Further Investigation of a Four-Layer, 4-cm-Bore Dipole Design

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Introduction

In a previous report [1], I outlined a procedure for designing a four-layer dipole using the same conductor in the inner two layers and a different conductor in the outer two layers, and investigated the potential increase in operating margin and the field quality for such a design. I concluded that such a design warranted further investigation. This, then, is Stage 2. The purpose is to show what can be done with such a design rather than to present specific design proposals.

Design Procedure

The design procedure is as follows: We select a certain number of turns for each layer. We then adjust the two conductor azimuthal thicknesses to make b_2 and b_4 exactly zero. The b_6 term might not be satisfactory, the transfer function might not be as great as we think it can be, or one or both of the conductors might be too thick or too thin. We select a new set of turns, and try again.

I considered the conductors to be fully keystoned in Layers 2 and 4, that is, the conductor surfaces lie on radial planes. The keystoning is deficient in Layers 1 and 3, so the conductor surfaces are at an angle to the radial, the maximum angle being at the pole. This maximum angle turns out to be less than the maximum deviation from radial for the C358 design.

I define the packing factor at the inner edge of the conductor as $\pi d/(2w_1)$ [3], where d is the strand diameter, and w_1 is the thickness at the thin edge of the conductor. For the proposed KEK design, the thin-edge packing factor for the inner cable is 1.1168; for the outer cable, 1.1304. In this study I use a maximum packing factor of 1.1300. I use essentially the same insulation

thicknesses used by Morgan for the C358 design. I thickened the collars a wee bit to account for the thicker coil.

For this study, I used the formulas for the multipoles applicable to radial-sided blocks, which made my procedure run perhaps 100 times faster than if I had used the "exact" conductor configuration. (There are no exact methods of modeling real things; there are only various degrees of approximation.) For the present purpose—to see what can be done, rather than come up with a specific design—this approximation is plenty good. I used the Newton-Raphson method, with analytical derivatives, to obtain the solution. After trying to adjust the numbers of turns by hand, and getting nowhere, I rigged my program to cycle through a number of sets of turns. Some 400 combinations of turns were tried; I am reasonably certain that I covered all potentially applicable ones.

Comment

This is a different ball game from the usual one. The usual procedure is to divide each layer into several blocks of conductors separated by wedges, select the number of turns for each block, then adjust the positions of the blocks—by adjusting the wedge thicknesses—to eliminate the appropriate number of higher-order multipoles. The conductor thickness remains fixed. I don't think anyone has regarded the conductor thickness as a free variable before, except when I made my investigation of the proposed KEK two-layer, 5-cm design [2].

Results

For many turns combinations, the b_6 term is well below tolerance—much less than 0.1 units. For those cases in which the b_6 term is very small, however, the b_8 term is large, usually of the order of 0.15 units, which is much larger than that predicted in Ref. 1, for reasons I don't know. By letting the b_6 term be greater, it was possible to reduce the b_8 term. However, for only one combination the b_8 term is as small as 0.10 units, although there are several for which b_8 is 0.12 units or less. From among those with acceptable field quality, one would select one that has a high transfer function, which implies a large number of turns and conductor thicknesses approaching the lower limits. It turns out that the combination having the highest transfer function of the whole bunch also has one of the best field qualities.

The largest transfer function is 2.635 T/kA. To get the transfer function in terms of current per strand, to compare with C358, we must multiply by the number of strands: 2.635 × 13 = 34.26 T/(kA per strand). The corresponding number for C358 is 1.0395 × 23 = 23.909 T/(kA per strand). The increase is a factor of 34.26/23.91 = 1.433, about equal to the 1.414 predicted in Ref. 1.

The parameters for several of the most likely candidates are presented in the table.

Parameters of Some Four-Layer Design Candidates

Turns in layer				Cond. thkns.(mm)* Layers		Transfer function	Multipole coef.		
1	2	3	4	1, 3	2, 4	(T/kA)	b_6	b_8 (Units)	b_{10}
22	23	27	17	1.388	1.019	2.4898	0.38	0.22	0.05
22	22	27	18	1.390	1.021	2.5145	0.32	0.21	0.05
22	22	28	17	1.389	0.994	2.5156	0.37	0.21	0.05
22	22	28	18	1.391	0.997	2.5400	0.32	0.21	0.05
22	23	27	17	1.373	0.990	2.5192	0.67	0.29	0.06
22	23	27	18	1.375	0.993	2.5440	0.62	0.29	0.06
22	22	28	19	1.394	0.997	2.5649	0.26	0.20	0.05
22	21	28	19	1.408	1.027	2.5393	0.035	0.125	0.035
22	21	28	20	1.414	1.025	2.5588	0.094	0.116	0.037
22	21	29	19	1.409	1.003	2.5600	0.026	0.120	0.037
22	21	29	20	1.411	1.002	2.5846	0.083	0.111	0.035

*at middle of conductor

Conclusions

The four-layer design, using two kinds of conductor, appears to be a promising way to get more than a 10 percent operating margin without having to develop a new cable strand. However, it would be a mistake not to look at other ways of increasing the margin. Three-layer or four-layer designs that fit within the present coil envelope are possibilities.

Many factors must be considered. The present data—pathetically scant—suggests that if finer-filament material is used, the degradation will be too severe for the degree of compaction assumed in this study. End designs must be considered. And the analysis presented does not include peak-field determinations (although experience indicates that the field rise for the thicker coil will be no greater than that of C358).

References

1 Preliminary Investigation of a Four-Layer, 4-cm-Bore Dipole Design. R.B. Meuser, July 14, 1989. SSC-N-658.

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

3 Rehashing of the Furukawa Cable-Compaction Data. R.B. Meuser, May 3, 1989. SSC-N-640.