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Magnetic Measurements MBHSP102

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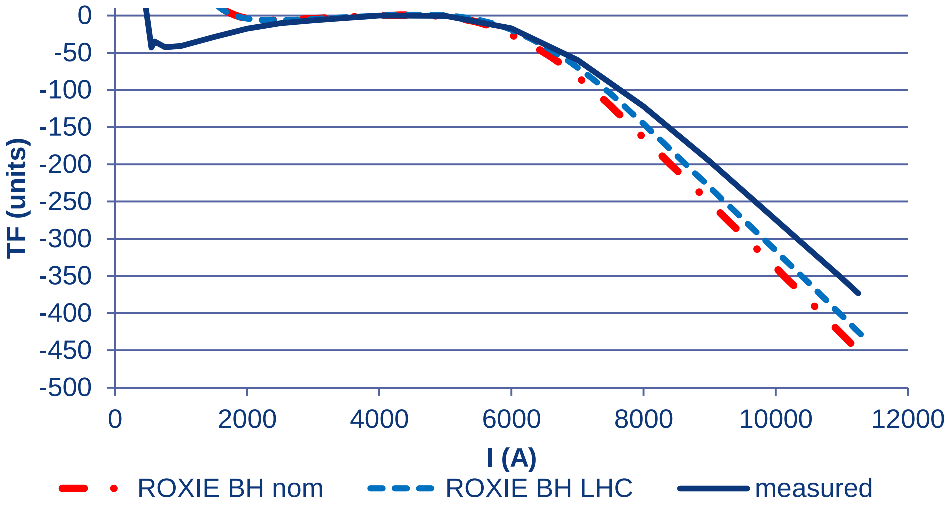
- Geometric
  - Allowed harmonics
  - Non allowed harmonics
- Inter Strand Coupling Currents

Transfer function

- Discrepancy ~ 50 units between measured and expected values.
- Measurements very consistent in MBHSP101 and MBHSP102

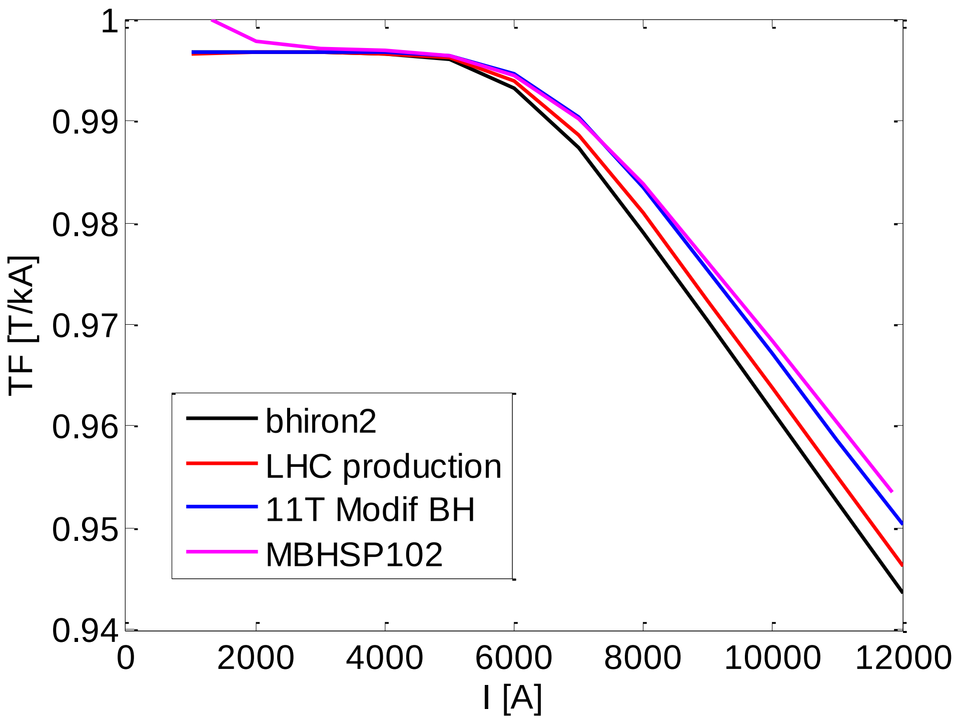


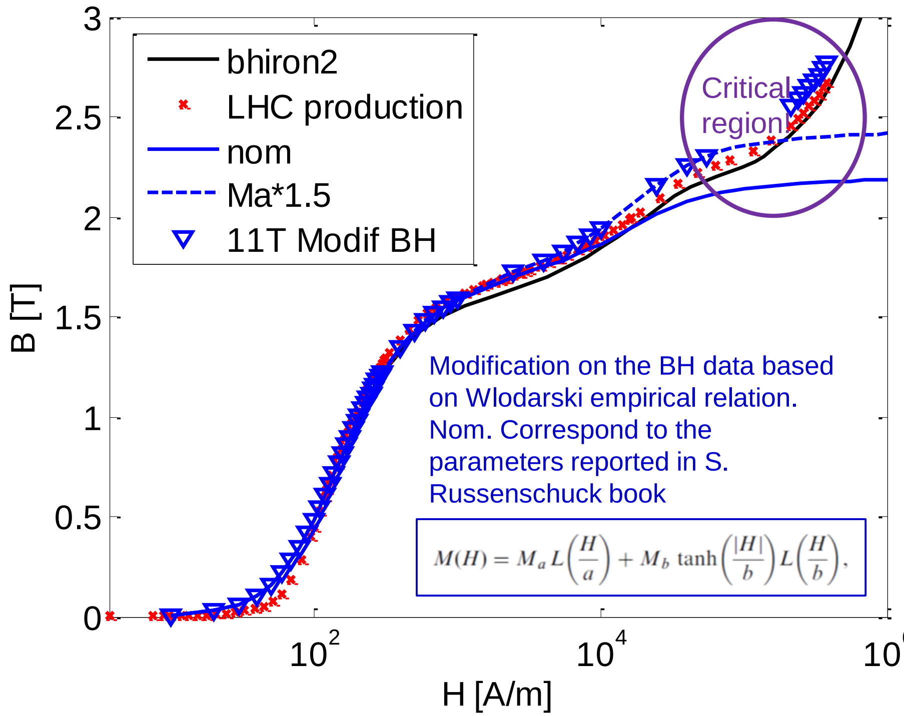
Possible sources of error:

- Iron properties
  - Going from the standard ROXIE bhdata2 to measured data from LHC production, discrepancy decrease by 20 units (from 70 to 50)
- Packing factor of the yoke laminations
  - Can explain up to 15 units (out of 50)
- Geometric
  - Rather big displacements needed to explain 35 units (350 µm smaller coil ~ 15 units in the TF)

Transfer function

- The main source of error is the magnetic properties of the iron:
  - Discrepancy ~ 80 units using ROXIE bhdata2
  - Discrepancy ~ 55 units using LHC production data
  - Discrepancy ~ 15 units using a modified bh data based on [1] fit





[1] Z. Wlodarki. Analytical description of magnetization curves

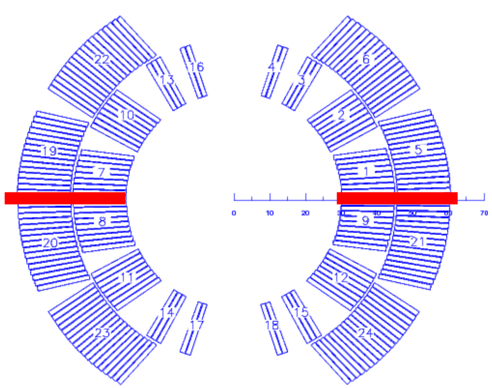
Allowed harmonics

MBHSP101* (mid plane 125 um off)	RT	After collaring	After shell welding	1.9K 5 kA	1.9K I_{nom}
b3			7.00	5.25	5.25
b5			0.14	1.43	1.43
b7			0.18	-0.22	-0.22
b9			0.76	0.85	0.85

MBHSP102 (mid plane OK)	RT	After collaring	After shell welding	1.9K 5 kA	1.9K I_{nom}
b3		1.71	9.50	11.82	11.82
b5		2.24	1.56	1.39	1.39
b7		0.11	0.16	0.10	0.10
b9		0.88	0.83	0.64	0.64

* Inom 11.25 instead of 11.85

- Shift on b_3 of 6.5 units between the first and second aperture.
- The main difference among them is the mid-plane shim:
  - MBHSP101 : 250 µm excess (0.125 µm per coil)
  - MBHSP102 : nominal
- ROXIE-ANSYS interface to evaluate the impact of the actual coil geometry on the harmonics.



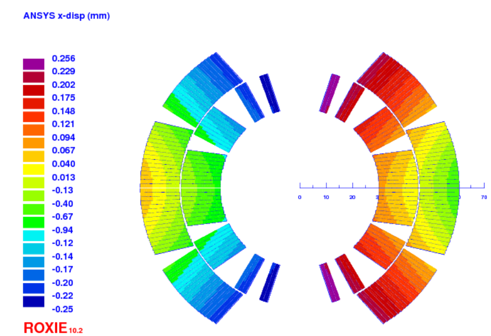
ANSYS displacements

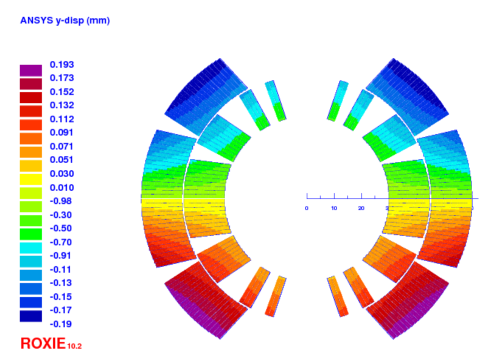
↓

Apply displacement in ROXIE strands

↓

Study impact of the displacements on field quality in ROXIE





Allowed harmonics

- It is pretty reasonable for b3 ☺
- Still a discrepancy on b5

MBHSP101* (mid plane 125 um off)	RT	After collaring	After shell welding	1.9K 5 kA	1.9K I_{nom}
b3			7.00	5.25	5.25
b5			0.14	1.43	1.43
b7			0.18	-0.22	-0.22
b9			0.76	0.85	0.85

* Inom 11.25 instead of 11.85

	ROXIE		ROXIE + ANSYS		ROXIE		ROXIE + ANSYS	
Midplane 125 um off	After collaring	After shell welding	After collaring	After shell welding	1.9 K 5 kA	1.9 K Inom	1.9K 5 kA	1.9K I_{nom}
b3	-5.58	2.57			2.55	1.79		5.04
b5	-1.41	-1.45			-1.49	-1.25		-0.78
b7	-0.64	-0.50			-0.52	-0.55		-0.21
b9	1.00	0.42			0.82	0.87		0.81

Allowed harmonics

- It is pretty reasonable for b3 ☺
- Still a discrepancy on b5, but about half of what we have in MBHSP102

MBHSP102 (mid plane OK)	RT	After collaring	After shell welding	1.9K 5 kA	1.9K I_{nom}
b3		1.71	9.50	11.82	11.82
b5		2.24	1.56	1.39	1.39
b7		0.11	0.16	0.10	0.10
b9		0.88	0.83	0.64	0.64

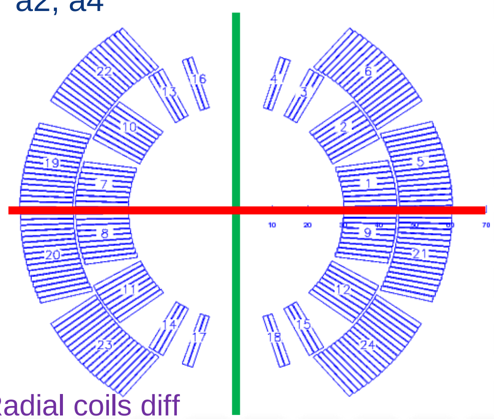
	ROXIE		ROXIE + ANSYS		ROXIE		ROXIE + ANSYS	
Midplane OK	After collaring	After shell welding	After collaring	After shell welding	1.9 K 5 kA	1.9 K Inom	1.9K 5 kA	1.9K I_{nom}
b3	-0.40	6.76			6.77	6.22		12.70
b5	0.49	0.08			0.06	0.38		-0.05
b7	-0.12	-0.09			-0.10	-0.10		0.04
b9	1.11	0.89			0.91	0.96		0.84

Non Allowed Harmonics

- For the non-allowed, only a_2 is not within the boundaries set by the manufacturing tolerances.
- It can be easily explained by the differences in coil outer radial insulation

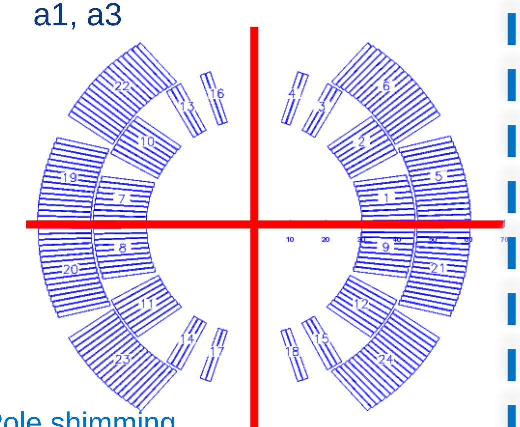
	300 K at 20 A		300 K at 20 A		1.9 K at 5 kA						Manufacturing tolerance	
	Collared coil		Cold mass		seg3		seg4		seg5			
n	**bn**	**an**	**bn**	**an**	**bn**	**an**	**bn**	**an**	**bn**	**an**	**bn**	**an**
2	0.00	8.72	0.33	6.76	1.75	2.73	1.22	3.56	0.69	3.67	1.93	2.87
3	1.71	-0.93	9.50	-0.84	11.32	-1.78	11.82	-1.38	10.75	0.25	1.24	1.66
4	0.21	1.66	0.24	1.28	0.54	0.19	0.32	-0.33	-0.29	-0.2	0.6	1
5	2.24	-0.01	1.56	-0.02	1.17	-0.59	1.39	0.2	1.65	0.58	0.31	0.64

Right/left symmetric
Tom/bottom anti-symmetric
a2, a4



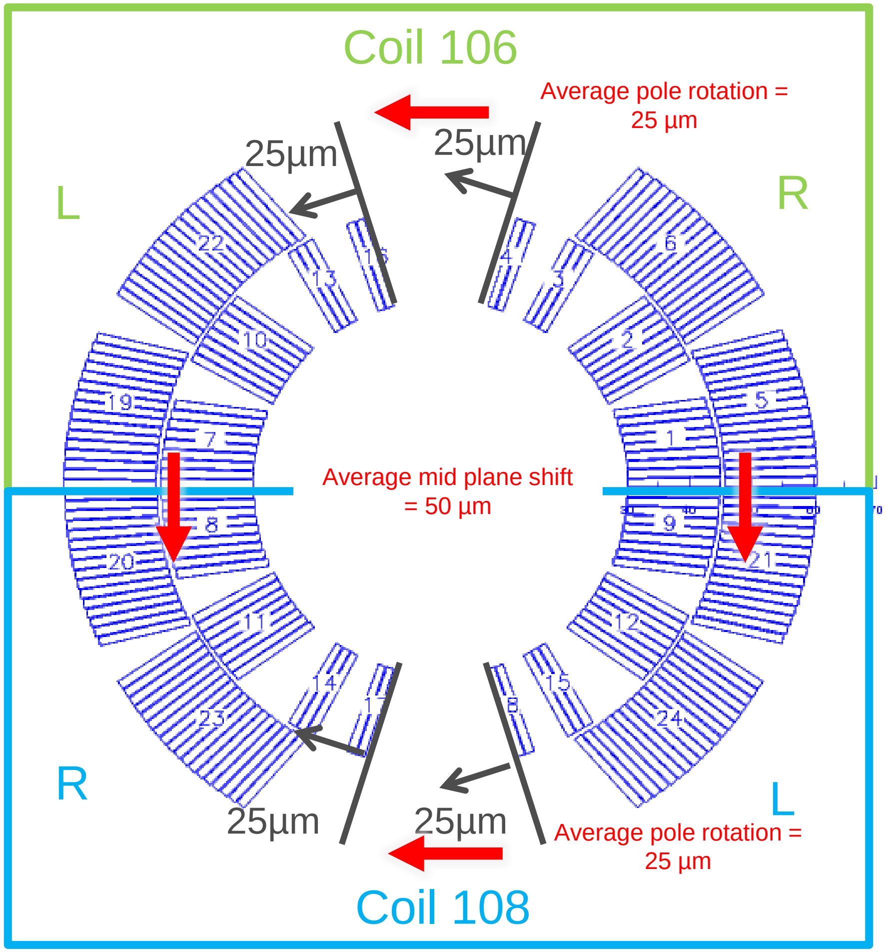
Radial coils diff

Right/left anti-symmetric
Tom/bottom anti-symmetric
a1, a3



Pole shimming

Coil Geometry



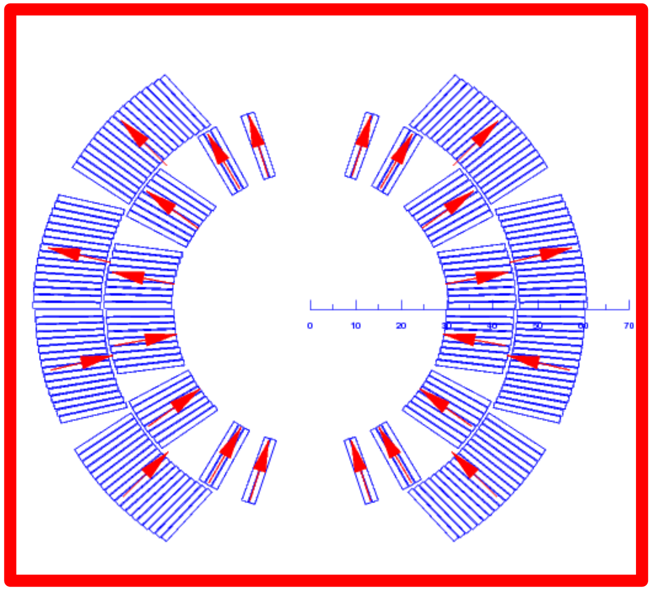
Pole shimming	SS-316	Kapton
Nominal	0.125	3x0.125
106 right	0.1	3x0.125
106 left	0.15	3x0.125
108 right	0.15	3x0.125
108 left	0.1	3x0.125

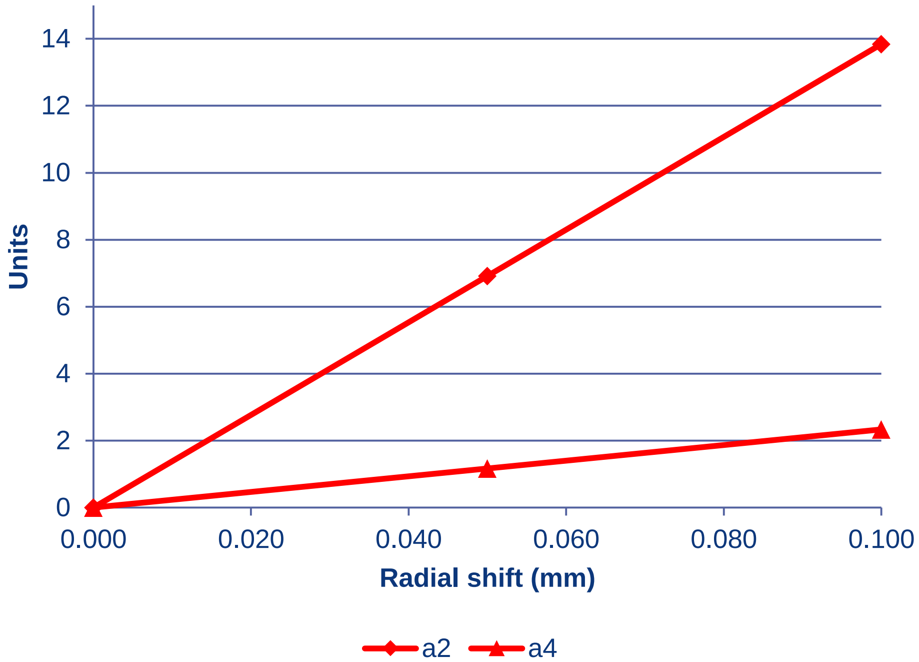
Radial Insulation	S2-Wrap	Kapton
Nominal	0.2	0.5
106 inner	0.0	0.5
106 outer	0.0	0.5
108 inner	0.1	0.5
108 outer	0.1	0.5

Non Allowed Harmonics– a_2,a_4

A radial shift of 50 µm explain a2 and a4, which is reasonable considering that coil 106 has 100 µm less of radial insulation

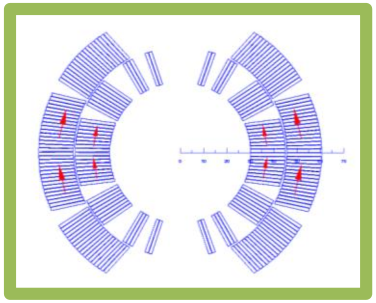
CC	R22		ROXIE	
	0.795		0.798	
n	bn	an	bn	an
2	0.00	8.72	0.00	0.00
3	1.71	-0.93	-0.40	0.00
4	0.21	1.66	0.00	0.00
5	2.24	-0.01	0.49	0.00

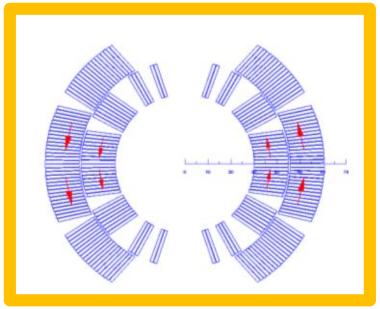




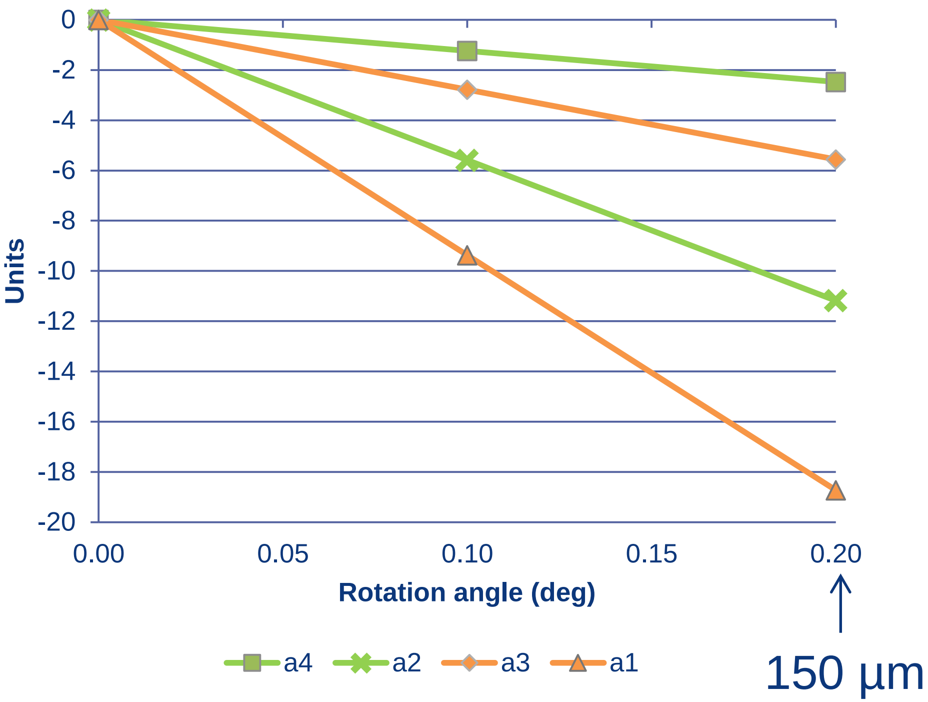
Non Allowed Harmonics– a_3, a_5

- To explain a3/a5 we need anti-symmetry in both axis
- 20 µm of rotation on the mid-plane is enough to justify a_3,
- But from mechanical measurements it seems that the mid-plane is shifted (i.e. a_2 a_4) and not rotated. 70 µm of rotation in the mid-plane explain the measured a2 and a4 (which can be also explain with the differences in coil radial shimming).





CC	R22		ROXIE	
	0.795		0.798	
n	bn	an	bn	an
2	0.00	8.72	0.00	0.00
3	1.71	-0.93	-0.40	0.00
4	0.21	1.66	0.00	0.00
5	2.24	-0.01	0.49	0.00



Inter-Strand Coupling Currents

- Very small dynamic effects observed.
- Comparing to HQ, R_c should be about 100 times more, this is too much, additional model validation needed!
- Remark! core coverage in HQ/11T is different:
  - HQ02 ~ 60 % core coverage
  - 11T ~ 80 % core coverage

Cable transposition pitch (mm)	Rc (μΩ)	Ra (μΩ)	
100	30	0.3	
5kA	20A/s	50A/s	100A/s
b3	1.39	1.97	2.93
b5	-0.15	-0.42	-0.86
b7	-0.19	-0.20	-0.21

Cable transposition pitch (mm)	Rc (μΩ)	Ra (μΩ)	
100	300	3	
5kA	20A/s	50A/s	100A/s
b3	1.04	1.08	1.16
b5	0.01	-0.01	-0.06
b7	-0.18	-0.18	-0.19

HQ:
- Rc ~ 0.3 μΩ for un-cored cable (HQ01)
- Rc ~ 3 μΩ for cored cable (HQ02)

[X. Wang] Multipoles Induced by Inter-Strand Coupling Currents in LARP Nb3Sn Quadrupoles

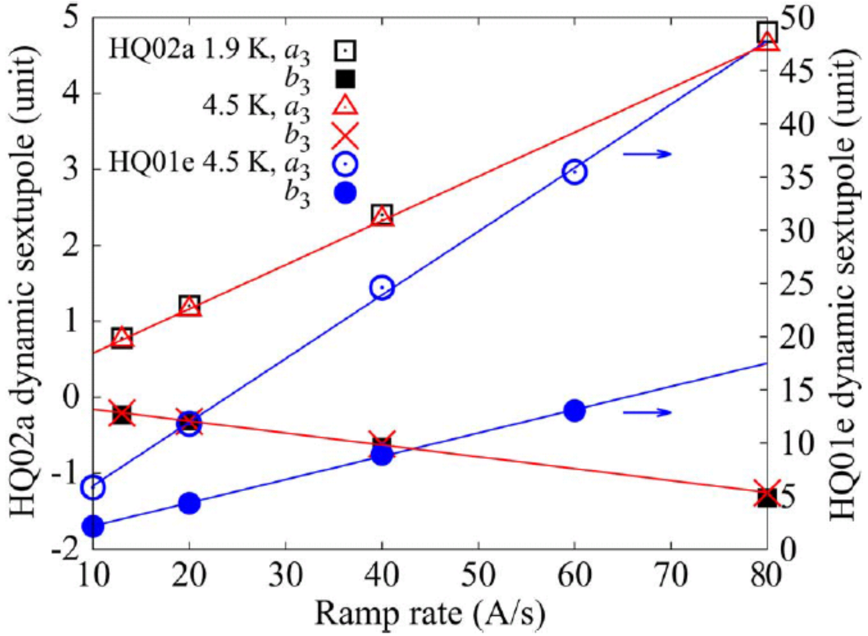


Fig. 8. Comparison of dynamic sextupoles as a function of ramp rate betwee HQ02a (primary y-axis) and HQ01e (secondary y-axis) at 10 kA. The soli lines are least-square linear fits of the data. R_{ref} = 40 mm.