Water-cooled copper septum for FFA
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Abstract

As a result of the insight which led to the ZA redesign in https://jlabdoc.jlab.org/docushare/dsweb/View/Collection-55035 I reduced the pole spacing in the FFA septem from 9 cm to 4 cm as discussed in the 14-17 October addition to https://jlabdoc.jlab.org/docushare/dsweb/Get/Document-259879/22-037.pdf . This reduced the AT required to ~14000 AT in each of the two bedsteads. Since the coil and cryostat between them in the SC septum are 3.5 cm wide by 4.5 cm half-height, the possibility of using a conventional conductor beckoned. In what follows I show that this is feasible with fewer water connections than in the ZA redesign if one accepts a booster pump to 25 bar for the LCW.

Discussion

The conductively cooled superconducting septum for 22 GeV FFA assumes a 15 mm thick cryostat on all sides of a 0.5 cm wide by 3 cm half-height pair of bedsteads. It follows that the central gap in the steel is 3.7 cm wide by 4.5 cm half-height. The notch in the pole at outer edge was only 2 cm as the cryostat was allowed to stick out beyond it; only the coil need be under the pole. Widening the steel by 1.2 cm to make the outer notch 3.2 cm wide by 4.5 cm high would allow 10 mm square copper conductor to be used for the coil. Three turns wide by four high, coil section 3 cm by 4 cm, 12 turns in each of two bedstead coils. Roughly 14000 AT turns needed, so 1166 A. Luvata has dies for a 10 mm square conductor with 7.5 mm hole, 1 mm corner radius. Assuming four turns is 2800 cm long and the average copper temperature is 60 C (resistivity 2E-6 ohm-cm), resistance per four-turn pancake is 10.19 mΩ. At 1166 A, ~12V/pancake and ~72 volts for the full coil. 13830 W per pancake. Using http://www.pressure-drop.com/Online-Calculator/ I get 22.7 bar pressure drop for a tube 7.5 mm ID, 28 m long, internal roughness 0.01 mm, 310 cc/sec. Given calculated power, 45 C rise. With 35 C water and 2.3 bar back pressure, 25 bar water pump needed. MOLLER led to 20 bar LCW supply in Hall A; this isn't too much worse. 80 C exit temperature expected. This scheme reduces the number of water connections per bedstead from 24 to 6, a significant reduction in complexity. And of course a conventional coil is a lot less complex than a conductively cooled superconductor and cryostat.

I also looked at a 9 mm square conductor with 5 mm hole. In this case each turn must have its own water path, 700 cm, as in the present ZA. At 100 cc/sec only 5.21 bar is needed and the temperature rise will be less than 32 C for the calculated 3140 W. With existing 7 bar differential pressure, less temperature rise. But a lot more complicated water connection system.

Finally, I looked at 9.52 mm square, 6.35 mm hole aka 3/8" square with 1/4" hole, used in many existing CEBAF dipoles. Over 28 m, 200 cc/sec yields 23 bar pressure drop. 14000 W in the higher energy spreader. 70 C temperature rise, too large given 35 C inlet. OTOH, if one connects three turns in series, since coil is three wide and four high, length will be 21 m and 230 cc/sec requires 22.4 bar, comparable to four turns of the 10 mm conductor. Temperature rise 44 C, also comparable. This layout would have 8 water connections per bedstead vs 24 in the ZA and 6 in the layout using 10 mm conductor. Engineering choice.

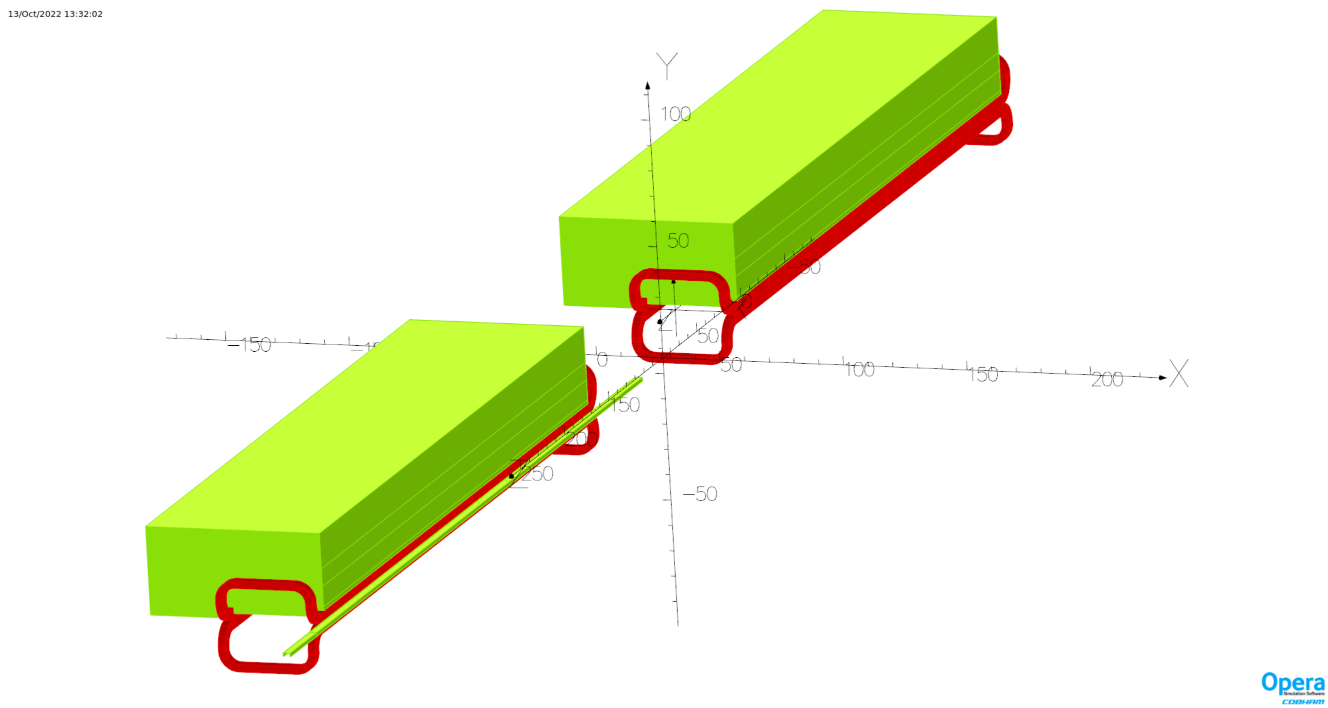

Figure 1. FFA septum pair with water-cooled copper coil. The 1.5 m spacing between the magnets is still necessary to put the passing beam far enough away from the second magnet in the pair. It's no longer needed for cryogenic refrigerators in addition to beam displacement. Exact layout of turns including water connections not relevant magnetically.

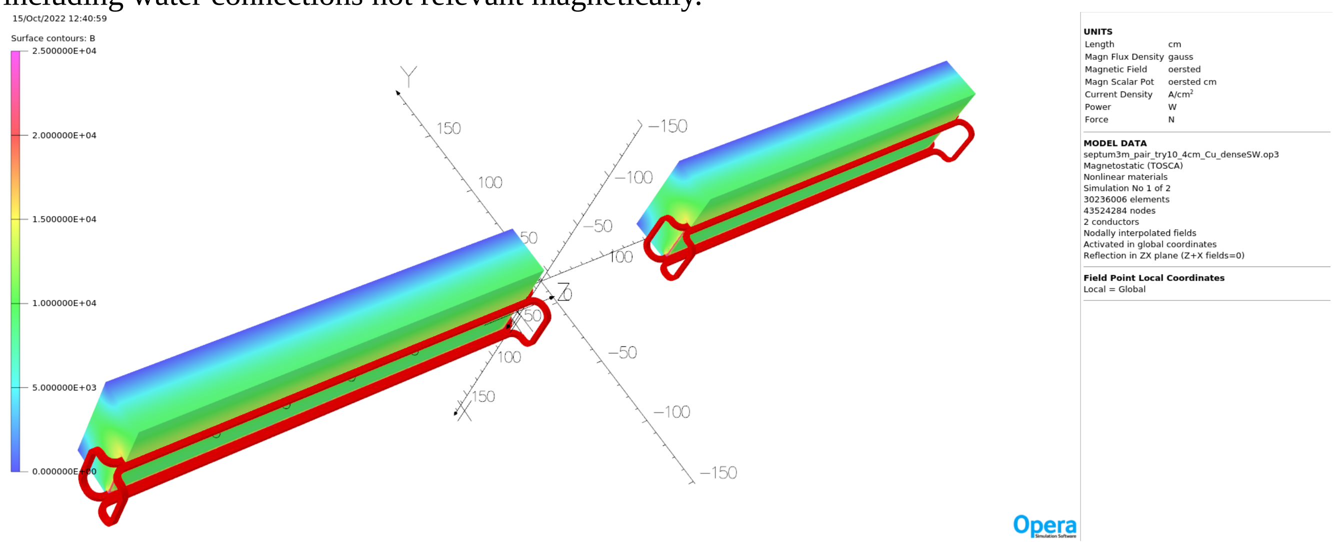

Figure 2. Field on the surface of a dense model with drive appropriate for SW spreader. Tube is missing because I had meshing issues with it that I chose not to take the time to resolve.

Using the same command files used in TN-22-037 I computed harmonic content. The table on the next page compares harmonic content of models with at 5 mm thick SC septum between flat steel poles (9 cm pole gap), 5 mm SC septum with 4 cm pole gap and the 30 mm thick by 40 mm half-height water cooled copper septum shown above.

Conclusion: The water-cooled copper septum is a viable alternative to the conductively cooled SC septum for the FFA energy upgrade.

	energy (MeV)	Cos0	Cos1	Cos2	Cos3	Cos4	Cos5	Cos6	Cos7	Cos8	Cos9
try6, SC, 9 cm gap	8350	-2715798	-24269	-7443	-1298	-93	21.7	6.3	1.8	-1.1	0.1
try8, SC, 4 cm gap	8350	-2664172	20671	13606	4985	663	-329.0	-218.9	-40.8	11.2	10.2
try10, Cu, 4 cm gap	8350	-2662116	22852	15160	5757	945	-262.7	-220.2	-52.0	5.8	10.4
try6, SC, 9 cm gap	9450	-2799159	-20160	-6400	-1216	-129	4.1	2.1	1.0	-1.4	-0.1
try8, SC, 4 cm gap	9450	-2760532	12670	8888	3848	974	38.4	-94.3	-46.4	-12.0	0.6
try10, Cu, 4 cm gap	9450	-2758108	13977	9782	4289	1144	88.3	-82.8	-44.2	-12.4	-0.6
try6, SC, 9 cm gap	10550	-5370076	-10664	-3593	-762	-115	-10.3	-2.9	-0.2	-1.7	-0.1
try8, SC, 4 cm gap	10550	-5353327	3041	2056	1022	365	97.2	14.4	-0.9	-2.7	0.5
try10, Cu, 4 cm gap	10550	-5352134	3328	2272	1122	397	107.7	17.3	-1.1	-1.7	-0.3
try6, SC, 9 cm gap	11650	-5549161	-9434	-3216	-692	-108	-10.9	-3.5	-0.2	-1.5	-0.4
try8, SC, 4 cm gap	11650	-5535545	2282	1468	734	268	73.8	13.2	1.4	-2.4	-1.1
try10, Cu, 4 cm gap	11650	-5532448	2472	1628	815	292	80.4	13.8	2.2	-1.2	-1.9
try6, SC, 9 cm gap	12750	-5354037	-36	-112	-14	-7	-0.2	-1.6	-0.2	-0.9	0.1
try8, SC, 4 cm gap	12750	-5355188	271	13	1	-3	-1.1	0.5	0.5	-0.3	-0.4
try10, Cu, 4 cm gap	12750	-5354043	282	7	-3	-2	-0.4	1.3	0.8	-1.0	-0.3
try6, SC, 9 cm gap	13850	-5535208	14	-93	-10	-6	-0.2	-1.8	0.2	-0.8	-0.2
try8, SC, 4 cm gap	13850	-5537246	269	15	2	-2	-0.9	0.7	0.3	-1.8	-0.5
try10, Cu, 4 cm gap	13850	-5534151	289	10	-1	-3	-3.3	1.8	2.6	-1.1	-1.3
try6, SC, 9 cm gap	14950	-5354066	618	-197	44	-10	1.2	-1.6	0.1	-0.7	0.0
try8, SC, 4 cm gap	14950	-5355209	185	13	-3	1	-0.4	-1.8	-1.3	1.2	0.7
try10, Cu, 4 cm gap	14950	-5354040	183	9	1	3	1.0	-1.7	-1.1	0.8	0.8
try6, SC, 9 cm gap	16050	-5535609	766	-249	56	-12	1.6	-1.9	0.3	-0.7	0.2
try8, SC, 4 cm gap	16050	-5537395	167	16	-4	2	-1.3	0.1	1.8	-0.2	-1.4
try10, Cu, 4 cm gap	16050	-5534283	172	6	-3	4	-2.3	0.2	0.4	-1.9	0.3
try6, SC, 9 cm gap	17150	-5356328	2370	-790	174	-30	3.7	-2.5	0.2	-1.0	0.1
try8, SC, 4 cm gap	17150	-5355097	11	103	-46	15	-3.3	0.5	-1.3	-0.3	0.4
try10, Cu, 4 cm gap	17150	-5353931	-15	144	-57	18	-6.6	-2.3	0.7	1.3	-0.9
try6, SC, 9 cm gap	18250	-5539595	3654	-1215	263	-44	5.0	-2.5	0.2	-1.1	0.1
try8, SC, 4 cm gap	18250	-5537193	-196	237	-111	39	-12.9	1.6	0.8	-0.2	0.0
try10, Cu, 4 cm gap	18250	-5534050	-292	305	-132	47	-15.3	2.0	2.3	-1.2	-0.9
try6, SC, 9 cm gap	19350	-5363035	7015	-2303	483	-73	6.7	-3.0	0.3	-1.3	0.2
try8, SC, 4 cm gap	19350	-5354307	-1107	902	-435	150	-37.6	3.8	0.3	-2.0	0.4
try10, Cu, 4 cm gap	19350	-5352955	-1394	1072	-498	171	-45.7	7.4	0.7	-2.6	0.3
try6, SC, 9 cm gap	20450	-5553188	12728	-4063	800	-101	3.3	-0.9	-0.4	-1.9	0.4
try8, SC, 4 cm gap	20450	-5534395	-4223	3054	-1355	388	-54.5	-15.6	9.9	-4.1	-0.1
try10, Cu, 4 cm gap	20450	-5530659	-5025	3539	-1558	452	-72.5	-5.6	8.6	-5.2	0.1
try6, SC, 9 cm gap	21550	-5377752	16702	-5268	1005	-113	-1.5	0.8	-0.8	-1.5	0.2
try8, SC, 4 cm gap	21550	-5350096	-7087	4940	-2049	481	-7.1	-45.6	17.5	-4.5	-0.7
try10, Cu, 4 cm gap	21550	-5348012	-8267	5682	-2370	596	-45.4	-37.1	18.1	-1.9	-2.5