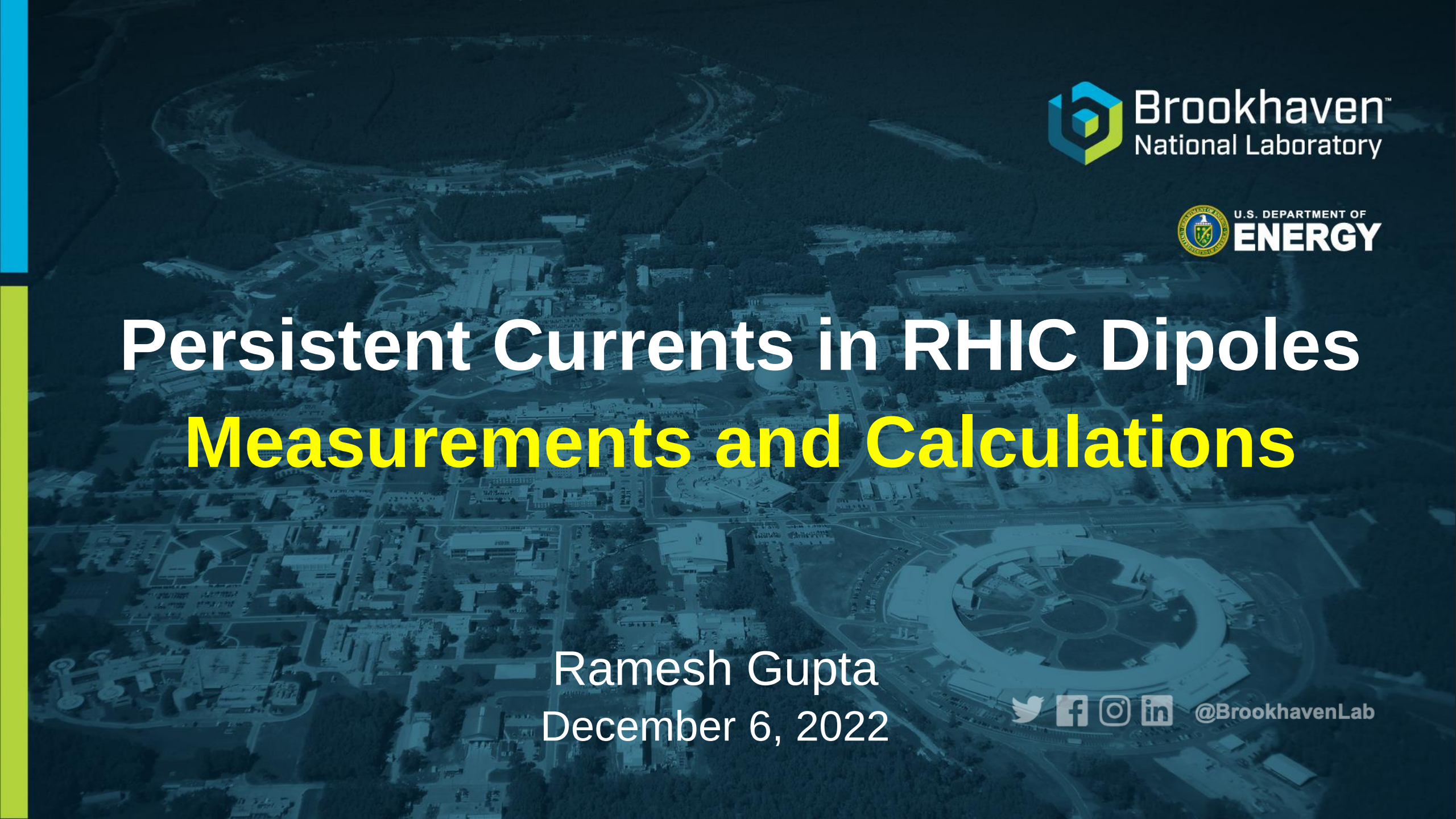


Persistent Currents in RHIC Dipoles
Measurements and Calculations

Ramesh Gupta

December 6, 2022

Introduction

- At the request of CAD, detailed measurements of persistent current induced harmonics were performed in 2002 in an 80 mm aperture RHIC dipole (Magnet chosen: D96525, a spare dipole with a magnetic length of 2.95 m).
- Later, there was an interest in 2018 in operating RHIC at an energy lower than initially contemplated or designed. Major concern- persistent current induced harmonics in RHIC dipoles (bore: 80 mm, magnetic length: 9.45 m).
- As a part of that exercise, several simulations were carried out with ROXIE both (a) for optimizing cycles for this new operation, and (b) cycles used for the measurements performed in 2002.
- This presentation is to review the 2002 measurements and simulations performed for them. Many simulations have been run again, including a set of simulations in a model simplified to reduce the computation time.
- **Important: Not verified yet the properties of superconductor used (important)**

Table 1-2 Magnet Nomenclature - Magnet/Cold Mass

Magnet/Cold Mass	Quan.†	Ø(cm)	L(m)	Location	Fabr.	Magnet ID	Coil ID
Dipole	264 (-)	8	9.45	Arc	GAC	DRG###	DCG####
	13 (1)	8	6.92	D5I	GAC	D5I###	DCJ####
	13 (1)	8	8.71	D5O	GAC	D5O###	DCK####
	25 (1)	8	2.95	D6	GAC	D96###	DCH####
	34 (10*)	8	9.45	D8	GAC	DR8###	DCG####
	24 (-)	8	2.95	D9	GAC	D96###	DCH####
	26 (2)	10	3.6	D0	BNL	DRZ###	DCZ####
	12 (2)	10	10.4	IR's	BNL	HRD###	HSD###
	13 (1)	18	3.7	DX	BNL	DRX###	DCX####
Quadrupole	282 (6)	8	1.13	Arc	GAC	QRG###	QCG####
	26 (2)	8	1.83	Q4	GAC	QR4###	QCH####
	25 (1)	8	1.13	Q5	GAC	QRG###	QCG####
	24 (-)	8	1.13	Q6	GAC	QRG###	QCG####
	26 (2)	8	0.95	Q7	GAC	QR7###	QCF####
	25 (1)	8	1.13	Q8	GAC	QRG###	QCG####
	24 (-)	8	1.13	Q9	GAC	QRG###	QCG####
	26 (2)	13	1.44	Q1	BNL	QRI###	QCI####
	26 (2)	13	3.40	Q2	BNL	QRK###	QCK####
	26 (2)	13	2.10	Q3	BNL	QRJ###	QCJ####
Trim quads	78 (6)	8	0.75	Q4,5,6	EEC	QRT###	QCT####
Corrector	100 (4)	8	0.5	Arc + Ins - Style B	BNL	CRB###	
	136 (4)	8	0.5	Arc + Ins - Style C	BNL	CRC###	
	78 (-)	8	0.5	Arc + Ins - Style D	BNL	CRD###	
	78 (-)	8	0.5	Arc + Ins - Style E	BNL	CRE###	
	40 (4)	8	0.5	Arc + Ins - Style F	BNL	CRF###	
	13 (1)	13	0.5	Q2 Outer - Style I	BNL	CRI###	
	13 (1)	13	0.5	Q3 Inner - Style J	BNL	CRJ###	
	26 (2)	13	0.5	Q3 - Style K	BNL	CRK###	
	13 (1)	13	0.5	Q3 Inner - Style L	BNL	CRL###	
	13 (1)	13	0.5	Q3 Outer - Style M	BNL	CRM###	
Sextupole	300 (12)	8	0.75	Arc,Q9	EEC	SRE###	SCE####

† Quantities listed include spares which are listed in parentheses, ( )
* The total of 10 spares are constructed as DR8 type and are interchangeable with DRG type, but not vice versa.

Table 1-3. Magnet Nomenclature - Assembly

Assembly	Quan.†	Ø(cm)	L(m)	Location	Fabr.	Magnet ID
CQS	282 (6)	8	3.4	Arc	BNL	CQS###
	12 (-)	8	3.4	Q9	BNL	CQS###
CQT	26 (2)	8	4.1	Q4	BNL	CQ4###
	25 (1)	8	3.4	Q5	BNL	CQ5###
	24 (-)	8	3.4	Q6	BNL	CQ6###
CQ	26 (2)	8	2.5	Q7	BNL	CQ7###
CQ	25 (1)	8	2.6	Q8	BNL	CQ8###
CQBlank	12 (-)	8	3.4	Q9	BNL	CQ9### ††
Dipole	13 (1)	10	4.4	D0	BNL	DIZ###
Q	13 (1)	13	1.9	Q1	BNL	CQ1###
CQ	13 (1)	13	4.4	Q2	BNL	CQ2###
CQC	13 (1)	13	4.0	Q3	BNL	CQ3###
Dummy Assembly	24 (-)	8	2.6	Q4/Q5	BNL	DU4###
	24 (-)	8	6.0	Q6/D6	BNL	DU6###
	24 (-)	8	11.9	Q7/Q8	BNL	DU7###
	24 (-)	8	6.0	Q9/D9	BNL	DU9###

† Quantities listed include spares which are listed in parentheses, ( )
†† 2 assemblies do not contain blank iron

Measurements

A Brief

Summary of Results from Special Measurements in the RHIC Dipole D96525

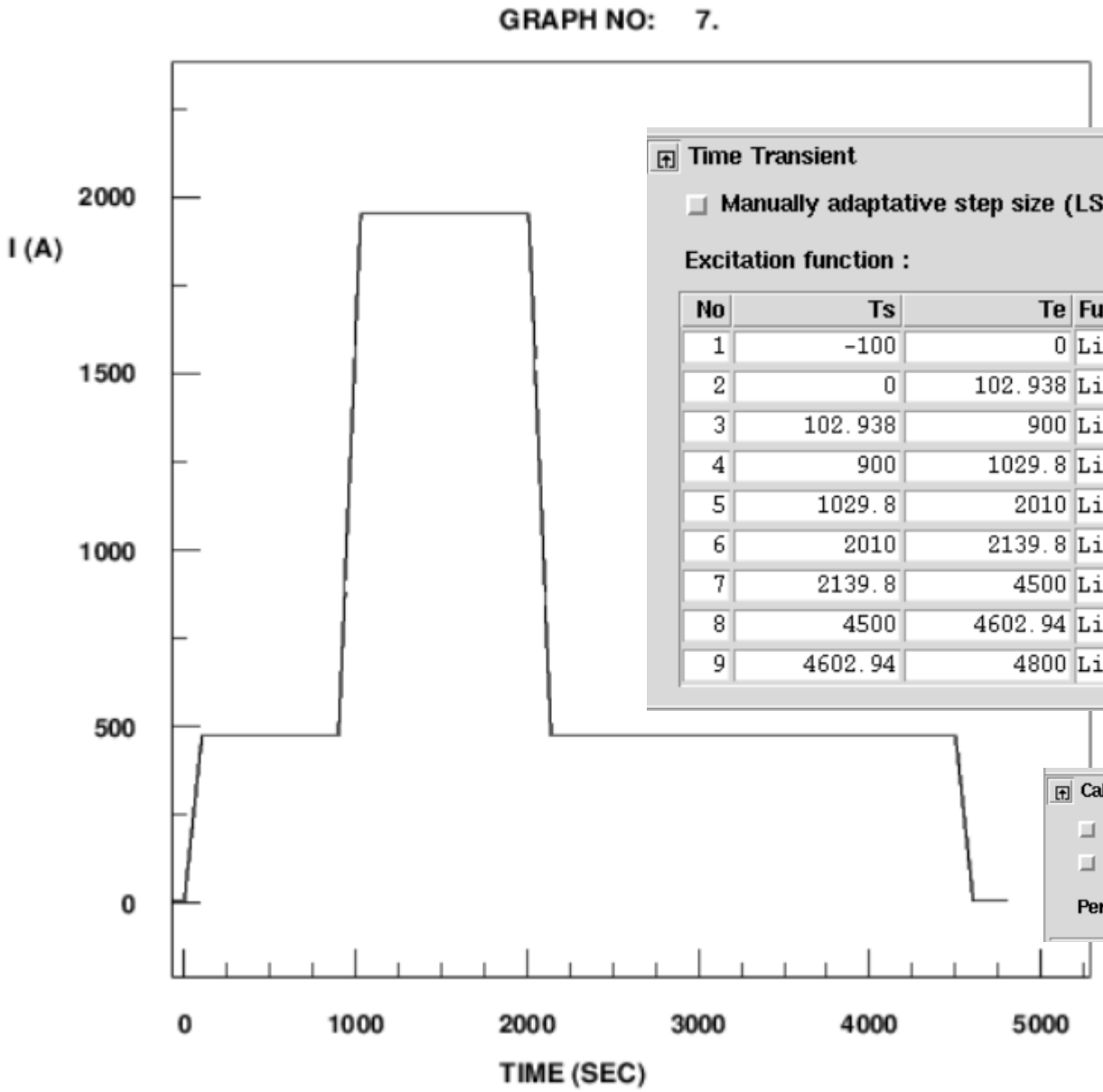
Animesh Jain
(On behalf of the Magnet Test Group)
Superconducting Magnet Division
Brookhaven National Laboratory, Upton, NY 11973

January 16, 2003

Three Measurement Segments

- **Part I:** Ramp from 50 A to 473 A at 5.5 A/s. Data taken during this part give time decay at injection on the up ramp.
- **Part II:** Ramp from 473 A to I_{max} (1952 A or 5046 A) at a chosen ramp rate (20 A/s, 25 A/s or 16 A/s). Data taken during this part provide up ramp branch of hysteresis curves, as well as time decay at I_{max}.
- **Part III:** Ramp down from I_{max} to 473 A at the chosen ramp rate. Data taken during this part give the down ramp branch of the hysteresis curves, as well as time decay at injection on the down ramp.

Persistent Current Cycle Used in ROXIE



Time Transient

Manually adaptative step size (LSTEP)

Excitation function :

No	Ts	Te	Function	A	B	N/a	N/a	Nsteps	Groups
1	-100	0	Linear	0.05	0.05	0	0	4	1-2
2	0	102.938	Linear	0.05	4.73	0	0	20	1-2
3	102.938	900	Linear	4.73	4.73	0	0	5	1-2
4	900	1029.8	Linear	4.73	19.52	0	0	40	1-2
5	1029.8	2010	Linear	19.52	19.52	0	0	5	1-2
6	2010	2139.8	Linear	19.52	4.73	0	0	40	1-2
7	2139.8	4500	Linear	4.73	4.73	0	0	5	1-2
8	4500	4602.94	Linear	4.73	0.05	0	0	20	1-2
9	4602.94	4800	Linear	0.05	0.05	0	0	4	1-2

Cable Eddy Currents

IFCC (magnetization model) (LIFF) ISCC (magnetization model) (LICCA) ISCC (network model) (LICC)

Mut. inductances (LICCIND) Nonlinear inner iterations (LITERNL)

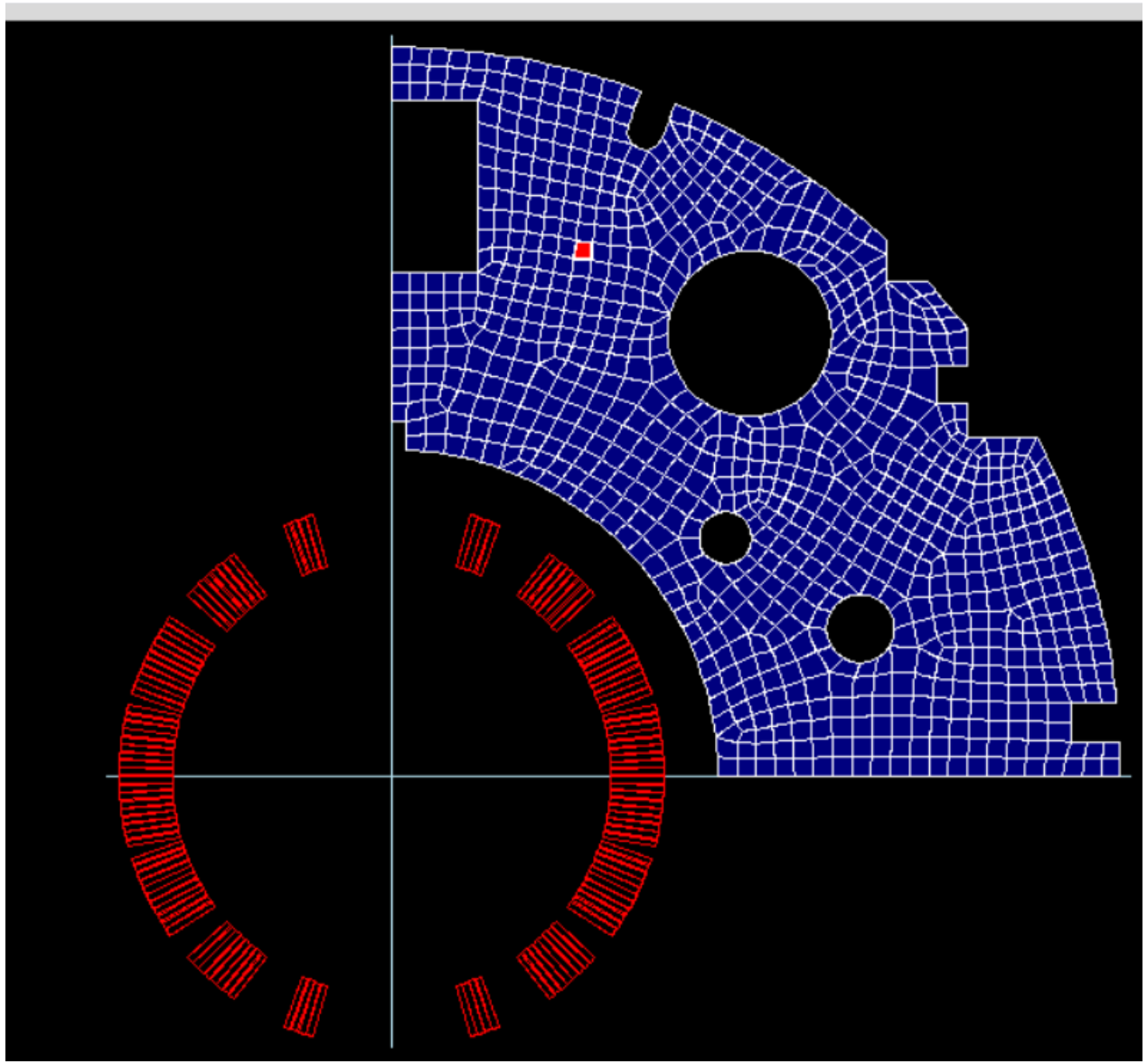
Pers current (Mag. model) : Scalar model

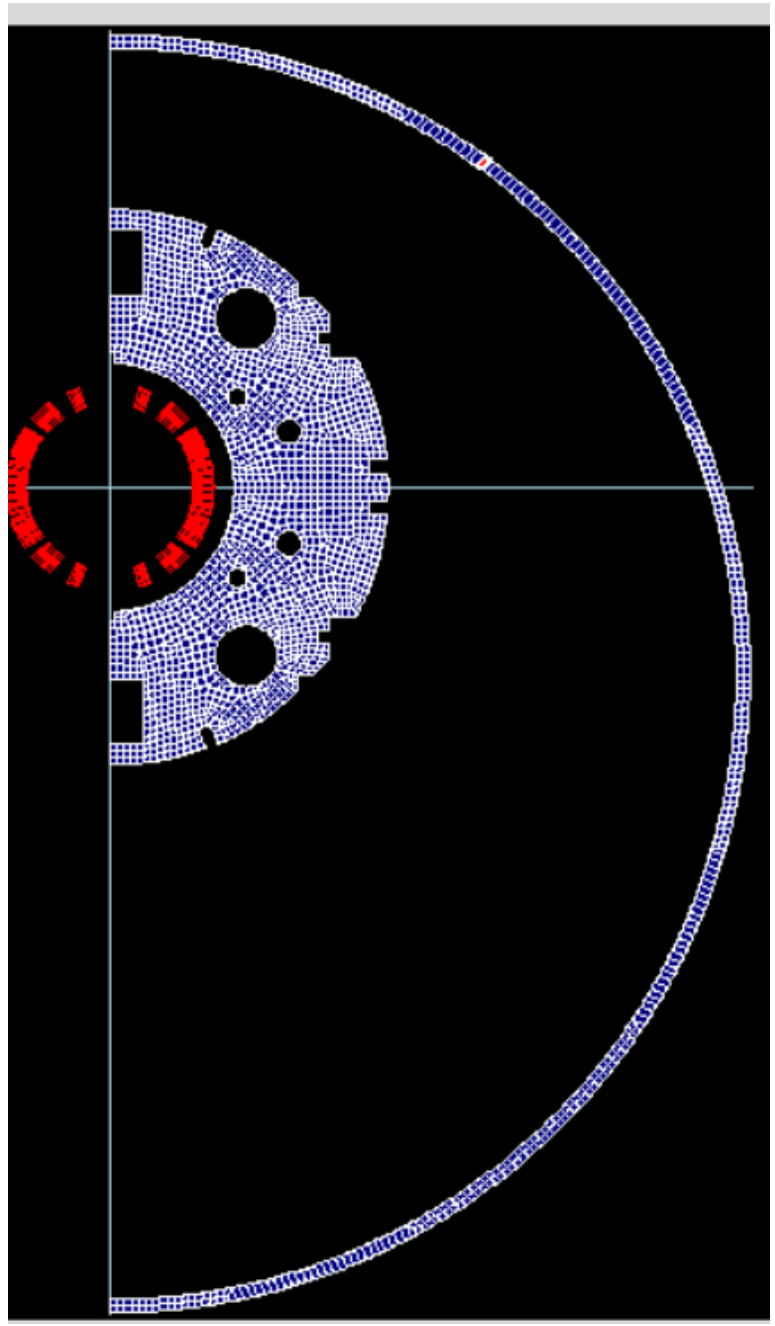
Several options were examined to see the sensitivity on the results

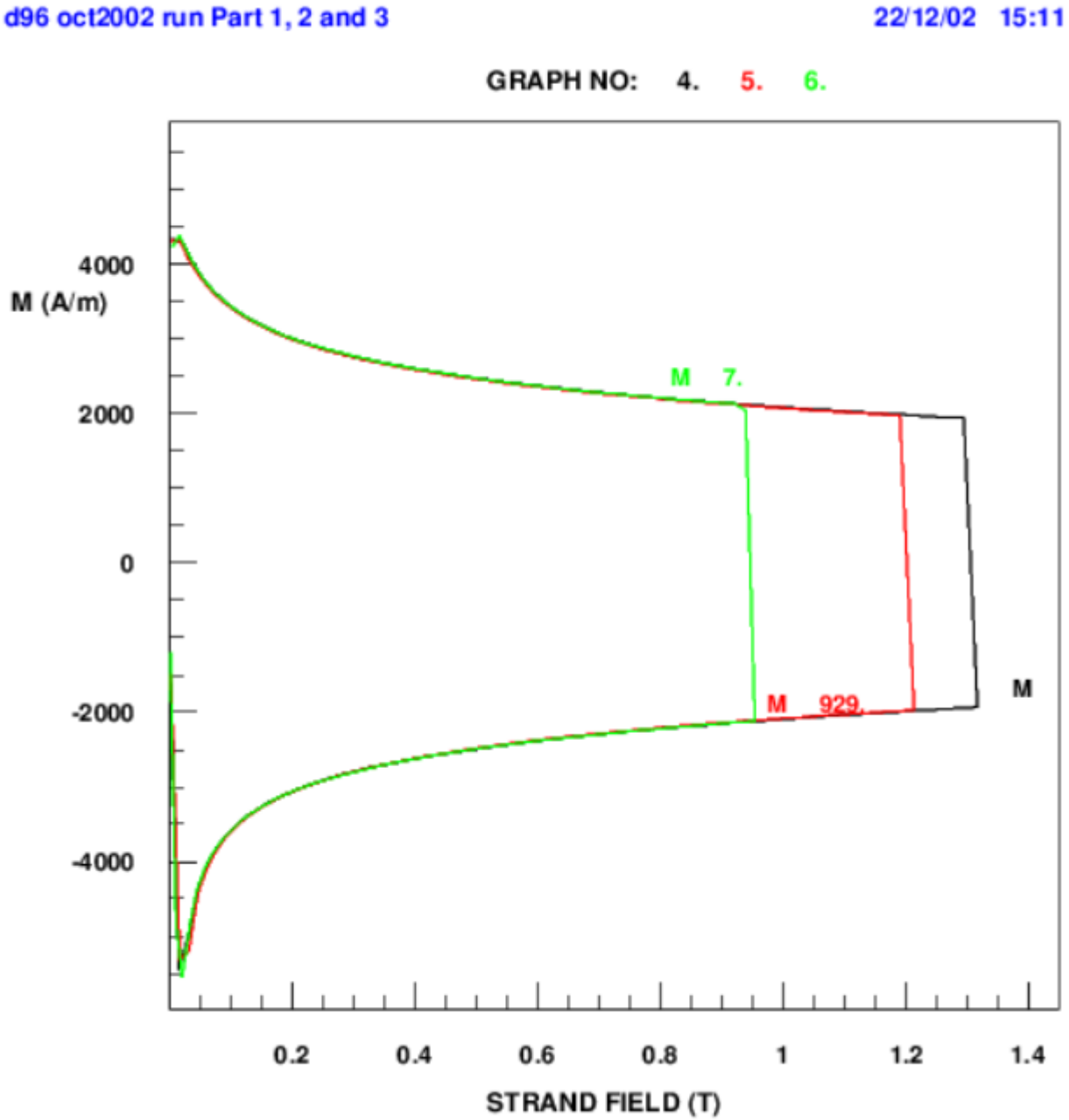
ROXIE Models

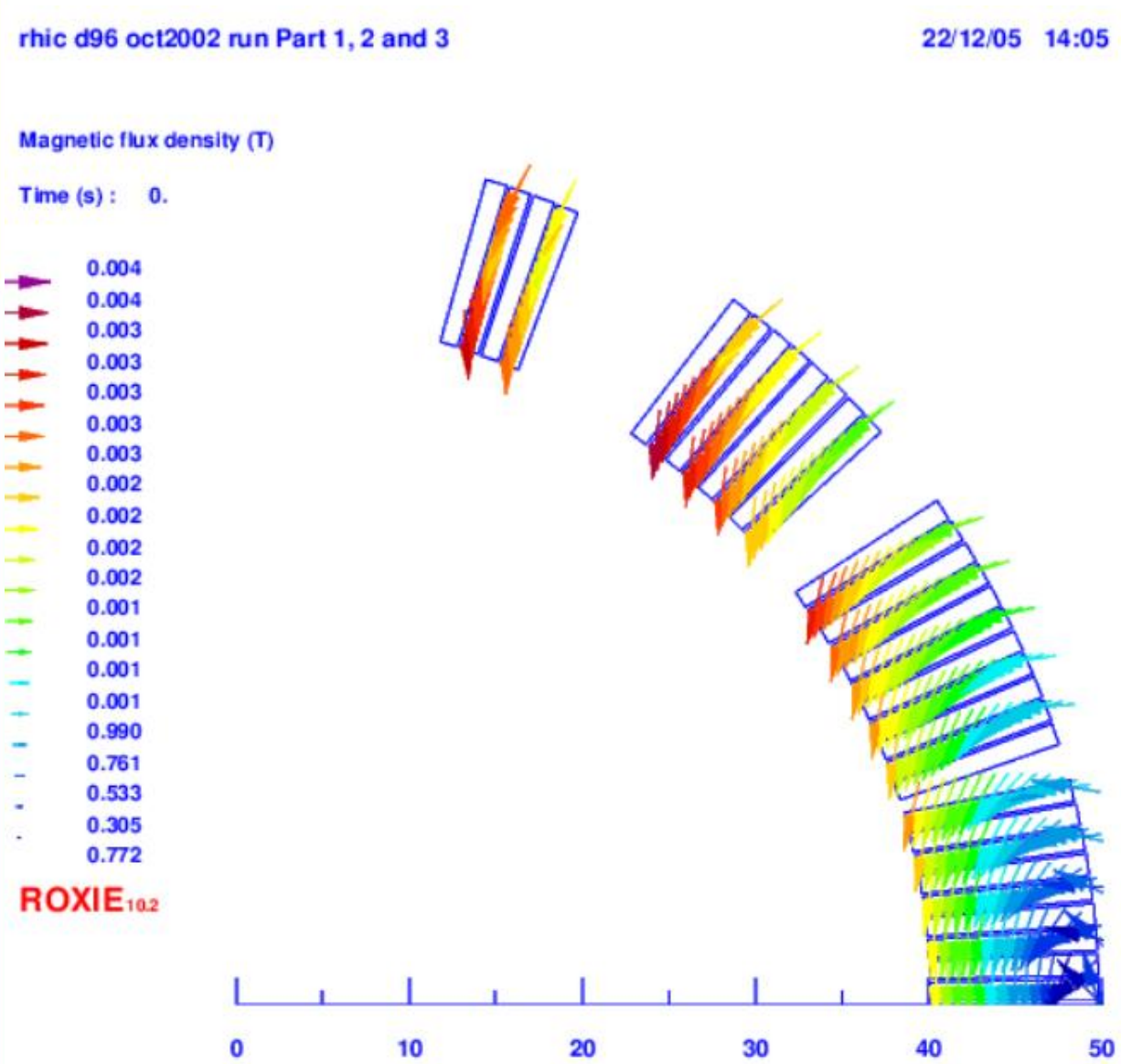
Simplified (4-fold) no cryostat

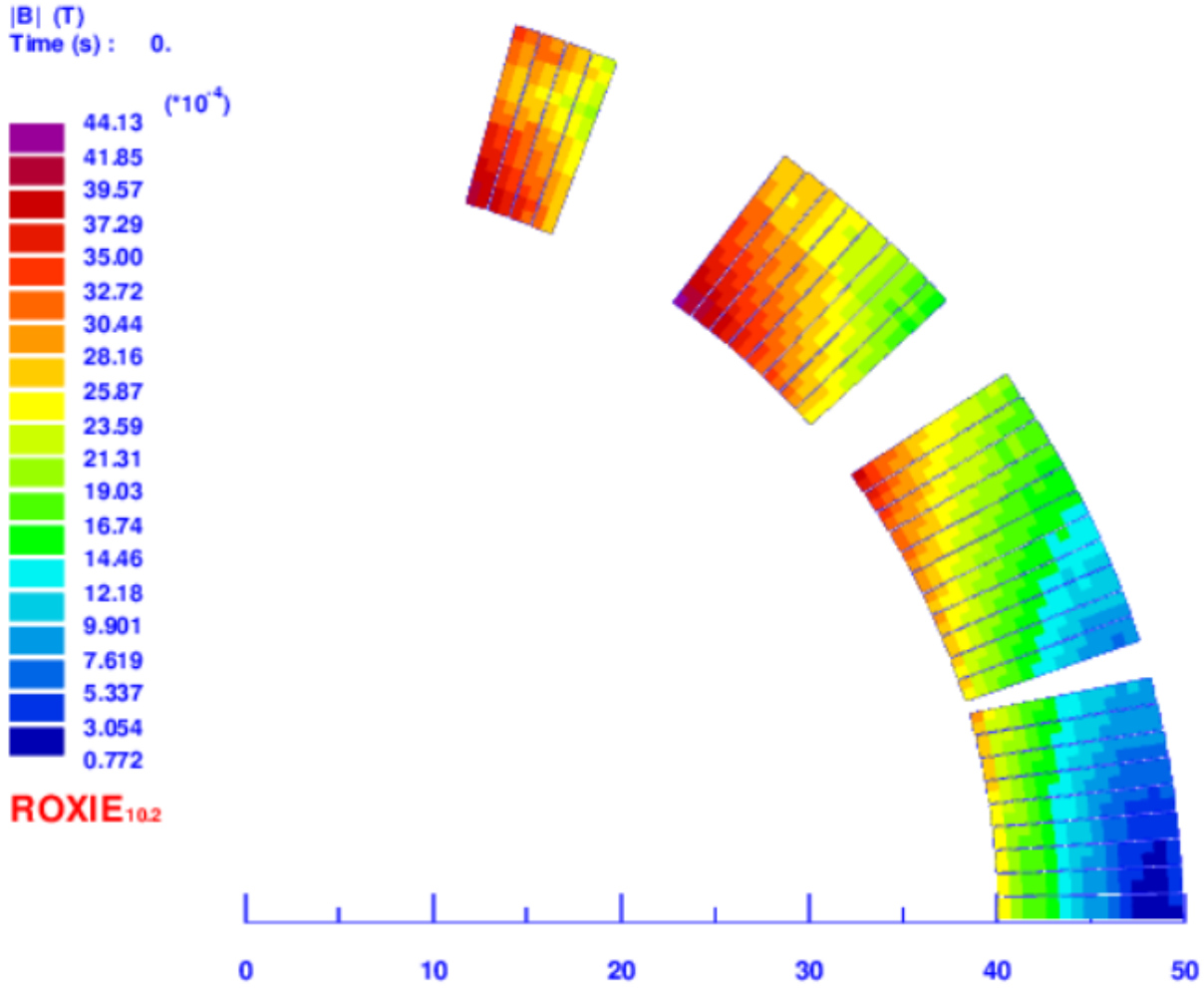
Complete (half) with cryostat

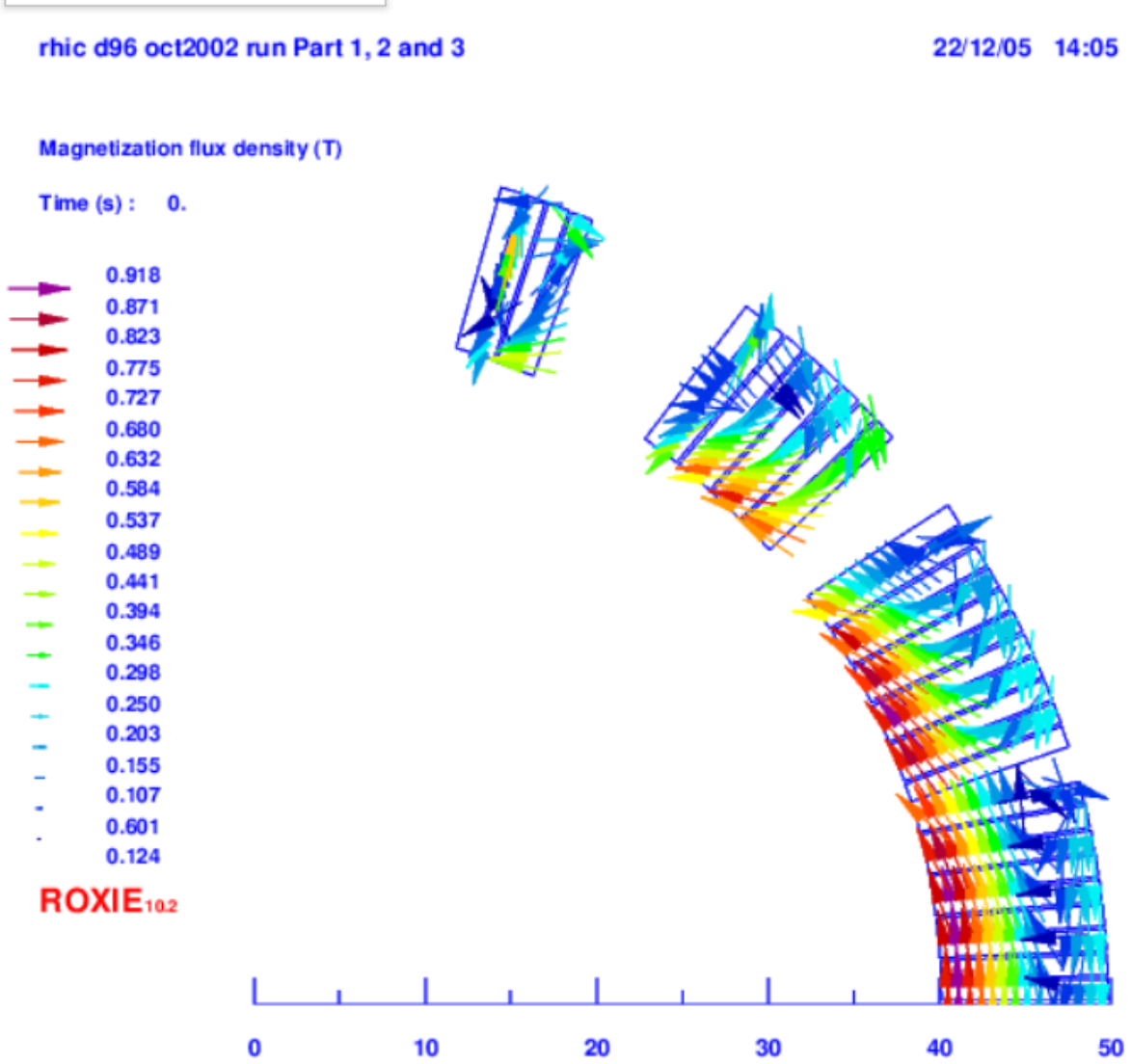


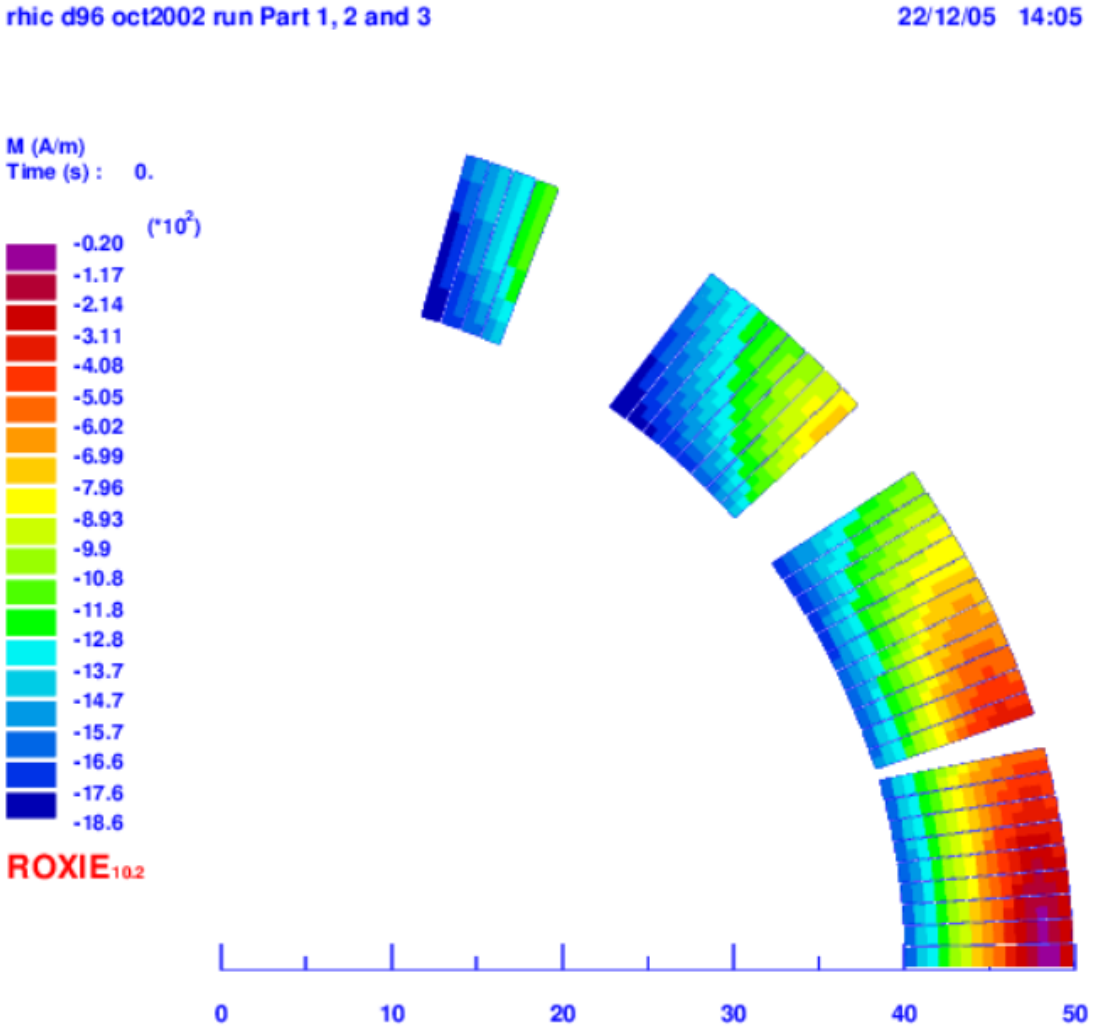


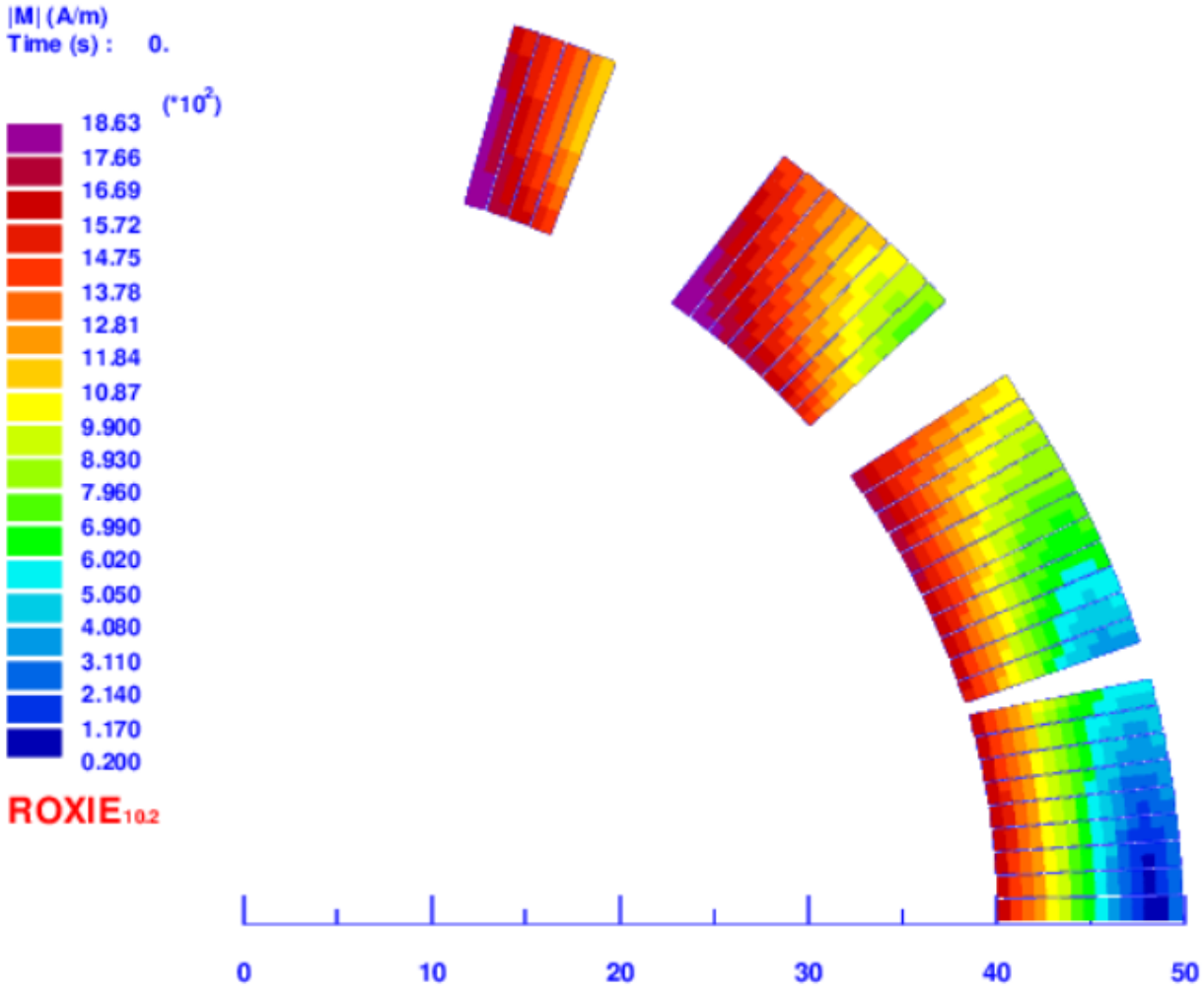

rhic d96 oct2002 run Part 1, 2 and 3
22/12/02 15:11
GRAPH NO: 4. 5. 6.
4000
M (A/m)
2000
0
-2000
-4000
M 7.
M 929.
M
0.2
0.4
0.6
0.8
1
1.2
1.4
STRAND FIELD (T)

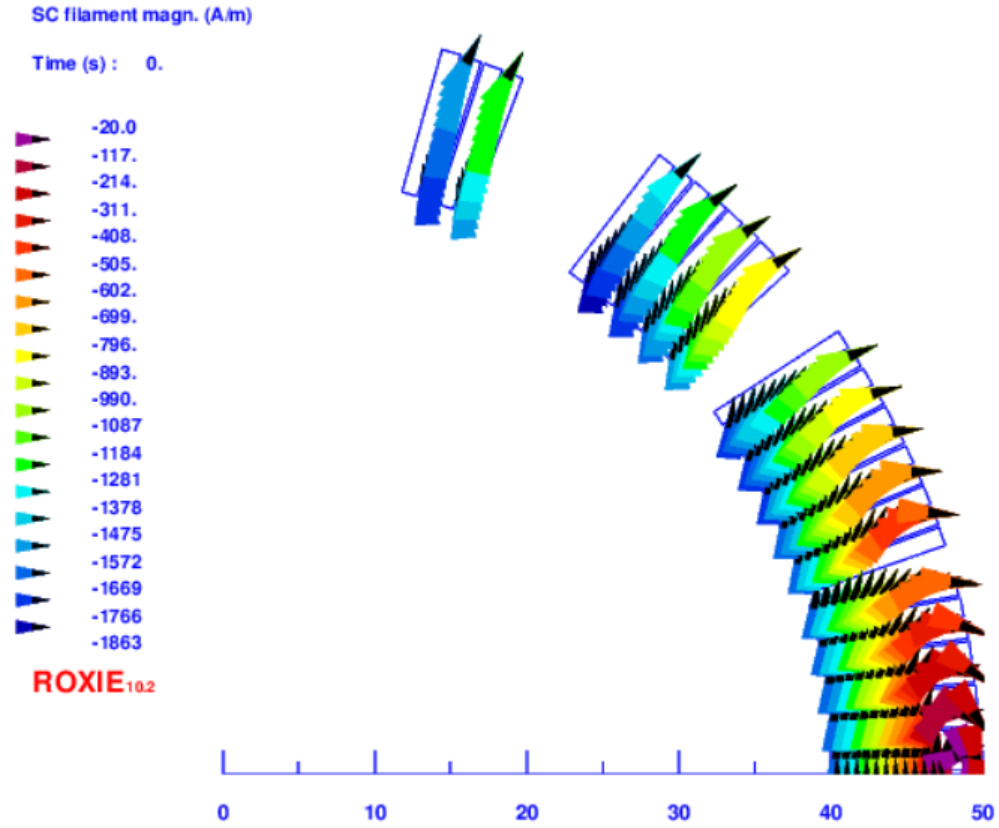

rhic d96 oct2002 run Part 1, 2 and 3
22/12/05 14:05
Magnetic flux density (T)
Time (s) : 0.
0.004
0.004
0.003
0.003
0.003
0.003
0.003
0.002
0.002
0.002
0.002
0.001
0.001
0.001
0.001
0.990
0.761
0.533
0.305
0.772
ROXIE10.2
0
10
20
30
40
50

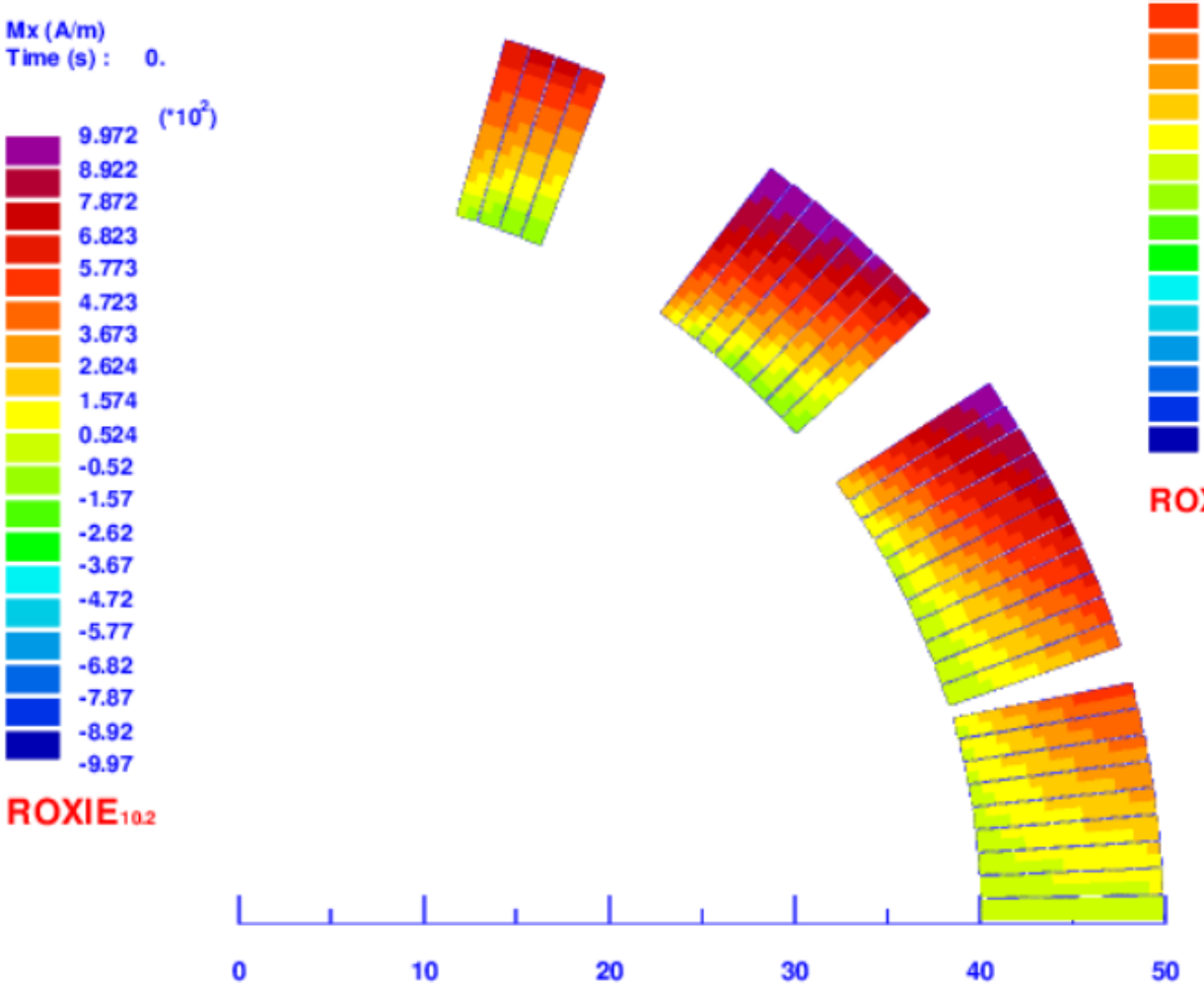

|B| (T)
Time (s) : 0.
(*10-4)
44.13
41.85
39.57
37.29
35.00
32.72
30.44
28.16
25.87
23.59
21.31
19.03
16.74
14.46
12.18
9.901
7.619
5.337
3.054
0.772
ROXIE10.2
0
10
20
30
40
50

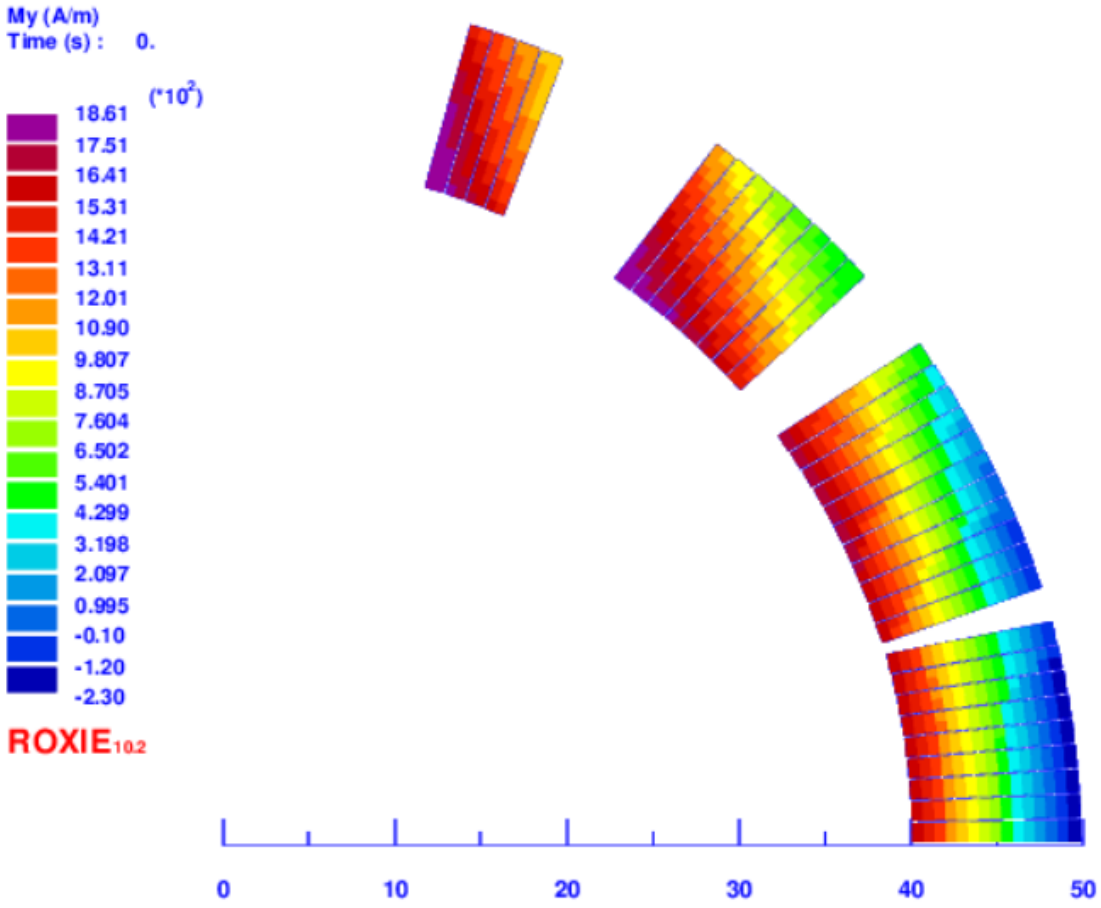

rhic d96 oct2002 run Part 1, 2 and 3
22/12/05 14:05
Magnetization flux density (T)
Time (s) : 0.
0.918
0.871
0.823
0.775
0.727
0.680
0.632
0.584
0.537
0.489
0.441
0.394
0.346
0.298
0.250
0.203
0.155
0.107
0.601
0.124
ROXIE10.2
0
10
20
30
40
50


rhic d96 oct2002 run Part 1, 2 and 3
22/12/05 14:05
M (A/m)
Time (s) : 0.
(*10²)
-0.20
-1.17
-2.14
-3.11
-4.08
-5.05
-6.02
-6.99
-7.96
-8.93
-9.9
-10.8
-11.8
-12.8
-13.7
-14.7
-15.7
-16.6
-17.6
-18.6
ROXIE10.2
0
10
20
30
40
50

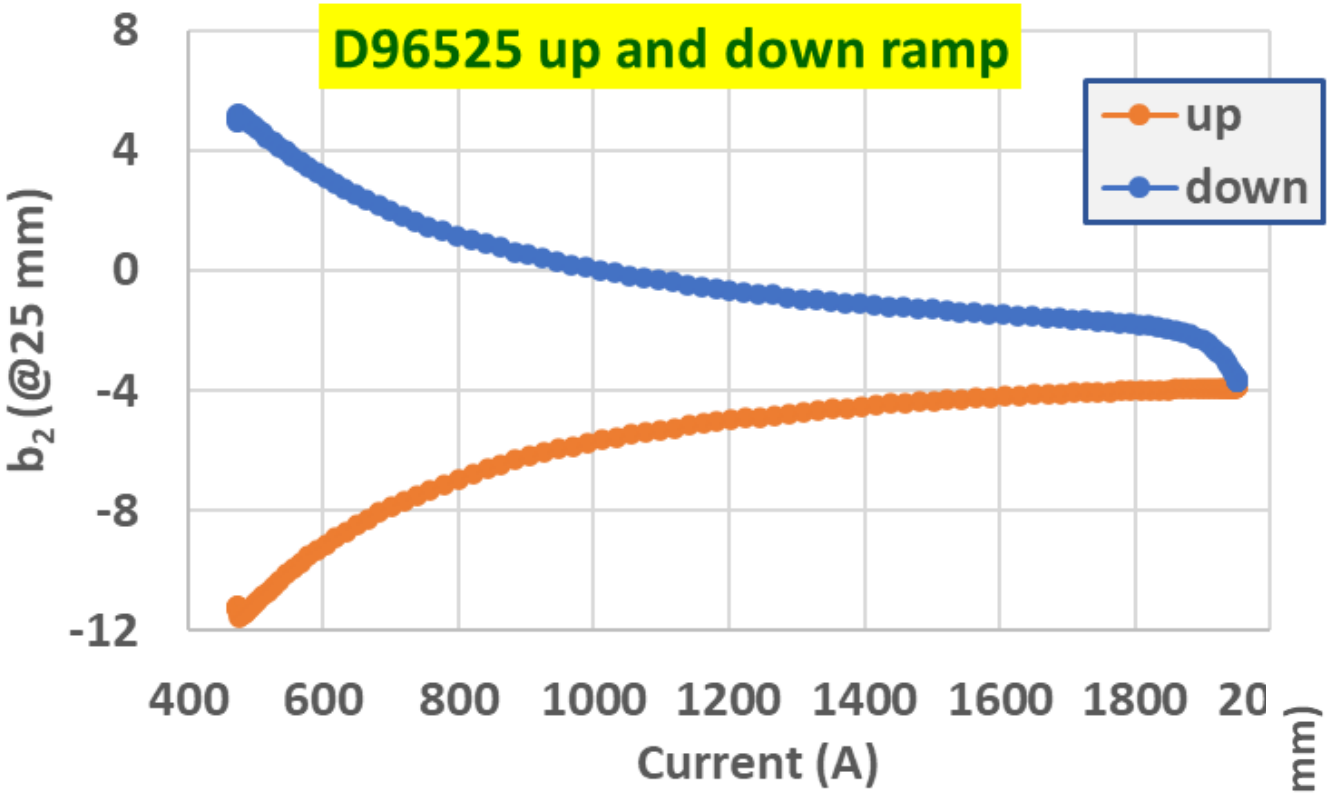

|M| (A/m)
Time (s) : 0.
(*10^2)
18.63
17.66
16.69
15.72
14.75
13.78
12.81
11.84
10.87
9.900
8.930
7.960
6.990
6.020
5.050
4.080
3.110
2.140
1.170
0.200
ROXIE10.2
0
10
20
30
40
50

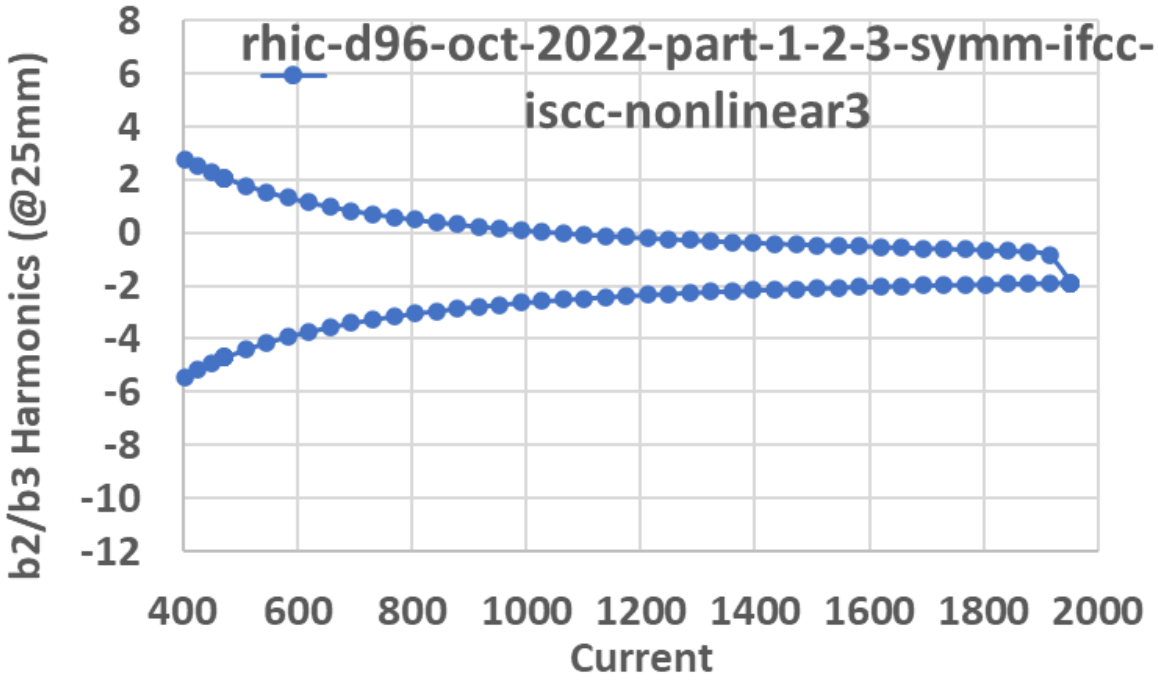

SC filament magn. (A/m)
Time (s) : 0.
-20.0
-117.
-214.
-311.
-408.
-505.
-602.
-699.
-796.
-893.
-990.
-1087
-1184
-1281
-1378
-1475
-1572
-1669
-1766
-1863
ROXIE10.2
0
10
20
30
40
50


Mx (A/m)
Time (s) : 0.
(*10^2)
9.972
8.922
7.872
6.823
5.773
4.723
3.673
2.624
1.574
0.524
-0.52
-1.57
-2.62
-3.67
-4.72
-5.77
-6.82
-7.87
-8.92
-9.97
ROXIE10.2
0
10
20
30
40
50

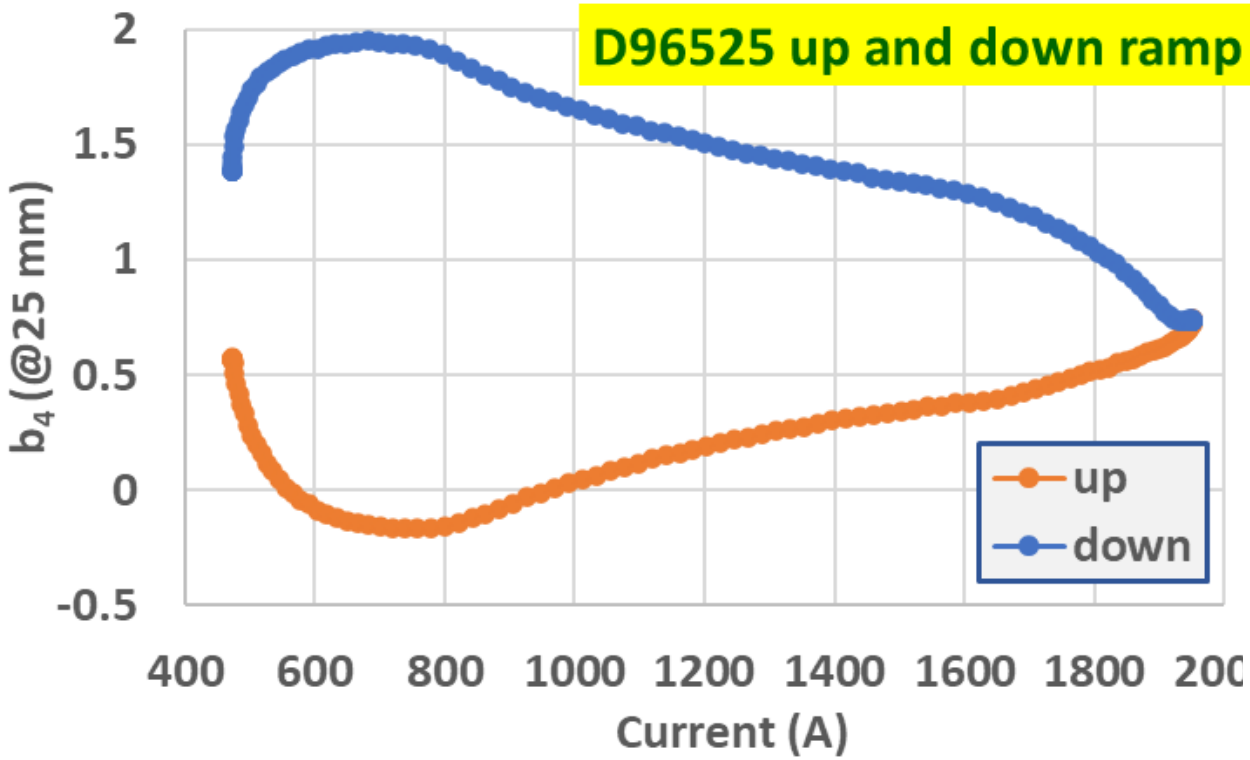

My (A/m)
Time (s) : 0.
(*10^2)
18.61
17.51
16.41
15.31
14.21
13.11
12.01
10.90
9.807
8.705
7.604
6.502
5.401
4.299
3.198
2.097
0.995
-0.10
-1.20
-2.30
ROXIE10.2
0
10
20
30
40
50

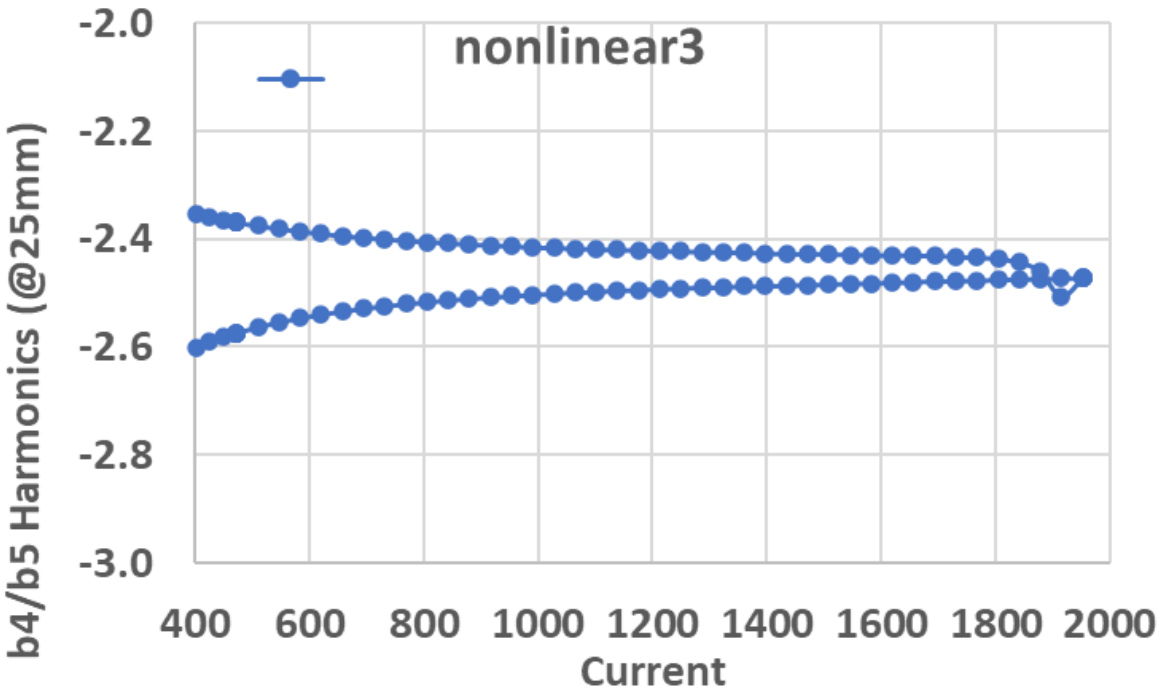
Initial First Look at Comparing





Initial First Look at Comparing





Initial First Look at Comparing