Development of MQYY: a 90 mm NbTi Double Aperture Quadrupole Magnet for HL-LHC

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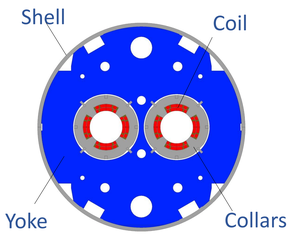
In the framework of HL-LHC: a large aperture MQYY (Q4) magnet is being developped

MQYY conceptual design

- Single aperture short model MQYYM (CEA/CERN)
- Full scale prototype in industry (CERN, CEA, CIEMAT, NCBJ)
  - EU H2020 Pre-commercial Procurement (PCP)
  - 3 phases: conceptual design, engineering, manufacturing
  - Competitive process 4/3/2 companies => 2 MQYY prototypes: 06/2020

QUACO

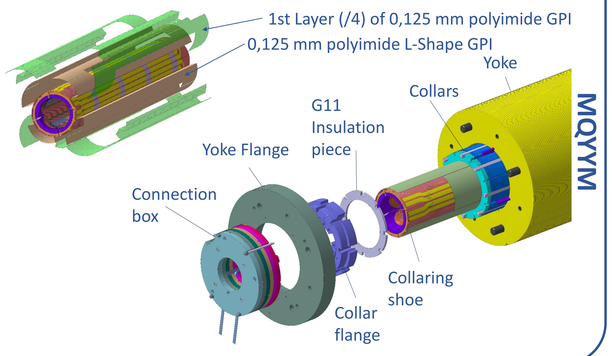
Magnet Overview



- Decision on change of baseline conductor in Sept. 2015
- MQM conductor as new baseline
- Aperture independtly powered
- Up to 50 % current imbalance

Magnet parameters	MQYY	MQYYM
Interbeam distance at 1.9 K	194 mm	Na
Yoke outer diameter at 293 K	614 mm	360 mm
Nominal gradient	120 T/m	
Nominal current I_{nom} at 1.9 K	4590 A	4550 A
Margin along the load line	23 %	23 %
Magnetic length at 1,9 K	3,67 m	1,215 m
Peak field at nominal current	6,4 T	6,4 T
Fx per octant at I_{nom}	395 MN/m	397 MN/m
Fy per octant at I_{nom}	-527 MN/m	-527 MN/m
Total stored energy at I_{nom}	0,22 MJ/m	0,11 MJ/m
Inductance per aperture	10,2 mH/m	10,2 mH/m

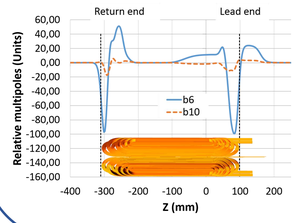
Conductor parameters	
Strand diameter	0,48 mm
Cu.Sc ratio	1,75 +/- 0,05
Extracted strand RRR (mea/spec)	250/80
Extracted strand Ic at 1,9 K and 8 T	189 A
Number of strands	36
Bare cable width	8,8 mm
Bare cable thin/thick edge	0,77/0,91 mm
Insulation thickness at 50 MPa	0,080 mm

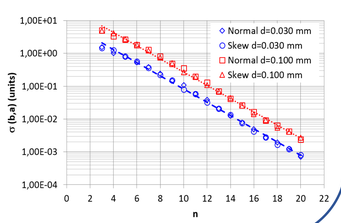


Field Quality

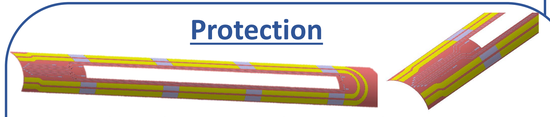
- Coil double layer with layer jump
- Inner / outer layer: 25 / 26 turns
- 0,5 mm interlayer
- 0,125 mm midplane shim

	I(kA)	b1	b3	b4	b5	b6	b10	b14
0 % imbalance								
Right	4,59	-0,44	-0,17	0,09	0,07	0,00	-0,01	1,32
Left	4,59	-0,44	-0,17	0,09	0,07	0,00	-0,01	1,32
20 % imbalance								
Right	4,59	-0,35	-0,57	0,05	-0,02	-0,02	0,00	1,32
Left	3,67	0,53	0,34	0,31	-0,04	-0,54	0,01	1,32
50% imbalance								
Rigth	4,59	-0,84	-0,56	0,08	-0,02	-0,02	0,00	1,32
Left	2,29	-0,78	0,34	0,38	-0,09	-0,7	0,01	1,32



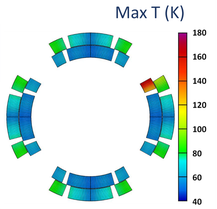


Protection



- Through Protection heaters only
- Stainless steel / Copper plating (60 / 120 mm)
- Heat deposition 125 W/cm^2
- Vthreshold = 0,1 V Tdet = 6 ms
- Tvalidation = 10 ms $T_{PHactivation}$ = 10 ms
- PH power: 125 W/cm^2
- PH delay ~ 20 ms

	Hotspot Temp.	Max V to Ground
MQYY	165 K	120 V
MQYY 50 %*	210 K	257 V
MQYYM	164 K	45 V
MQYYM 50 %*	201 K	50 V



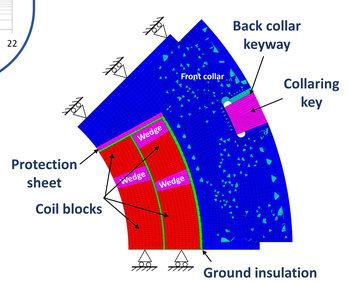
* 50 % PS failure. Quenching coil unprotected

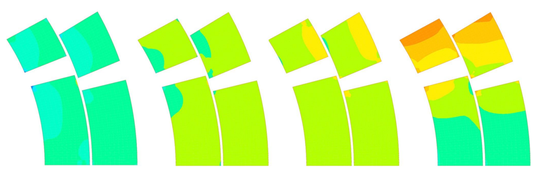
Mechanical analysis

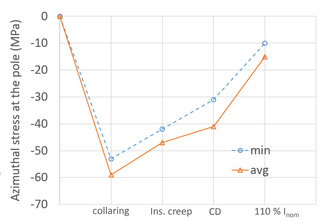
	Coil	Collars
Eyoung at 300 K	5,4 GPa	190 GPa
Eyoung at 1,9 K	7,9 GPa	210 GPa
Thermal contraction	5 mm/m	2,4 mm/m

4 steps of computation:

- Collaring
- Creeping of the insulation
- Cool-down
- Excitation at 110% I_{nom}







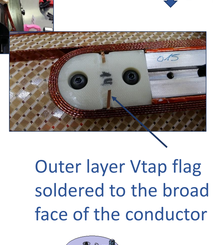
	collaring	creeping	Cool-down	110 % I_{nom}
σ_θ peak	-93	-75	-51	-62
σ_θ Avg	-59	-47	-41	-42

CAST3M models

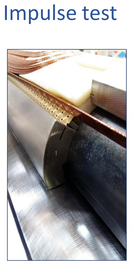
Fabrication, Assembly and Test of MQYYM

Coil fabrication process at CEA
134 m of cable continiously wound

- Winding of 1st layer
- Curing of 1st layer at 185 °C
- Winding of second layer
- Curing of the total coil at 185 °C
- R measurement
- Impulse test



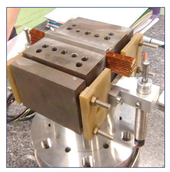
Outer layer Vtap flag soldered to the broad face of the conductor

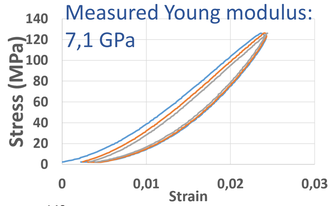


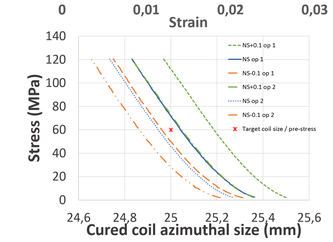
Curing shim determination to ensure appropriate preload during collaring

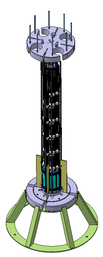
9 samples of 18 cable stacks cured in 3 cavities:

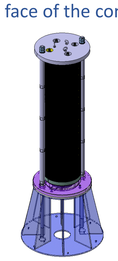
- Nominal size NS (insulation at nominal thickness)
- NS-0,1 mm and NS+0,1 mm
- Displacement results scaled to 25 turns
- Determination of the shim/60 MPa prestress couple





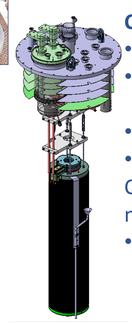






Assembly at CERN in 927

- Vertical collaring
- Connection box
- Magnetic measurements
- Yoke assembly

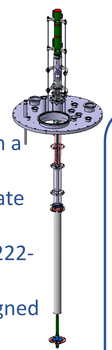


Cold Test foreseen in Fall 2018

- Saturated bath 1,9 K 23 mbar
- 8 m-long cryostat equipped with a 3-m-long sock
- Adaptation of an existing top plate
- Cold Magnetic measurement:

Cold probe: 47 mm diameter, five 222-mm long rotating coil modules

- A sealing system had to be designed to preserved the saturated bath integrity



Summary

Completion of:

- MQYY conceptual design
- MQYYM engineering design

MQYYM assembly spring 2018
MQYYM Cold Test: Fall 2018
MQYY proto under development in industry. 2 protos in summer 2020