Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

Q1ApF Cross section for 2K Operation (one design study)

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Basic Parameters of the current Q1ApF Design

Parameters from pCDR:

Table 6.2: Parameters of the Q1ApF magnet.

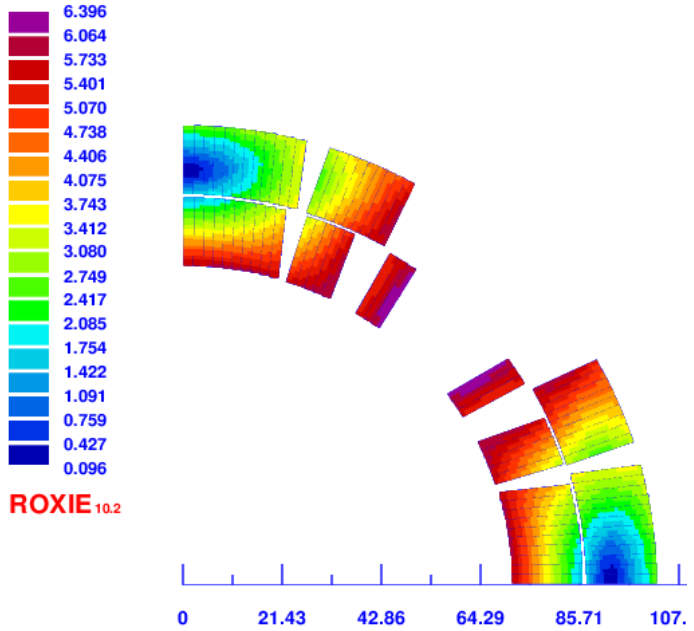
Parameter	Value
Magnetic length [m]	1.46
Maximum gradient [T/m]	72.6
Aperture diameter [m]	0.1120
Required field quality	1×10^{-4}
Physical length [m]	1.48
Physical width [m]	0.182
Physical height [m]	0.182
Superconductor type	NbTi
Conductor	Cable $20 \times 2\,mm^2$
Current density [A/mm] ^{2}	512
Cu:Sc ratio	1.3
Temperature [K]	1.8
Peak field wire [T]	6.85
Magnetic energy [J]	360000
Ampere turns [kA·t]	360
Number of turns	18
Current [kA]	20
Inductance [mH]	1.8
Margin loadline [%]	32

Parameters used in the current design:

- Gradient: 72.6 T/m (revised from pCDR, current ~75 T/m)
- Physical Length: 1.48 m

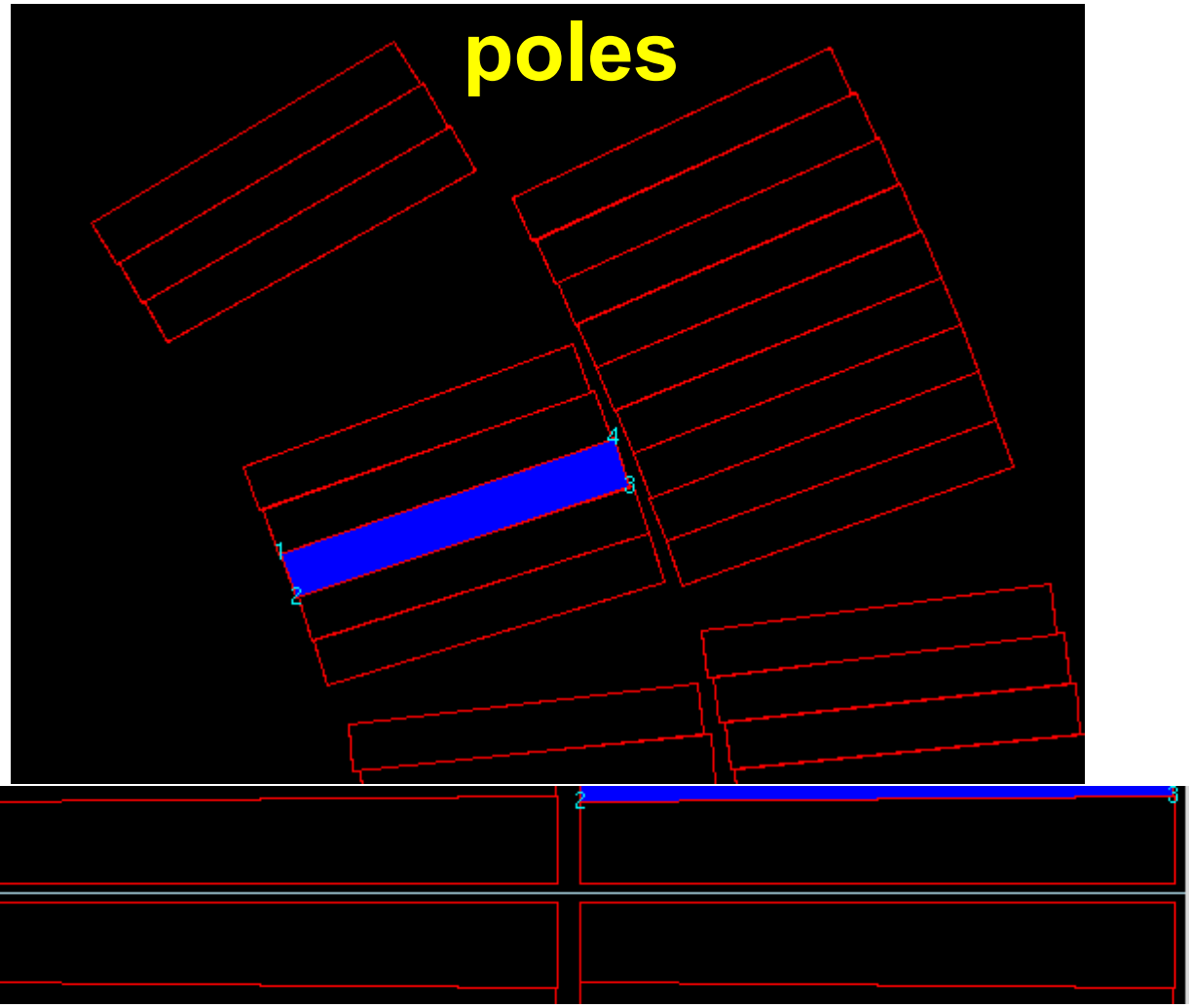
(not fixed, depends on Q1BpF)

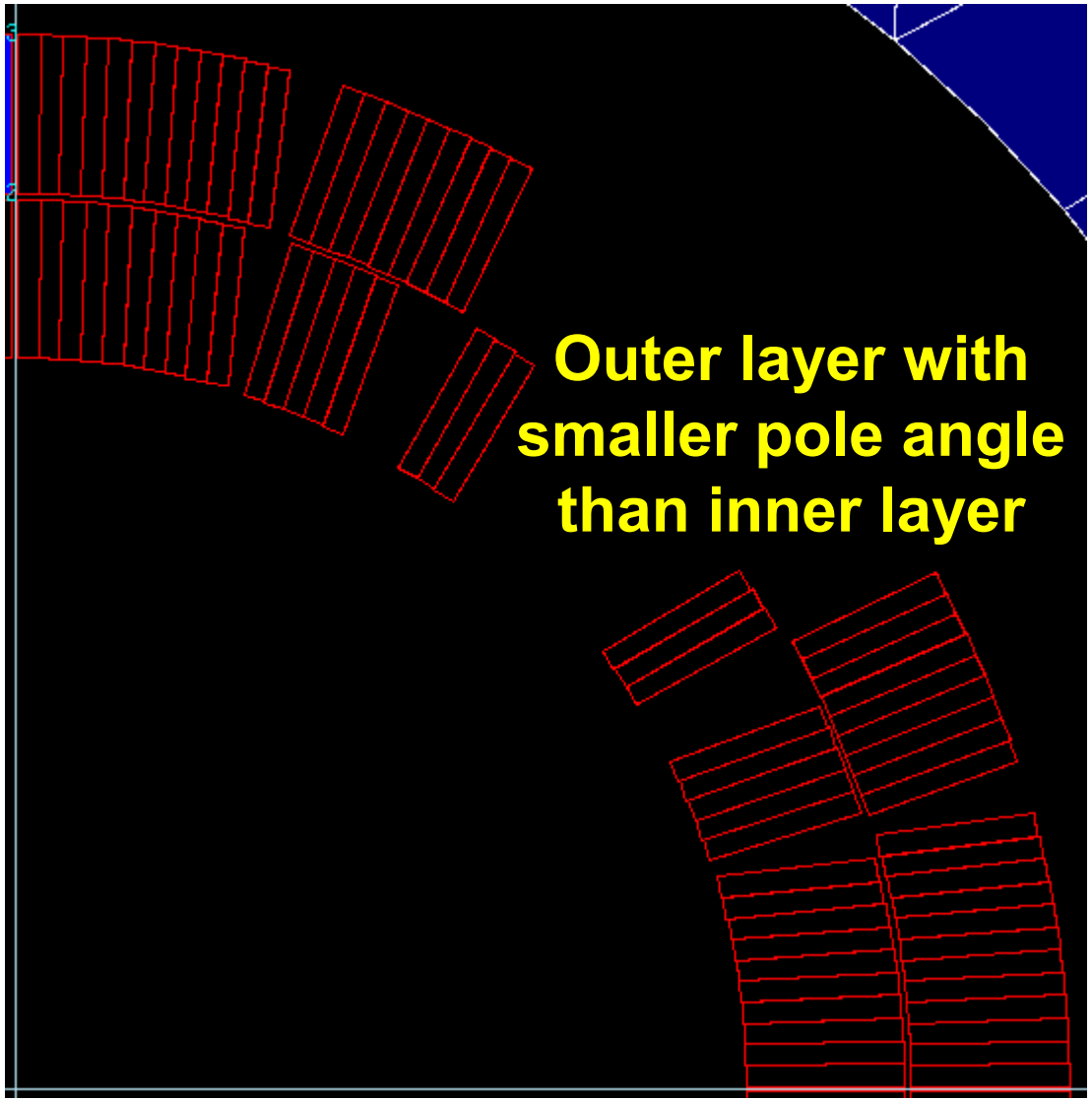
- Coil inner radius: 71 mm
- Estimated effective length: 1.48 - 0.071 = ~1.4 m
- Estimated gradient in body: 75*1.48/1.4 = ~79.3 T/m
- Cable: 15 mm
  - LHC inner type
  - Also used in B1pF/B1ApF
- Cu/SC: 1.6
- Temperature: 2 K



Optimization of Coil Geometry (pictorial)

- Angle for poles for collars, two layers, wedges, gap at midplane (+/- 0.25 mm)





Optimization of Coil Geometry – ROXIE Input

Input to coil geometry

Xroxie [/home/gupta/EIC/cable15mm/Q1ApF/05r-Q1APF-b1b-NON-IP10kA.data]

File Edit Display Run

Comment : Q1APF 15mm EIC-LHC-B cable@2K, 30 mm collar RG

Main Options

3D geometry (LEND) | Endspacers (LWEDG) | Time transient (LPERS)

Quench simulation (LQUENCH) | Optimization (LALGO)

Cable data path : /home/gupta/EIC/cable15mm/Q1ApF/roxie-eic.cadata Browse View file

2D Options

Fields & forces in coil (LPEAK) | Margin to linear Jc-approx. (LINMARG) | Margin to Jc-fit (LMARG)

Self field in strands (LSELF) | Enthalpy margins (LMQE) | Inductance and energy (LINDU)

Cable eddy currents (LEDDY) | Axi-symmetry (for solenoids) (LSOLE)

Block Data 2D

No	Type	NCab	R	φ	α	Current	Cable name
1	Cos	10	71	0.2017	0	10000	EICLHCB2K
2	Cos	5	71	17.518	20	10000	EICLHCB2K
3	Cos	3	71	30.897	32	10000	EICLHCB2K
4	Cos	12	87	0.1646	0	10000	EICLHCB2K
5	Cos	9	87	17.518	25	10000	EICLHCB2K

Midplane half-gap = 0.25 mm (both layers)

Design Variables

Optimization algorithm : 1 Extrem ?

No	Xl	Xu	Xs	String	Act	N/a
1	1	5	1.43	PHIR	2	2
2	10	14	10.7145	ALPHR	2	2
3	1	9	5.0778	PHIR	2	3
4	6	9	8.8244	ALPHR	2	3
5	1	7	1.3611	PHIR	2	5
6	12	12	12	ALPHR	2	5

Edit Cable Data [/home/gupta/EIC/cable15mm/Q1ApF/roxie-eic.cadata]

File Display

Cable parameters

Insulation

No	Name	Radial	Azimut	Comment
1	BARE	0	0	BARE
2	ALLPOLYIL	0.15	0.12	POLYIMID MB INNER
3	ALLPOLYOL	0.15	0.13	POLYIMID MB OUTER
4	ALLPOLMQY	0.08	0.08	POLYIMID MQY,MQM
5	ALLPOLMQ	0.13	0.11	POLYIMID MQ

Jc-Fit

No	Name	Type	C1	C2	C3	C4	C5	C6	C7	C8
1	FIT1	1	3E+09	9.2	0.57	0.9	2.32	27.04	14.5	0
2	TES1	1	3E+09	9.2	0.57	0.9	2.32	27.04	14.5	0
3	GSIFIT	1	3E+09	9.2	0.7	1.57	1	25	14.5	0
4	SISFIT	1	3E+09	9.33517	0.68	0.8477	2.23234	25	14.5	0

Filament

No	Name	fildiao	fildiai	Jc-Fit	Comment
1	TESTI1	6	0	TES1	NBTI INNER CABLES
2	TESTO1	5	0	TES1	NBTI INNER CABLES
3	NBTII	7	0	FIT1	NBTI INNER CABLES
4	NBTIO	6	0	FIT1	NBTI OUTER CABLES
5	NB3SN	22	12	FIT1	NB2SN TWENTE

Strand

No	Name	diam.	cu/sc	RRR	Tref	Bref	Jc@BrTr	dJc/dB	Comment
1	STREIC1	1.065	1.6	70	1.9	10	1591	500.34	EIC BRUKER-CERN SCALED,7%DEGRA
2	STR01	1.065	1.6	70	1.9	10	1433.3	500.34	MB INNER
3	STR02	0.825	1.9	80	1.9	9	1953	550.03	MB OUTER, MQ
4	WIRE3	0.93683	1.6	70	4.222	5	2640	606.8	MCS,MCD,MQT?
5	GSI1STRA	0.648	2.21	187	4.2	5.5	2495.24	583.898	GSI001 (RHIC) STRANDS

Transient

Quench Material Properties

Cable Geometry

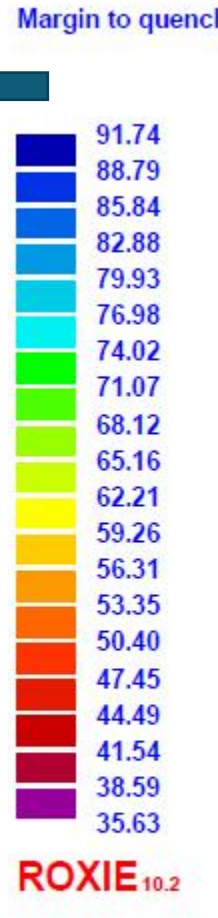
No	Name	height	width_i	width_o	ns	transp.	degrd	Comment
1	EICLHCB	15.1	1.816	1.984	28	115	5	LHC IN KEYSTOE FOR EIC DIPOLE
1	EICLHCQ	15.1	1.79	2.01	28	115	5	LHC IN KEYSTONE FOR EICIR QUAD
1	EICLHC01	15.1	1.786	2.014	28	115	5	LHC CABLE KEYSTOR FOR EIC 4.2K
2	EIC3642	19.4	1.773	2.027	36	115	3	EIC 36 STRAND @4.2K
3	EIC3618	19.4	1.773	2.027	36	115	3	EIC 36 STRAND @1.8K

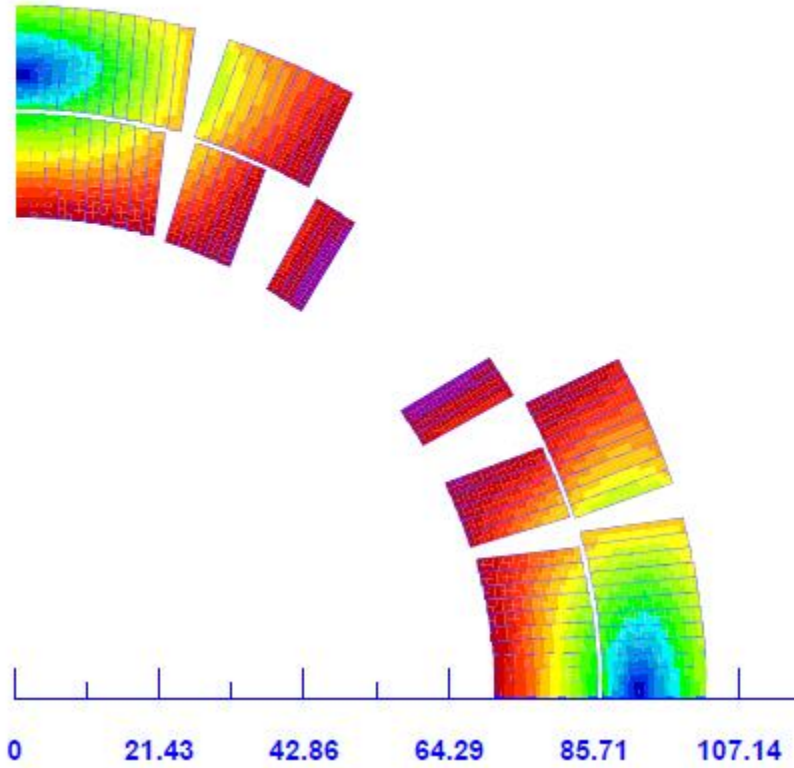
Cable Definition

No	Name	Cable Geom.	Strand	Filament	Insul	Trans	Quench Mat.	T_o	Comment
1	EICLHCB2K	EICLHCB	STREIC1	NBTII	ALLPOLYIL	TRANS1	NONE	2	LHC INNER FOR EIC IR Dipole@2K
2	EICLHCQ2K	EICLHCQ	STREIC1	NBTII	ALLPOLYIL	TRANS1	NONE	2	LHC INNER FOR EIC IR Quad @2K
3	LHCIN42K	EICLHC01	STREIC1	NBTII	ALLPOLYIL	TRANS1	NONE	4.2	LHC INNER FOR EIC @4.2K
4	YELLONIN	CABLE01	STR01	NBTII	ALLPOLYIL	TRANS1	NONE	1.9	V6-1 DESIGN DIPOLE INNER
5	YELLONOU	CABLE02	STR02	NBTIO	ALLPOLYOL	TRANS1	NONE	1.9	V6-1 DESIGN DIPOLE OUTER

Quench Margin in the X-section of the Q1ApF @2K

MAIN FIELD (T)	-3.384763
MAGNET STRENGTH (T/(m^(n-1))	-79.8293
BLOCK NUMBER	23
PEAK FIELD IN CONDUCTOR 156 (T)	6.3964
CURRENT IN CONDUCTOR 156 (A)	10000.0000
LOWEST FIELD IN CONDUCTOR 154 (T)	5.0786
SUPERCONDUCTOR CURRENT DENSITY (A/MM2)	1042.3804
COPPER CURRENT DENSITY (A/MM2)	651.4877
PERCENTAGE ON THE LOAD LINE	64.3614
QUENCHFIELD (T)	9.9383
TEMPERATURE MARGIN TO QUENCH (K)	3.2390
PERCENTAGE OF SHORT SAMPLE CURRENT	28.3054





- Operational margin = 100/64.4 = >55%

Recall 75 T/m meant and estimated integral of 79.3 T/m. We have a healthy margin

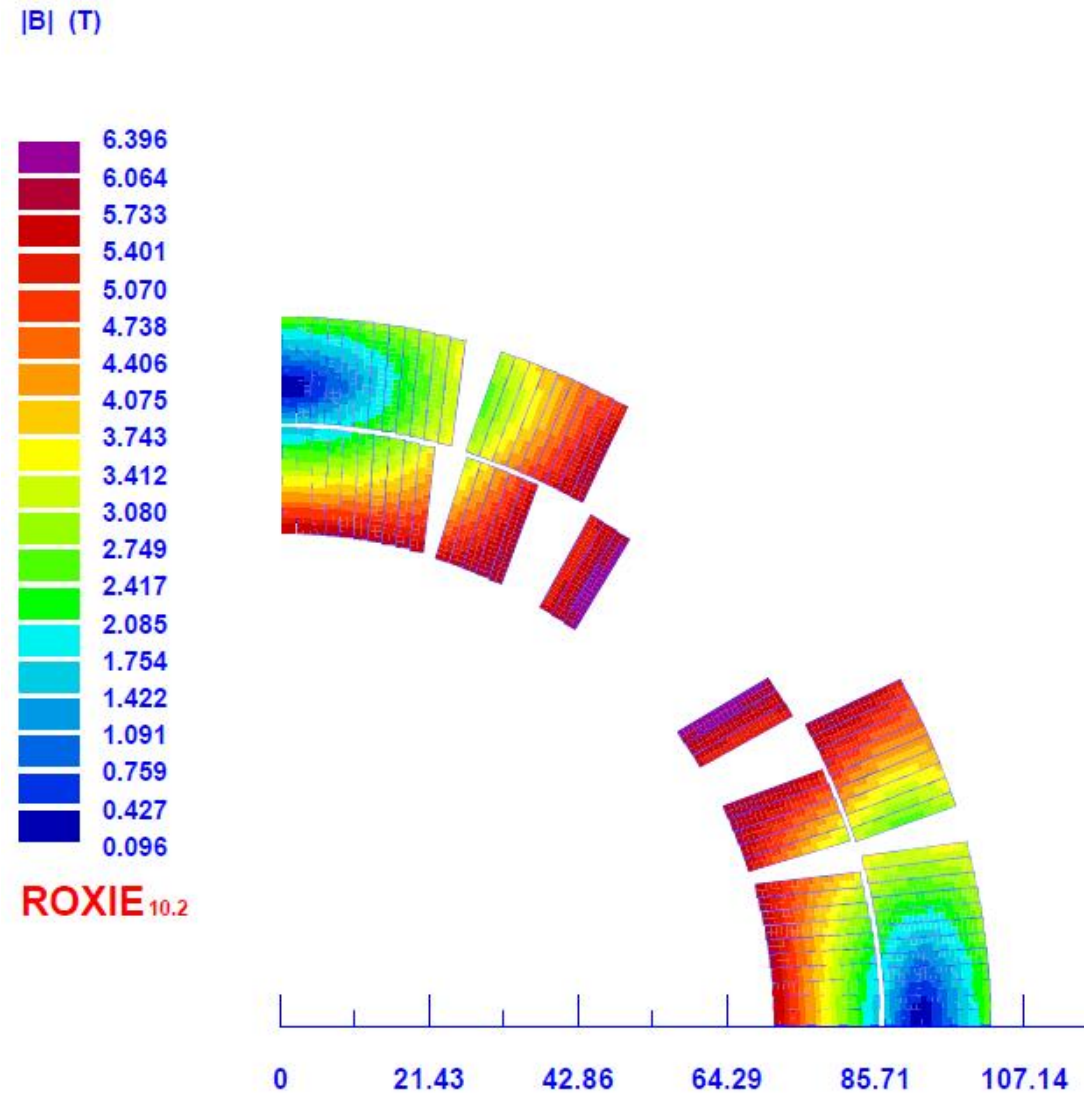
Should be able to operate @80 T/m (~84.6 T/m in body), with a good margin

Quench Margin in the Current X-section of the Q1ApF

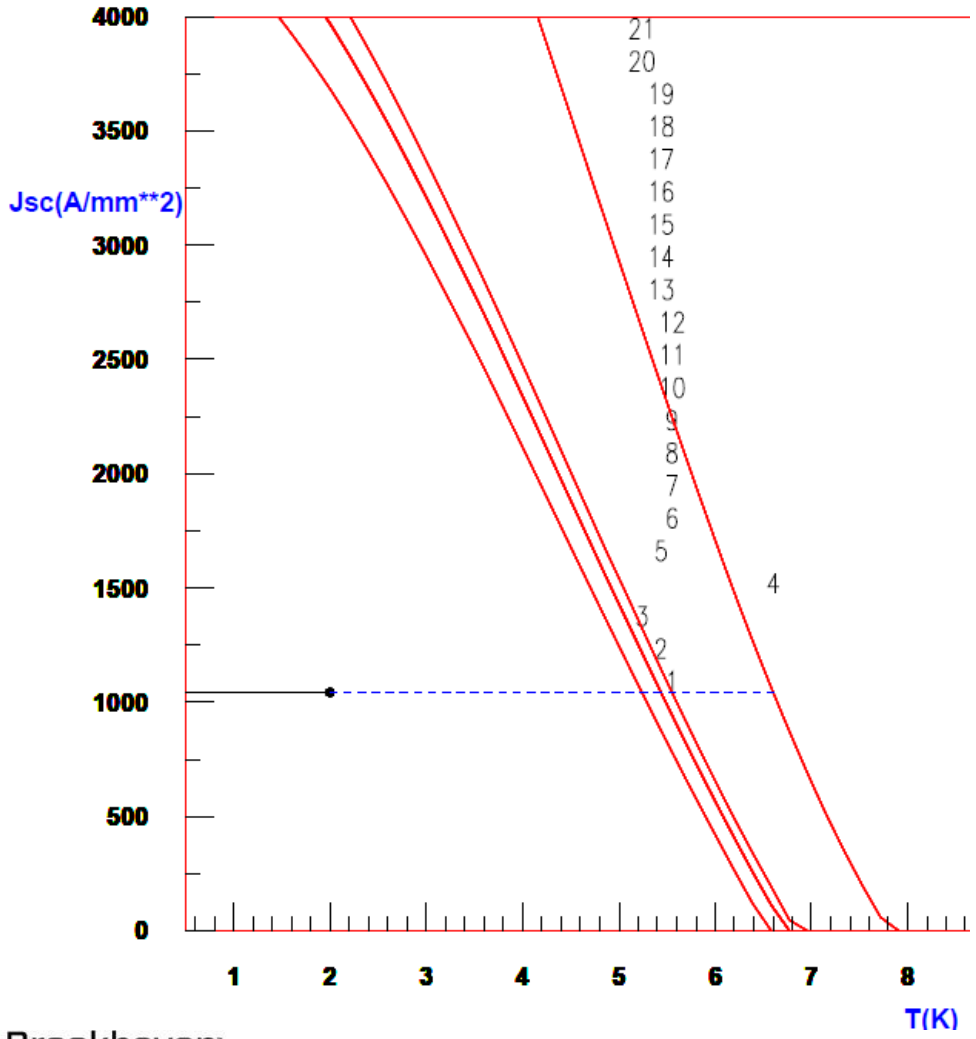
Peak Field Enhancement

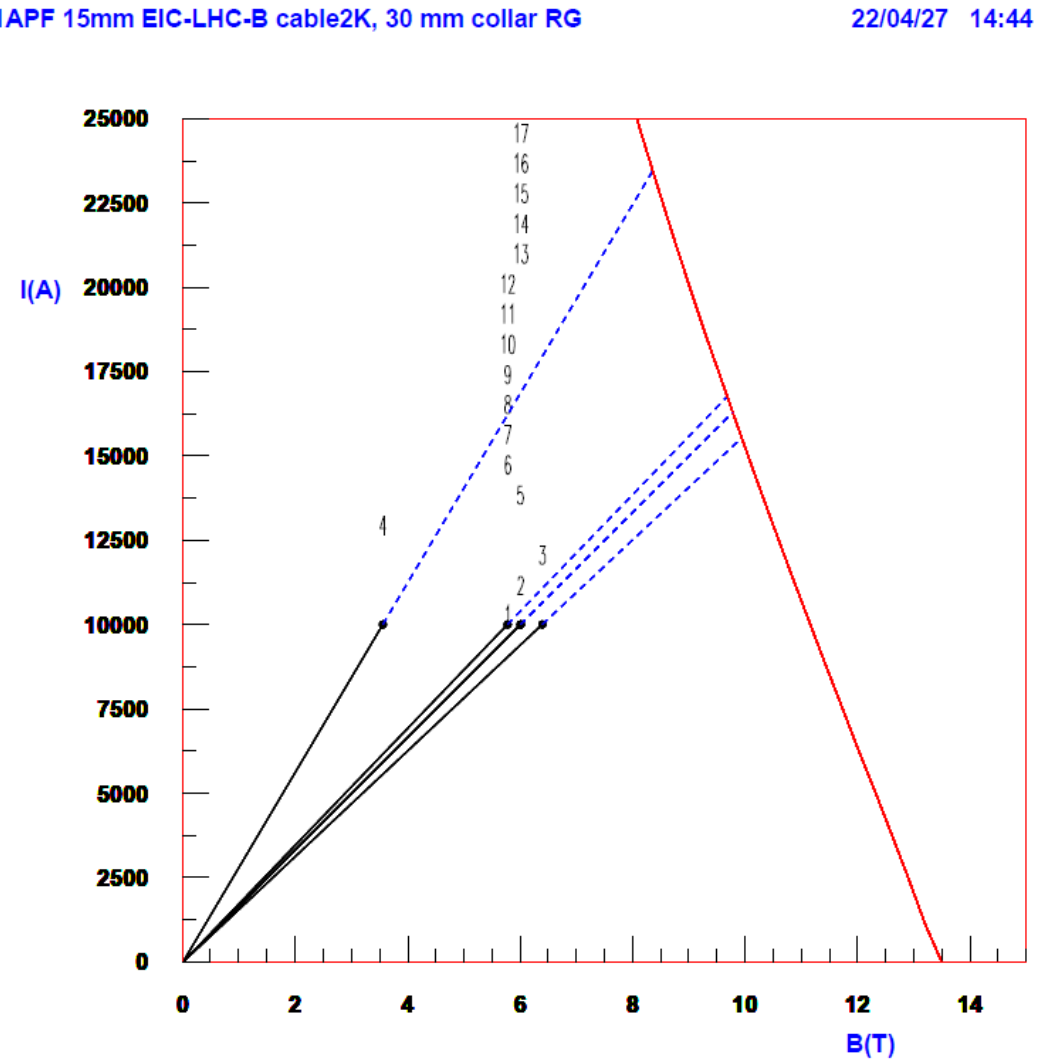
- Field gradient = 79.8 T/m (@10kA)
- Coil Radius = 71 mm
- Computed midplane field at coil radius = 0.071 * 79.83 = 5.668 T
- Peak field enhancement = 6.396/5.668 = 12.8%

Making outer layer smaller than inner layer reduces peak field significantly



Quench Margin in the Current X-section of the Q1ApF at 2 K

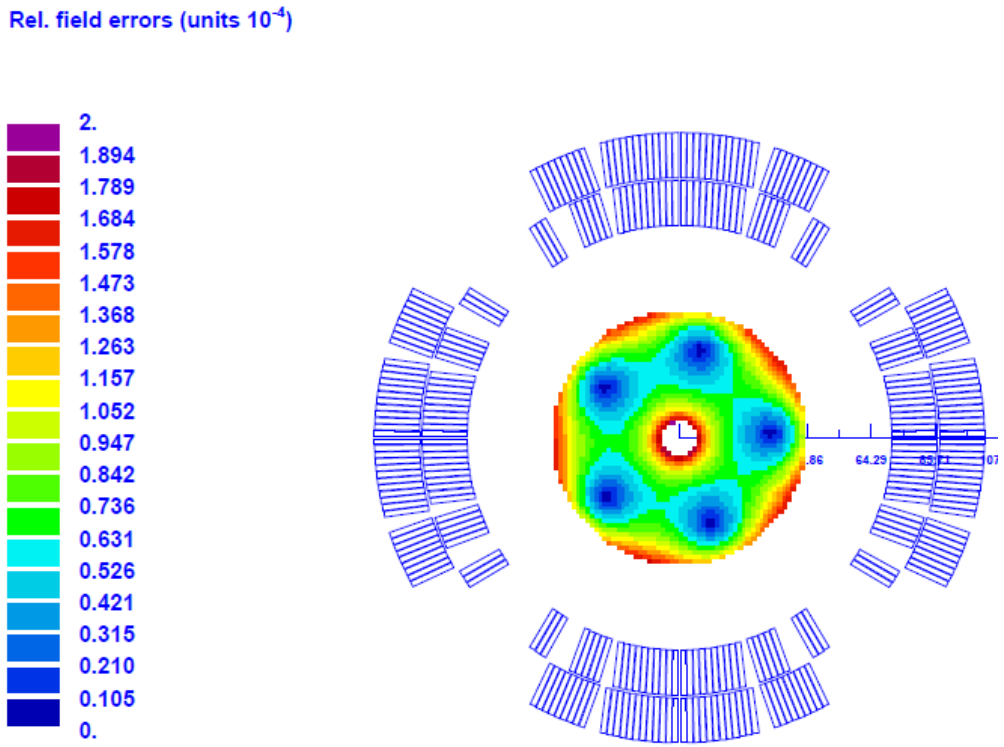




Field Quality (Geometric Harmonics @2kA)

GOAL: Obtain low field harmonics in a geometry which is good mechanically

Field quality at 2kA

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HARMONIC ANALYSIS NUMBER ..............................          1
MAIN HARMONIC ..........................................          2
REFERENCE RADIUS (mm) ..................................      42.4000
X-POSITION OF THE HARMONIC COIL (mm) ...................       0.0000
Y-POSITION OF THE HARMONIC COIL (mm) ...................       0.0000
MEASUREMENT TYPE ......................... ALL FIELD CONTRIBUTIONS
ERROR OF HARMONIC ANALYSIS OF Br .....................   0.6637E-05
SUM (Br(p) - SUM (An cos(np) + Bn sin(np))

MAIN FIELD (T) .........................................    -0.684996
MAGNET STRENGTH (T/(m^(n-1)) ...........................     -16.1556

NORMAL RELATIVE MULTIPOLES (1.D-4):
b 1:     -0.08823  b 2:  10000.00000  b 3:     -0.00288
b 4:     -0.00176  b 5:     -0.00101  b 6:     -0.00053
b 7:     -0.00004  b 8:     -0.00001  b 9:     -0.00000
b10:      0.00002  b11:     -0.00000  b12:      0.00000
b13:     -0.00000  b14:     -0.02185  b15:     -0.00000
b16:     -0.00000  b17:      0.00000  b18:      0.00290
b19:      0.00000  b20:     -0.00000  b
```

Note: Above plot is at 10 kA

➢ **All geometric harmonics are small**

Saturation-induced Harmonics

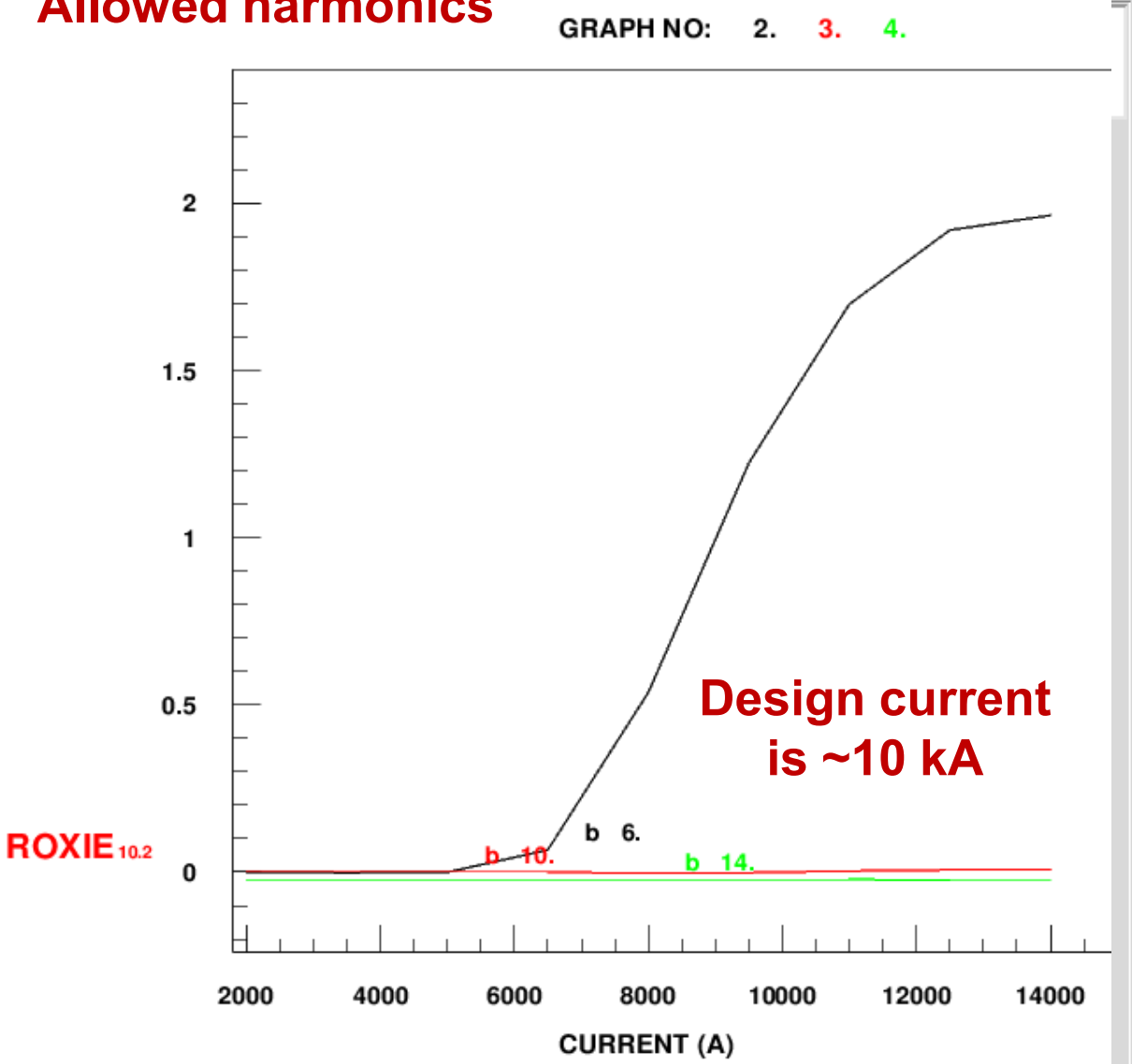
(examine the impact of non-liner properties of iron at high fields)

Current nominal operating range of EIC (Holger Witte): 41 GeV to 275 GeV
Minimum to Maximum Ratio: 1 to 6.7; Maximum current: ~10 kA

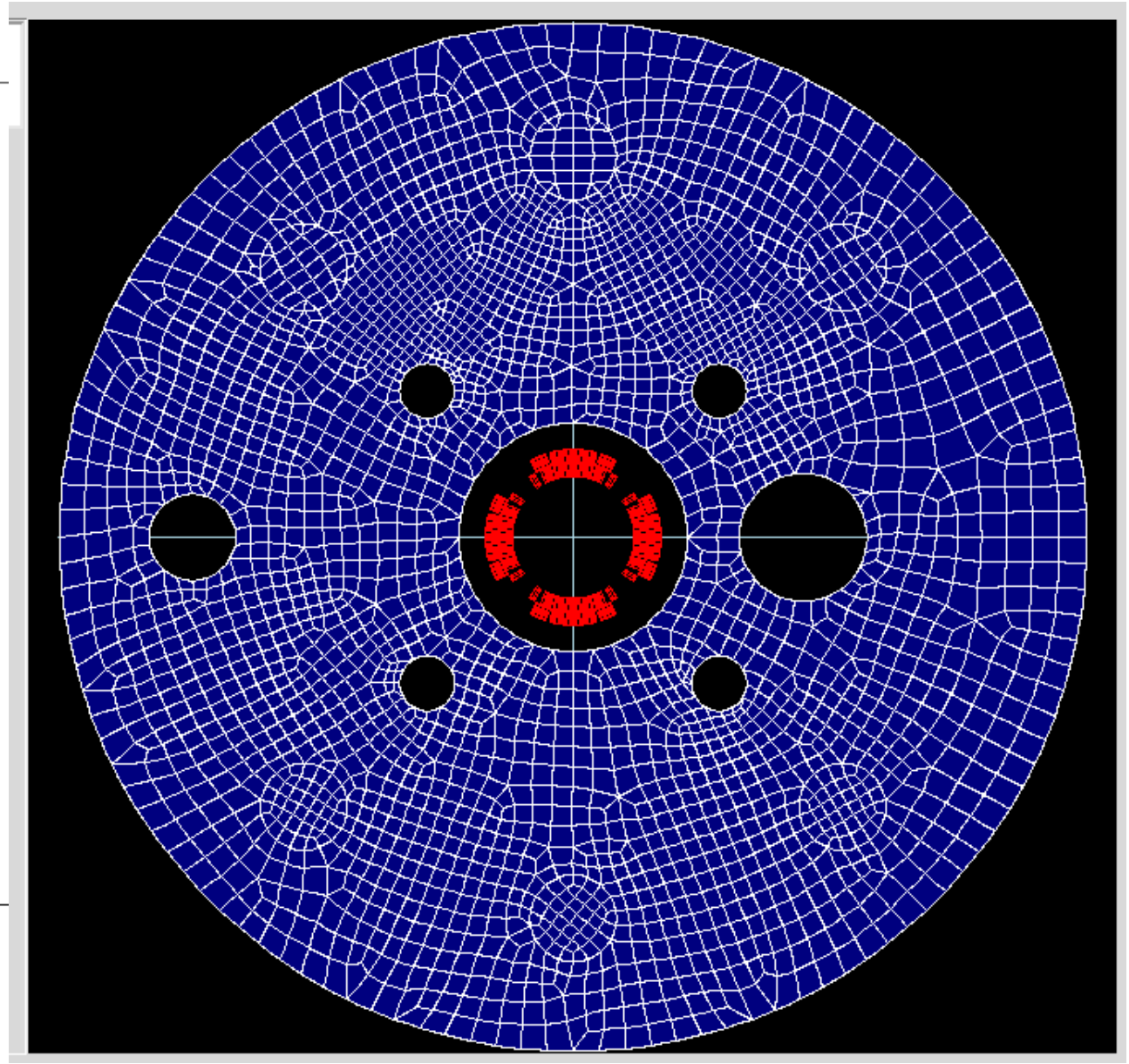
(Note: Optimization of yoke with holes, and onion ring, etc. not done yet)

Field quality in operating range (saturation-induced harmonics)

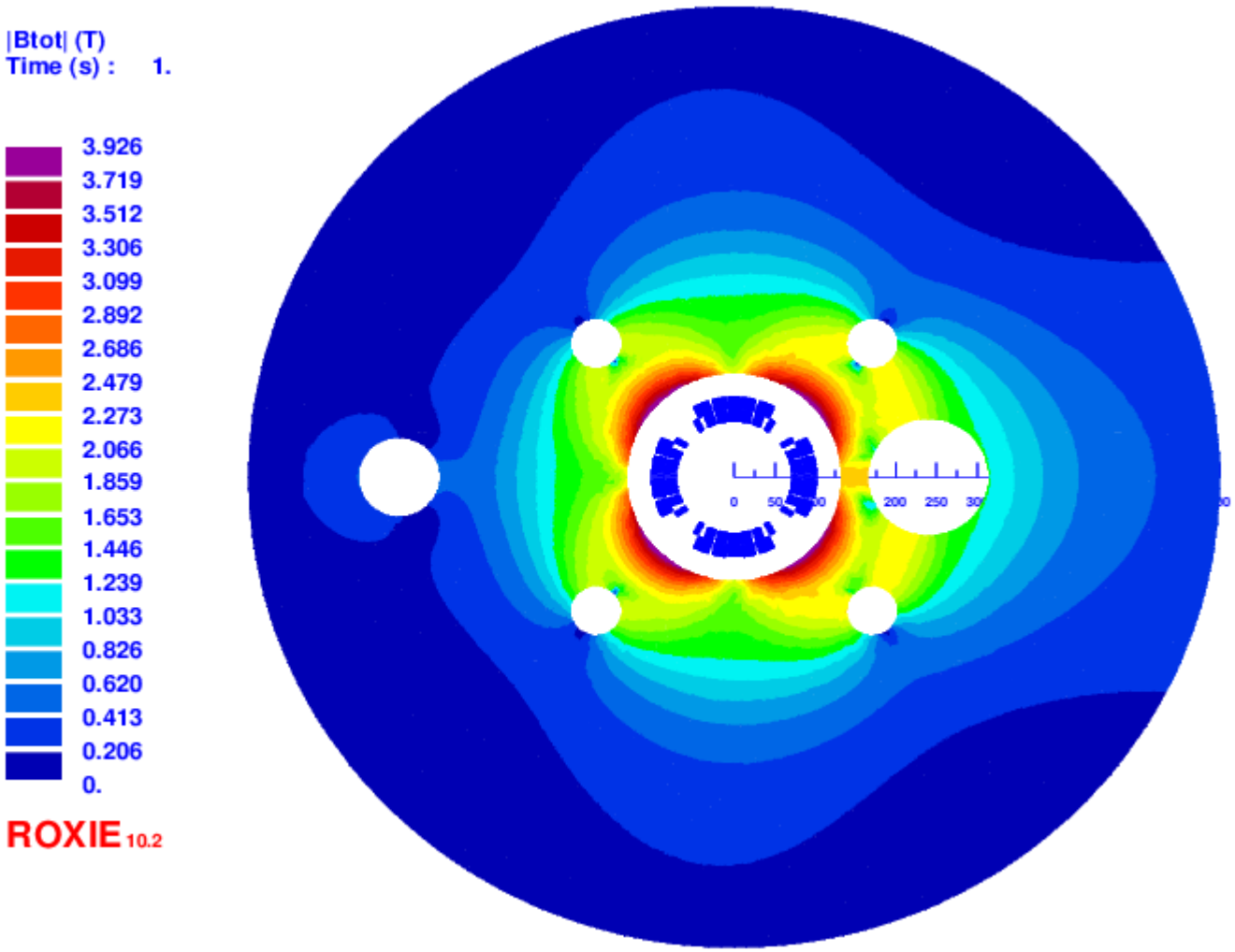
Allowed harmonics



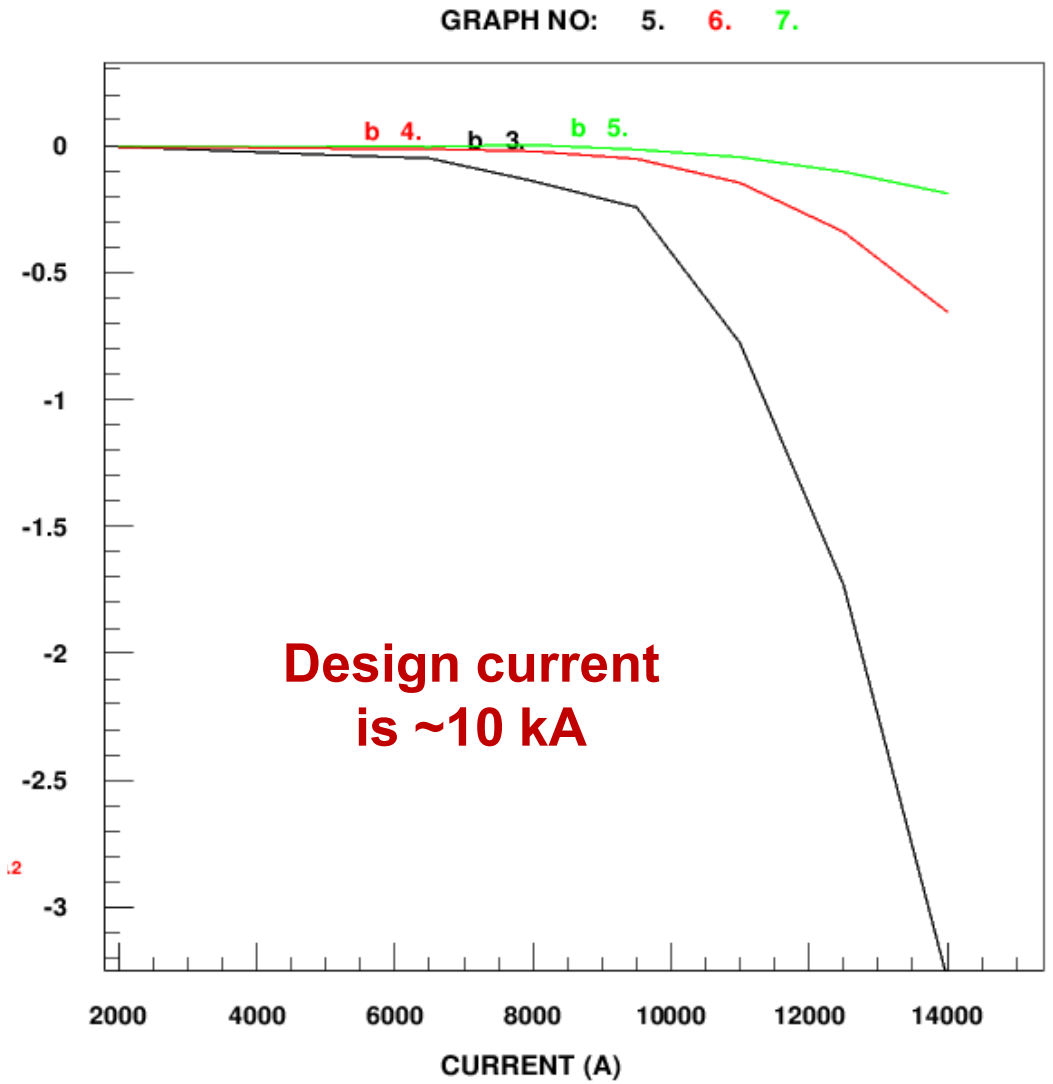
Design current is ~10 kA



Field quality in operating range (saturation-induced harmonics)



Non-allowed harmonics



Note: difference in field between left and right at the midplane of yoke