PRELIMINARY INVESTIGATION OF A FOUR-LAYER, 4-cm-BORE, DIPOLE DESIGN

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Introduction.

At a recent meeting that I didn't attend, Gary Morgan suggested a new, four layer, dipole design. Layers 1 and 2 would use a cable consisting of 13 strands of .0318-in.-diam wire; Layers 3 and 4 would use a cable consisting of 17 strands of .0255-in.-diam wire. These wire diameters are the same as those of the present two-layer design. There would be no wedges. A compromise keystone angle would be used for each pair of layers so that there would be only two kinds of conductor. The narrower conductor would be easier to wind, so it should be possible to form the conductor to get a better field quality in the end regions. With four free variables -- the number of turns in each of the four layers -- the field quality should be ok. That' how it it was presented to me by Bob Schermer; he asked me to look into it, so here goes.

First we look at the effect on load-line slope and operating margin; finallay we look at the effect on field quality.

Load-Line Slope and Operating Margin.

Since both the two-layer and four-layer designs use the same strand diameters, we can compare the two load-line slopes on the basis of (field strength)/(current per strand). The performance is dominated by the innermost layers, and the various ratios we will look at are roughly the same for the inner layers and the outer layers, so we need only look at the inner layers.

The load-line slope, then, is proportional to the number of strands per pole divided by some sort of effective mean coil radius. The number of strands per pole, in turn, is affected by the inner radii of the the layers and the thickness of the thin edge of the conductors, the number of layers, and the number of strands per conductor.

When I speak of "the ratio" in the following discussion, I mean the ratio of an attribute of the four-layer design compared to that of the present two-layer design.

The ratio of strands per conductor is 13/23=0.565 for the inner conductor. (It is 17/30=0.567 for the outer.)

The ratio of the number of layers, of course, is 2.000.

The average inside radius of the inner two layers of the four-layer design determines how many conductors can fit into those two layers. The inside radius of the inner coil of the two-layer magnet tells how much conductor will fit into that layer.

4-layer:	(20.00+25.84)/2=22.92mm	
2-layer:	20.00mm	The ratio is 1.146.

It is assumed that the same thin-edge conductor thickness as presented in the Japanese proposal [1] is to be used for the four-layer design. The ratio is 0.873.

The ratio of the mean coil radii, weighted 2-to-1 in favor of the inner layers, is 1.053.

Putting this all together, we get an increase in load-line slope of 0.567 x 2.000 x 1.146 / 0.873 / 1.053 = 1.414. This 41.4% increase, when combined with the conductor characteristic curve [2], results in an increased margin of 41.4 x .31 = 12.8%. This is more than adequate to provide a viable design.

Field Quality.

The business about the four free variables for tuning the field quality isn't really correct. The number of turns in each layer are certainly variables, but they are not continuous variables; it is extremely difficult to put a non-integer number of turns in a layer. However there are two continuous variables: the conductor azimuthal thicknesses of the two conductors. We only have to adjust, at most, about plus or minus half a conductor thickness in each layer-pair, which doesn't amount to much per turn. So we have really six free variables: two continuous ones, four stepwise ones.

The question, then, is "What sort of field quality can we expect from such a magnet?"

We start with an assumed conductor azimuthal thickness for each layer-pair, and an assumed number of turns in each layer. Then we adjust the conductor thicknesses to make b_2 (sextupole) and b_4 (decapole) exactly zero. We repeat the process with different numbers of turns, until it appears that we can make no further improvements. At worst, when we are close to the goal, we are within plus-or-minus half a turn of the optimum.

Using some assumed values for the upper-edge angles of each layer, and treating each layer as a thin shell -- a sufficiently good approximation for the purpose -- I have calculated the effect of adding a half turn to each layer. The results are shown below.

The table shows the effect of adding a half turn to each layer. The absolute maxima are all in the innermost layer. The total of absolute values is the absolute worst that could happen. The rms sum, assuming equal probability that the layer angle that would make the four additional multipoles go away is anywhere within the +1/2-turn range, is my best guess as to how well one could do. Conceivably one could do a lot better, but it isn't likely.

The b_6 (14-pole) term -- 0.13 units -- is a bit greater than the tolerance that appears in the literature -- 0.07 units. The higher-order terms are within tolerance.

Conclusion.

The design deserves further consideration.

References.

1 Comments on the 5-cm-Bore Dipoles Proposed by K.E.K. R. B. Meuser, June 2, 1989. SSC-N-642.

2 Superconducting Magnets: Effect of Perturbations of Magnet Parameters on the Operating Point. R. B. Meuser, June 6, 1989. SSC-N-643.

MULTIPOLE COEFFICIENTS, UNITS

n	LAYER 1	LAYER 2	LAYER 3	LAYER 4	TOTAL OF ABSOLUTE VALUES	RMS
6	-.565807	-.066598	.040311	-.012798	.685514	.164914
8	.128499	-.005723	-.000527	-.000355	.135104	.037132
10	-.027032	.001994	-.000263	.000021	.029309	.007825
12	.005336	-.000265	.000013	.000003	.005616	.001542
14	-.000992	.000017	.000001	.000000	.001010	.000286
16	.000173	.000001	-.000000	-.000000	.000174	.000050
18	-.000028	-.000000	-.000000	-.000000	.000028	.000008