

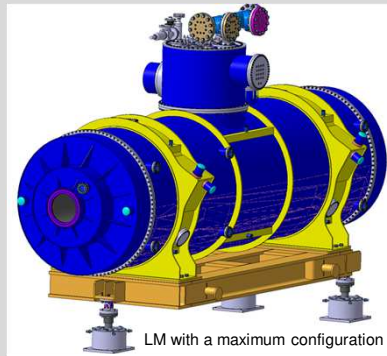
Magnetic Design for the Superferric Multipole Magnets of the Super-FRS

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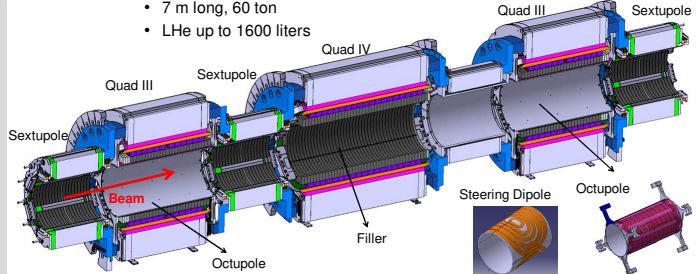
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Superconducting FRAGMENT Separator (Super-FRS) Multiplets



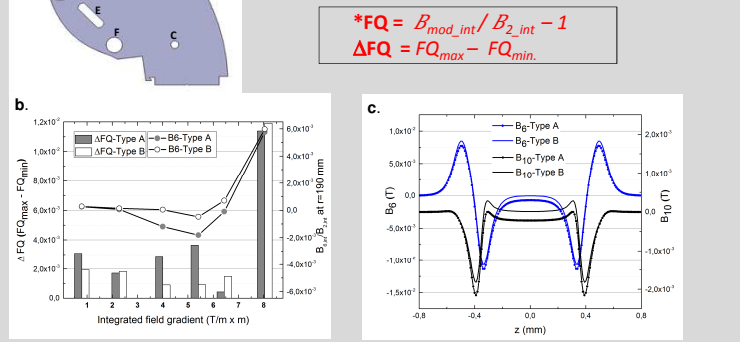
- Iron dominated (cold iron)
- Warm beam Pipe (Bore radius 192 mm)
- Design pressure of the cryostat 20 barg (PED category IV)
- DC magnets powered individually
- Self-protecting magnets
- 24 long multiplets (LMs)
- 7 short multiplets (SMs)



- LM with a maximum configuration
- 7 m long, 60 ton
 - LHe up to 1600 liters

3D Magnetic Design

- The initial design of sextupole meets the field quality requirement for all operating range ($\Delta FQ = 3 \times 10^{-3} < 10.0 \times 10^{-3}$).
- **Quadrupole Design**
 - Minimize B_6 and the ΔFQ^* especially for $4 \sim 6.4$ T/m x m (main operating regime)
 - Type A ; hyperbola pole shape + a rectangular racetrack coil
 - Type B ; Type A + **three holes**
 - 'A', 'B', 'C' for tie rods to lock lamination during the assembly
 - 'D', 'E', 'F' for magnetic field optimization
- 3D Model and magnetic field calculation with Opera TOSCA.
 - BH curve of Thyssen M1200- 100A
 - Packing factor 98%
 - Integration length +/- 2 m



Design Parameters of the Main Multipoles

	Quad III	Quad IV	Sext.
Number of magnets	44	32	39
Length of iron (mm)	800	1200	500
Pole tip radius (mm)	250	250	237
Warm bore radius (mm)	192	192	192
B_{max} (T/m, T/m ²)	10	10	40
Ramping rate(sec)	120	120	120
I_{max} (A)	300	300	291
Inductance @ I_{max} (H)	16	21	0.88
Stored Energy @ I_{max} (kJ)	664	952	37
Number of layer	26	26	22
Number of turn/layer	48	48	11
B_{Peak} in the conductor @ I_{max} (T)	4.2	4.2	1.9
Magnet weight (ton)	8	12	2.5
Field Quality and ΔFQ at 190 mm	$\pm 1.0 \times 10^{-3}$, $2.0 \times 10^{-3} < 0.8 * (1.2)^{**} g_{max}$ $\pm 6.0 \times 10^{-3}$, $12.0 \times 10^{-3} > 0.8 * (1.2)^{**} g_{max}$		$\pm 5 \times 10^{-3}$, 10.0×10^{-3}

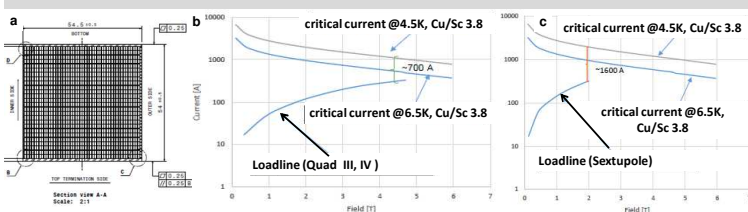
* : for Quad III, ** : for Quad IV

Superconducting wire

- Cu/ NbTi ratio 3.5 ± 0.3 , RRR > 100
- Twist pitch < 30 mm, filament diameter < 40 μ m
- Bare conductor dimension(mm) : 1.9 x 0.9 (H x W)
- Insulated conductor dimension(mm) : 1.98 x 0.98 (H x W)
- Formvar insulation
- ~ 2K, ~ 700 A margin for the quadrupoles
- ~ 2K, ~ 1600 A margin for the sextupoles

Coils assembly

- Top/bottom ground insulation : 0.8 mm NEMA G 10
- Side ground insulation : 1 mm glass epoxy
- Insulation resistance, R > 1 Gohm at 3.2 kV for the Quad IV



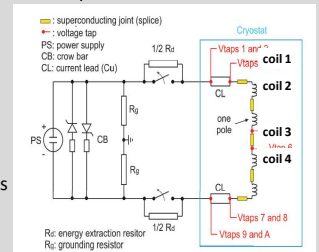
Quench and Magnetic Interference

Quench Calculation

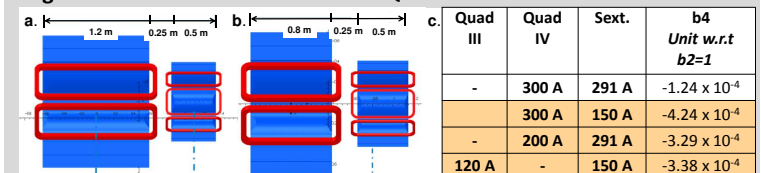
- Model and calculation with Elektra/Quench tool of Opera
- Starting temperature 4.5 K
- Quench starts on coil 1 where B-field is max.
- Threshold differential voltage, 0.6 V
- Time delay for the breaker opening, 60 ms
- The coils are adiabatic.
- $R_d = R_{d1} + R_{d2} = 2.8$ Ohm (only for the Quads.)

Worst case scenario for the Quad IV

- Fail to detect a quench or open the breakers
- $I = 330$ A only for the cold test at CERN
- $T_{max} = 140$ K, V_{max} (coil to ground) = 1600 V



Magnetic field crosstalk between the Quad. and the Sext.



Manufacturing of the 1ST of series SM

