Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

End Optimization of B1pF (300 mm)

Mechanical and Magnetic

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@BrookhavenLab

Overview

We want to make ends as short as possible because as they reduce the field integral or require higher than necessary central field.

Components driving the optimization of ends:

1. Minimization of peak fields in the ends for *shortest length*
2. Minimization of field harmonics in the ends for *shortest length*
3. Minimization of strain in the Rutherford cable for *shortest length*

Primary topic for this meeting is item #3.

The relative ratio of the "***length of the turn in the end***" to the ***coil radius***" (sometime also called *ellipticity*) should reduce in going from small aperture to large aperture for the same cable (we are using the same cable in 300 mm coil id that was used in 56 mm coil id).

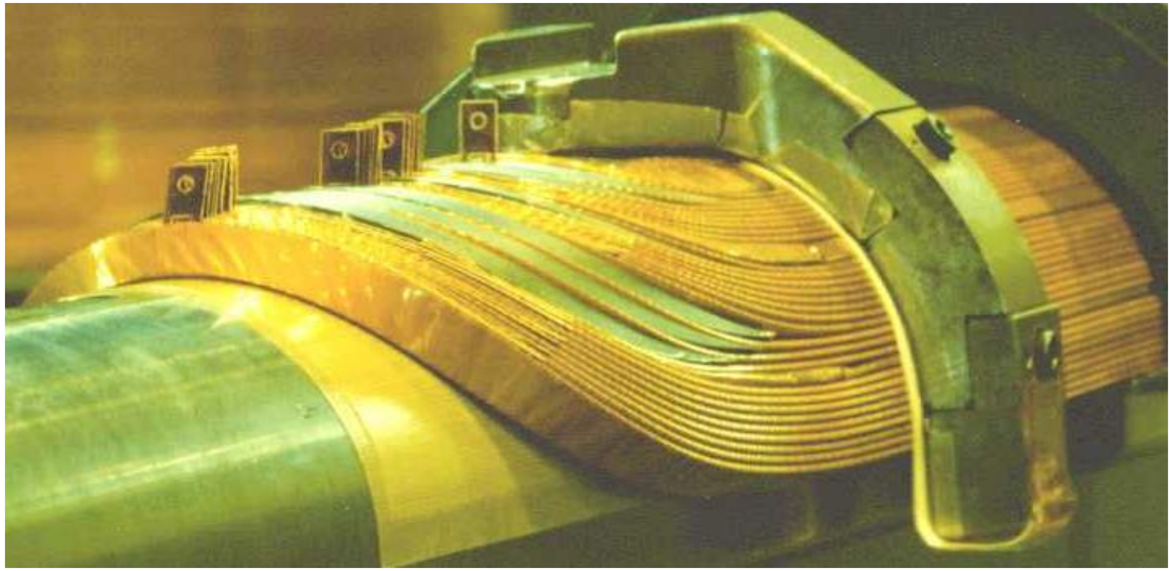
Ends with Rutherford Cable

In small aperture magnets, the pole angle plays a significant role, as we don't want to bend cable in a too tight bend radius. In large aperture magnets, the same pole angle gives much larger bend radius and is no longer a major issue.

Major length driver in a large aperture coil is the turns at the midplane.

To understand it better consider two components: (a) "*easy way*" bend and (b) "*hard way*" bend then they determine the length of the magnet.

- **Please feel the actual cable at midplane for different aperture.**
- **Try to feel bend easy way & hard way**



- Mechanical properties of the cable should determine the length (ellipticity) and layout of the midplane turns

More on coils with a large number of turns

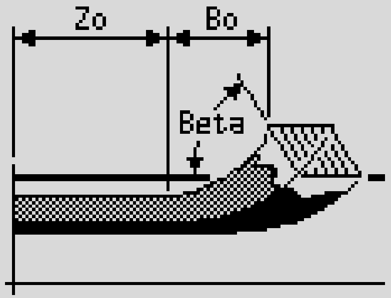
- Other considerations in winding coils with a larger number of turns (including large number of turns in a block) are (a) buildup of the fluffiness and (b) buildup of tilt angle due to keystone in cable.
- It maybe better if a block will large number of turns is divided in two.
- Curing of a large coil and applying prestress on the coil become (such as RHIC DX and even more so in B1pF) become major issue as loads don’t get transferred uniformly when number of turns are large.
- Small differences in cable size (even within spec but prepare to accommodate a bit out of spec due to schedule pressure) adds up

Role of modern codes and practice winding

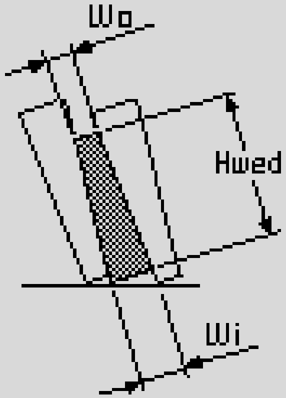
- Modern codes can compute and minimize strain on the Rutherford cable for given parameters, such as ellipticity and tilt angle at the pole
- They can also vary and in principle optimize ellipticity and tilt angle
- They will layout the optimized path of the cable from midplane to pole

- However, there are many solutions covering a range of parameters that have major impact on the magnet length and layout of turns.
- The use of them and the past experiences go only so far when we are trying to optimize a magnet with very different parameters.
- A rapid-turn-around practice winding with 3d printed parts should give a good direction for various blocks (may be just the first and last turn)

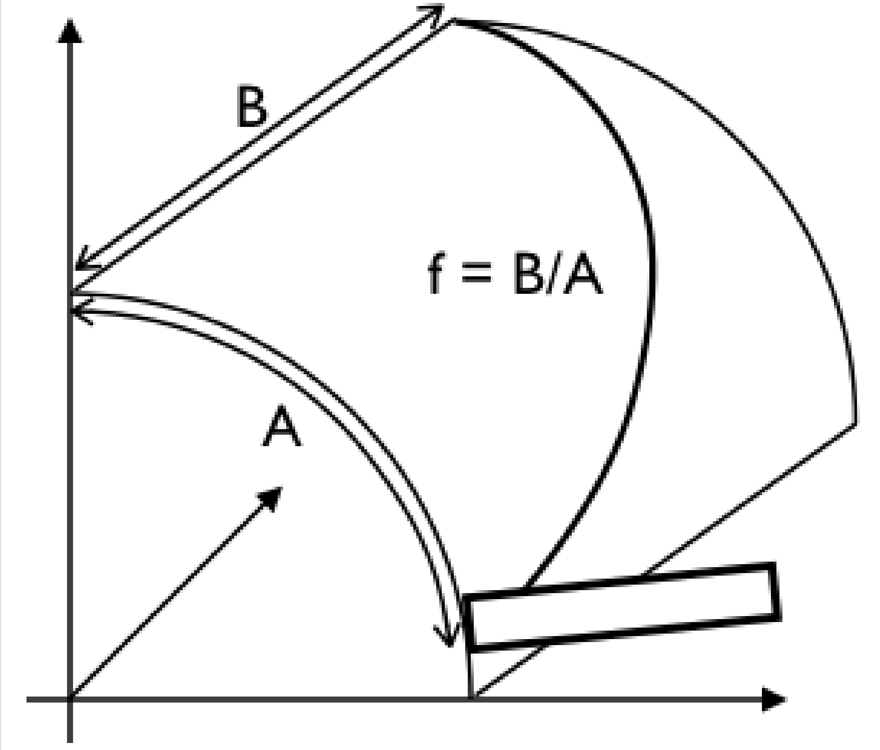
β	f=B/A	Zo	Wi	Wo	Hwed	Horder



'β' is the inclination angle (deg) to the z-axis of the first conductor of the block in the yz plane.



'Wi' is the inner width of the 'inter-turn' spacers wound between each cable of the block at the coil end. These spacers can be used to compensate for dekeystoning and adjust the position of each cable in the winding.



Ellipticity of the coil-end baseline. f=B/A describes a mean ellipticity between upper and lower edge of the inner-most cable in the block.

Horder is the order of the hyperellipse that defines the baseline of the winding of the inner-most turn on the mandrel. Horder = 2 yields an ellipse. Horder > 2 makes the coilend more 'rectangular', Horder < 2 makes it more 'triangular'.

Initial Design Challenge of the RHIC IR Quadrupoles

A Practical Challenge:

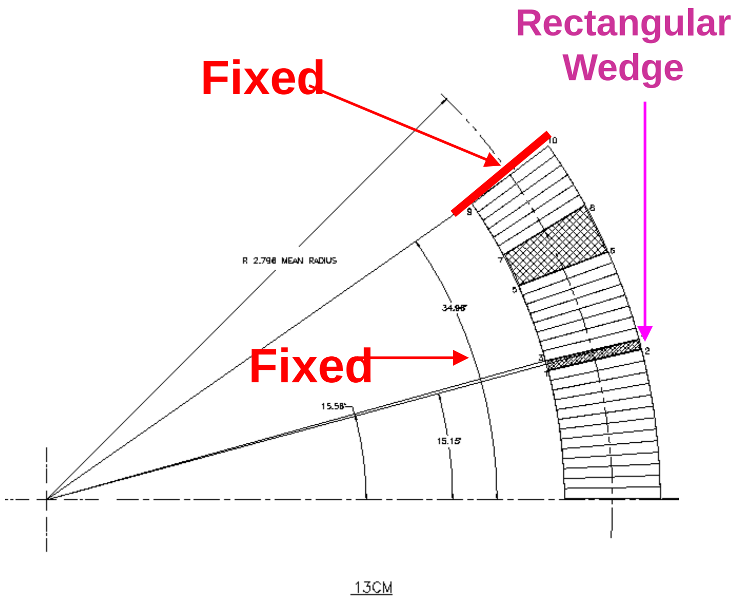
This could still be the case

Started out with ~ 1 mil (25 µm) uncertainty in cable thickness, as cured.

- Total ~27 mils (order of magnitude more than the typical 2 mil) in overall coil dimensions for 27 turns.
- Conventional Approach : Fix cable first.
- Alternate Approach :

A field quality design that can absorb this.

⇒ Developed a design in which all of the difference was absorbed in a rectangular wedge!
⇒ No change in pole angle means:
  - ⊗ No change in coil curing press
  - ⊗ No change in collar/spacer
  - ⊗ No change in first allowed harmonic (b_5)



Coil Cross section of the 130 mm aperture RHIC insertion quadrupole

Develop a similar approach for ends?

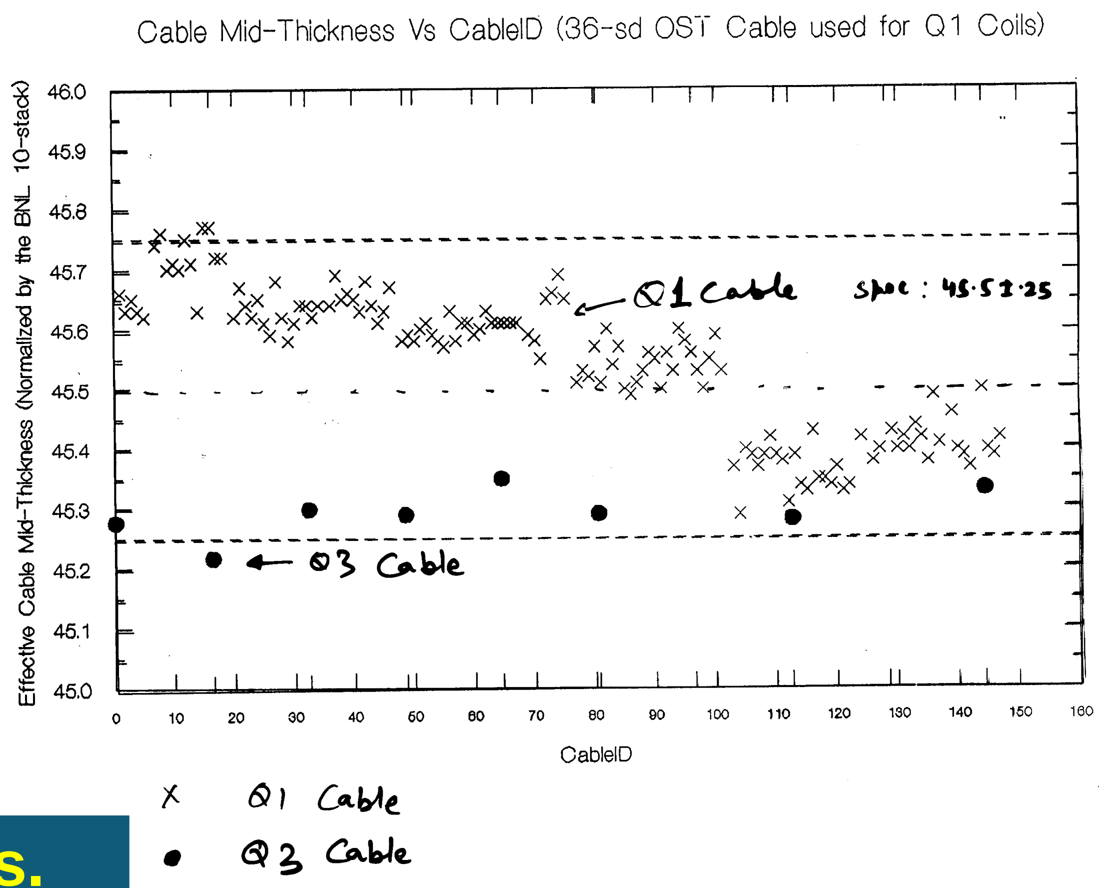
Different Size Cable (within spec) from Two Different Vendors

Specifications : +/- 0.25 mil (6.5 micron); 0.5 mil variation (13 micron)

Two vendors gave cable which differ systematically (but within specifications) by ~ 0.35 mil
(however, had a small RMS)

27 turns => 9 mil (0.24 mm)
much larger than desired.

- More possible for 63 turns in B1pF (31 mil)

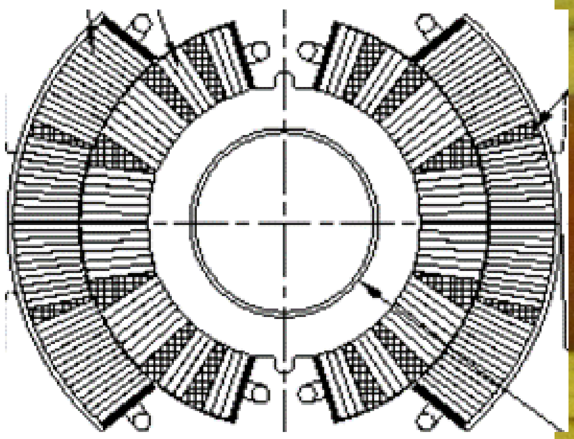


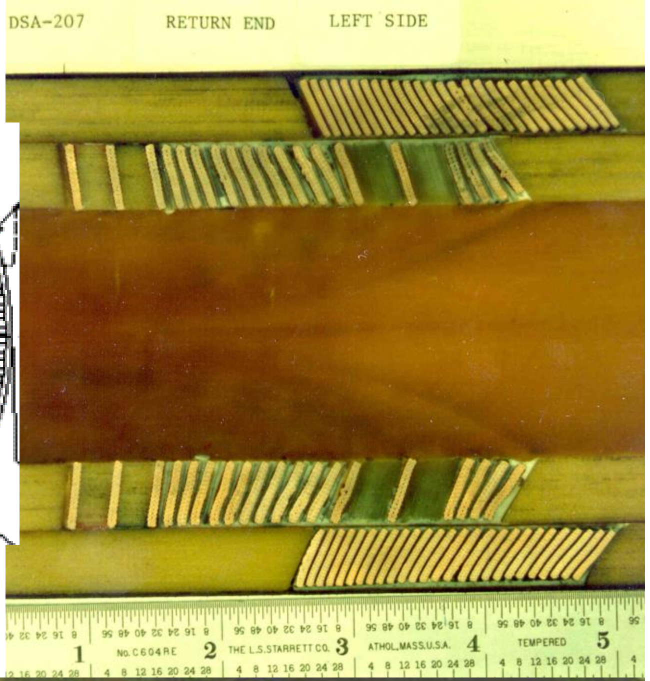
In RHIC DX, we even had to add extra turns. Consider developing an approach for the ends as well as the cross-section of EIC B1pF

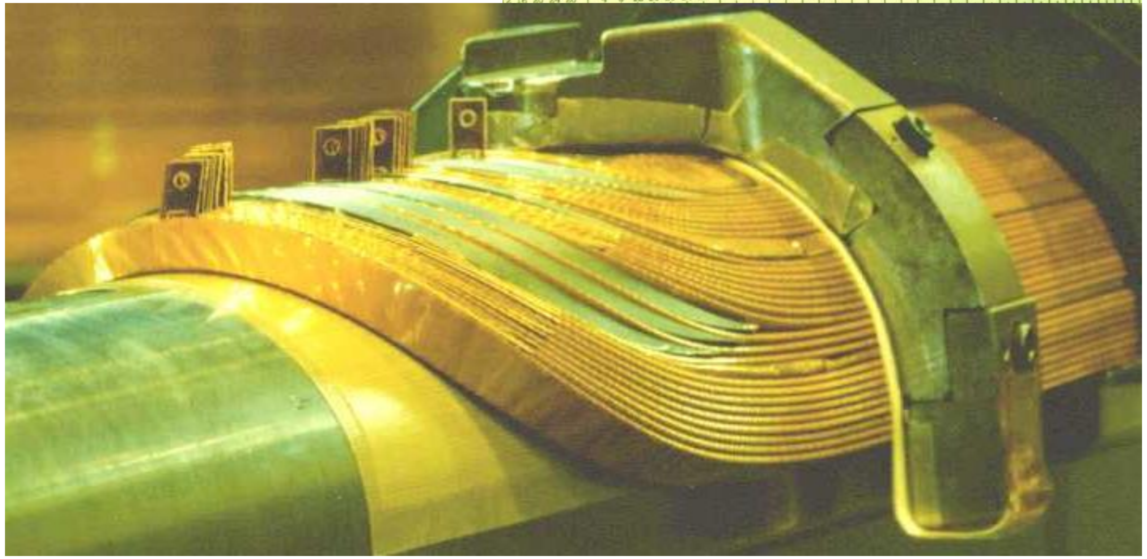
Extra Slides

Cable Layout (path) in the Cosine theta Ends

- One major source of challenge in the cosine theta ends is the length of the cable between the path at inner radius and at outer radius when traversing from side to the other side. The difference is maximum for the midplane turn
- Rutherford cable can be starched a bit, can be deformed a bit also; but too much of that causes cable to degrade
- The cable is tilted to reduce the length at the outer side and increase at the inner side. A perfect constant perimeter end will have that.
- In reality, it can’t be done. The level of the complexity depends on the ratio of cable width to the coil radius.
- In optimizing ends, the change in tilt angle is made gradual, change in path length between the two sides is minimized from the centerline, sudden changes are avoided, and strain on cable is minimized.
- Some time we add extra spacers, to minimize bunching of a large number of turns to avoid making the block too soft







Basic Guidelines to be Expanded

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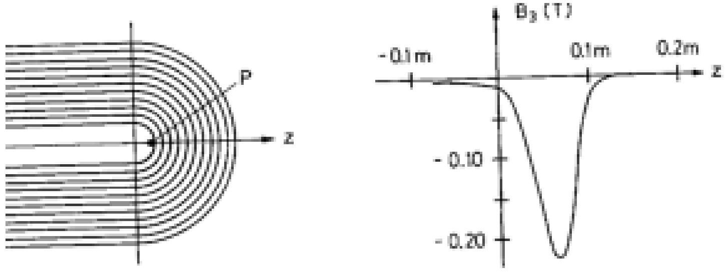
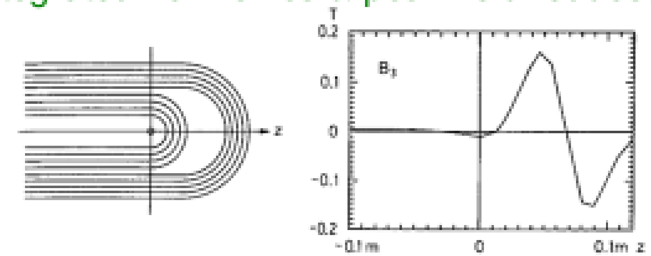
End Harmonic Optimization (conceptual)

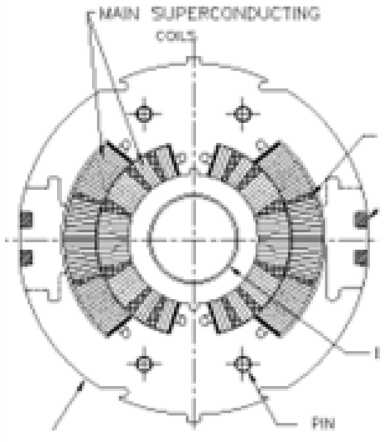
Ends without spacer
(large harmonics and peak field)

Ends with spacer
(integrated harmonics & peak field reduced)





a) Schematic view of HERA coil head with spacers
b) Computed sextupole field of HERA dipole



- 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 spacers 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.

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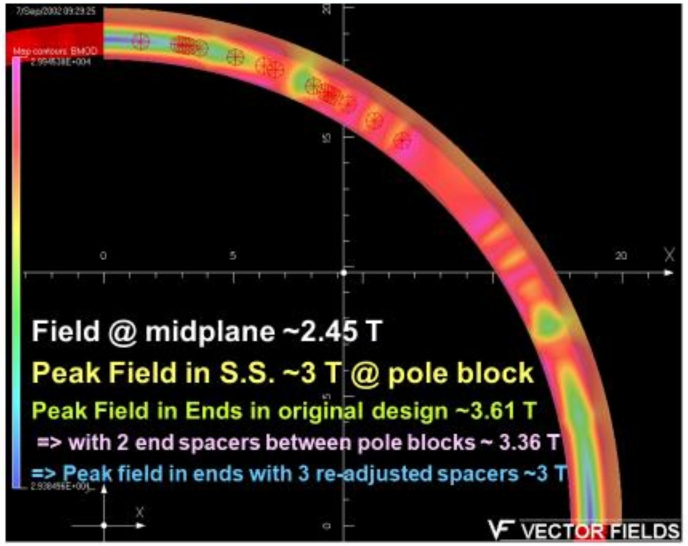
Peak Field Straight Section vs. Ends



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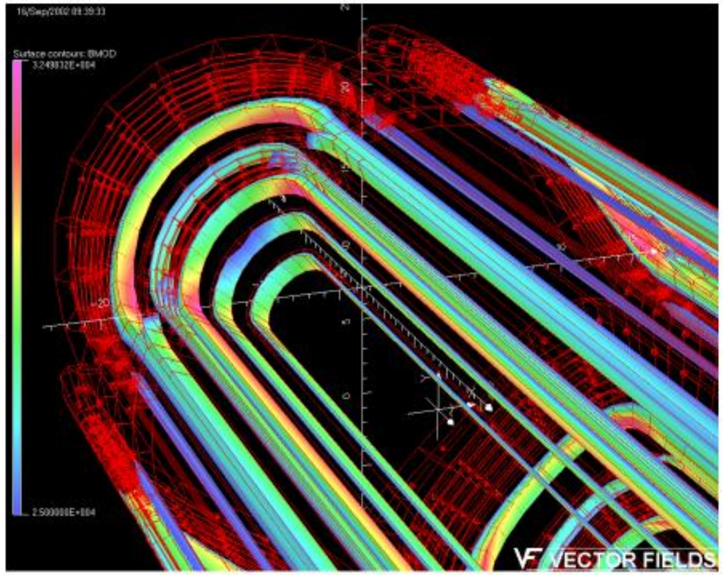
Ends with 3 Re-adjusted Spacers

Example (optimized):

Re-adjusted end spacer brings field in the ends down to S.S. level.



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Optimize the design to add spacers at the strategic location