Field Calculations

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DOE/HEP Review of LBNL Superconducting Magnet Program

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Overview

- **Calculations for RD3 magnet**
  - Recall: RD3 is not a field quality common coil magnet design
  - Design criteria : Minimize peak fields and stresses on the conductor for a ~14 T design

- **Investigations for a field quality magnetic design**

(unlike cosine theta magnets, little to nothing exists to base various aspects of the design on)

  - develop design concepts and develop tools to optimize them

    Important addition: ROXIE for optimizing common coil design

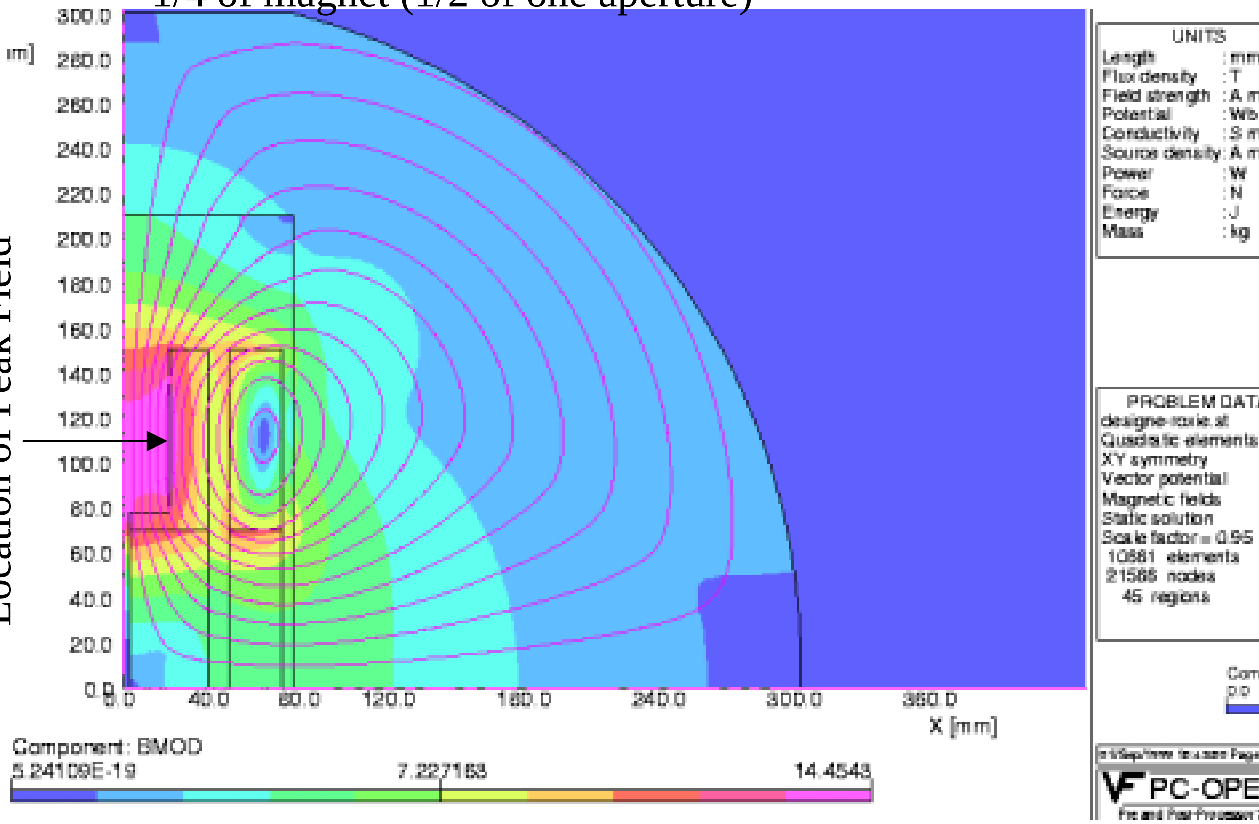
  - Initial results on body and end field optimization

Design Calculations for RD3 - Body

Magnitude of field and Field lines in RD3 at Bo = 13.7 T

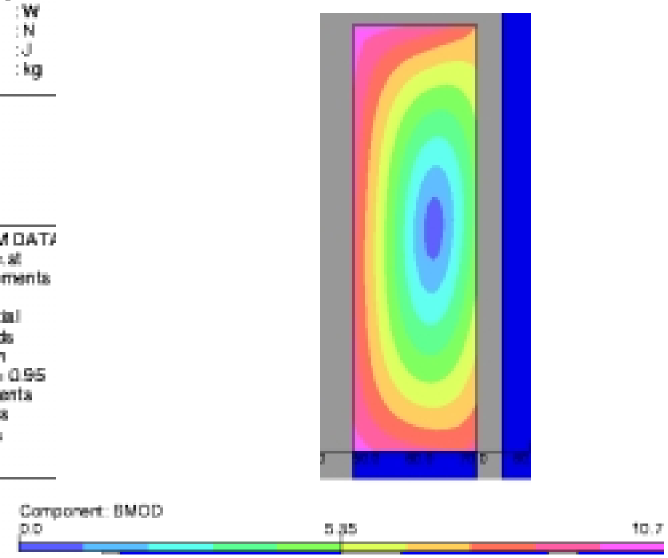
1/4 of magnet (1/2 of one aperture)

Location of Peak Field



Field on

Outer Coil



All design calculations for RD3 were initially done with OPERA.

Design Calculations for RD3 - Ends

Initial design consideration for magnet ends:

Iron over ends (same mechanical & magnetic material in body and ends)

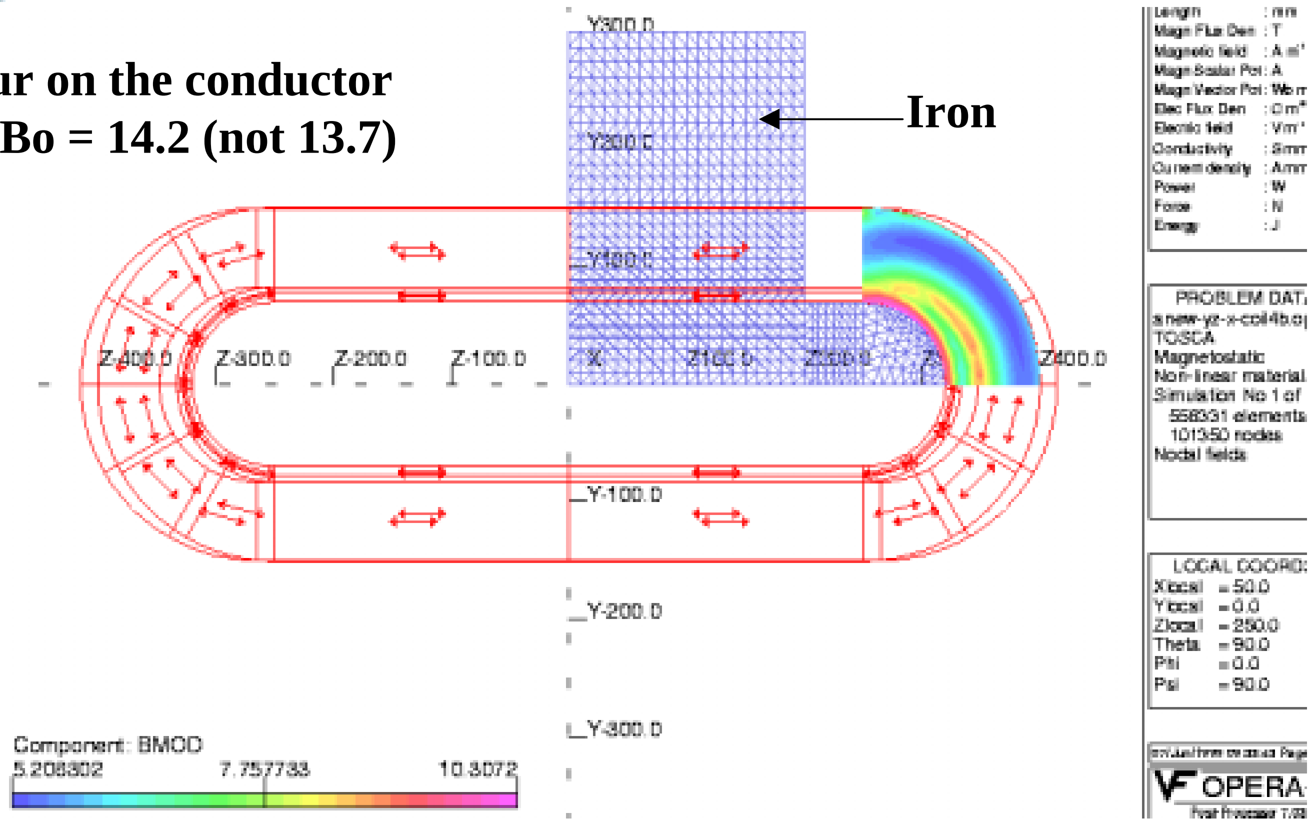
Vs. *Non-magnetic material over ends*

	Iron over ends	Non-magnetic material over ends
Mechanical	+	-
Peak field on conductor	-	+
Stress accumulation/concentration	-	+

- Initial attempt was to use Iron over ends (mechanical reasons). It was estimated that longer outer coil straight section (+/- 50 mm) will be enough to make the peak field in the ends less than that in the body.
- (a) ANSYS calculations found a large accumulated stress concentration in ends (b) Detailed TOSCA calculations with iron also found a higher peak field in the ends then in the SS. Peak field could be reduced by adding end-spacers and/or increasing length difference further, etc., however, stress accumulation (a major issue in Nb_3Sn) not.
- Therefore, at this stage (May, '99, prior to detailed drawings), the end design was changed to non-magnetic material over (common for high field magnets). New OPERA3d and ANSYS calculations done.

Calculations for RD3 Ends with OPERA3d (TOSCA)

Peak field contour on the conductor in <u>outer layer</u> at Bo = 14.2 (not 13.7)



Peak field in <u>ends</u> for Bo = 13.7 T : ~10.0 T (estimated error < 0.4 T)

Peak field in <u>body</u> for Bo = 13.7 T : ~10.7 T (estimated error < 0.2 T)

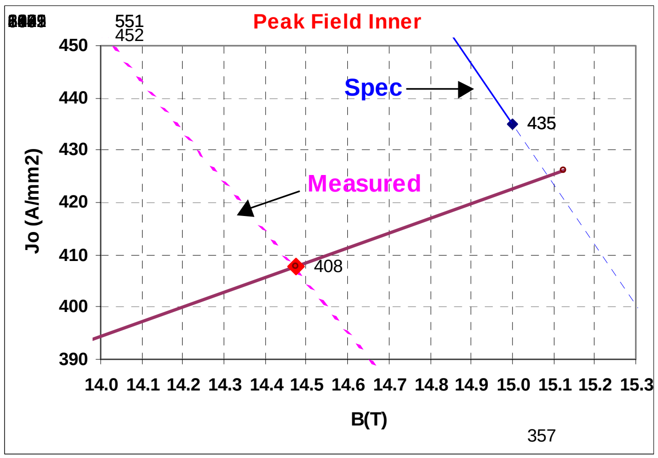
Note: The performance of RD3 is <u>limited by the inner conductor</u> (in the magnet body).

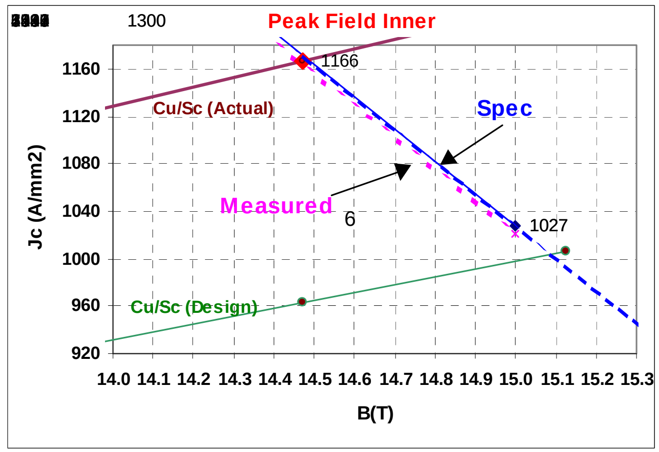
Computed Short Sample for RD3

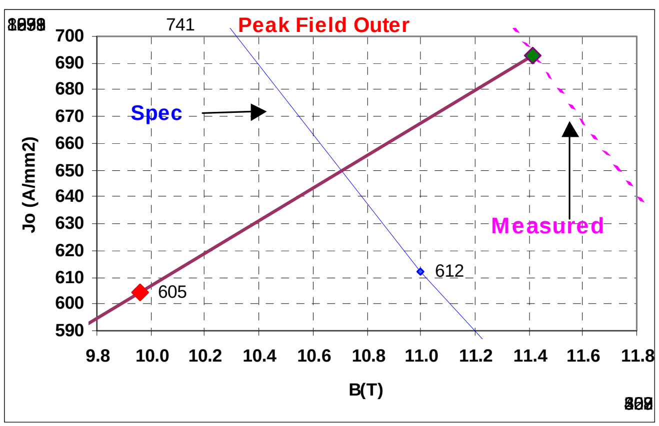
Jo: Overall Current Density in Coil

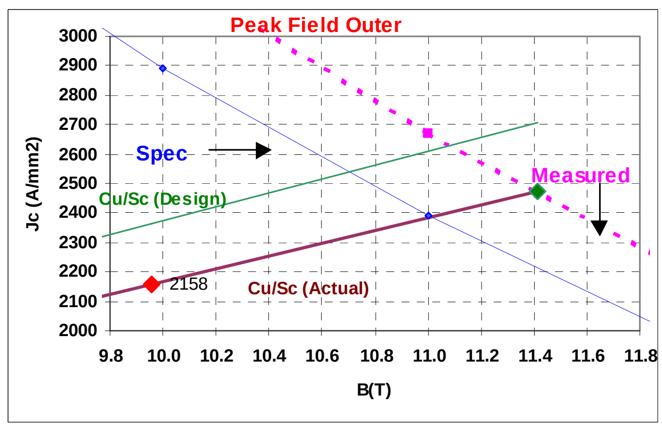
Jc: Current Density in Superconductor

New Computed Values		Bpk(Inner)	*14.5 T*	Bquench (Inner)		14.5 T
Bss =	*13.7 T*	Bpk(Outer)	*10.0 T*	Bquench(outer)		11.4 T
Margin	===>	Inner	0%		Outer	14%









Original Design:

~14.3 T at 4.3K

Expected. Bss in outer coil test :

12.7 T in RD3 structure

12.1 T in RD2 structure

Note:

Strand performance is used.

Not included:

- *degradation in cabling operation*
- *degradation due to Lorentz stresses/strain.*

To be revised based on NHMFL measurements.

Next Step: Investigations for a Field Quality Magnetic Design

Development of a conceptual design

• Major Issues : A racetrack coil geometry (not a cosine theta with a lot of experience) where up-down symmetry is inherently broken - *both in body and in ends*

Development of tools

Computer code ROXIE (Routine for the Optimization of Magnet X-sections, Inverse Field Calculation and coil End Design) from CERN (Primary author: Stephan Russenschuck)

• Further adopted/modified at LBNL for common coil magnet design optimization in last 3 months by Suitbert Ramberger (Post-doc with significant experience on ROXIE)

• 2nd International ROXIE Users Meeting and Workshop at LBNL (Aug 9-11, 1999)

Use tools to further optimize and develop concepts

• Initial results of an ongoing optimization process that has just begun

Development of Tools

Computer code ROXIE has been adopted for optimizing the magnetic design of a common coil magnet.

Unique features of ROXIE that are important here:

(a) Racetrack coil geometry optimization

(b) Optimization of a coil in a rectangular (NOT circular) iron aperture

(c) End geometry optimization for common coil design

Design Optimization Strategies for Body Harmonics (2-d)

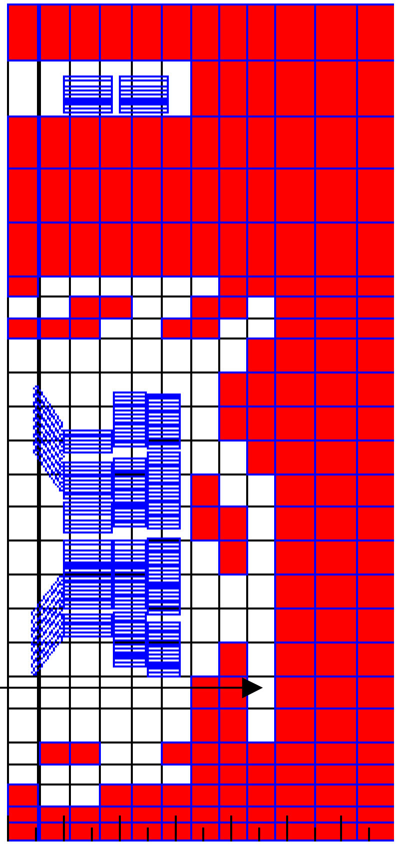
<u>Coil</u>

Optimize a block coil design so that it simulates an elliptical coil geometry

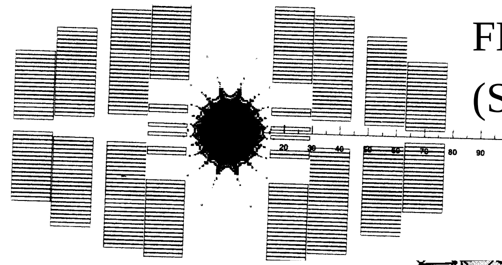
<u>Yoke</u>

Optimize iron to minimize saturation induced normal and *skew harmonics* while making the design compact

- Based on understanding of the influence of holes, etc. by varying parameters by hand
- In future optimizations, use also *"Genetic Algorithm"* (an initial setup by Suitbert Ramberger)



Field Quality Design Optimization Options for Magnet Body Harmonics



FNAL

(Sabbi, et.al)

- With no auxiliary coil
  - very simple
  - uses 30-50% more conductor for a field quality similar (?) to a typical cosine theta collider magnet design
  - Ref: Model of Sabbi@FNAL
  - Ref: Wipf (sort of no auxiliary coil)

Wipf

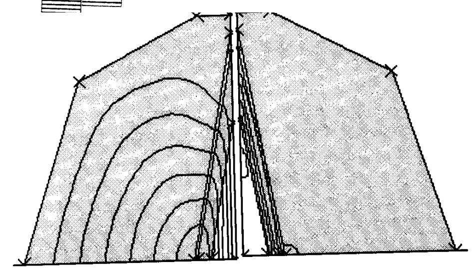
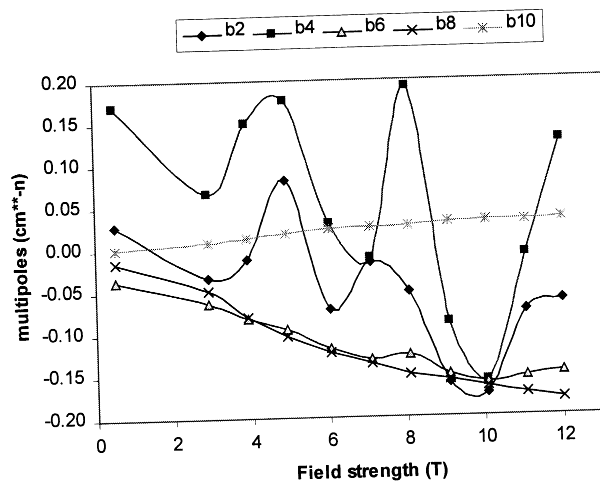
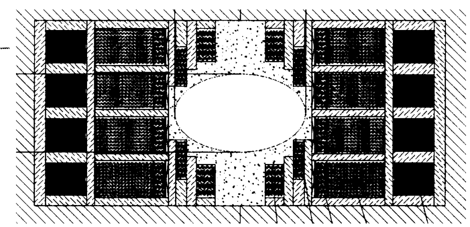


Fig 21: Idea for possible high field dipole based on Leeb and Umstatter design [22]: picture shows flux lines on left hand side and constant field contours on right left hand side

- With auxiliary coils
  - field quality similar to cos theta
  - Ref: Texas A&M - Peter McIntyre (sort of auxiliary coils)
  - Next few slides: Options that are being investigated at LBNL

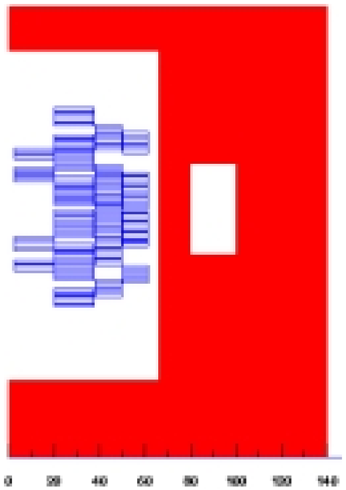




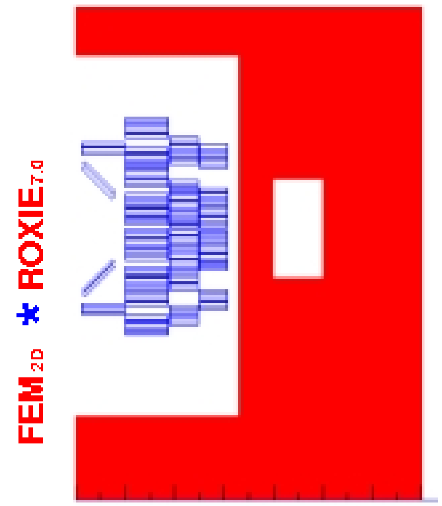
Texas A&M

(McIntyre, et.al)

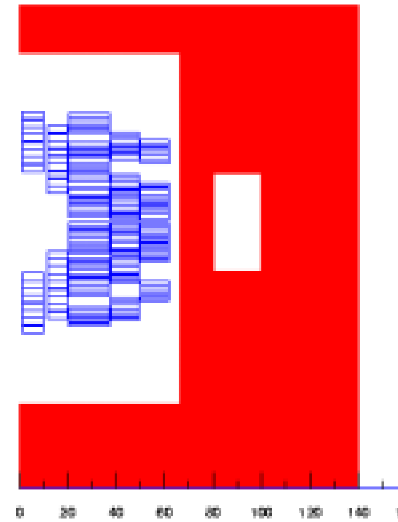
A Few Possible Configurations for Auxiliary Coils



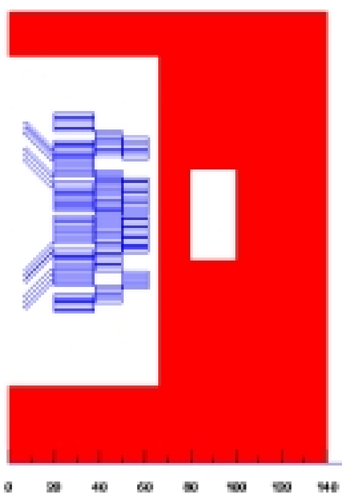
Case 1a



Case 1c



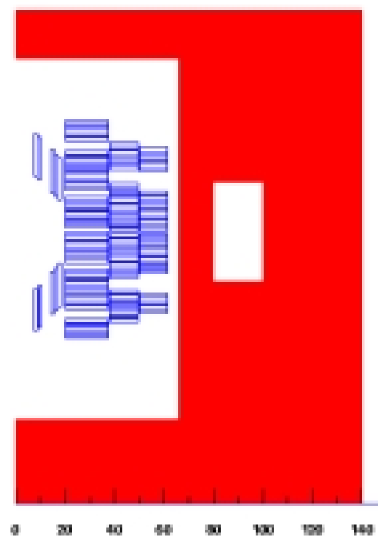
Case 2



Case 1b

Possibility of Case 1a Type ends in Case 1c

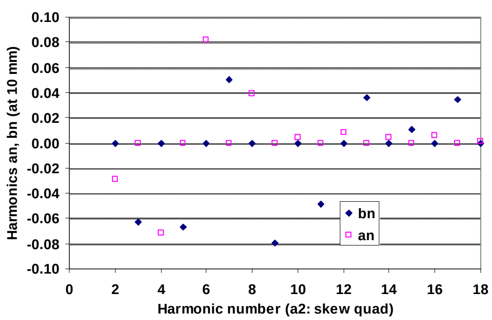
Case 1c is better from field quality point



Case 3

An Example of a Preliminary Optimized Design: Magnet Body

n	bn	an
2	0.00	-0.03
3	-0.06	0.00
4	0.00	-0.07
5	-0.07	0.00
6	0.00	0.08
7	0.05	0.00
8	0.00	0.04
9	-0.08	0.00
10	0.00	0.00
11	-0.05	0.00
12	0.00	0.01
13	0.04	0.00
14	0.00	0.00

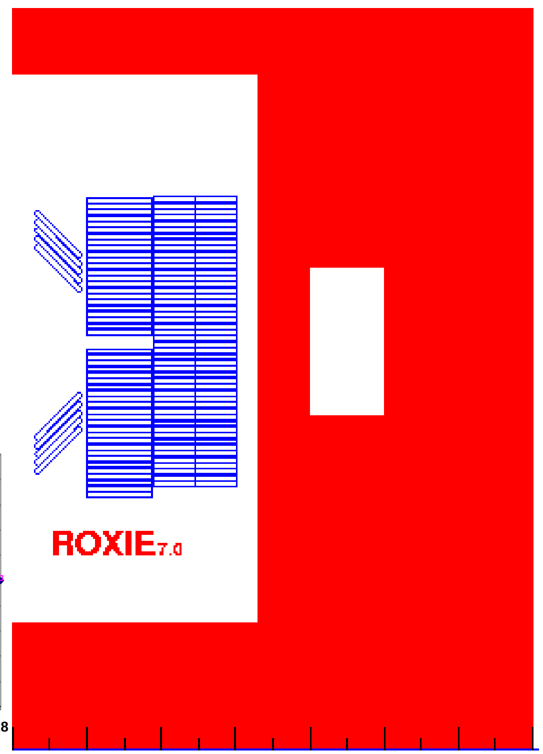


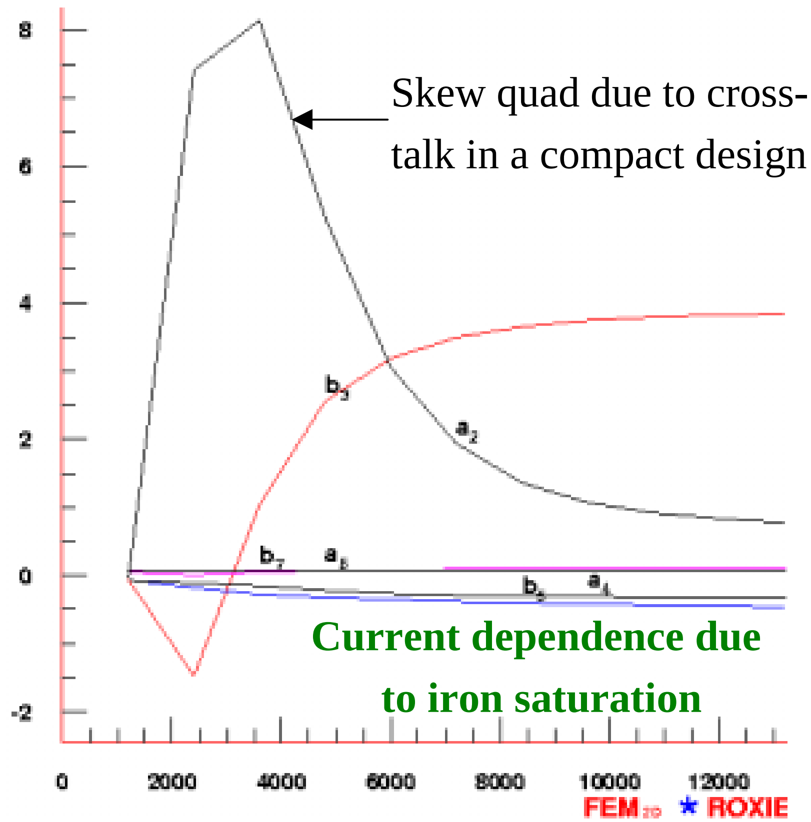
All "Geometric Harmonics" at 1.89 T are less than 10^{-5}.

Small saturation induced harmonics with a single power supply in a compact cross section (4-in-1 magnet: 280 mm X 600 mm - H X V).

b_3 and a_2 saturation can be further optimized (a_2 saturation has been ~ few units).

Note: a_2 is skew quadrupole





Design Optimization Strategies for End Harmonics (3-d)

The top-bottom symmetry is highly violated in the ends (example:RD3). In a design with “no end-spacers”, it creates very large skew harmonics in addition to normal sextupole.

Compare this to early cosine theta designs which had large sextupole in the ends.

- Must do some thing to reduce them qualitatively.

Strategy:

- Use spacers to reduce peak field and to minimize field harmonics (as done in a typical cosine theta design, but do it here for both normal and skew harmonics). As usual, the field harmonics are minimized in an integral sense.
- Make coils above the midplane (in the upper aperture) go further out in the ends to compensate for the higher conductor volume below the midplane.

B_z is not zero locally in an individual end. But is zero in integral sense.

B_z in the ends of two nearby magnets cancel each other. AP issues?

An Example of End Optimization with ROXIE (iron not included)

Proof:

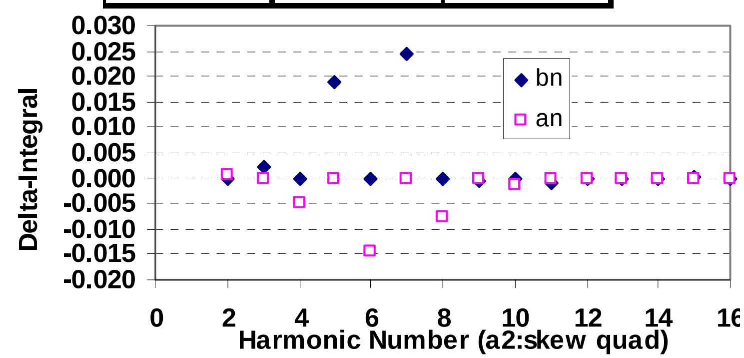
End harmonics can be made small in a common coil design.

End harmonics in Unit-m

n	Bn	An
2	0.00	0.00
3	0.01	0.00
4	0.00	-0.03
5	0.13	0.00
6	0.00	-0.10
7	0.17	0.00
8	0.00	-0.05
9	0.00	0.00
10	0.00	-0.01
11	-0.01	0.00
12	0.00	0.00
13	0.00	0.00
14	0.00	0.00
15	0.00	0.00
16	0.00	0.00
17	0.00	0.00
18	0.00	0.00

Contribution to integral (a_n,b_n) in a 14 m long dipole ($<10^{-6}$)

n	bn	an
2	0.000	0.001
3	0.002	0.000
4	0.000	-0.005
5	0.019	0.000
6	0.000	-0.014
7	0.025	0.000
8	0.000	-0.008
9	-0.001	0.000
10	0.000	-0.001
11	-0.001	0.000
12	0.000	0.000



The additional influence of iron in a re-optimization will be included later with the help of TOSCA. The influence of iron can also be included using the CERN version of ROXIE.

SUMMARY

- Calculations for RD3 is completed with OPERA.

- Tools, structure and strategies are in place for field calculations and optimizations for both body and end designs

  ROXIE will play a major role in optimizing a detailed magnetic design.

- Proof of principle design for field quality optimization in ends.