DS11 T
Transfer function, integral field and coil length

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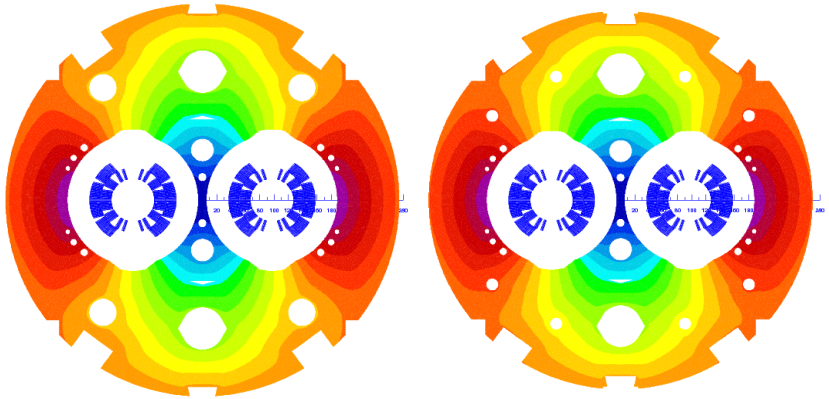
Requirements and design evolution

- **Requirement**:
  - 119.2 Tm at 11.85 kA

- Main **design evolution features** from the first to the second short model (and prototype):
  - Outer yoke radius 275 mm → 270 mm (to be compatible with LHC-MB tooling)
  - Iron laminations at the magnet extremities replaced by non-magnetic laminations (to decrease the peak field in the coil ends)

MBHDP101

MBHDP102/ Prototype/ Series



- Due to time constrains and additional uncertainty on the final coil length (mainly due to the lack of experience in terms of dimensional changes during heat treatment in 5.5 m length Nb_3Sn coils), the **coil length of the prototype coils was not modified to account for the design evolution**.

- Aim of today: **summarize** the **available data** from the short model program (and prototype collared coils assemblies) and **propose adjustments for the series coils.**

Collared coil magnetic measurements (RT)

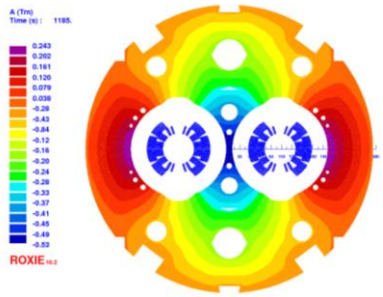
- Transfer function in the straight section, integral field and magnetic length is within 10 units the expected values
- Difference among apertures in terms of integral field:
  - Around 25 (σ) units in the short models (6 apertures measured)
  - Around 10 (σ) units in the prototype (3 apertures measured)

Collared Coil Room temperature measurements (± 20 A)	Short models			Prototype		
	TF (T/kA) Central Segment	Integral (Tm/kA)	Magnetic length (mm)	TF (T/kA) Central Segment	Integral (Tm/kA)	Magnetic length (mm)
Average all single apertures	0.7969	1.3460	1689	0.7940	4.2221	5317.8
STD (units)	7	23	21	2	6	7
ROXIE 3D	0.7972	1.3473	1690	0.7947	4.2272	5319
diff to ROXIE 2D (units)	28	n.a	n.a	-10	n.a	n.a
diff to ROXIE 3D (units)	-4	-10	-7	-10	-12	-2

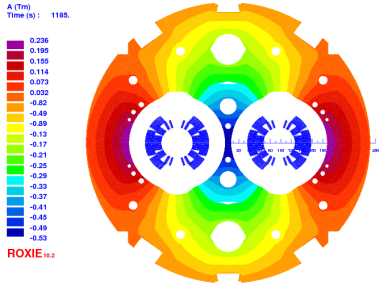
Cold mass magnetic measurements (RT)

- Field in the magnet centre is within 10 units the expected value for the double aperture magnets.
- Integral field is 24 units larger than measured in average, with difference in between the two apertures up to 36 units.
  - In the single aperture models, the difference in between magnets was up to 60 units.

DP101



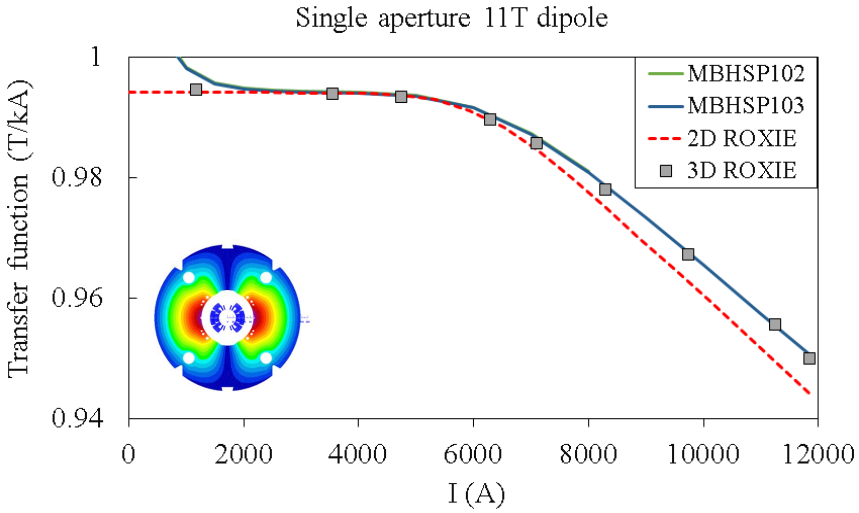
DP102 and Prototype

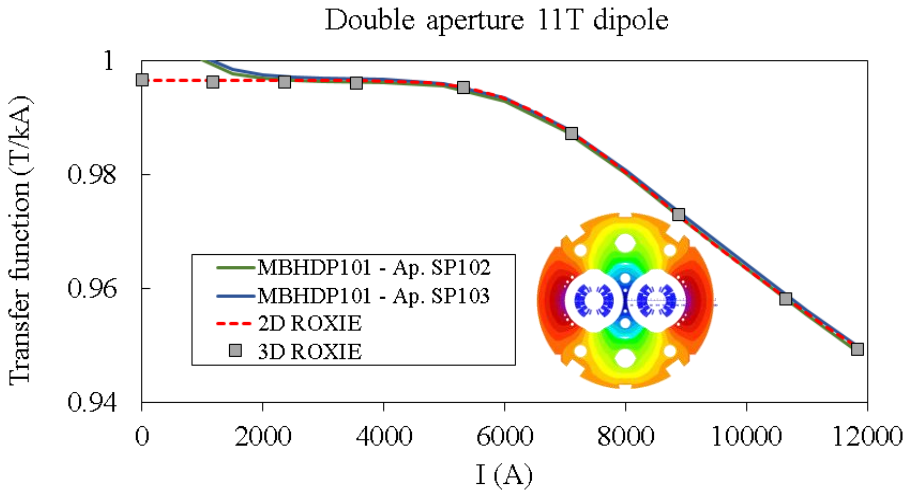


Cold Mass Room temperature measurements (± 20 A) (double aperture)	TF (T/kA) Central Segment		Integral (Tm/kA)		Magnetic length (mm)	
Magnet	DP101	DP102	DP101	DP102	DP101	DP102
Average two apertures	0.9903	0.9910	1.6772	1.6627	1694	1678
STD (units)	1	5	18	6	17	1
ROXIE 3D	0.9912	0.9909	1.6732	1.6587	1688	1674
diff to ROXIE 2D (units)	-20	-12	n.a	n.a	n.a	n.a
diff to ROXIE 3D (units)	-9	1	24	24	33	23

Magnetic measurement operation conditions

- Iron saturation effects are well captured by ROXIE when considering the 3D model.
- The measured field in the straight part is within 10 units the expected value for all current levels.
- Since measurements in the short models are performed using a rotating shaft at cold, there is not an accurate evaluation of the integral field and magnetic length available.





From short model experience to prototype and series magnets

Expected field in the prototype magnet	Cold mass, RT - 20 A	1.9 K, 11.85 kA
TF (T/kA)	0.9922 (±10 units)	0.9478 (±10 units)
Integral (Tm/kA)	5.2391 (+20, -10 units)	4.9897 (+20, -10 units) REQUIREMENT: 5.0301
Lm (mm)	5280 (+20, -10 units)	5264 (+20, -10 units)

Possible action to adjust integral field in the series magnets:

- **Option 1:** Physical coil length is modified in order to reach the target integral field in the series magnet
  - Coil has to be 33-48 mm longer than in the prototype
- **Option 2:** The difference on the integral field with respect to the target is compensated using the trim circuit
  - This will mean that at nominal magnet current, the trim should operate at 65-100 A (instead of ~ 0 A)

Proposed solution

- Increase the coil physical length by 40 mm in the straight section. This action can be done with minor impact in the cold mass assembly and coil production process.

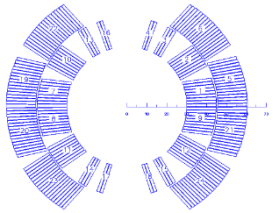
- After the full magnetic characterization of the prototype magnet, a more accurate evaluation of the expected field for the series magnets can be done. Deviations from nominal case can still be corrected by:
  - Increasing or reducing the number of non-magnetic laminations in the magnet extremities.
    - Maximum increase of the magnetic length is 14 mm, and increases the peak field in the coil ends by 0.2 T.
  - Modifying the trim circuit current profile.
    - 10 mm deviation on the magnetic length corresponds to ~ 20 A shift in the trim circuit current at nominal current.

Additional slides

Feedback from short models program

MBHSP101*

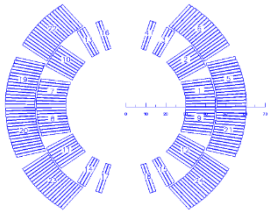
Coil 106
(RRP 108/127)



Coil 107 (limiting coil)
(RRP 108/127)

MBHSP102

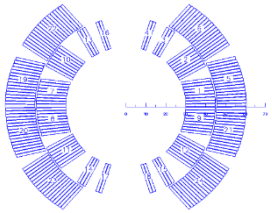
Coil 106
(RRP 108/127)



Coil 108
(RRP 132/169)

MBHSP103

Coil 109
(RRP 132/169)

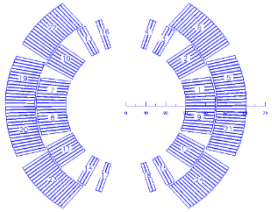


Coil 111
(RRP 132/169)

Assembled in MBHDP101

MBHSP104/4b

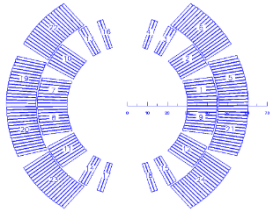
Coil 112
(RRP 132/169)



Coil 113 (limiting coil)
→ 109 in SP104b
(RRP 132/169)

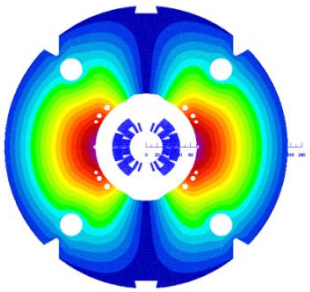
MBHSP105/5b

Coil 114
(RRP 150/169)

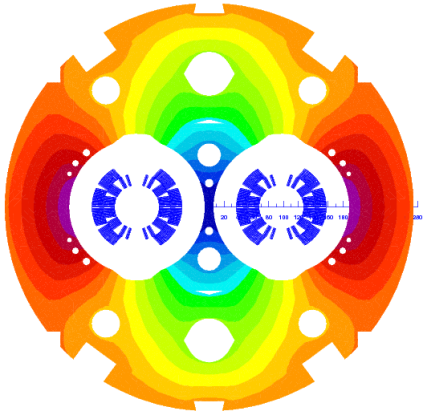


Coil 115
(RRP 150/169)

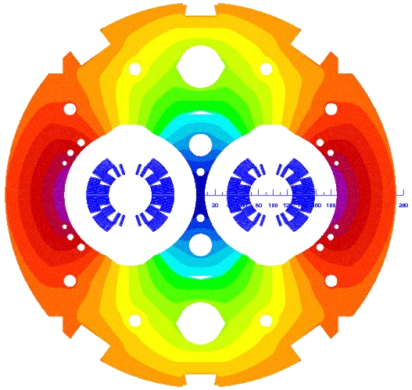
Assembled in MBHDP102



MBHSP#



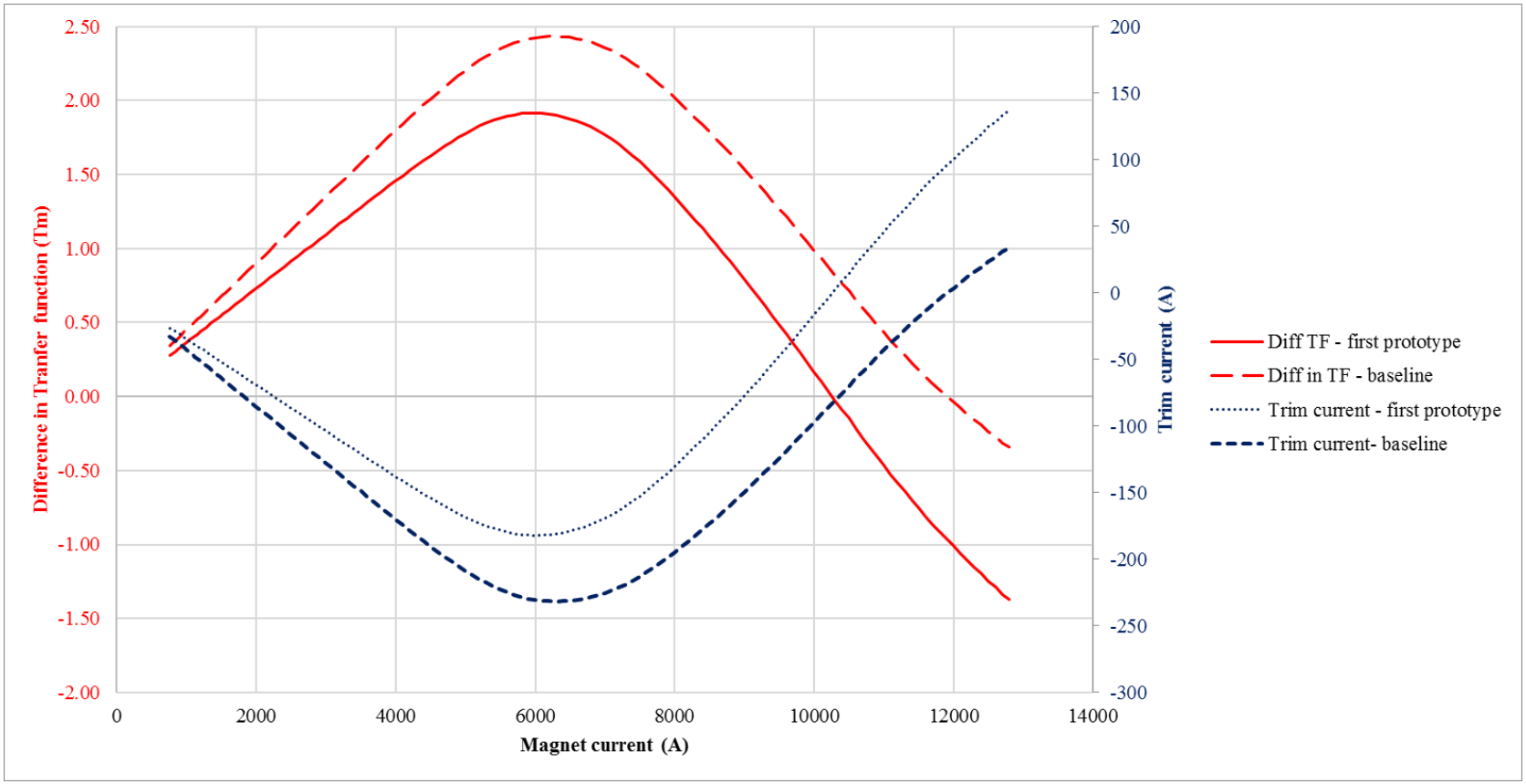
MBHDP101



MBHDP102

* Magnetic measurements performed with a different shaft, issues on the collared coil measurements, calibration questionable, so not accounted for this analysis

Trim current assuming the prototype is 43 mm shorter than nominal



Coil Manufacturing data – Prototype coils

Collared Coil CR0002	CR4	CR5
Start fabrication	23/02/2016	17/06/2016
End fabrication	16/03/2017	24/04/2017
Cross section ID	1st Gen	1st Gen
Conductor and cable		
Strand lay-out	RRP 132/169 &150/169	RRP 132/169 &150/169
Cable ID	H15OC0194A	H15OC0196A
Azimuthal coil size dev.(μm)		
Min	-58	-125
Max	165	228
25 %	30	-43
75 %	75	34
Median	54	-10
Average	52	0
Coil length (mm)	LHCMBH_C0005	
Nominal post length	5113	5113
Nominal coil length	5559	5559
Post length for winding	5111.5	5113.1
Post length after curing	5106.4	5108.6
Post length after react.	5110	5112
Post length after impr.	5112.12	5113.2
Coil length after impr.	5561.95	5560.8

Collared Coil CR003	CR6	CR7
Start fabrication	09/02/2016	12/04/2016
End fabrication	/2017	/2017
Cross section ID	1st Gen	1st Gen
Conductor and cable		
Strand lay-out	RRP 108/127	RRP 108/127
Cable ID	H15OC0209 A	H15OC0210 A
Azimuthal coil size dev.(μm)		
Min	-0.474	-0.222
Max	-0.038	0.390
25 %	-0.164	-0.020
75 %	-0.001	0.180
Median	-0.076	0.052
Average	-0.079	0.076
Coil length (mm)	LHCMBH_C0005	
Nominal post length	5113	5113
Nominal coil length	5559	5559
Post length for winding	5108	5109
Post length after curing	5107	5107
Post length after react.	5114	5113
Post length after impr.	5116	5110
Coil length after impr.	5560	5562

Coil Manufacturing Data from MTF