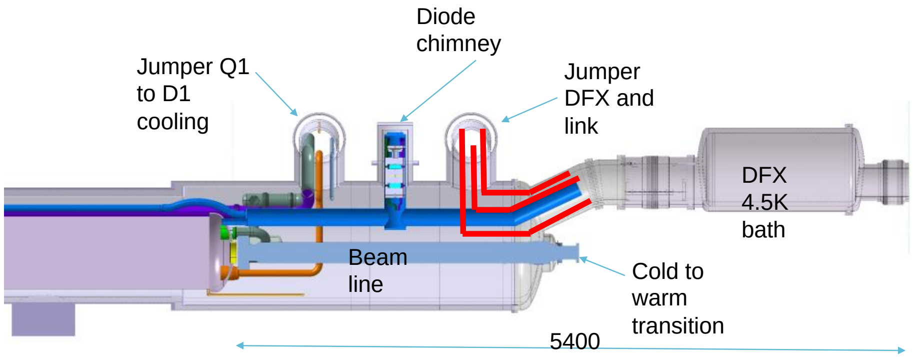
The diode path

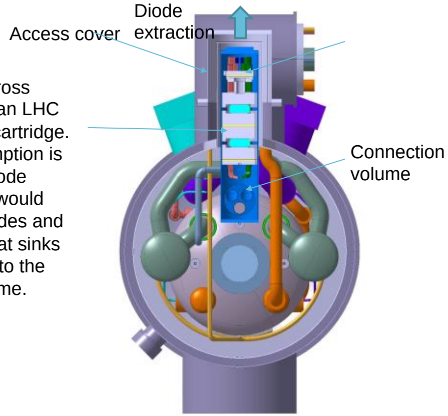
- Launching a **validation or development programme** on cold, radiation tolerant diodes is something CERN should maybe do for the future, result in 2-3 years
- Preliminary integration studies show space allocation could be feasible between jumpers – see next
- Diode bus-bars could be designed in a way to have the by-pass function added to the voltage balancing and "decoupling" ones
  - In this way, only the quenching magnet would be by-passed
  - The rest of chain is discharged using the crow-bar voltage
  - The temperature monitoring of the link allows using slow discharge in case of problems, not FPA
- Diodes at warm seems a less robust solution
  - For Q1, paralleling of trim1, trim1a, CLIQ and diode should be carefully studied

Cold diodes: Integration pre-study

D. Ramos, Y. Leclecq, C. Eymin, H. Prin

March 16, 2017





This is a cross section of an LHC SS diode cartridge. The assumption is the new diode assembly would have 4 diodes and smaller heat sinks all fitting into the same volume.

Alternative orientations of diode cartridge:
- at an angle in case of interference with tunnel ceiling
- horizontal for better accessibility and cooling

Integration study: Conclusion and remarks

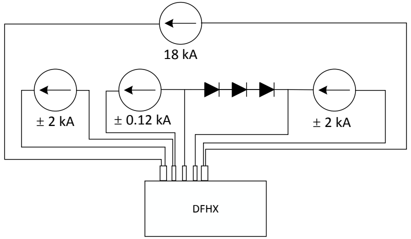
- This integration pre-study suggests that it is possible to integrate one cartridge that can be accessed for maintenance or replacement in situ. It is assumed that 4 diodes can be placed inside one cartridge of the same size as that of an SSS.
- Overall length combined with the DFX is still within the reservation given by the machine integration drawings.
- If a cold diode system is adopted as baseline:
  - The diodes will be significantly higher than the cold mass. The impact that this will have on 1.9 K cooling must be adressed.
  - Engineering aspects related with supports of several lines and thermal contraction management are to be studied.
  - Alignment of the beam line must be studied.
  - Space around the jumpers and diode access ports for welding and cuttting must be studied together with the QXL integration in the tunnel.

TRIMS

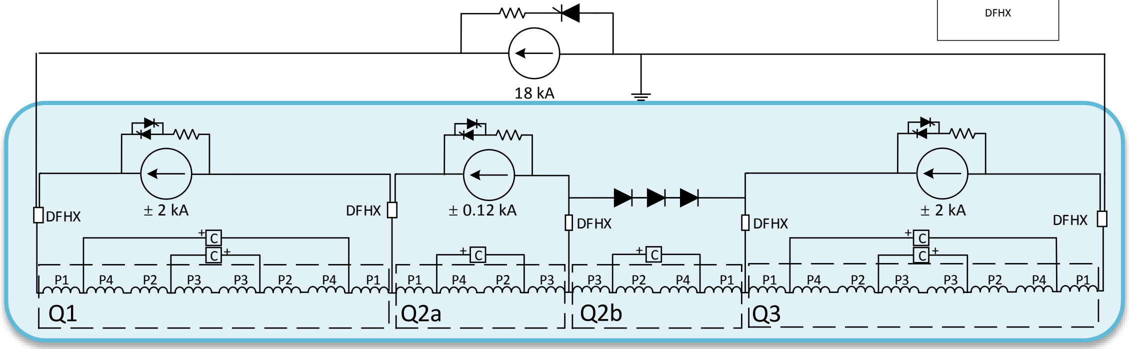
- Consensus that trim on Q2A can be suppressed. The 120A current lead and corresponding link conductor and bus bar must be kept (voltage balancing reason) and upgraded to cope with the overcurrent/quench load
- New trim Q1A: Rogelio has communicated that 30 A in half the Q1 should be sufficient at beta*=20cm
  - Lead should be protected from new over-currents by increasing the impedance in the circuit
- Thermal effect of trim powering abort on cold diode

Circuit layouts

Inner Triplet and Correctors

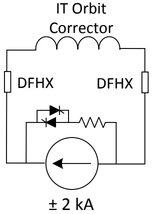


- 1 Circuit per IP side
- Power Converters:
  - 1 x18 kA 2 quadrants
  - 2 x 2 kA 4 quadrants
  - 1 x 0.12 kA 4 quadrants
  - Location: UR
- Cold Powering:
  - 2 x 18 kA leads
  - 3 x 2 kA leads (over currents due to failure scenarios are not taken into account)
  - Feedbox: DFHX @ UR
- Quench Protection:
  - Outer layer quench heaters
  - CLIQ
  - Inner layer quench heaters



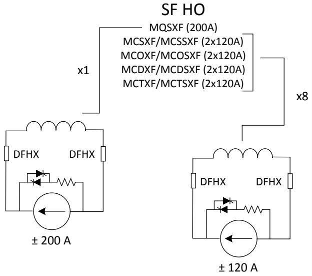
IT Orbit Correctors

- 6 Circuits per IP side
- Power Converters:
  - 6 x 2 kA 4 quadrants
  - Location: UR
- Cold Powering:
  - 12 x 2 kA leads
  - Feedbox: DFHX @ UR
- Quench Protection:
  - Quench heaters (baseline)
  - Energy extraction (Option)



Superferric High Order Correctors

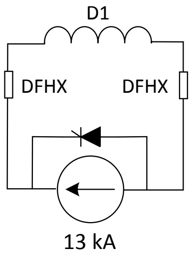
- 9 Circuits per IP side
- Power Converters:
  - 1 x 0.2 kA 4 quadrants
  - 8 x 0.12 kA 4 quadrants
  - Location: UR
- Cold Powering:
  - 2 x 0.2 kA lead
  - 16 x 0.12 kA leads
  - Feedbox: DFHX @ UR
- Quench Protection:
  - PC crowbar
  - EE option for order 2



D1, D2 and its Correctors and 11 Tesla

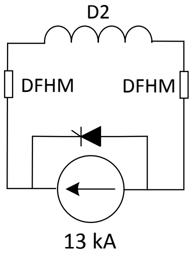
D1

- 1 Circuit per IP side
- Power Converters:
  - 1 x 13 kA 1 quadrants
  - Location: UR
- Cold Powering:
  - 2 x 13 kA leads
  - Feedbox: DFHX @ UR
- Quench Protection:
  - Quench heaters



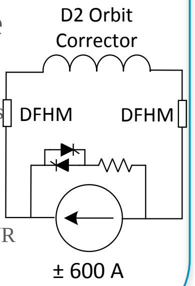
D2

- 1 Circuit per IP side
- Power Converters:
  - 1 x 13 kA 1 quadrants
  - Location: UR
- Cold Powering:
  - 2 x 13 kA leads
  - Feedbox: DFHM @ UR
- Quench Protection:
  - Quench heaters



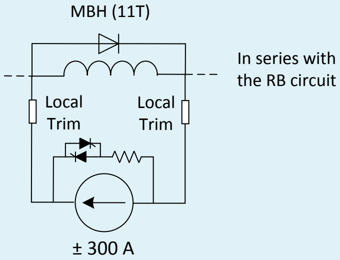
D2 Orbit Correctors

- 4 Circuit per IP side
- Power Converters:
  - 4 x 0.6 kA 4 quadrants
  - Location: UR
- Cold Powering:
  - 8 x 0.6 kA leads
  - Feedbox: DFHM @ UR
- Quench Protection:
  - PC Crowbar



11 Tesla Dipole

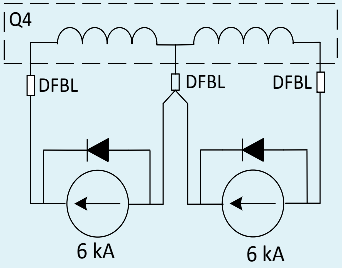
- Power Converters:
  - One trim power converter per circuit rated at ± 300 A
- Cold Powering:
  - Copper cables will be placed between the power converters placed in the RR and the local current leads of 11T trim.
- Quench Protection:
  - Quench heaters
  - Existing RB EE



Quadrupoles Q4, Q5 and Q6 and Correctors

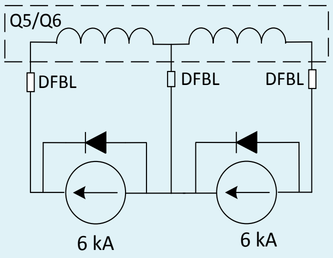
Q4

- 2 Circuit per IP side
- Power Converters:
  - 2 x 6 kA 1 quadrants
  - Location: RR
- Cold Powering:
  - 3 x 6 kA leads
  - Feedbox: DFBL @ RR
- Quench Protection:
  - Quench heaters



Q5/Q6

- 2 Circuit per IP side
- Power Converters:
  - 2 x 6 kA 1 quadrants
  - Location: RR
- Cold Powering:
  - 3 x 6 kA leads
  - Feedbox: DFBL @ RR
- Quench Protection:
  - Quench heaters



Q4 orbit corrector

- 8 Circuit per IP side
- Power Converters:
  - 8 x 0.12 kA 4 quadrants
  - Location: RR
- Cold Powering:
  - 16 x 0.12 kA leads
  - Feedbox: DFBL @ RR
  - Local powering (tbd)
- Quench Protection:
  - PC Crowbar

Q5 orbit corrector

- 6 Circuit per IP side
- Power Converters:
  - 6 x 0.12 kA 4 quadrants
  - Location: RR
- Cold Powering:
  - 12 x 0.12 kA leads
  - Feedbox: DFBL @ RR
  - Local powering (tbc)
- Quench Protection:
  - PC Crowbar

Q6 orbit corrector

- 2 Circuit per IP side
- Power Converters:
  - 2 x 0.12 kA 4 quadrants
  - Location: RR
- Cold Powering:
  - 4 x 0.12 kA leads
  - Local Powering
- Quench Protection:
  - PC Crowbar