Coil Optimization

Ramesh Gupta
BNL

Note: A significant portion of this talk was given in non-electronic format

Incomplete Talk

Sorry Plastic Slides Not-included

Coil Cross-section Optimization

The basic minimization of the coil cross-section involves

- Minimizing field harmonics
- Maximizing Transfer Function for a lower number of turns
- Minimizing Peak Field (Max. field on the conductor for given central field)

This has become a fairly routine process, thanks to modern codes such as ROXIE and PAR2DOPT, etc.

But advanced cross-section optimization is a bit more than that.

- Avoid designs that create mechanical difficulties
- Look for flexibility in the design

Look for individual application.

One strategy fits all, may not always be an optimal solution.

The initial design, quiet often sets, the final performance and difficulties in manufacturing and adjusting.

As compared to building magnets, design process takes a relatively small resources. Spent time in looking as many possibilities/options as possible.

How to Look for Optimal X-section

- Look for designs that look similar to cosine theta distribution

- Use special techniques (such as Genetic Optimization, Neural network in ROXIE), etc.

- Cover a large range of combinations and find the best

Personal Preference (style)

It does not take long to look a large number of possibilities

< 1 minute per case if peak field is not computed

compute peak field in solutions that are promising

A front end program to automatically create several cases for optimization (run)

Vary number of blocks and number of turn per block

Vary starting condition of wedges, etc.

Post-process solution with auto filtering based on results

Compute peak field

Go book and optimize a few cases in more detail

(for example by changing parameters as per manufacturing consideration), e.g. SSC

Current Dependence in Non-allowed (Un-allowed) Harmonics

Non-allowed harmonics are those that are not allowed by magnet symmetry.

Current dependence means:

either the iron is not symmetric and/or the Lorentz forces are not

Allowed harmonics in dipoles:

Dipole, sextupole, decapole, … (Bo, b2, b4, b6, …, etc.) b_{2n}

Non-allowed harmonics in dipoles:

quadrupole, octupole, … (b_{2n+1}) : left-right assymetry

All skew harmonics a_n : top-bottom difeerences

Allowed Harmonics in quadrupole

Quadrupole (B1), b5, b9, …

All others are not allowed

Current Dependence in Skew quad Harmonic (a_1) in Dipole

Skew quad harmonic (a_1) in dipole reflects a top-bottom asymmetry

Suspect: Somehow the total amount of iron is not same on top and bottom
(at low field, not much iron is needed so it matters less
as long as the geometry is the same)
Another source: asymmetric Lorentz forces (unlikely)

Integral Difference: Overall asymmetry

Location-to-location Difference: Local asymmetry

Adjustment After Construction

Some time it is cheaper and easier to correct the errors after the construction.

Especially in very high field quality magnets which would put high tolerances in parts and manufacturing.

This is definitely more flexible.

Feedback in design from HERA experience: The Real Magnet Vs. Paper Design

Note: Integral B.dl

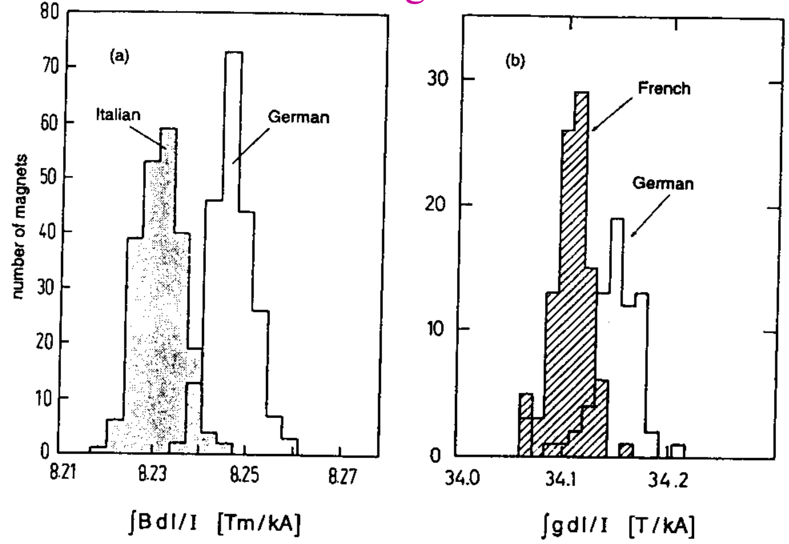
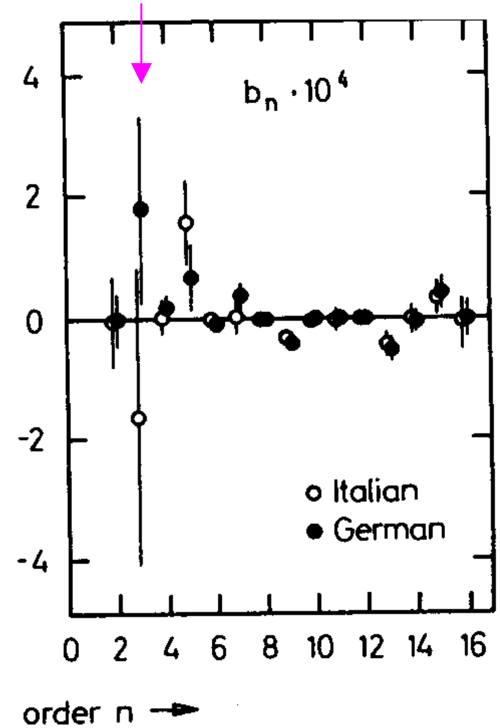


Figure 5.5: (a) Field integral of all HERA dipoles, normalized to coil current. (b) Integrated gradient of all quadrupoles, normalized to coil current (Brück et al. 1991).

Note: Sextupole



- Parameters do deviate from nominal value.
- It takes time to locate the cause of the problem and then fix it (conventionally that included a cross section iteration). Takes too long and the magnet production can not stop.
- *A good design strategy would anticipate such deviations.*
- *Make a flexible design that assures good field quality despite such deviations.*

Feedback in design from HERA experience

A Method to Adjust Integral Field and Skew Quad

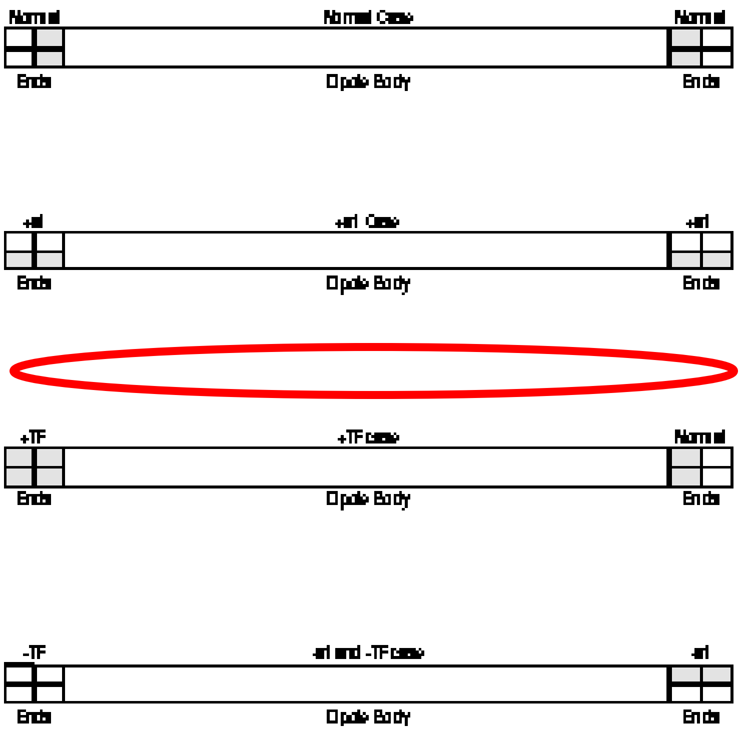
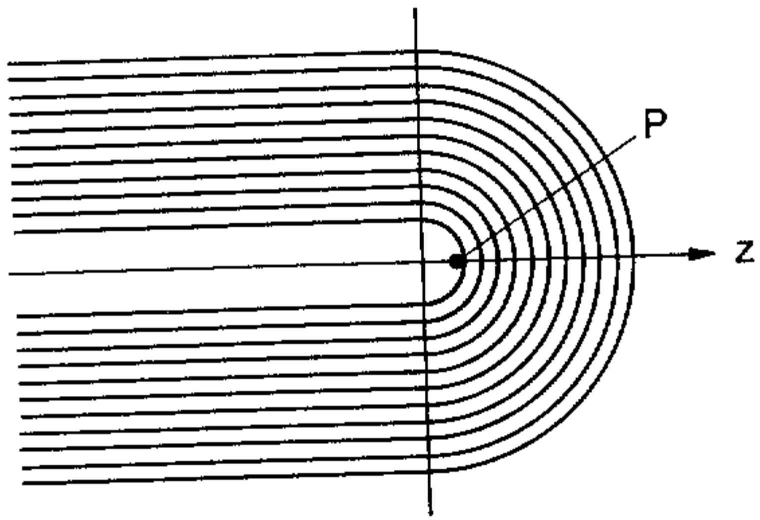


Figure 6.3.1: A conceptual diagram for correcting the integral a_1 harmonic and integral transfer function in a superconducting dipole magnet. The proposed adjustment is applied in the end region of the magnet. The actual starting point would be somewhere in the dipole body where the field is still high. In the normal case (top figure) the change between the magnetic, low carbon steel laminations (dark or filled) and non-magnetic stainless steel laminations (light or empty) occurs at a nominal location. Interchanging the stainless steel and low carbon steel laminations between top and bottom halves (second figure) creates an a_1 which can be used to compensate the measured a_1 in a magnet. Increasing the number of low carbon steel magnetic laminations increases the integral transfer function (third figure). An adjustment (decrease) in both a_1 and integral transfer function can be obtained together by mixing the two schemes in the same magnet (bottom figure).

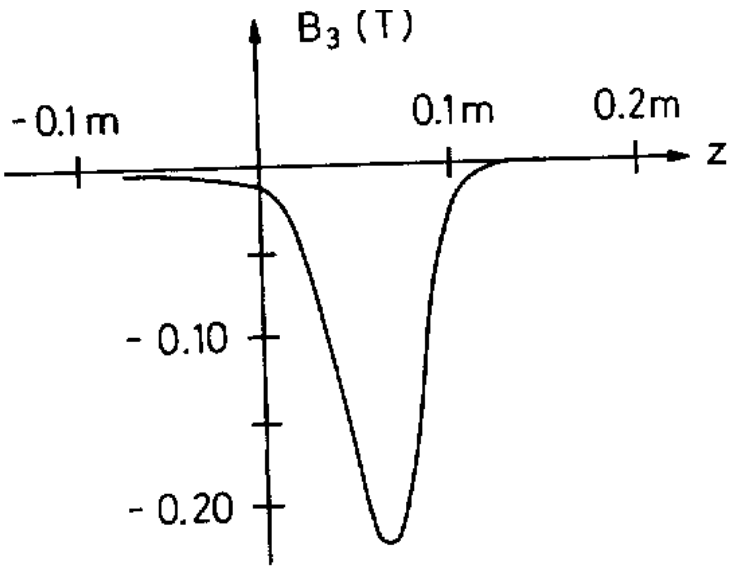
Iron laminations were successfully used in RHIC to adjust transfer function saturation in different length magnets and to control skew quad in main dipoles.

Simple Magnet Ends

As such, the coil ends have a high field (peak field) at point P and have a large integrated sextupole



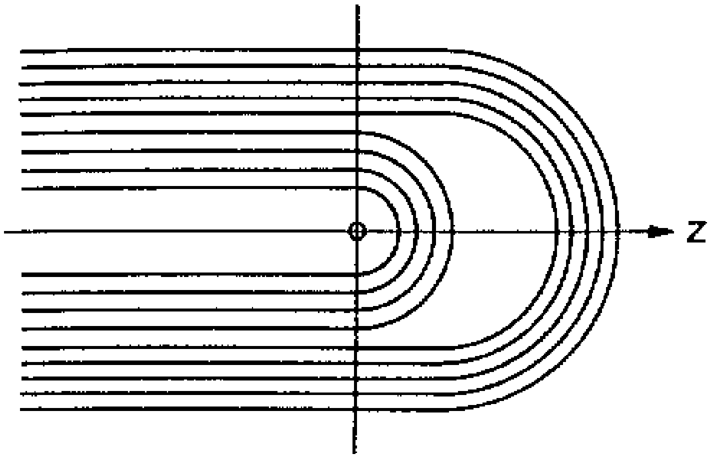
a) Unwrapped view of simple coil head configuration. The highest field in the coil is at the point P.



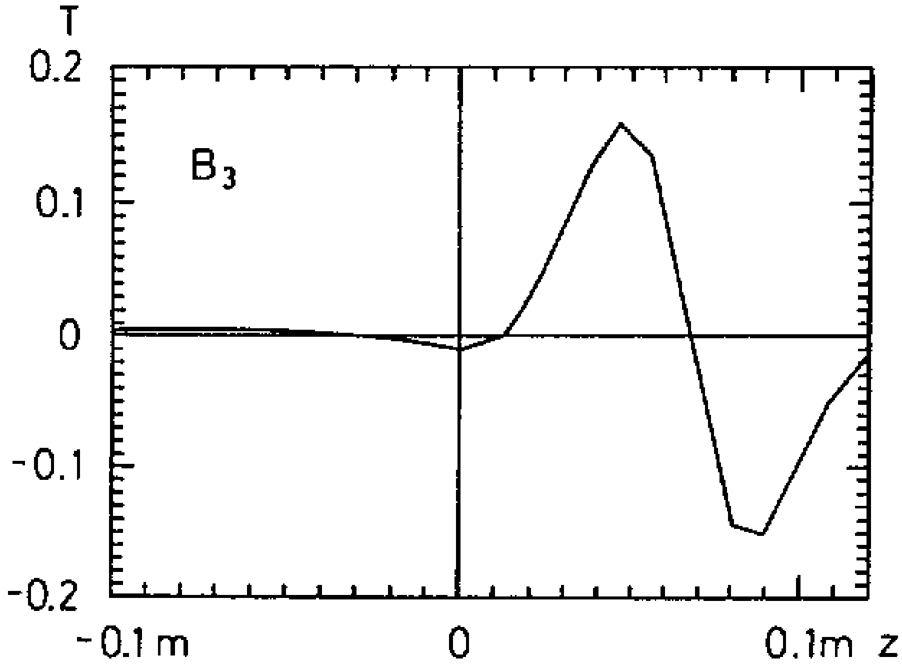
b) Sextupole field in the coil head for a central field of 4.5 T.

Magnet Ends With End Spacers

Spacers in the ends (like wedges in the cross-section), reduce the peak field and reduce the integrated value of sextupole and other harmonic components



a) Schematic view of HERA coil head with spacers



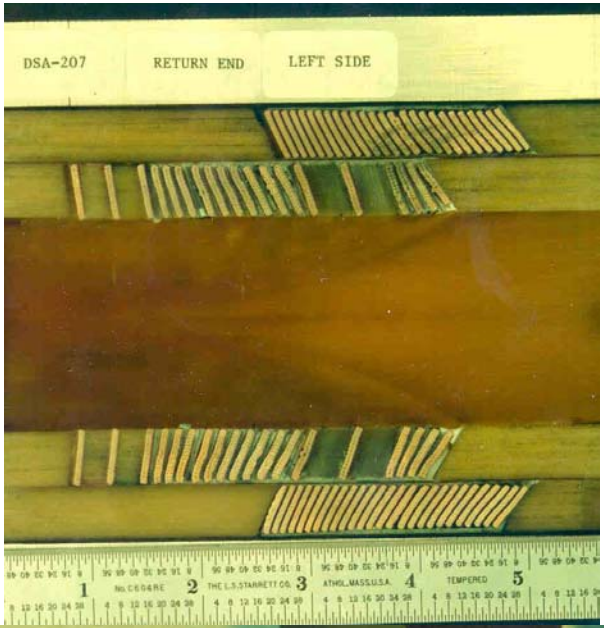
b) Computed sextupole field of HERA dipole

Pictures of Magnet Ends

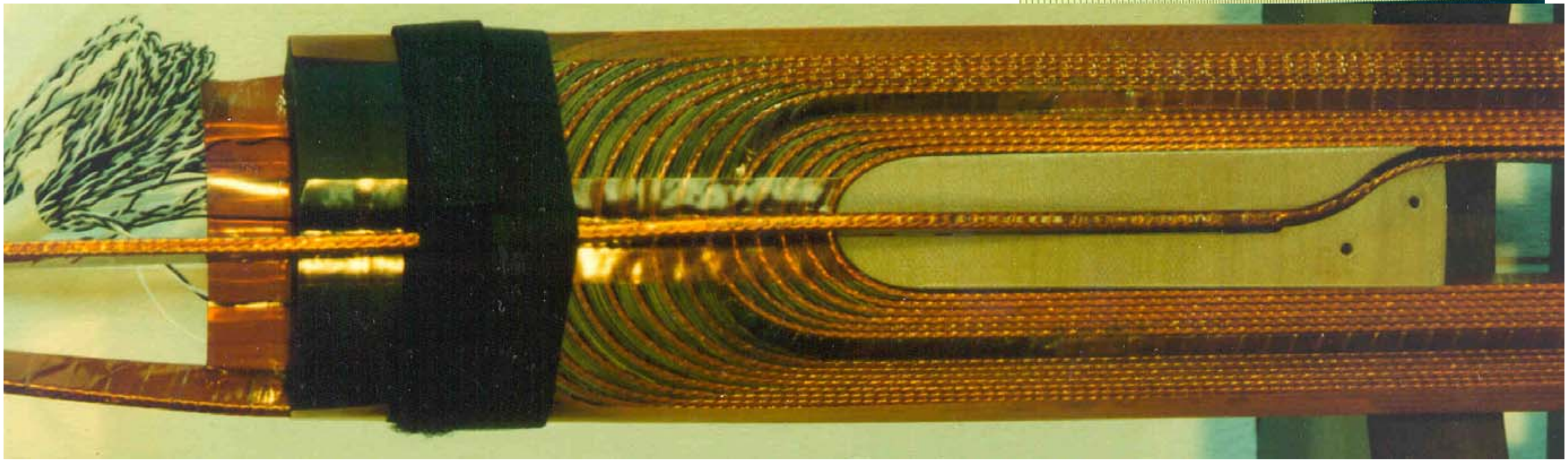
Upper Coils →

Ends of a SSC 50 mm dipole magnet (two 2 layer coils), cut on vertical axis

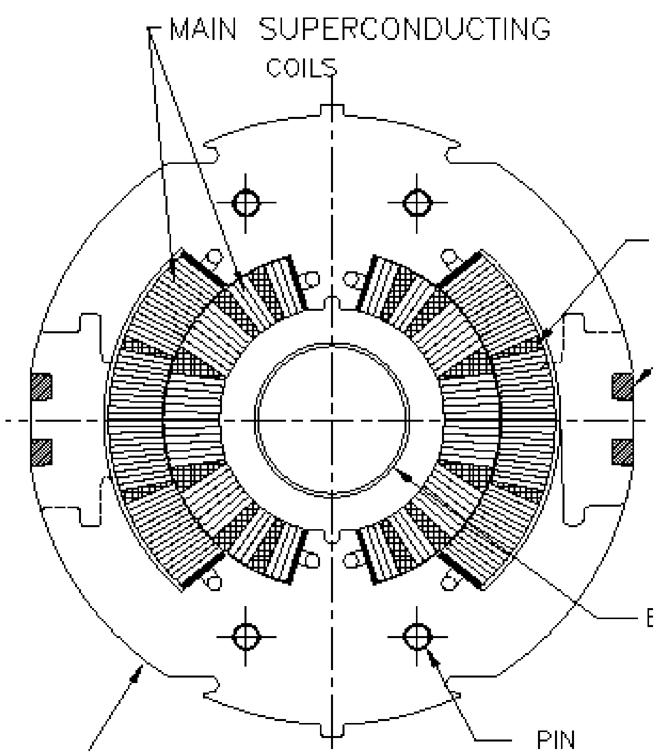
Lower Coils →



End view of a RHIC magnet coil



Conceptual Optimization of Magnet Ends



- End spacers increase the straight section length of some turns (turns at midplane go further out)
- Now consider the integral field generated by each turn. The harmonic component generated by a turn will depend on the angular location of it. The integral strength will depend on the length.
- A proper choice of end spacer can make integral end-harmonics small. However, note that the local values are large.
- Spacer also reduce the maximum value of field on the conductor (peak field) in the end.