



Magnetic measurements of the HO correctors at LASA

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Outlines

- Measurement setup
 - Rotating coil system and probe
- Tested magnets:
 - Latest magnetic measurements (MQSXF3, MCSXF06, MCOXF04b and MCOXF07)
 - Comparison with magnets previously tested

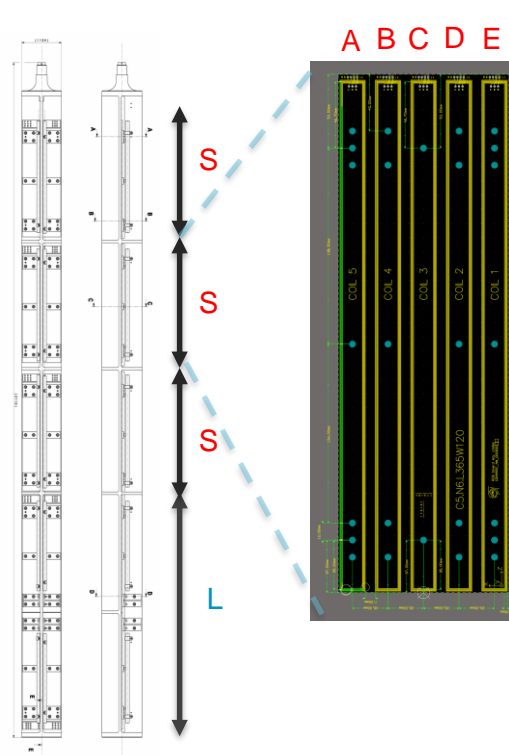
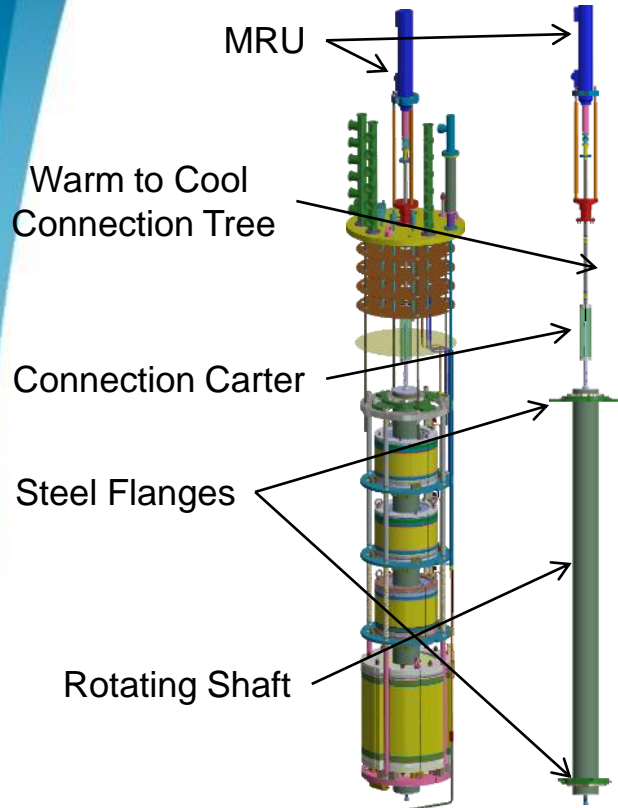
Measurement setup (1/2)

Rotating coil system (from CERN):

- Electronic rack
- 2 FDI (Fast digital Integrator)
- MRU motor unit (motor + encoder + slip rings)
- FFMM software (Flexible Framework for Magnetic Measurements)



Measurement setup (2/2)



Series Shaft (CERN)

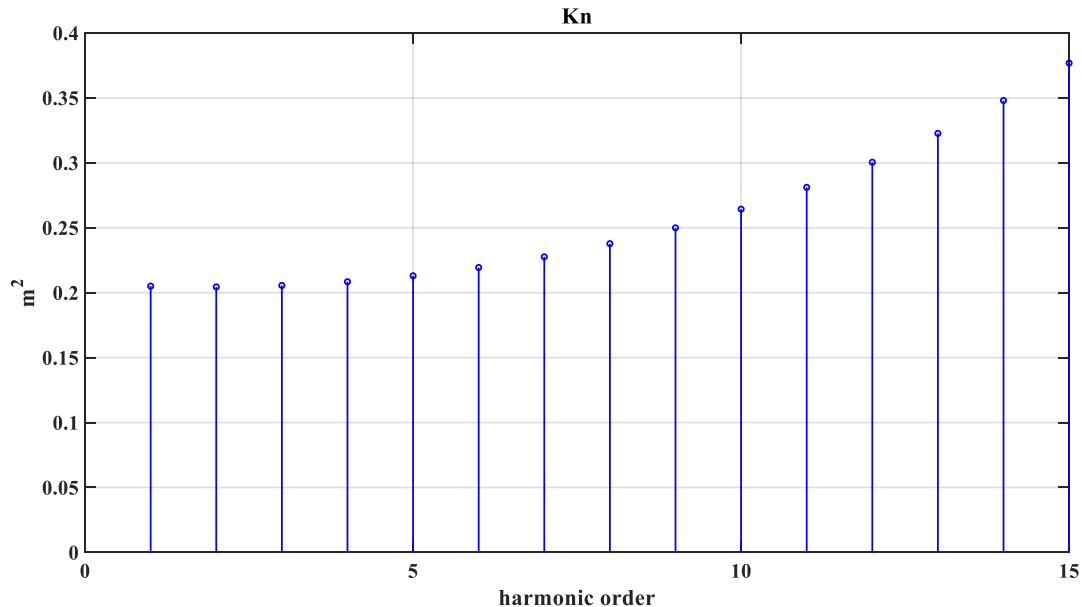
G-10 t-beam internal support

- Diameter ~130 mm
- Measurement radius 55 mm

5 equal PCB

- 1 segment for each **short** magnet
- 2 segments for **long** magnets
- Active length of 355 mm
- Compensation of vibrations by averaging the measurements from coils in opposite position (A and E) except for the quadrupole (compensation scheme A, A-B-C+D)

Sensitivity of the rotating coil probe

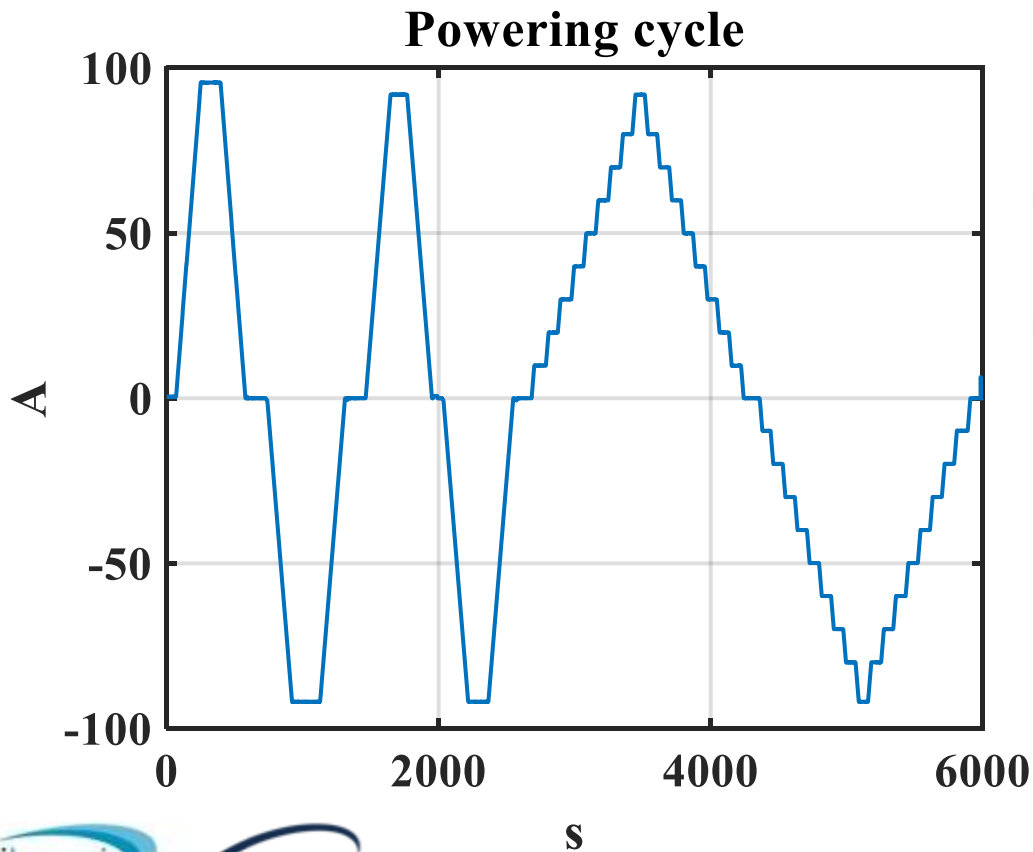


- A rotating coil based on radial coils doesn't have blind angle (as tangential coils)
- The sensitivity doesn't decrease with the order
- Measurements of the multipoles with $n > 15$ is possible but not reported

Measured Magnets

- Latest tested magnets:
 - MQSXF3, MCSXF06, MCOXF04b and MCOXF07
- Quadrupole and Octupoles with modified supports for wedges
 - Quad – #2 V- support instead of #4 per wedges
 - Octupoles - #2 V-supports added per wedges

Powering cycle for MM



- Two cycles up to +/- nominal current
- One stairs cycle up to +/- nominal:
 - 20 A steps for the quadrupoles;
 - 10 A steps for the others.

MQSXF3

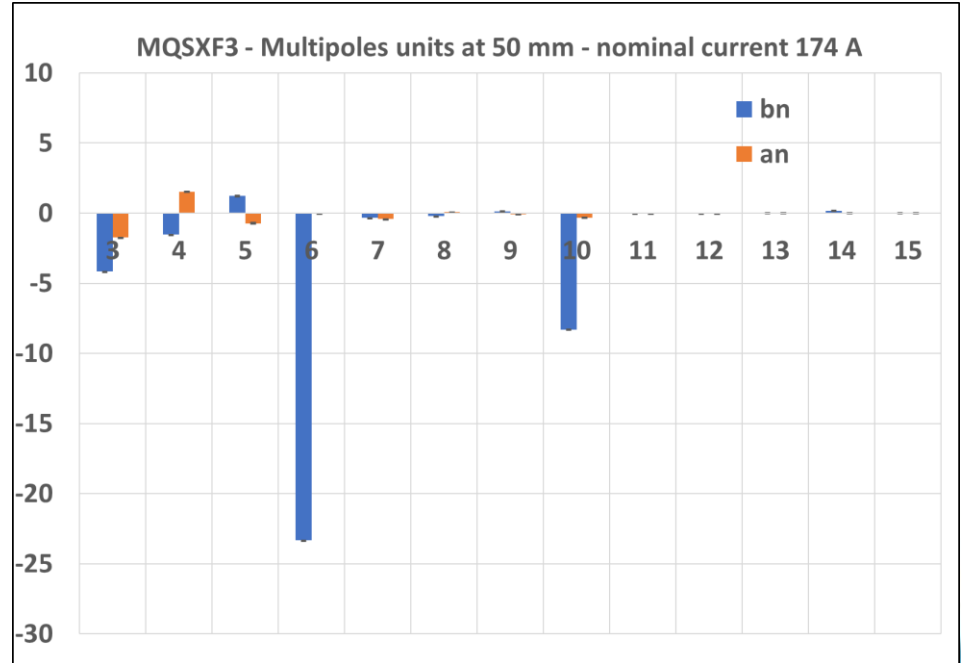
BdL

Field quality

MQSXF3	Measured (Calculated)
Nominal current I_{nom} Ultimate current I_{ult}	174 A 197 A
Integrated field @ I_{nom} @ 50 mm	719.6 T mm (700.0 T mm)
Integrated field @ I_{ult} @ 50 mm	771.5 T mm (753.2 T mm)

Difference with respect to calculations

$$\Delta = 2.8\% @ I_{nom} \text{ and } \Delta = 2.4\% @ I_{ult}$$



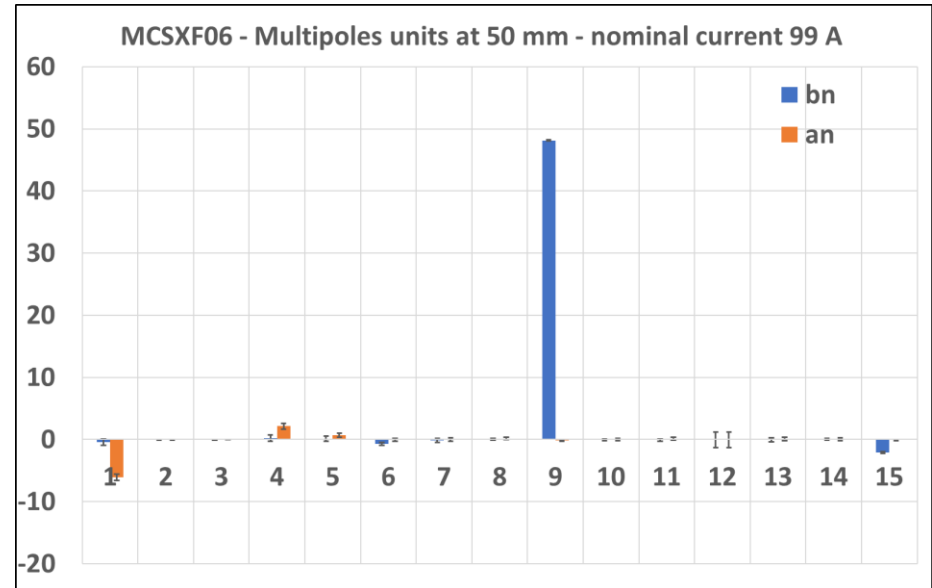
Multipoles well within requirements (<100 units)
b6 and b10 as expected by model

MCSXF06

BdL

Field quality

MCSXF06	Measured (Calculated)
Nominal current I_{nom} Ultimate current I_{ult}	99 A 112 A
Integrated field @ I_{nom} @ 50 mm	95.3 T mm (93.5 T mm)
Integrated field @ I_{ult} @ 50 mm	101.9 T mm (100.5 T mm)



Difference with respect to calculations

$$\Delta = 1.9\% @ I_{nom} \text{ and } \Delta = 1.4\% @ I_{ult}$$

Multipoles well within requirements (<100 units)
b9 units as expected by model

MCOXF04b

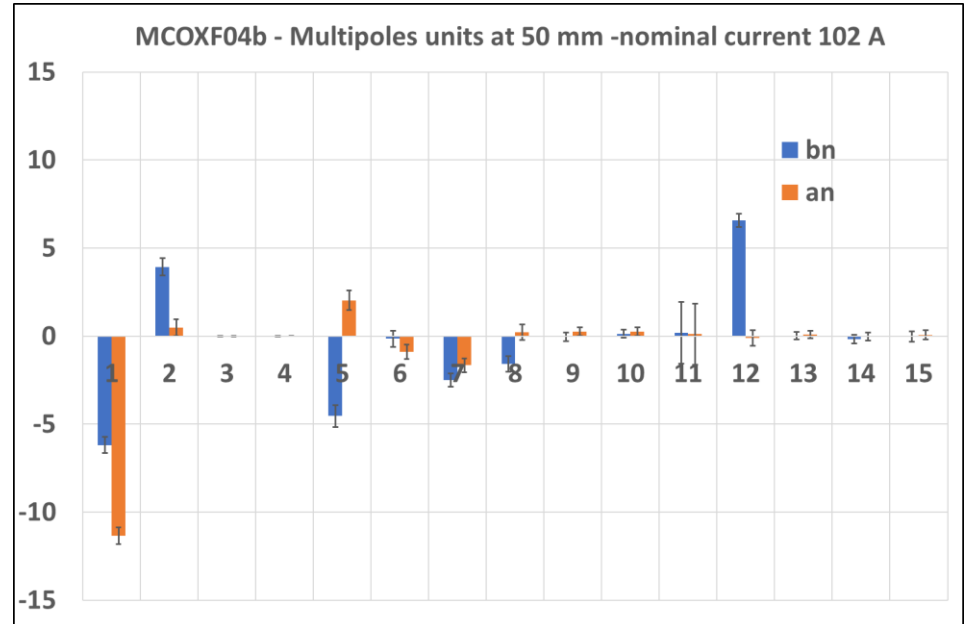
BdL

Field quality

MCOXF04b	Measured (Calculated)
Nominal current I_{nom} Ultimate current I_{ult}	102 A 115 A
Integrated field @ I_{nom} @ 50 mm	71.5 T mm (70.7 T mm)
Integrated field @ I_{ult} @ 50 mm	76.4 T mm (75.7 T mm)

Difference with respect to calculations

$$\Delta = 1.1\% \text{ @ } I_{nom} \text{ and } \Delta = 0.9\% \text{ @ } I_{ult}$$



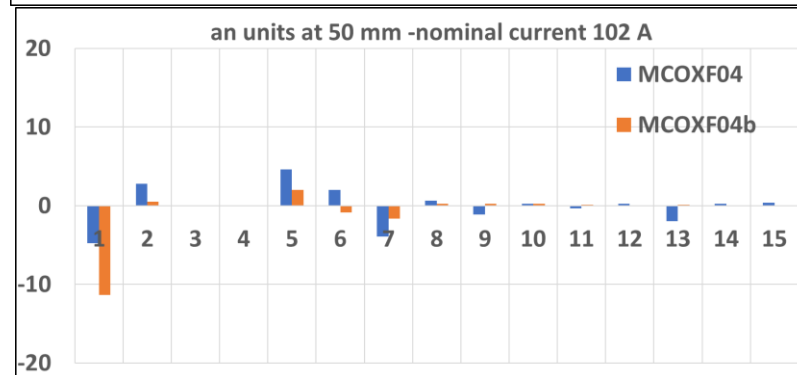
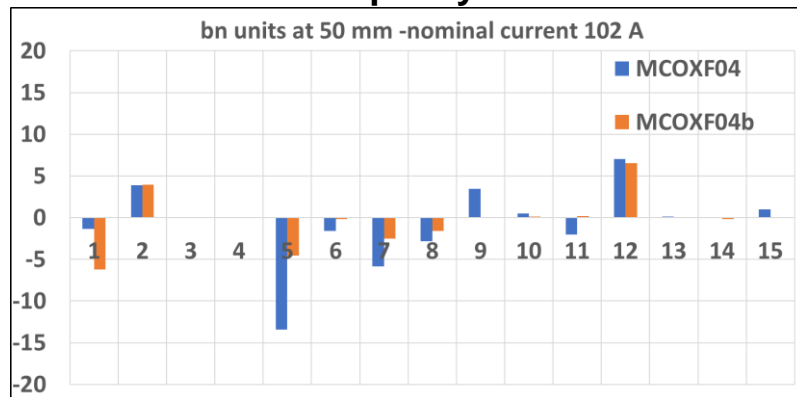
Multipoles well within requirements (<100 units)
b12 units as expected by model

MCOXF04 vs MCOXF4b

BdL

Field quality

Current	BdL – Meas (Calc) Tmm		Diff %	
	I_{nom} 102 A	I_{ult} 115 A	I_{nom} 102 A	I_{ult} 115 A
MCOXF04	71.5 (70.7)	76.4 (75.7)	1.2	1.0
MCOXF04b	71.5 (70.7)	76.4 (75.7)	1.1	0.9



Negligible effects on the integrated field due to V-supports

MCOXF04/MCOXF04b relative difference below 0.1%

Positive impact of the V-supports on the multipoles

MCOXF07

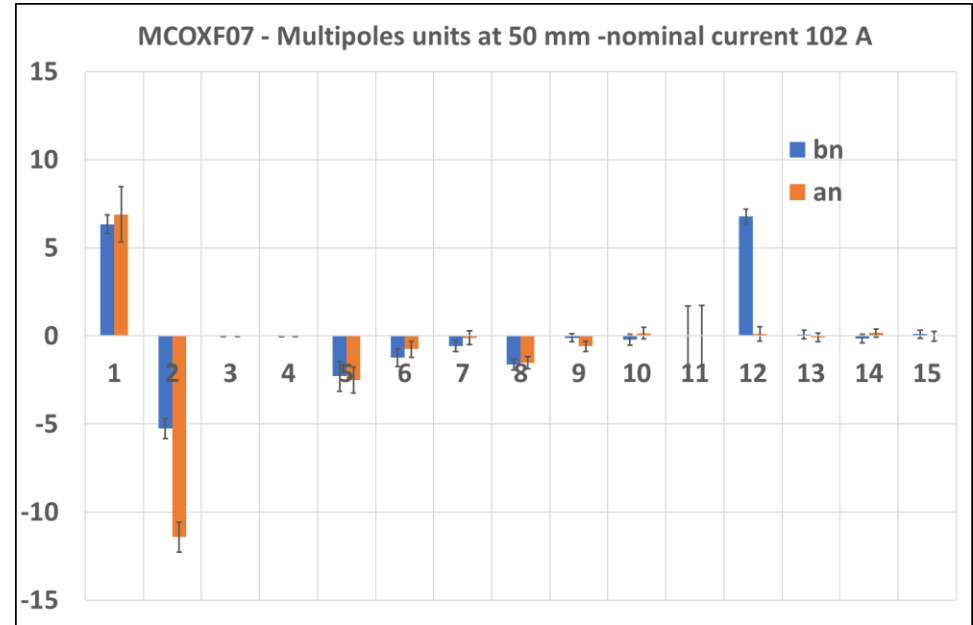
BdL

Field quality

MCOXF07	Measured (Calculated)
Nominal current I_{nom} Ultimate current I_{ult}	102 A 115 A
Integrated field @ I_{nom} @ 50 mm	71.6 T mm (70.7 T mm)
Integrated field @ I_{ult} @ 50 mm	76.5 T mm (75.7 T mm)

Difference with respect to calculations

$$\Delta = 1.3 \% @ I_{nom} \text{ and } \Delta = 1.1 \% @ I_{ult}$$



Multipoles well within requirements (<100 units)
b12 units as expected by model

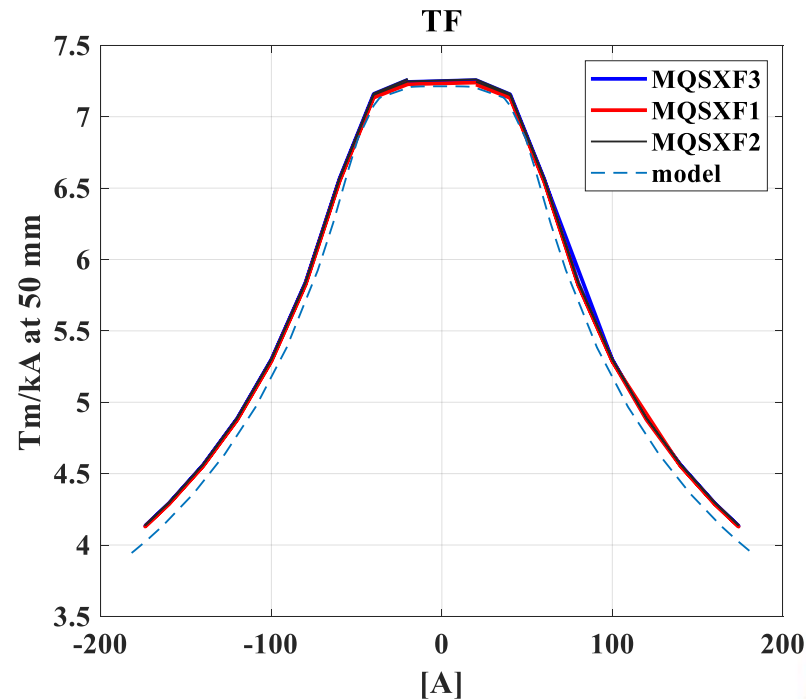
Measured Magnets Families

- We performed magnetic measurements of different magnets at LASA:
 - Quadrupoles: MQSXF1, MQSXF2, and MQSXF3
 - Sestupoles: MCSXF02, MCSXF03, MCSXF05 and MCSXF06
 - Octupoles: MCOXF03, MCOXF04, MCOXF04b and MCOXF07
- We can crosscheck the magnetic performance.

Quadrupoles – TF

Order	Magnet	Current [A]	Model			Measured at LASA	
			BdL [T mm]	BdL [T mm]	diff [%]	BdL [T mm]	diff [%]
2	MSQXF1	174	700.0	718.8	2.7		
	MSQXF2			720.36	2.8		
	MSQXF3			719.6	2.8		

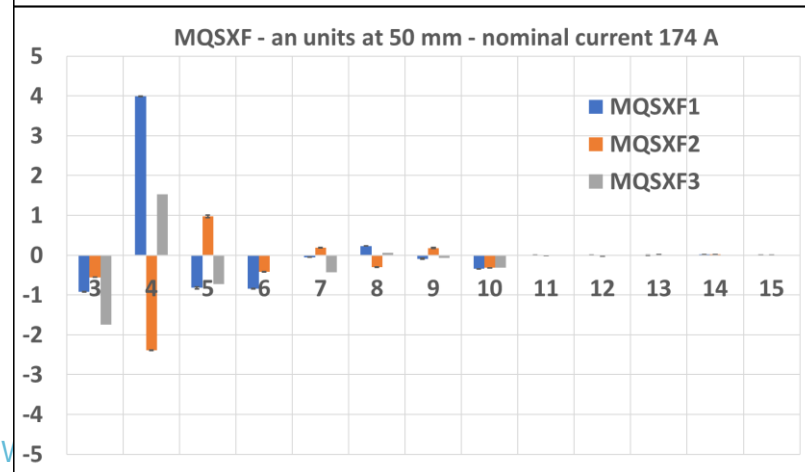
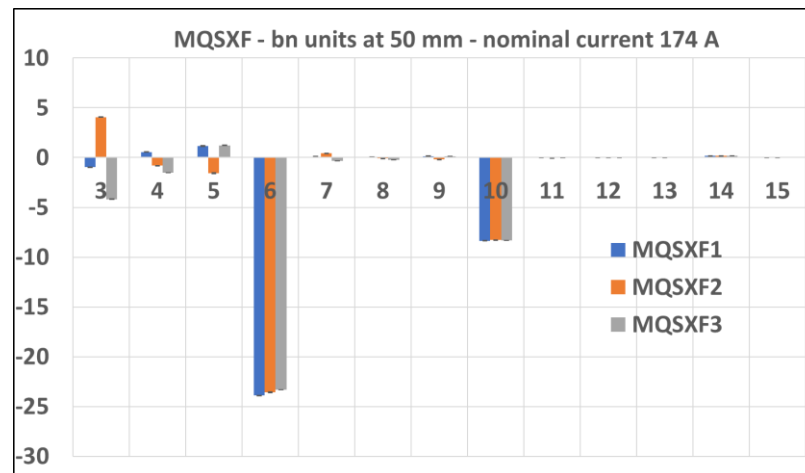
- Magnet-to-magnet repeatability among quadrupoles is 0.1%
- No effect about the V-supports modification
- Systematic error (Diff > 2%): correlation between BdL and pole length or B-H curve of the iron (model) – ongoing analysis



Quadrupoles – Field Quality

units at 50 mm - normal and skew						
I = ±174 A						
order	MQSXF1		MQSXF2		MQSXF3	
	bn	an	bn	an	bn	an
3	-0,97	-0,92	4,06	-0,55	-4,18	-1,74
4	0,55	3,99	-0,80	-2,38	-1,53	1,53
5	1,14	-0,82	-1,57	0,98	1,21	-0,73
6	-23,89	-0,84	-23,58	-0,42	-23,33	-0,02
7	0,08	-0,05	0,42	0,19	-0,34	-0,42
8	0,06	0,23	-0,08	-0,30	-0,21	0,06
9	0,13	-0,09	-0,20	0,18	0,13	-0,07
10	-8,36	-0,34	-8,29	-0,32	-8,31	-0,31
11	0,02	0,00	-0,04	-0,01	0,00	-0,01
12	0,01	0,00	-0,01	-0,02	-0,01	-0,01
13	0,00	0,00	0,01	0,01	0,00	0,01
14	0,17	0,02	0,17	0,02	0,18	0,01
15	0,00	0,00	0,00	0,00	0,00	0,00

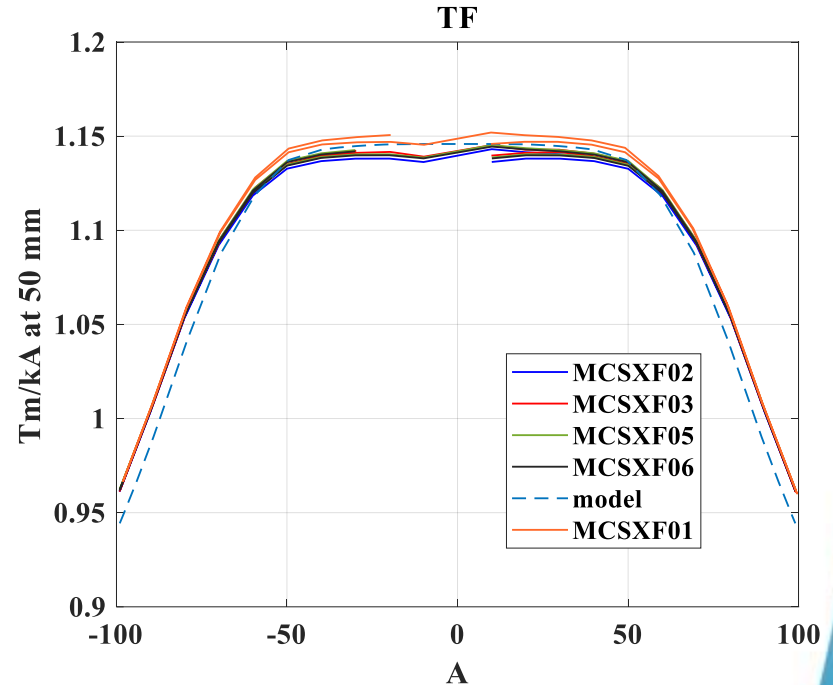
b6 and b10 well reproduced (+/- 1 units)



Sestupoles – TF

Order	Magnet	Measured at LASA			
		Current [A]	BdL [T mm]	BdL [T mm]	diff [%]
3	MCSXF01	99	93.5	95.29 (95.84)	1.9 (2.4)
	MCSXF02			95.22	1.8
	MCSXF03			95.22	1.8
	MCSXF05			95.31	1.9
	MCSXF06			95.27	1.9

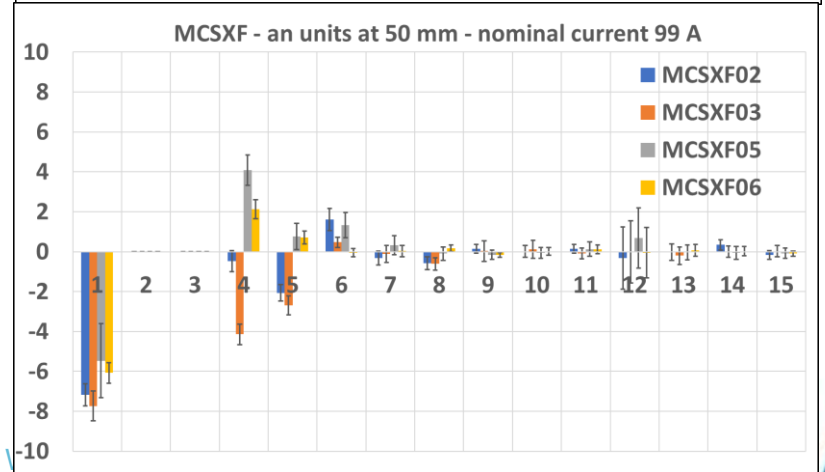
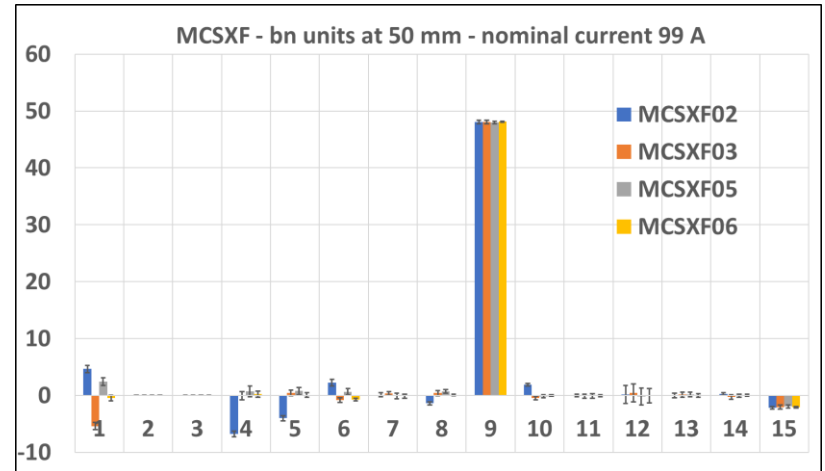
- Magnet-to-magnet repeatability among sestupoles is 0.1%
- MCSXF01 measured by the previous shaft of 1.3 m (before wedge preload change) and re-measured at CERN



Sestupoles – Field Quality

units at 50 mm - normal and skew multipoles								
I = ±99 A								
	MCSXF02		MCSXF03		MCSXF05		MCSXF06	
order	bn	an	bn	an	bn	an	bn	an
1	4,67	-7,18	-5,4	-7,7	2,4	-5,5	-0,5	-6,1
2	0,00	0,00	0,0	0,0	0,0	0,0	0,0	0,0
3	0,00	0,00	0,0	0,0	0,0	0,0	0,0	0,0
4	-6,80	-0,49	0,0	-4,1	0,7	4,1	0,2	2,1
5	-4,00	-2,07	0,5	-2,7	0,8	0,8	0,1	0,7
6	2,22	1,60	-0,8	0,5	0,7	1,3	-0,7	-0,1
7	0,11	-0,31	0,4	-0,1	-0,1	0,3	-0,1	0,0
8	-1,40	-0,58	0,4	-0,6	0,7	-0,1	0,1	0,2
9	48,07	0,14	48,0	0,0	48,0	-0,2	48,1	-0,2
10	1,90	0,01	-0,5	0,1	-0,1	-0,1	0,0	0,0
11	0,00	0,14	-0,1	-0,1	-0,1	0,1	-0,1	0,1
12	0,18	-0,33	0,4	0,0	-0,2	0,7	-0,1	-0,1
13	-0,01	-0,02	0,1	-0,2	0,2	0,0	0,0	0,1
14	0,29	0,34	-0,3	0,0	0,0	-0,1	0,0	0,0
15	-2,15	-0,16	-2,1	0,0	-1,9	-0,1	-2,1	-0,1

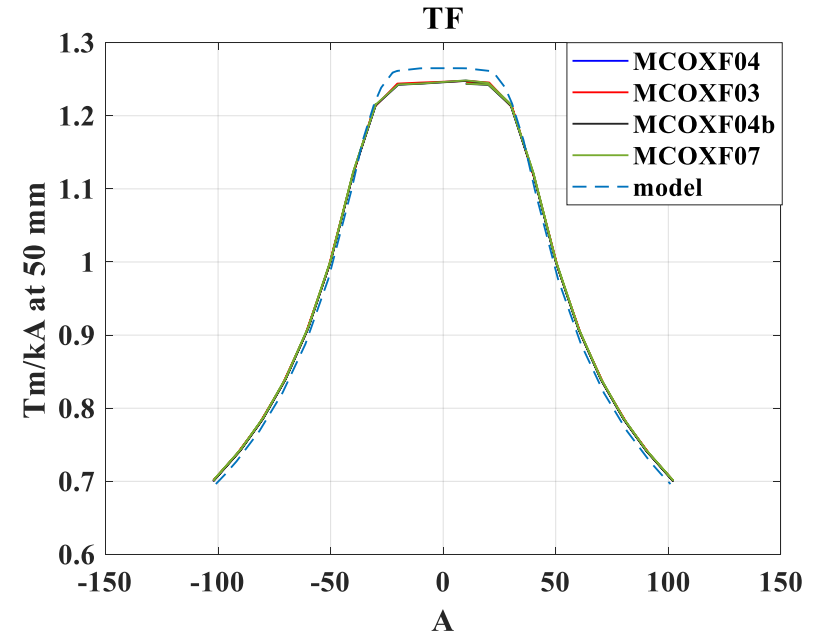
b9 well reproduced (<1 unit)



Octupoles – TF

Order	Magnet		Model	Measured at LASA	
		Current [A]	BdL [T mm]	BdL [T mm]	diff [%]
4	MCOXF02	102	70.7	71.32	0.9
	MCOXF03			71.59	1.3
	MCOXF04			71.54	1.2
	MCOXF04b			71.48	1.1
	MCOXF07			71.59	1.3

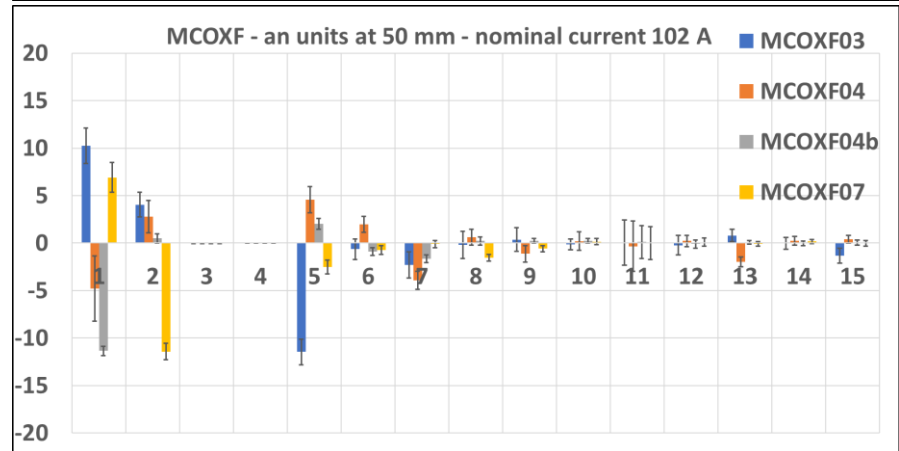
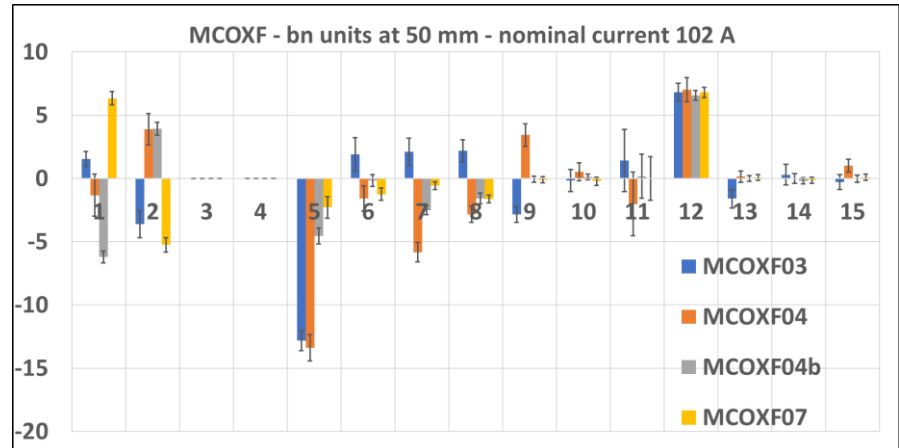
- Magnet-to-magnet repeatability among octupoles is 0.2%
- MCOXF02 – no TF measurements performed (no wedges movement)



Octupoles – Field Quality

units at 50 mm - normal and skew									
I = ±102 A									
order	MCOXF03		MCOXF04		MCOXF04b		MCOXF07		
	bn	an	bn	an	bn	an	bn	an	
1	1,5	10,3	-1,33	-4,78	-6,2	-11,3	6,3	6,9	
2	-3,6	4,0	3,89	2,80	3,9	0,5	-5,3	-11,4	
3	0,0	0,0	0,00	0,00	0,0	0,0	0,0	0,0	
4	0,0	0,0	0,00	0,00	0,0	0,0	0,0	0,0	
5	-12,8	-11,5	-13,40	4,57	-4,5	2,0	-2,3	-2,5	
6	1,9	-0,6	-1,58	1,97	-0,2	-0,9	-1,2	-0,7	
7	2,1	-2,3	-5,83	-3,94	-2,5	-1,7	-0,6	-0,1	
8	2,2	-0,2	-2,83	0,61	-1,6	0,2	-1,6	-1,5	
9	-2,8	0,4	3,43	-1,12	-0,1	0,2	-0,1	-0,6	
10	-0,2	-0,1	0,52	0,21	0,1	0,2	-0,2	0,2	
11	1,4	0,1	-2,01	-0,34	0,2	0,1	0,0	0,0	
12	6,8	-0,2	7,01	0,22	6,6	-0,1	6,8	0,1	
13	-1,6	0,8	0,15	-1,97	0,0	0,1	0,1	-0,1	
14	0,3	0,0	-0,01	0,26	-0,2	0,0	-0,1	0,2	
15	-0,3	-1,3	1,02	0,38	0,0	0,1	0,1	0,0	

b12 well reproduced (<1 unit)



Conclusions

- Magnetic measurements of the latest HO corrector series magnets:
 - Transfer function larger than 2% for the MQSXF3; about 1% for the MCOXF04b/07 and 2% for the MCSXF06;
 - Negligible effect of the V-supports on the magnetic performance (MQSXF3 and MCOXF04b);
 - Multipoles are within specs (<100 units) for all the magnets.
- Performance crosscheck of the same family magnets:
 - Quadrupoles, sestupoles and octupoles are very repeatable showing a relative difference within the same family of about 0.1-0.2 % for the TF;
 - Multipoles repeatability within 1 units for the expected ones.

Thanks for your attention!