

Magnetic measurement and analysis on MBHSP101

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Debriefing meeting on cold tests 27.01.2015

Outline

- Magnetic measurement systems
- Measurement results
 - At cryogenic temperature
 - TF
 - Allowed multipoles
 - Other multipoles
 - σ of multipoles and mechanical tolerances
 - Ramp rate dependence
 - Magnetization
 - Field repeatability
 - Effect of temperature
 - At ambient temperature (new results)
 - Cold/warm correlation
- New measurement shafts (update)
- Conclusions

Measurement system 300 K

- Motor + encoder + slip-ring unit (MRU)
- Fast Digital Integrator (FDI)
- FuG low voltage power supply (40 V, 20 A)
- DCCT Hitec MACC-plus
- Search coil shafts (radius 22 mm, length 1.2 m)
- Flexible software Framework for Magnetic Measurements (FFMM)

Number of turns	(-)	256
Inner width	(mm)	13.41
Inner length	(mm)	1195.6
Groove thickness	(mm)	1.4
Magnetic surface	(m ²)	3.3669
Center radius	(mm)	21.330

A measurement is an average over 1.2 m

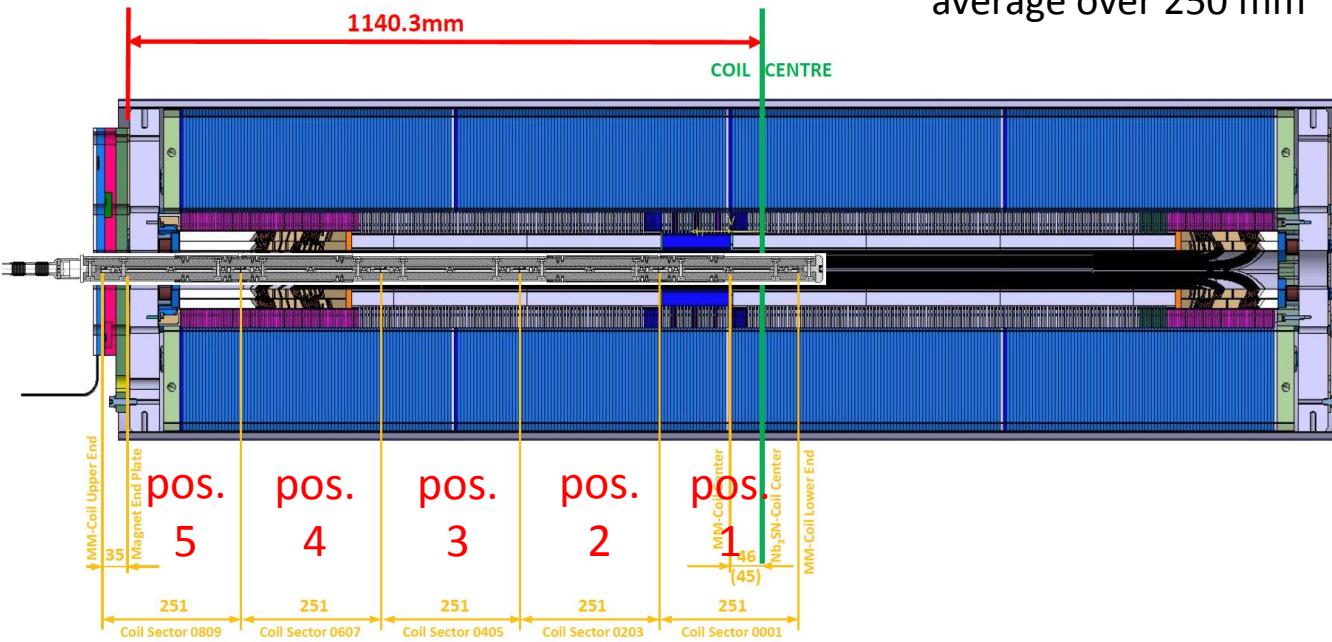


Measurement system 1.9 K

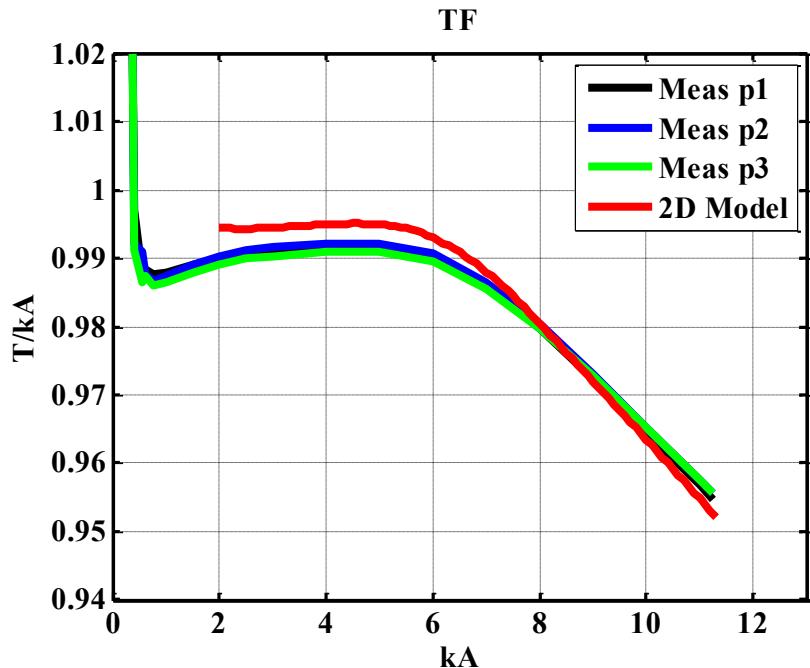
- Flexible software Framework for Magnetic Measurements (FFMM)
- Fast Digital Integrators (FDI)
- Motor + encoder + slip-ring unit (MRU)
- Vertical rotating shaft in liquid He

Number of turns	(-)	150
Inner width	(mm)	6.43
Inner length	(mm)	250.00
Groove thickness	(mm)	0.80
Magnetic surface	(m ²)	0.28197
Center radius	(mm)	18.91

A measurement is an average over 250 mm



Transfer function



At 1.9 K

- -30 units measured on geometric
- +55 units measured on saturation at 11 kA

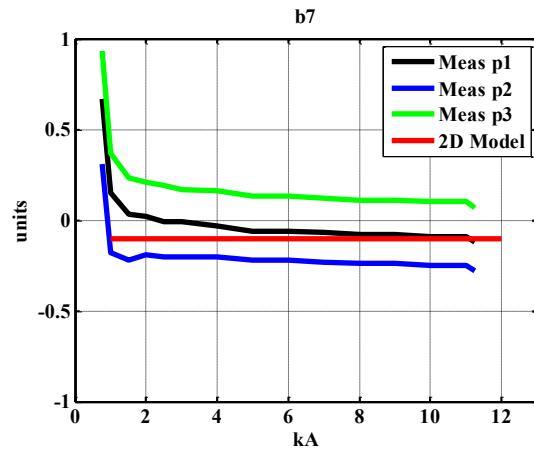
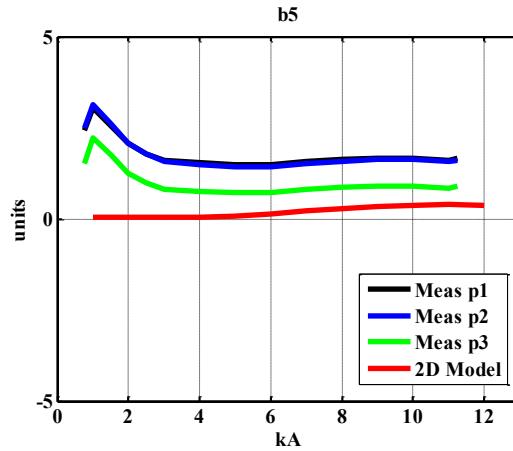
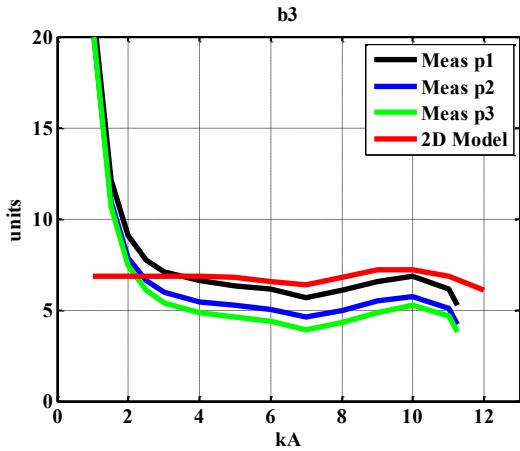
At 300 K

- +50 units measured on geometric

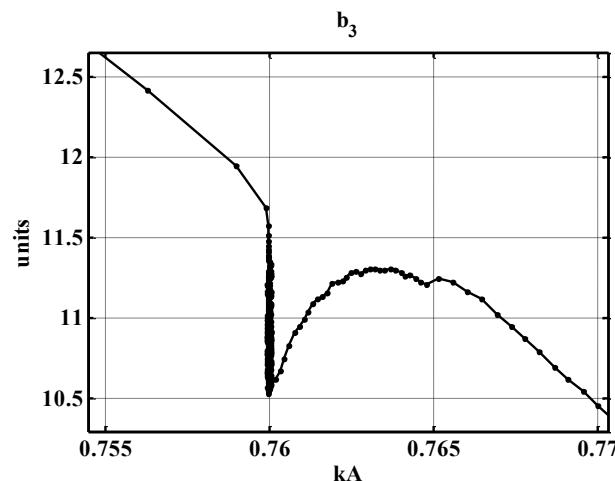
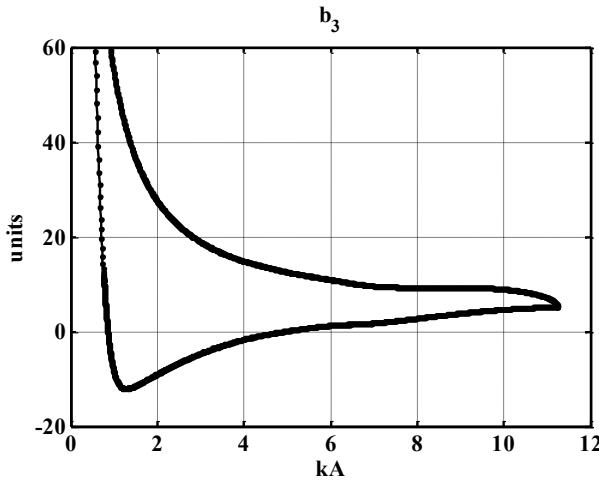
Measurements vs model			
Ambient temperature			
I	20	A	
center	+50	units	
1.9 K			
I	4	11	kA
pos. 1	-32	+21	units
pos. 2	-27	+29	units
pos. 3	-40	+29	units

Allowed multipoles

Stair-step cycle



Simulated machine cycle



- 25 unit of change during up-ramp from 760
- Decay and snap-back of ~1.2 units

Reference radius 17 mm

Other multipoles

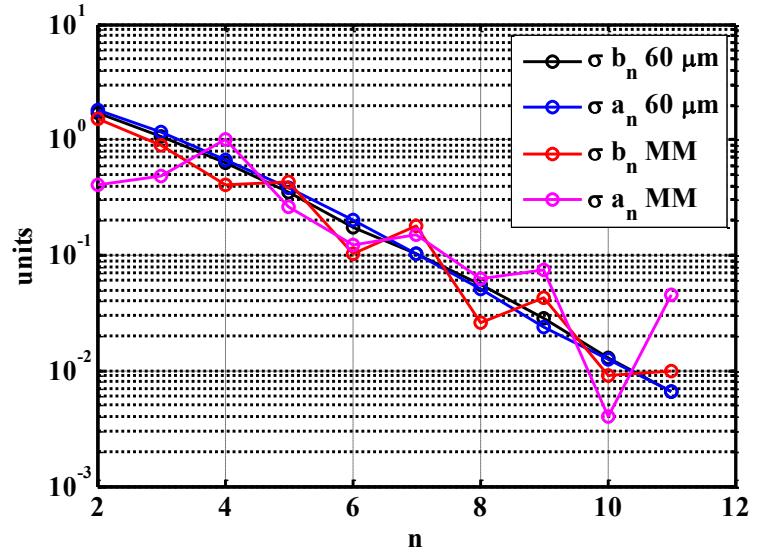
	pos 1		pos 2		pos 3		
Temp.	1.9		1.9		1.9		K
TF	9.930E-04		9.934E-04		9.922E-04		T/A
n	bn	an	bn	an	bn	an	
2	0.86	5.47	-0.59	5.11	-2.14	4.66	units at 17 mm
3	6.35	-1.21	5.25	-0.78	4.60	-1.75	
4	0.30	1.72	-0.51	0.99	-0.19	-0.26	
5	1.49	0.01	1.43	0.43	0.72	0.48	
6	0.01	0.49	-0.15	0.70	0.04	0.49	
7	-0.06	-0.19	-0.22	-0.07	0.13	0.11	
8	-0.01	0.10	-0.02	0.01	0.03	-0.01	
9	0.89	-0.20	0.85	-0.32	0.80	-0.33	
10	0.00	-0.00	-0.01	0.00	-0.02	0.01	
11	0.37	-0.06	0.37	-0.12	0.39	-0.14	

Reference radius 17 mm

σ of multipoles and tolerances

	measurements		tolerances		
σ_{TF}	6.23		-		
n	σ_{bn}	σ_{an}	σ_{bn}	σ_{an}	
2	1.50	0.41	1.70	1.82	
3	0.88	0.49	1.08	1.18	
4	0.41	1.00	0.62	0.67	
5	0.43	0.26	0.35	0.39	
6	0.10	0.12	0.17	0.20	
7	0.18	0.15	0.10	0.10	
8	0.03	0.06	0.06	0.05	
9	0.04	0.07	0.03	0.02	
10	0.01	0.00	0.01	0.01	
11	0.01	0.05	0.01	0.01	

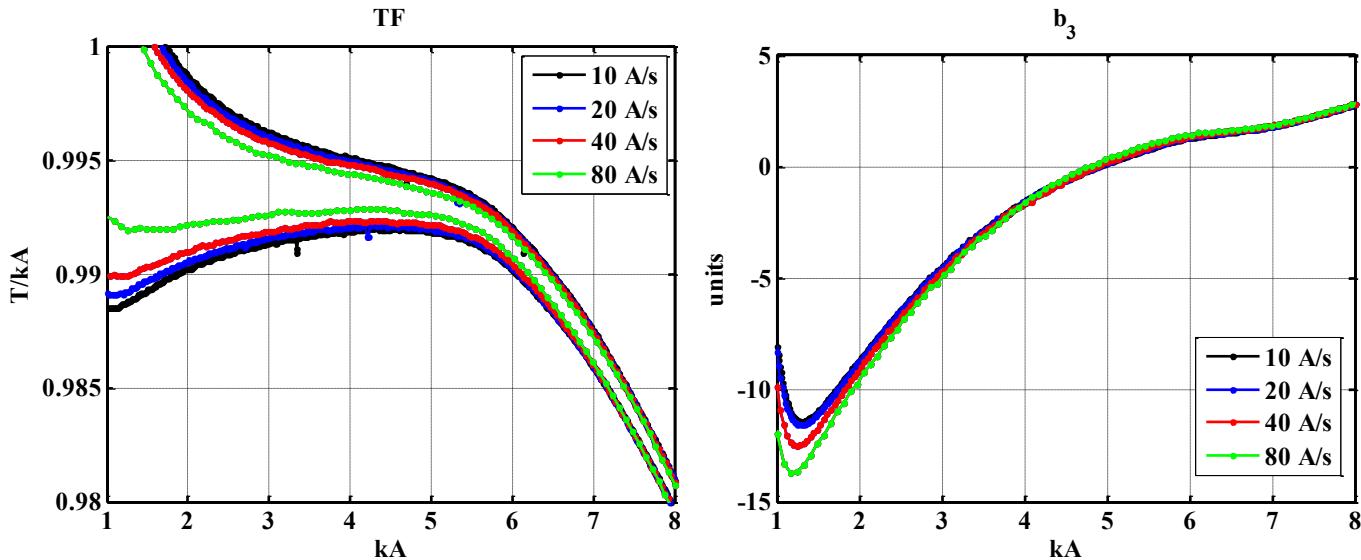
units at 17 mm



- σ of measured multipoles is compatible with random block displacements of 60 μm
- small sample size for statistics

Reference radius 17 mm

Ramp rate dependence



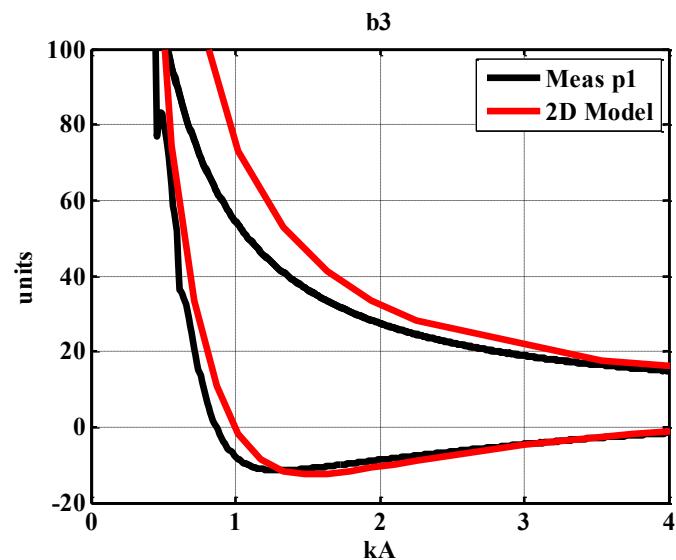
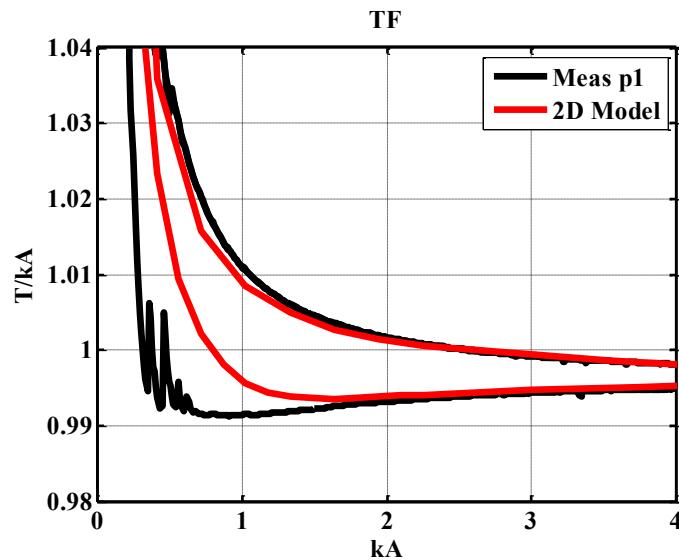
Small ramp-rate effects both on TF and multipoles.

Stainless steel core works well.

A/s	0	10	20	40	80	0	10	20	40	80
	Δb_n at 5 kA (units)					Δa_n at 5 kA (units)				
1	0.00	1.01	1.71	3.73	8.27					
2	0.00	0.10	0.05	-0.03	-0.20	0.00	-0.05	-0.11	-0.12	-0.13
3	0.00	0.03	0.05	0.06	0.16	0.00	0.02	-0.04	-0.15	-0.30
4	0.00	0.02	0.05	0.09	0.21	0.00	0.01	0.02	0.04	0.10
5	0.00	-0.04	-0.05	-0.10	-0.17	0.00	0.00	0.00	-0.01	-0.01
6	0.00	0.00	0.00	0.05	0.10	0.00	0.01	0.02	0.02	0.01
7	0.00	0.02	0.00	0.01	0.00	0.00	-0.03	-0.01	-0.03	-0.01
8	0.00	0.03	0.03	0.04	0.05	0.00	0.01	0.00	0.02	0.01
9	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.04
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Reference radius 17 mm

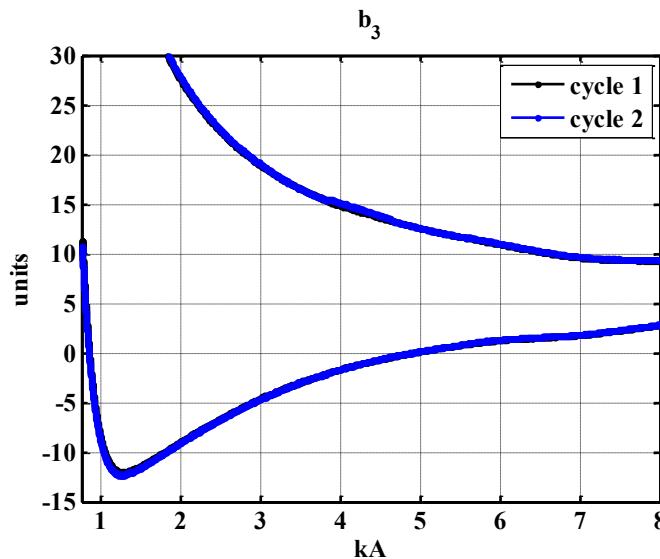
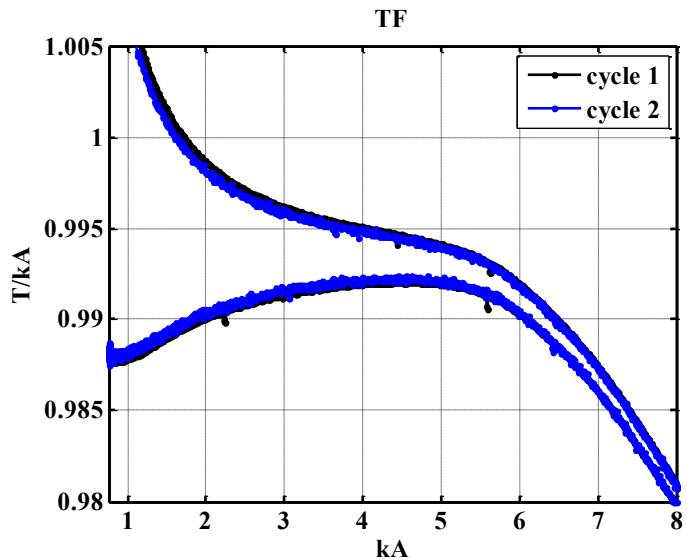
Magnetization at 1.9 K



- Difference on measured/modelled magnetization contribution on TF
- Better agreement on b_3

Reference radius 17 mm

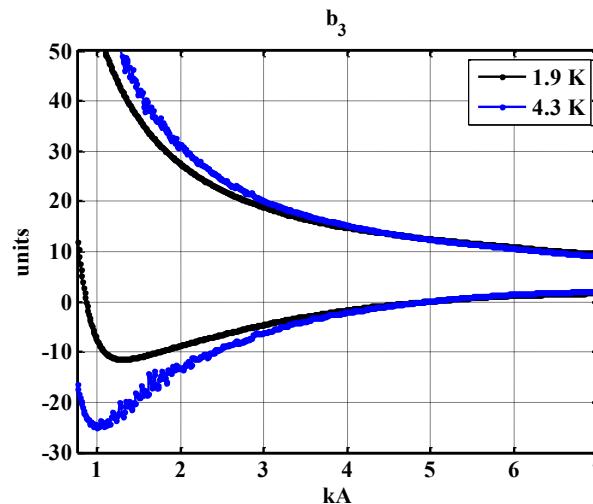
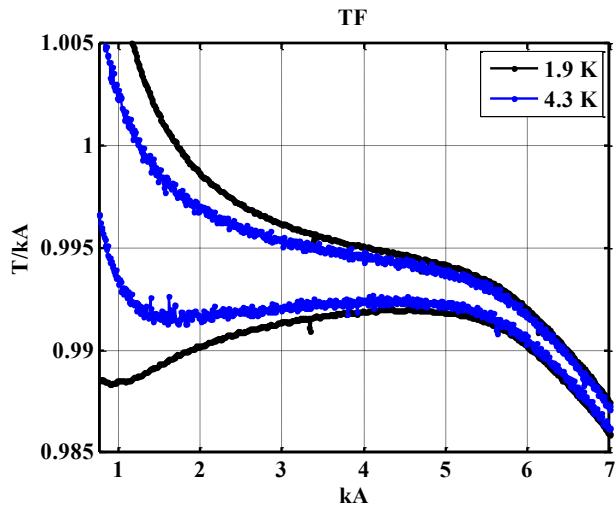
Field repeatability



- Above injection level the field is repeatable within the measurement precision both for TF and multipoles

Reference radius 17 mm

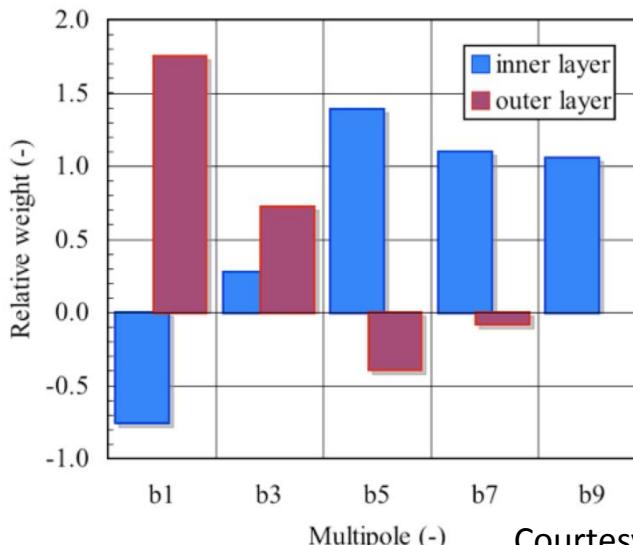
Effect of temperature



Magnetization contribution results to be

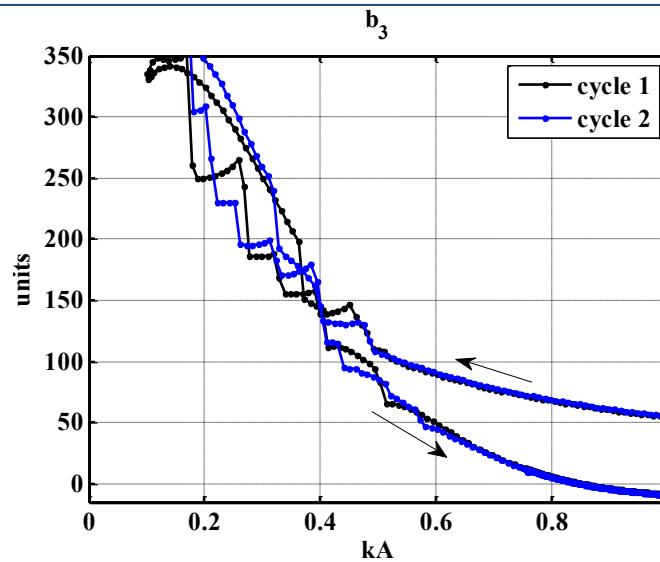
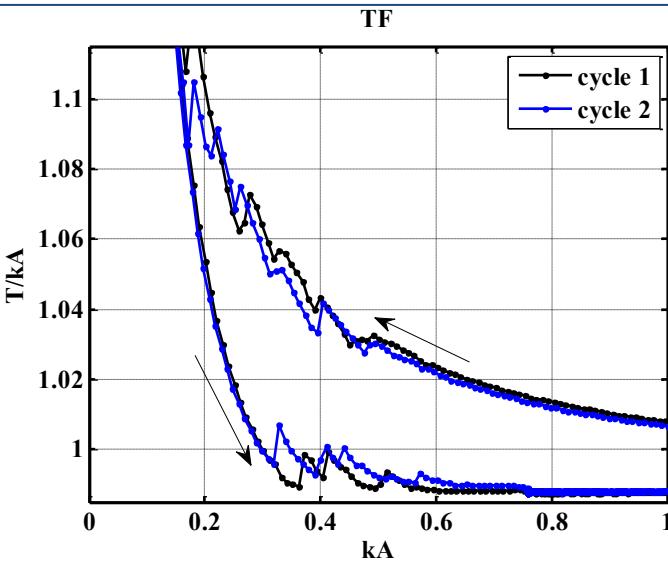
- larger at 1.9 K on TF
- smaller at 1.9 K on b_3

Measurements at 4.3 K show noise due to flux jumps



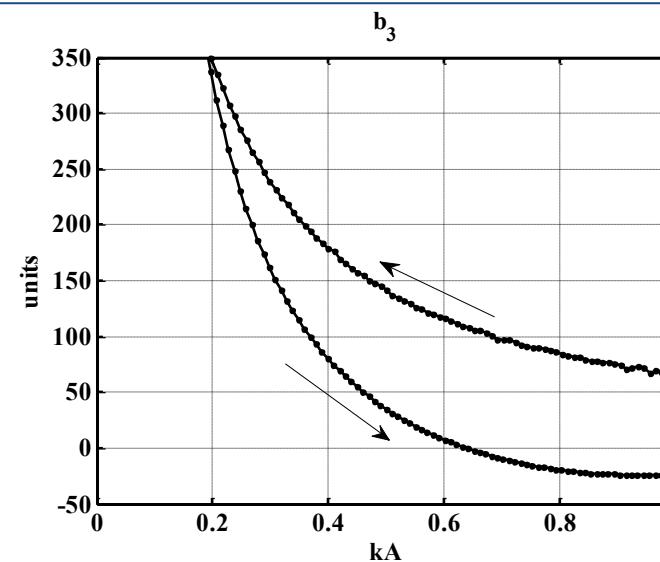
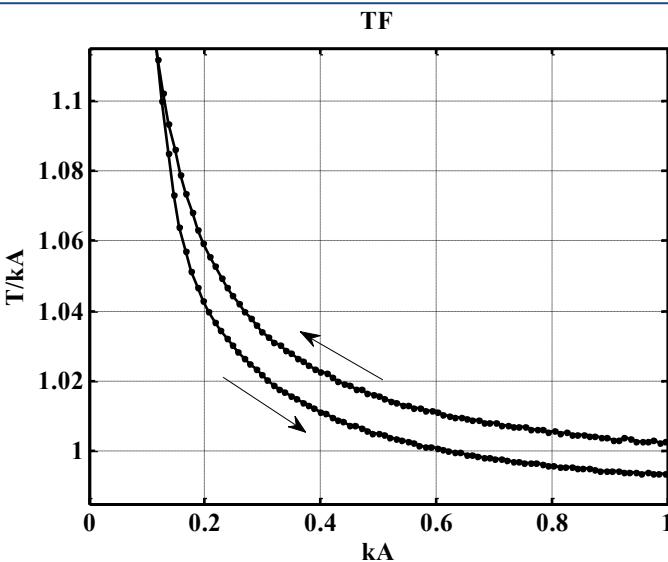
Courtesy of L. Bottura

Field repeatability at low field



At 1.9 K

- Noise up to 600 A
- Both on TF and multipoles



At 4.3 K

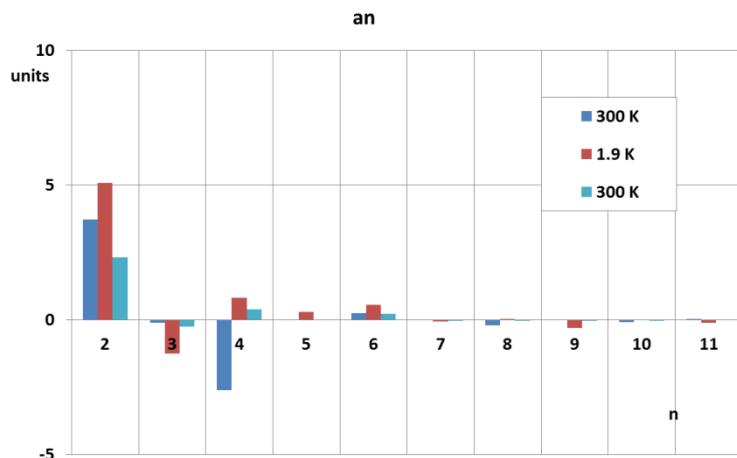
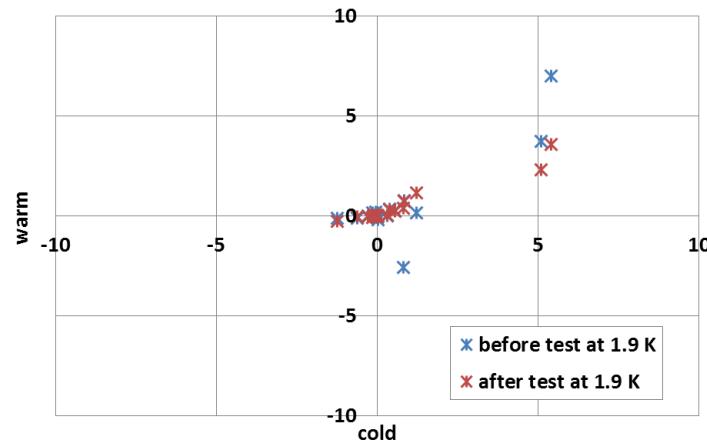
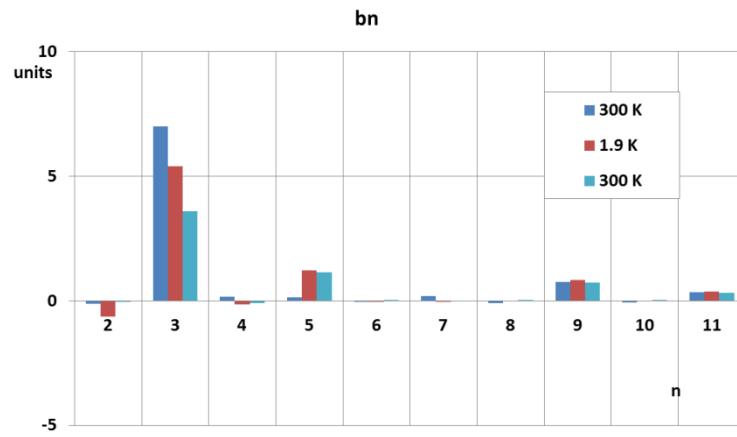
- No noise at low current
- Noise of smaller amplitude at higher current

Cold/warm correlation (centre)

	centre			average 1,2,3			centre	
Temp.	300 K			1.9 K			300 K	
TF	9.987E-04			9.929E-04			9.996E-04	
n	bn	an		bn	an		bn	an
2	-0.13	3.73		-0.62	5.08		-0.05	2.32
3	7.00	-0.11		5.40	-1.25		3.59	-0.26
4	0.16	-2.60		-0.13	0.82		-0.10	0.39
5	0.14	0.00		1.21	0.31		1.14	0.02
6	-0.03	0.25		-0.03	0.56		0.00	0.23
7	0.18	0.00		-0.05	-0.05		-0.01	-0.03
8	-0.09	-0.21		0.00	0.03		0.00	-0.02
9	0.76	0.01		0.85	-0.28		0.73	-0.04
10	-0.07	-0.08		-0.01	0.00		0.02	-0.02
11	0.34	0.04		0.38	-0.11		0.32	0.02

Reference radius 17 mm

Cold/warm correlation (centre)



- Changes on multipoles before/after test at cold
- Better cold/warm correlation with results taken at warm after cold tests
- Anyway not perfect correlation

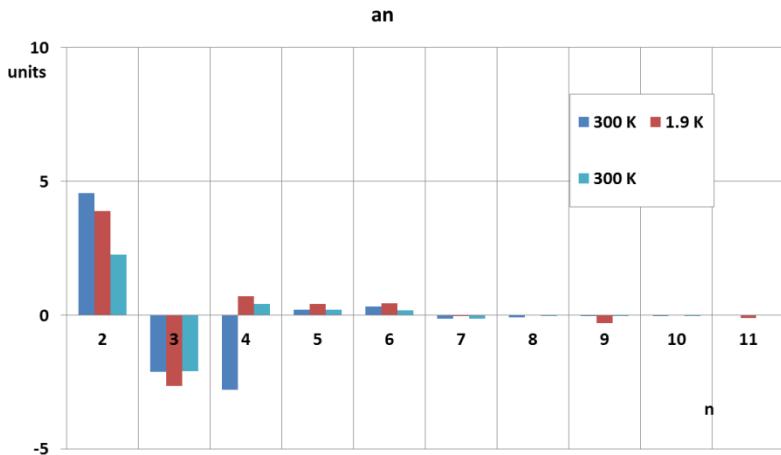
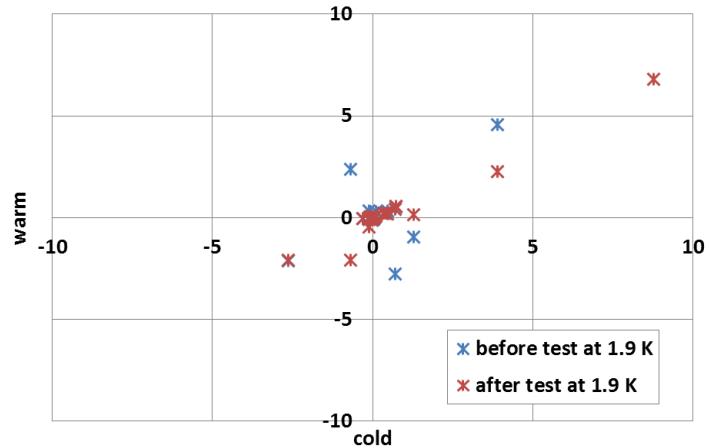
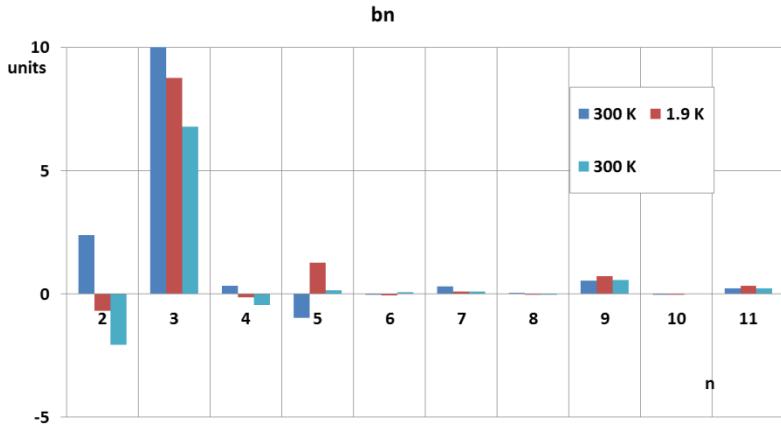
Reference radius 17 mm

Cold/warm correlation (half magnet)

	half magnet			half magnet			half magnet	
Temp.	300 K			1.9 K			300 K	
TF	7.35E-04			7.47E-04			7.36E-04	
n	bn	an		bn	an		bn	an
2	2.38	4.57		-0.68	3.89		-2.07	2.28
3	10.56	-2.12		8.77	-2.63		6.80	-2.08
4	0.33	-2.78		-0.12	0.70		-0.44	0.43
5	-0.96	0.22		1.28	0.43		0.15	0.22
6	-0.03	0.33		-0.05	0.46		0.07	0.18
7	0.30	-0.12		0.10	-0.01		0.09	-0.12
8	0.05	-0.08		-0.02	0.02		-0.01	-0.01
9	0.55	-0.02		0.72	-0.30		0.57	-0.03
10	0.00	0.00		-0.01	0.01		0.01	-0.02
11	0.23	0.02		0.33	-0.09		0.24	0.02

Reference radius 17 mm

Cold/warm correlation (half magnet)



- Changes on multipoles before/after test at cold
- Better cold/warm correlation with results taken at warm after cold tests

Reference radius 17 mm

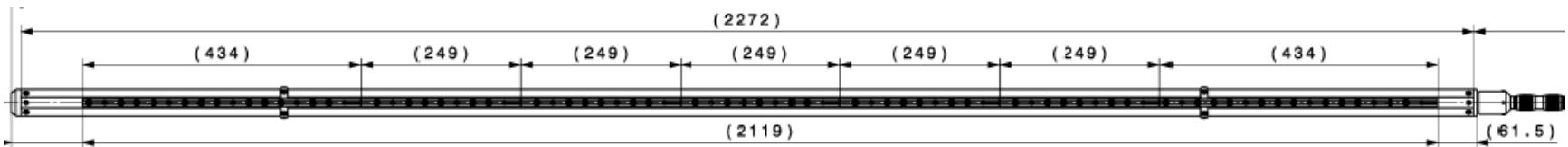
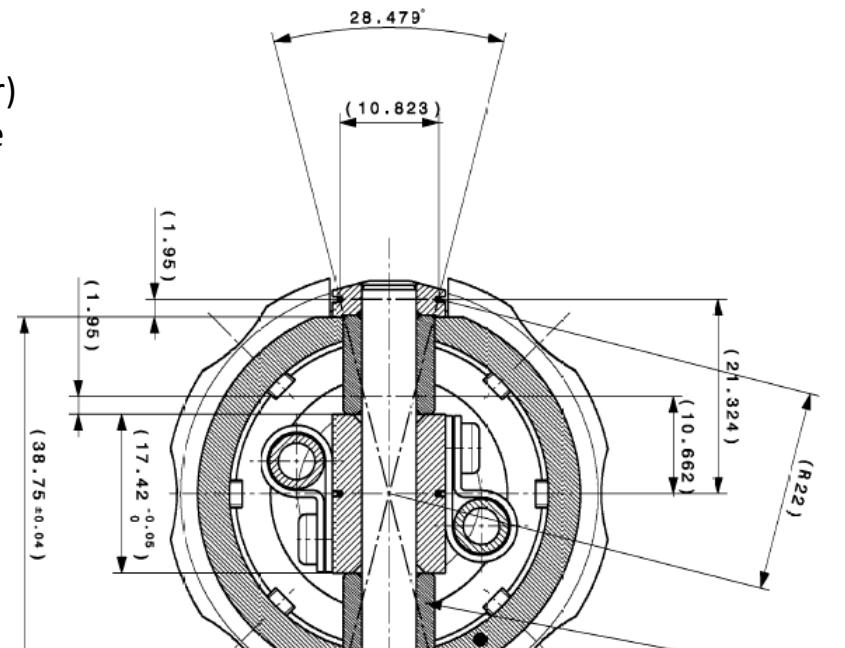
New shaft for 2-m models at 1.9 K

Design

- 7 sectors
- Dipole compensation scheme (3 tangential coils/sector)
- $l = 434$ mm to cover the coil heads, end field and splice region
- $l = 249$ mm in the straight part
- Measurement radius of 22 mm
- Full rotation symmetry for high rotation speed
- Possible use for quench location

Production baseline

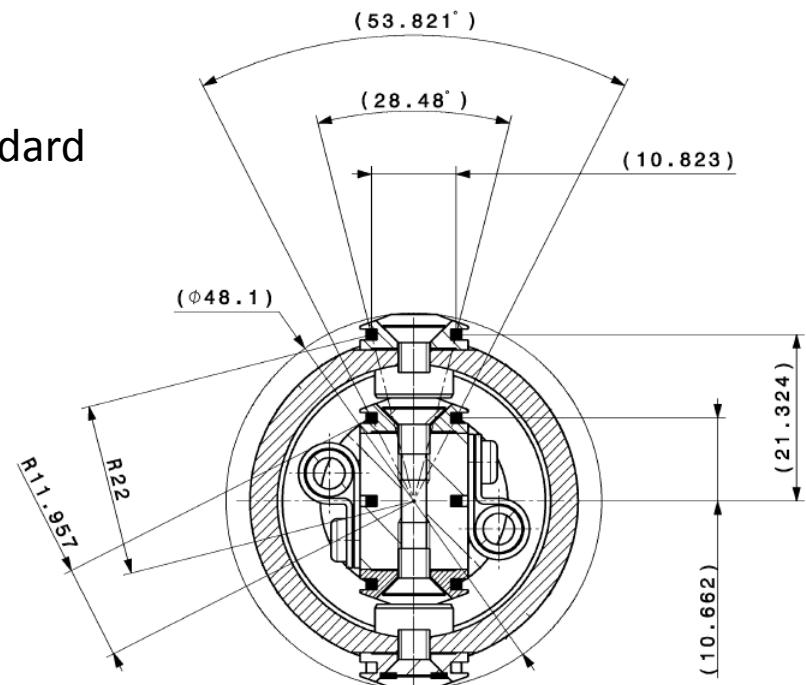
- Parts already Delivered
- Coil winding on going - issue on compensation coils
- New parts ordered
- Assembly and Calibration Feb. 2015
- Shaft operational Mar. 2015



New shaft for models at 300 K

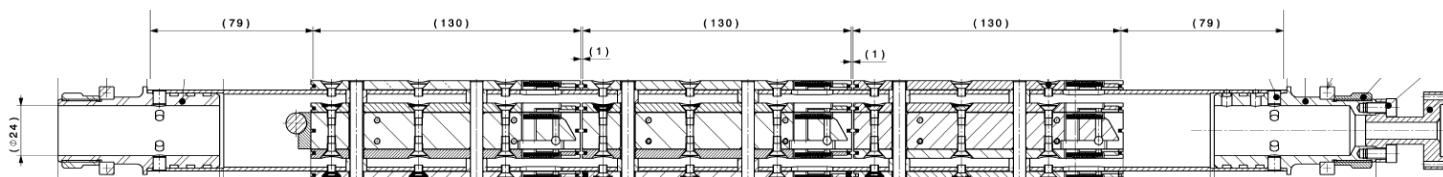
Shaft design

- 3 sectors, $l = 130 \text{ mm/each}$
- 5 tangential coils/sector – due to an existing standard
- Measurement radius 22 mm
- Horizontal position



Production baseline

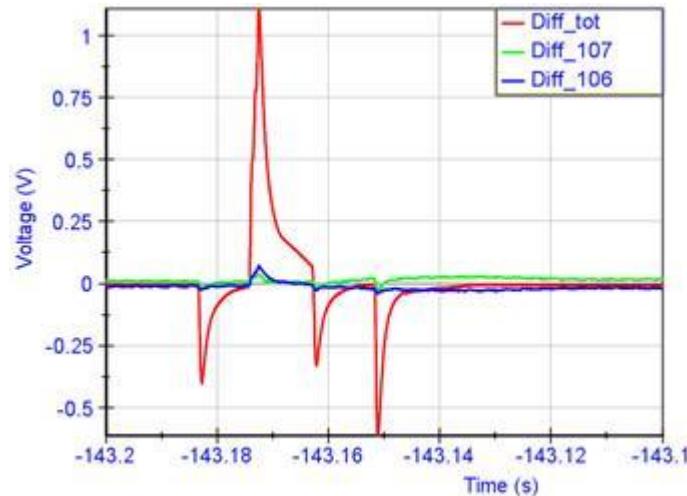
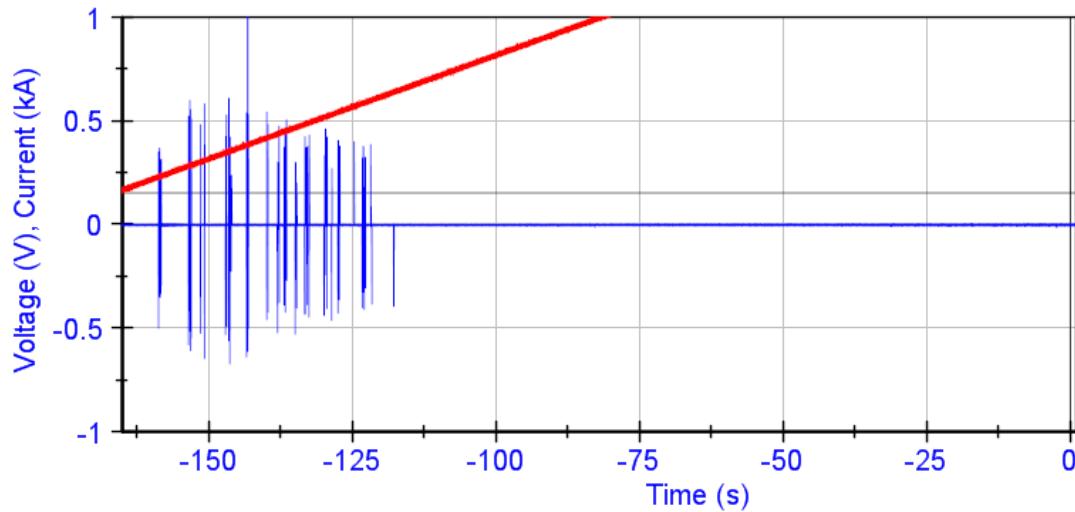
- Design ready
- Delivery expected next weeks
- Coil winding Feb. 2015
- Assembly and Calibration Mar. 2015
- Shaft operational Apr. 2015



Conclusions

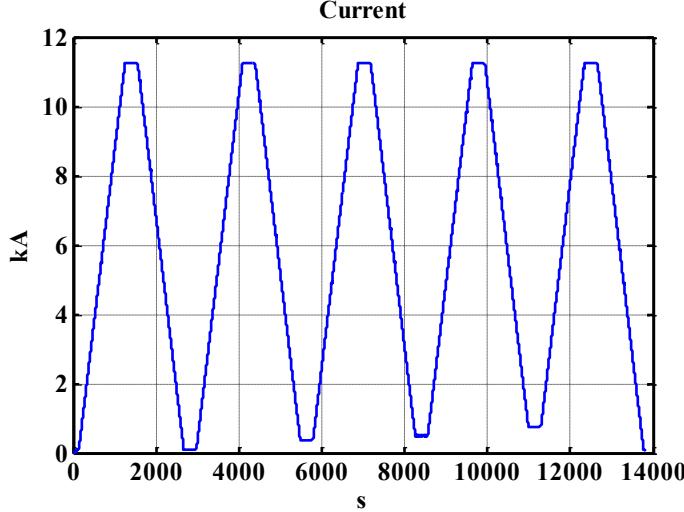
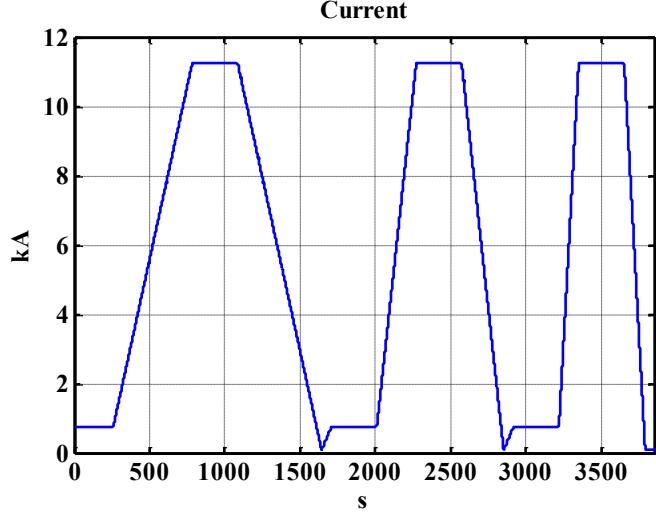
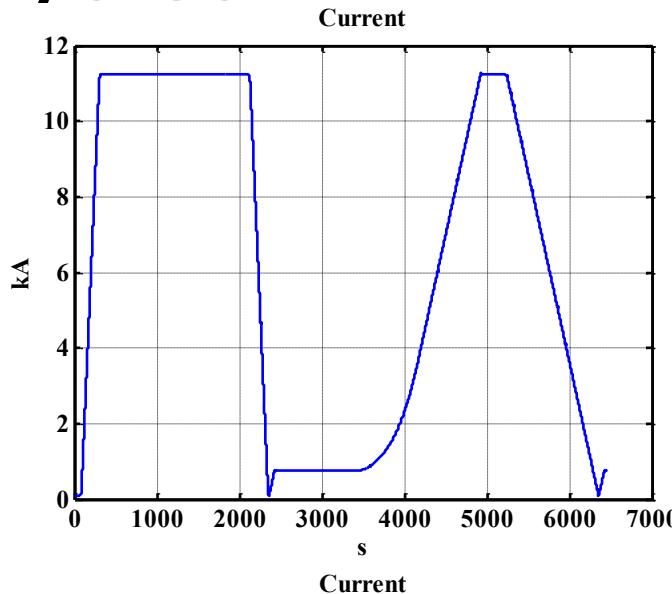
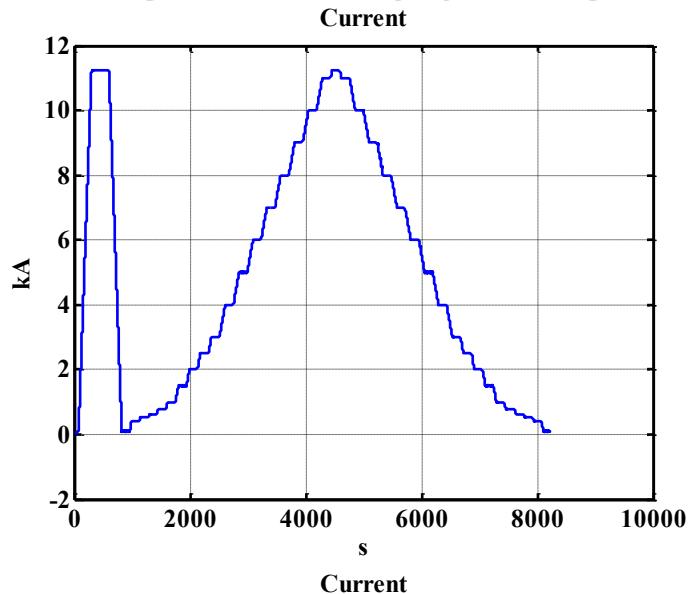
- MBHSP101 has been tested at
 - ambient temperature
 - cryogenic temperature
- Measured geometric TF is in general agreement with model
- Saturation seems to be overestimated by the model
- Difference on measured/modelled magnetization contribution on TF
- Allowed multipoles are in agreement with model
- Non-allowed are compatible with mechanical tolerances of 60 µm
- Low ramp rate dependence (as expected)
- Noise from flux jumps noticeable (?)
- Cold/warm correlation improves after tests at 1.9 K (?)

Annex 1: voltage jumps at 1.9 K

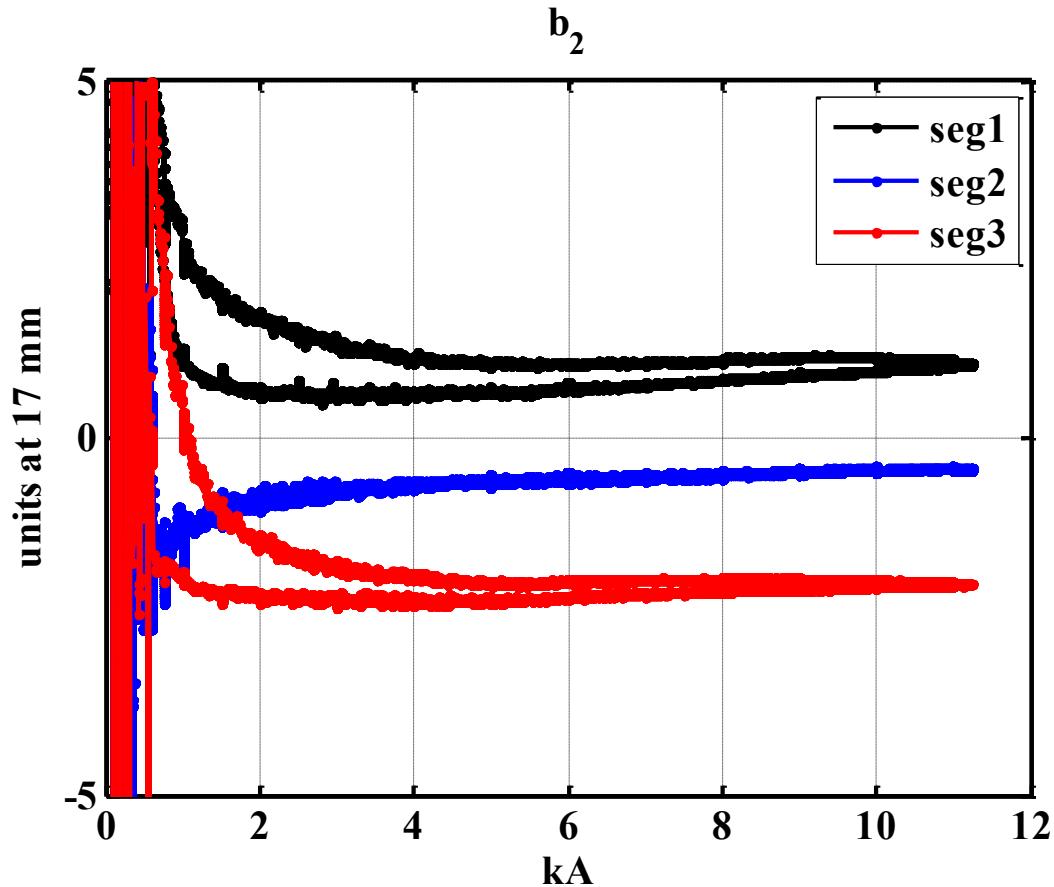


Courtesy of G. Willering

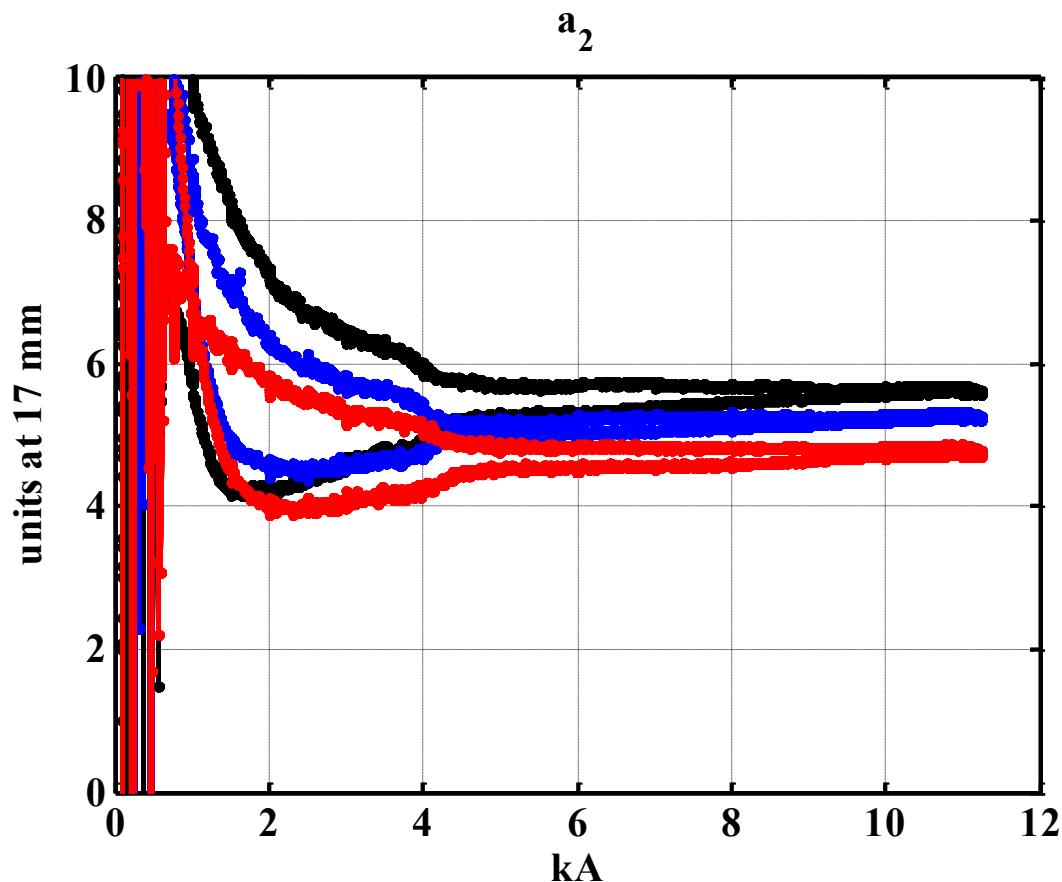
Annex 2: current cycles



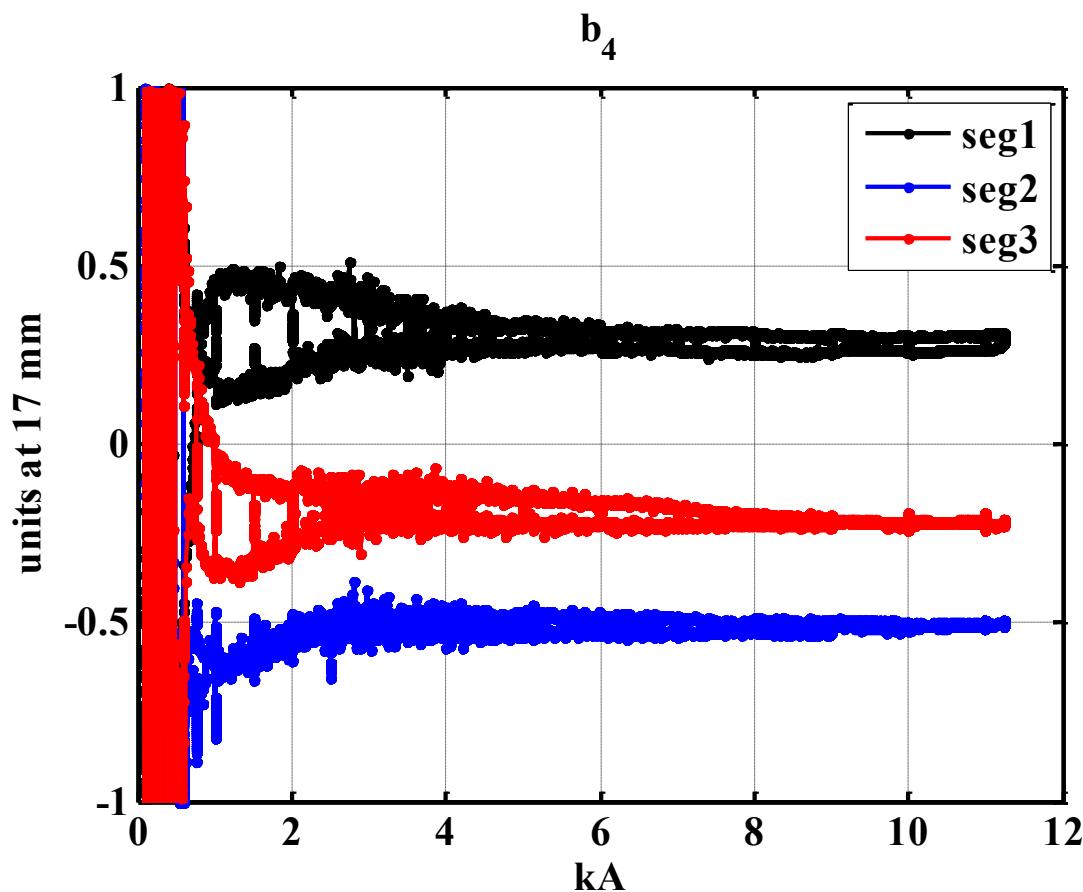
Annex 3: b_2 as function of current



Annex 4: a_2 as function of current



Annex 5: b4 as function of current



Annex 6: a_4 as function of current

