Evaluation of synchrotron radiation bucking coil locations in 4m arc dipole
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Abstract

Five cases of a detailed model of the XP 4m arc dipole were solved in TOSCA and the results compared. The five cases included four bucking coil locations and no coil (base). No significant effect on field quality was found for any of the four locations. The bucking coil $\delta B/B$ modeled was 8E-4, 10% above the requirement for arc 10.

Model

The figure below shows the basic model looking from -Z. Green is steel. Grey is air. The large red squares are the main racetrack coils also seen on the right of the figure. The small red squares are the four bucking coils. Steel and air are reflected about X=0 by symmetry conditions in the software to create the H magnet. Only half the Z extent was modeled, again by defining a symmetry condition. The model was run with all bucking coils off and then each of the four coils turned on individually. The first is designated hereafter "basic". The four cases with bucking coil are designated bottom-inboard (close to pole), bottom-outboard, midplane-inboard and midplane-outboard. I abbreviate these bot_in, bot_out, mid_in and mid_out. Bottom bucking coils are racetracks. Midplane coils are bedsteads, rising above the beam pipe at the ends as seen on the right side below. Mesh is 2mm between the poles and 3mm where the bucking coils reside.

I compared the models in two ways. First I used the post-processor table function to compute $B_y$ and $B_{mod}$ on a 2.5mm grid in the midplane encompassing $x=0,3$ and $z=0,225$. The steel is 200 cm long so the grid extends 25 cm beyond the steel. Half-sagitta is 2.455cm so 3cm x extent
covers the region in which $3\sigma$ of the electrons may be found including a 3mm steering allowance. Pole half-width is 6.51cm. Second, I used the post-processor to compute multipoles on 901 circles, 2cm diameter, arrayed at 2.5mm intervals along the arc of the 34.65m radius circle which is the nominal beam path inside the magnet. The small circles are normal to the large one which is the nominal beam path. The 25cm of this arc which is beyond the steel is within a few mm of the expected beam path at its end. The field is low at the end so the error in integrated multipoles from this approximation is negligible.

I would be happy to provide the spreadsheets to any reader who wishes to draw his/her own conclusions. I would also be happy to run any other post-processing jobs requested. Below I use Kaleidagraph (2D graphing package) and JMP (stat analysis) to plot some of the data to begin to back up the conclusion stated in the abstract. Full confidence can only be obtained by looking at the spreadsheets in detail.

Distributions of ratios of $B_{\text{mod}}$ values from tables for $z=[0,200]$cm to basic case without bucking coil. For all cases 99% of the values lie within $[0.00078,0.00081]$. One can see from the histogram that ~10000 of the 10413 points graphed are in the central peak. Below I graph the absolute difference in field for the full grid. All of the points outside the central peaks are also outside the steel. These values were evaluated for the 4m dipole. Each model took four days of computation time. The multipole amplitudes will change if the dipole is shortened but the conclusions won't.
Absolute differences from basic model. Below I show the 11713 values for the basic model. The values as the field falls off outside the steel are seen only in the outlier box plot above the histogram.
Normal quadrupole terms as a function of Z along arc of circle for five models. Lower graph is same data as upper with altered Y axis. No differences except near the bucking coil ends.
Note that each of the four models with bucking coils have the same values while all differ to a small extent from the basic model.

Skew quadrupole terms. Here there are three groupings, basic, bottom bucking coil racetracks and midplane bucking coil bedsteads. Still, differences are modest.
Sextupole for five models on two vertical scales. Nothing of interest here except a few mesh problems in the basic model.
Skew sextupole for five models on two vertical scales. Again, nothing to worry about. With 2mm mesh, numerical noise in skew multipoles is of order 10mG.
In the figure above, Mike Tiefenback took the large spreadsheet of table output I provided and plotted the differences between the basic XP model and the four models with bucking coils as a function of X and Z. The thirteen vertical "stripes" correspond to x= 0, 0.25, 0.5, …, 3.0 cm (0.25cm intervals). The horizontal axis is Z=[0,225]cm repeated thirteen times. The number on the horizontal axis is the row number in the spreadsheet, there are 13*901=11713 rows of data. He found that the two outboard locations (bottom traces) are slightly less variable than the inboard ones (upper pair). He also sees an increase in the width of the trace as x increases from 0 (midpole) to 3 cm, left to right in the figure. This is likely due to mesh size and saturation at the edge of the pole, even though the pole half-width is 6.5cm and the mesh is 2mm. See figure 4d of TN-08-024 for a picture of the pole mesh. The trace width at the right is about 1ppm of the bending field.

Conclusions

I conclude that any location of the bucking coil will do. Mike Tiefenback prefers the outboard locations or another location in which the bucking coil is not "seen" by the beam pipe. YMMV