Conventional Dipole for FFA Splitters
Jay Benesch
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Discussion

The conventional dipoles in TN-21-051 have asymmetric return steel and are 60 cm wide. In first splitter layout attempts, Ryan Bodenstein assumed dipoles with 50 cm cross-section and 300 cm length at up to 1.8T. Being lazy, I simply altered the return steel on the earlier model to a symmetric H magnet 50 cm square in cross-section, leaving the length at 380 cm. In hindsight I should have reduced the length. It proved possible to provide the needed field with the reduced cross-section.

Results

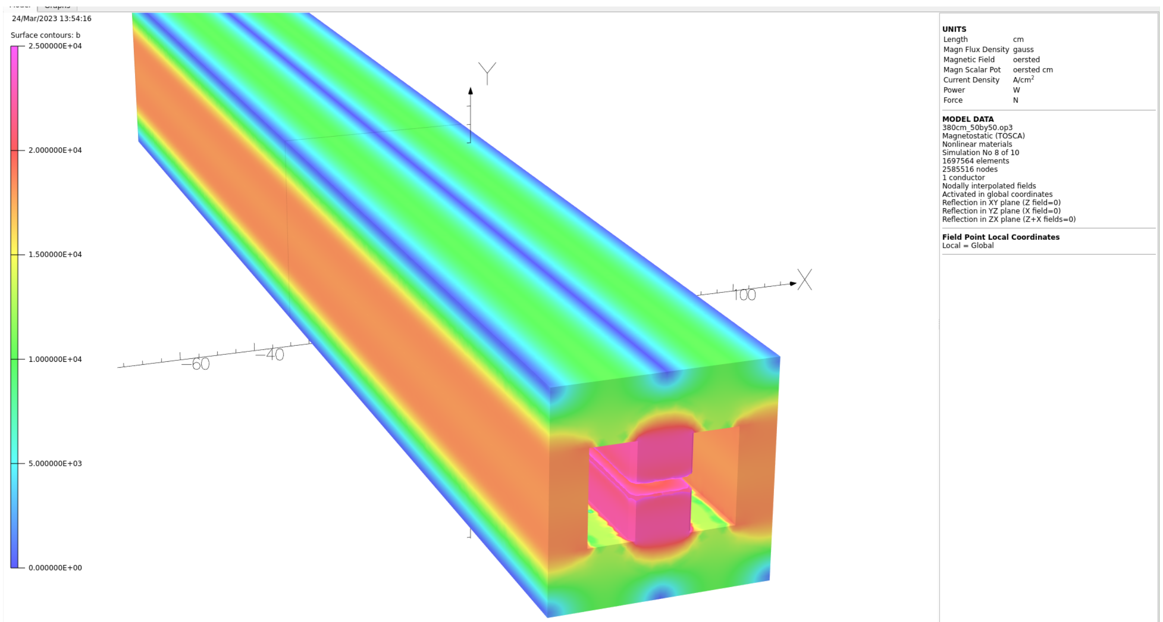

Figure 1 shows the field on the surface of the steel in the simulation with mean field 1.825 T, 900 A.

Ten turn double pancakes of approximate length 65 meters were assumed. Luvata 6815 was chosen as the design conductor. It is 14.5 mm square with a 8 mm diameter cooling hole and 1.5 mm radius corners. Copper area is 1.529 cm^2. To make the numbers easy, average resistivity of 2E-6 Ω-cm was used in calculation, this corresponds to an average conductor temperature ~60 C. Resistance of the double pancake is then 8.5 mΩ. Via http://www.pressure-drop.com/Online-Calculator/ I calculate that 150 cc/s of water in a straight 65 m tube with 8 mm ID yields 9.1 bar pressure drop. With bends, call it 10 bar. Inside bend radius of inner turn 6 cm, four times the insulated conductor width so strain 11.1% and keystoning is very unlikely. If the inside radius were 4.5 cm, three times the insulated conductor width, strain 14.3%. This choice would shorten the unit another 3 cm but pressure drop would increase TBD. If there were perfect heat transfer from copper to water, 150 cc/s with 50 C temperature rise corresponds to 7.5 kW of power. As will be seen below, the current needed for 1.825T is 900 A so the resulting power per double pancake is ~6900 W. Temperature rise then 46 C and the 60 C average copper temperature assumed is compatible with 35 C entry temperature and the calculated temperature rise. If the flow rate is reduced to 120 cc/second, 6.12 bar required for 65 m straight. At 6900 W, temperature rise 57.5 C resulting in exit temperature 92.5 C, uncomfortably close to boiling before copper resistivity is adjusted for higher average temperature. A pump to boost the water pressure is suggested so the 150 cc/sec can be achieved.

Table 1. H magnet results at 380 cm length

AmpTurns	BdL	Amps	BdL/380 (Gauss)
3375	1243260	112.5	3272
6750	2486170	225	6543
10125	3721700	337.5	9794
13500	4863820	450	12800
16875	5678430	562.5	14943
20250	6260460	675	16475
23625	6667280	787.5	17545
27000	6935570	900	18252

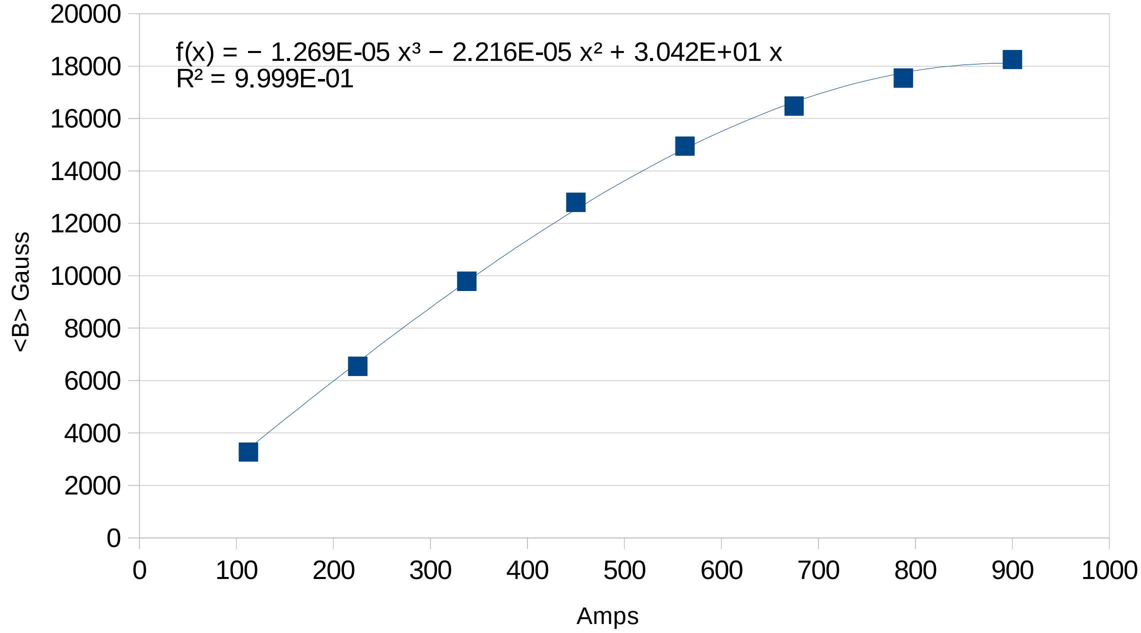

Figure 2. Plot of Table 1.

Conclusion

While the design can be pushed to 1.825 T it would be prudent to set the maximum current to 800 A and thus the field to 1.764 T. This would ease cooling requirement significantly as only 5440 W would be generated in each pancake, yielding 45 C rise at 120 cc/sec and ~6.2 bar pressure drop. Power supply voltage for six double pancakes at 8.5 mΩ each and 800 A is then 40.6 V plus leads. At 820 A, 1.78T, ~48 C rise at 120 cc/sec, 6.2 bar. Buy a 900 A, 50 V supply for each?

It has been suggested in the FFA working group that a hybrid scheme with permanent magnets and their associated corrector package (TN-22-034) be used in connection with an electromagnet shorter than 300 cm to make splitter layout easier. Others are working on that.