Feedback on quench heaters versus energy extraction on HL corrector magnets

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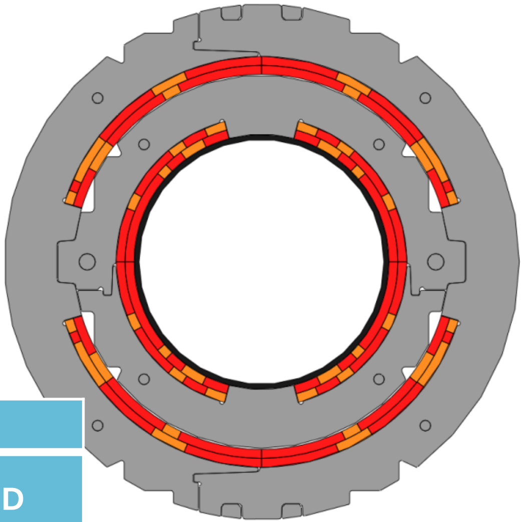
Introduction

- Following recommendations from the HL-LHC Magnet Circuits Review, energy extraction is under discussion for a number of corrector circuits as an alternative to quench heaters:
  - **Orbit correctors in IT (MCBXFA/B)**
  - Super-ferric quadrupole in IT (MQSXF)
  - Orbit correctors in D2 (MCBRD)

- As a decision has not yet been taken for these circuits, a strategy for all them is due for the development work within the upcoming months

The MCBXF magnet



- CIEMAT collaboration
  - CERN project engineer: J. C. Perez

Magnet	Units	MCBXFB		MCBXFA	
Inner Dipole (ID) & Outer Dipole (OD) parameters		ID	OD	ID	OD
Nominal field (Stand-alone)	T	2.11	2.23	2.11	2.23
Nominal Field (Combined)	T	3.07		3.07	
Nominal current	A	1630	1490	1530	1395
Coil peak field	T	4.1 (ID)		3.9 (ID)	
Working point	%	50.1 (ID)		47 (ID)	
Static self-inductance (nominal current)	mH	59.2	134.8	108.5	247
Magnetic stored energy (nom. Current)	kJ	78.6	149.6	127	240.3
Aperture	mm	156	230	156	230
Iron yoke Inner Diameter	mm	316		316	
Iron yoke Outer Diameter	mm	614		614	
Total number of turns	-	140	191	140	191
Cable length needed for each pole/coil	m	357	481	637	863
Turns per block in inner layer	-	50/10/11	45/39/21	50/10/11	45/39/21
Turns per block in outer layer	-	28/28/13	43/38/5	28/28/13	43/38/5

Protection

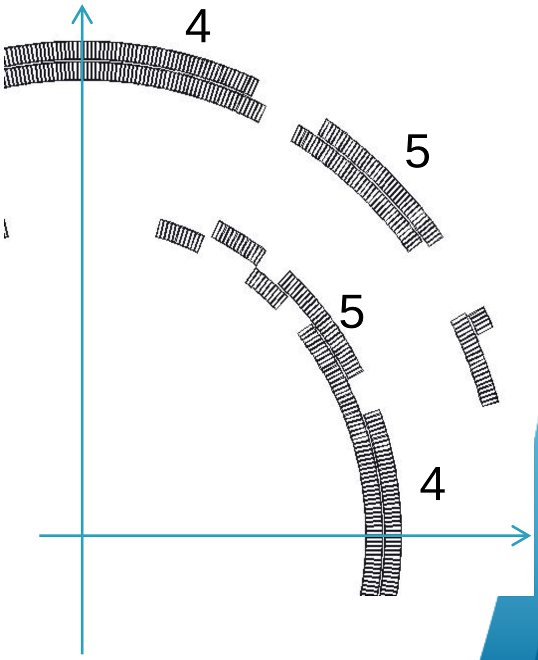
- Energy extraction on crowbar
  - at the limit for protection of the long magnet
- Results from simulations:
  - Here **50 V** assumed, i.e. resistance of 30 mΩ
  - One gets 410 K at 108% of nominal …

Hot spot temperatures (K)	Magnet type	Combined powering	Stand-alone powering
Inner dipole	Short	**196**	**220**
	Long	**267**	**305**
Outer dipole	Short	**232**	**260**
	Long	**311**	**355**

Simulation features

- Some features are not modelled:
  - The vertical transverse thermal conductivity is not properly modelled due to the **spacers** (optimistic).
  - **Quench-back** is not included, but it is not likely to help because the current decay is slow (pessimistic).
  - **Adiabatic** boundary conditions (pessimistic).
  - **AC losses** in nearby metallic parts are not included (pessimistic).
  - An approximate **field map** is used.
  - **Uncertainty** about material properties (mainly resin and Nomex).

Heaters in short prototype



- Decision is **taken**, that the ongoing **short prototype** will be equipped with heaters on blocks 4 & 5:
  - To be on the safe side.
  - To check the assembly feasibility.
  - To ease assembly of internal voltage taps.

Protection strategy

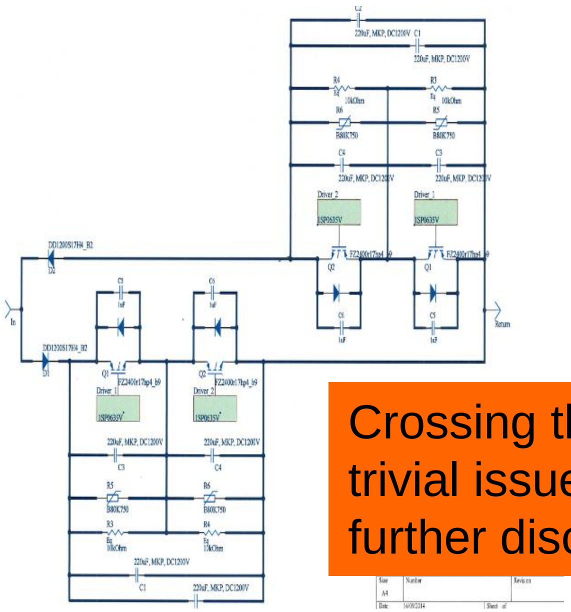
- Heaters will be explored
  - The coil is impregnated, hence the heater will be impregnated with the coil
  - The presence of double collaring implies difficulties, so if an energy extraction with reasonable cost is available this would reduce the risk

- We should consequently also explore energy extraction at 100 V or larger voltage

Energy Extraction Systems

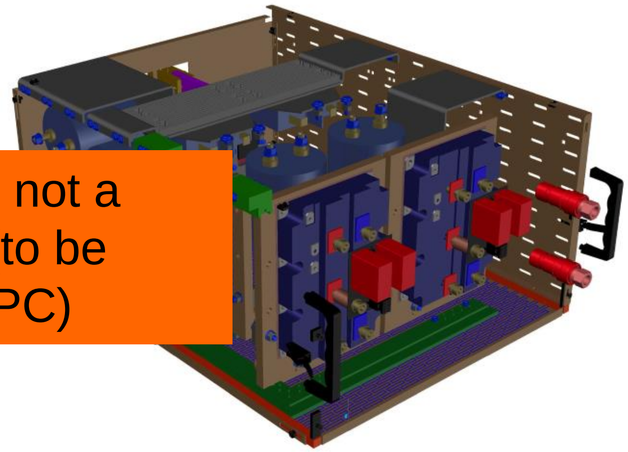
- TE/MPE is now envisaging the following alternatives in order to propose solutions in the 1 to 2 kA range:
  - as a by-product of the large effort put in place for the manufacturing of 7.5kA, IGBT-modules for SM18, IGBT-based systems have been designed also for these lower currents and a prototype is under construction with minor additional efforts
  - an Addendum is being prepared with the Łodz University of Technology (PL) – existing Framework Agreement– as to study and possibly develop energy extraction systems based on vacuum switches with different commutation techniques

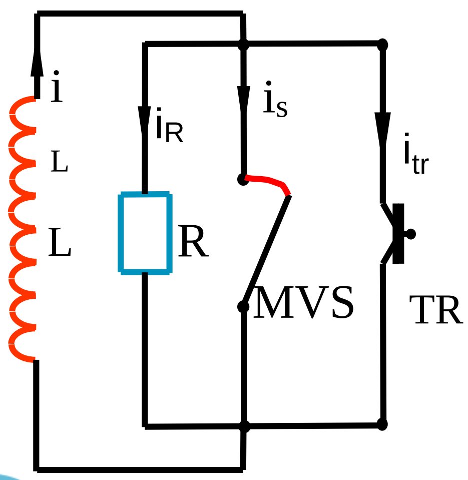
HL-LHC EE (some) alternatives



Bipolar 1 kA, IGBT-based system developed by MPE/EE (two basic modules).

Crossing through zero is not a trivial issue in this case (to be further discussed with EPC)



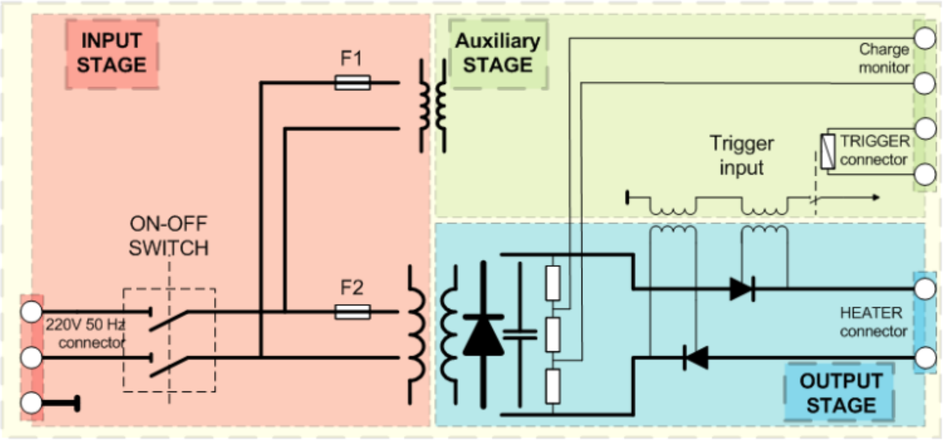


Switch system based on natural commutation, as developed by the Łodz University of Technology

3kV Vacuum circuit breakers family, 250, 400, 800 A for electrical railway traction vehicles (ŁUT, Łodz, Poland)

Quench Heater Discharge Supplies (HDS)

- The plan is to use the same units as the ones existing for LHC
  - Bipolar ± 450 V, 7.05 mF
  - High reliability shown during years of LHC operation (around 1/mil/year)
- Time for switching of thyristors in conduction has to be reduced to 1 ms from 4 to 5 ms at present
  - Relays to be replaced by solid-state devices
- Units have been sent to KEK and similar ones are being used at FNAL for the tests of the models and prototypes



EE vs QH comparison

Quench heater

- Intrusive element in magnet structure
- Low maintenance
- Heaters cost about 2 kCHF/meter of magnet
- Power supply costs about 5 kCHF/unit (to this, cost of QH + wiring is to be added)
- High availability
  - Connections to be consolidated
- Development costs (?)
- Less space (19”, 6U) (x 2 units/magnet?)

Energy extraction

- External element
- Yearly maintenance (if mechanical)
- Permanent losses (if IGBT)
- EE system costs about 32 kCHF/unit – based on IGBT systems
- High availability
- Development costs (estimated to 200kCHF)
- Space is one full rack/system (700x900x2000mm)

Summary of conclusions

- Heaters will be used on the first model
  - Important feedback on the magnet manufacturing
- Test results will allow to refine the model
  - Contribution of AC losses and quench back
  - Maybe the extraction at 50 V (crow-bar) is enough
- Extraction on larger voltages (larger resistance, above 50 mΩ) should continue to be explored
  - This implies energy extraction external to crow-bar
  - TE/MPE will proceed with development on the different axis
- Then (end of 2017) a decision will be taken for MCBXF
- Same strategy to be applied to the other magnets

Many thanks for your attention!