Modeling the SLAC/JLab Wien filter

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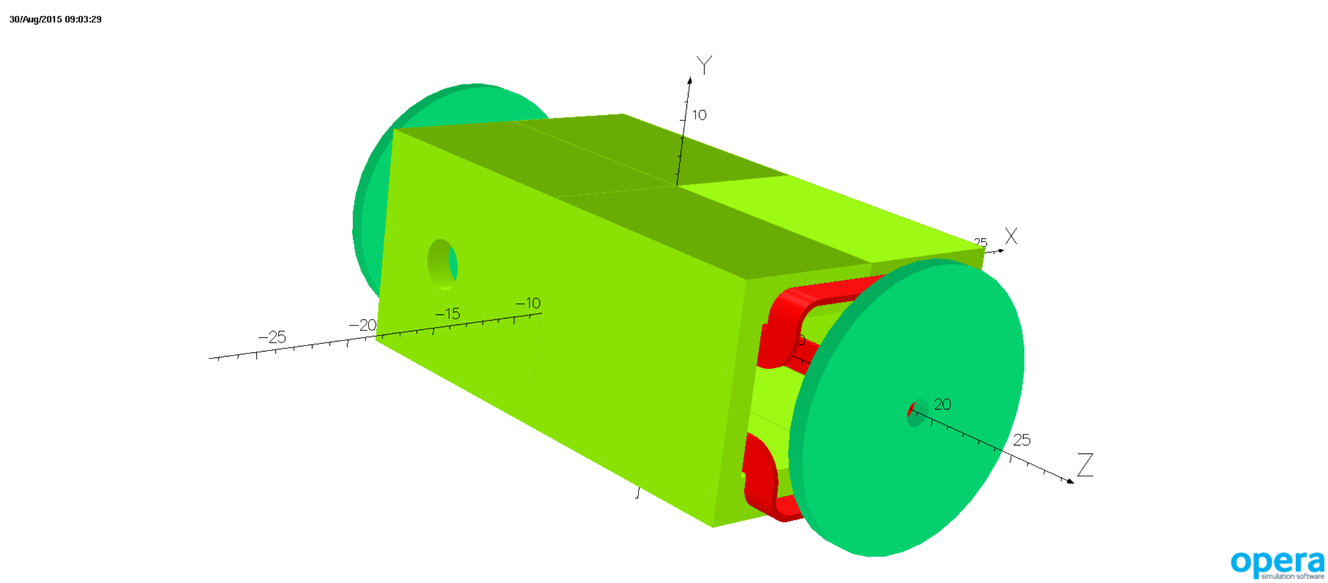
Abstract

The Wien filters used as spin precession devices at JLab are copies of the one developed at SLAC. In 2009 I created a TOSCA model of the unit. This was in preparation for my three-Wien filter effort to miniaturize the system so three could be placed on the chopper circle, one for each beam. The three-Wien system never progressed to a complete optics design. The CEBAF injector upgrade will include a higher voltage photo-gun. The increased magnetic and electric field requirements associated with higher kinetic energy were calculated and engineering solutions for the increases obtained. The minimum changes required are 30 kV voltage feedthroughs and power supplies and an increase in the magnet coil section to allow higher current at similar temperature rise. The latter is accomplished by replacing the 28 turns of #16 round wire with 26 turns of #13 square wire, increasing conductor section a factor of 2.5. Some mounting bolts may have to be shortened or changed to fine thread.

Wien drawings



The top level assembly drawing is 32893-E-0001. The coil outline is 32893-D-0031. It specifies a coil of two layers, 14 turns, #16 wire in a 0.125" by 0.75" envelope. The gap in which the coil resides is 0.197" thick, between steel shown in green and the unseen vacuum vessel. This allows for the increase in wire size to #13 square, 0.078" maximum material condition (MMC); 0.076" nominal, including heavy film insulation. I approximate the coils in my models with what OPERA calls a "bedstead". The real coil end has features at each end which allow it to be flattened against the end of the steel rather than sticking out as here. The coil ends are far enough away from the beam in the model that their direct fields don't influence behavior substantially. I was and am too lazy to build a better approximation to the real coils with bricks and arcs of current.

The HV feedthroughs to the electrodes use 1.125" holes in the sides of steel box, seen at the left in the figure. These holes are the constraint which limits the new coils to 13 turns: at MMC the turns will slightly overlap the hole but will not (barely) touch the 1" tube which passes through it. This is shown in the next figure.

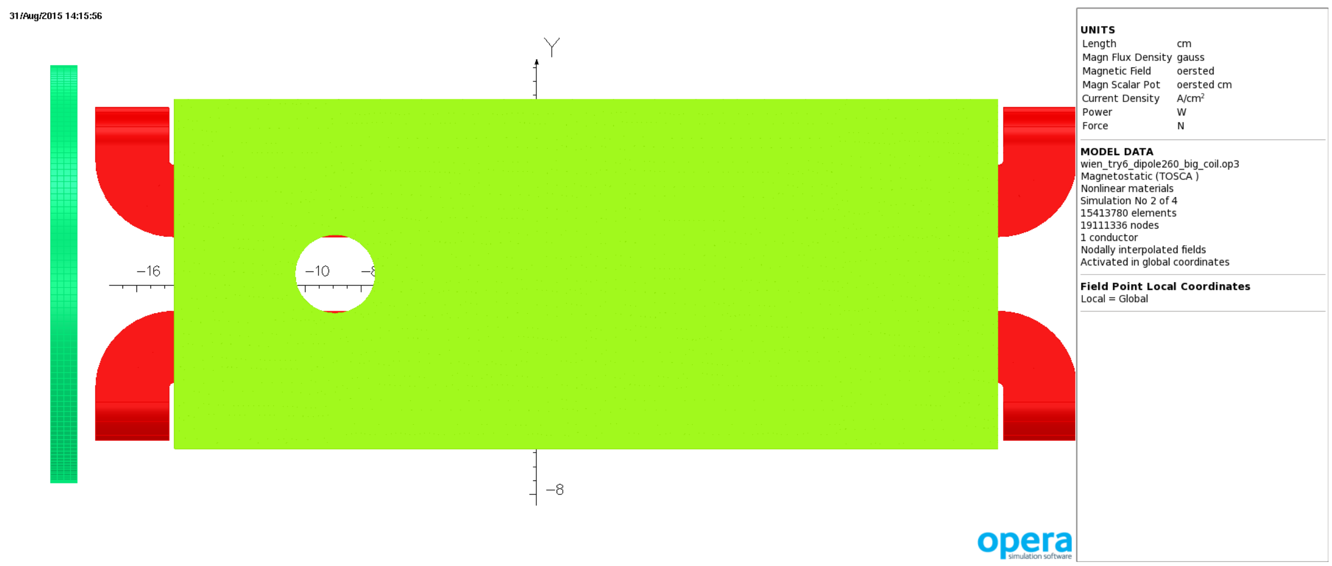


Figure 2. One sees the red of the wider coils through the holes in the steel. The coils are shown at MMC. The ends get closer to the nickel field containment plate than in the previous model, but again don't significantly affect model performance versus the more labor intensive coil that would be made of many bricks. The real coil will be folded back against the steel yoke.

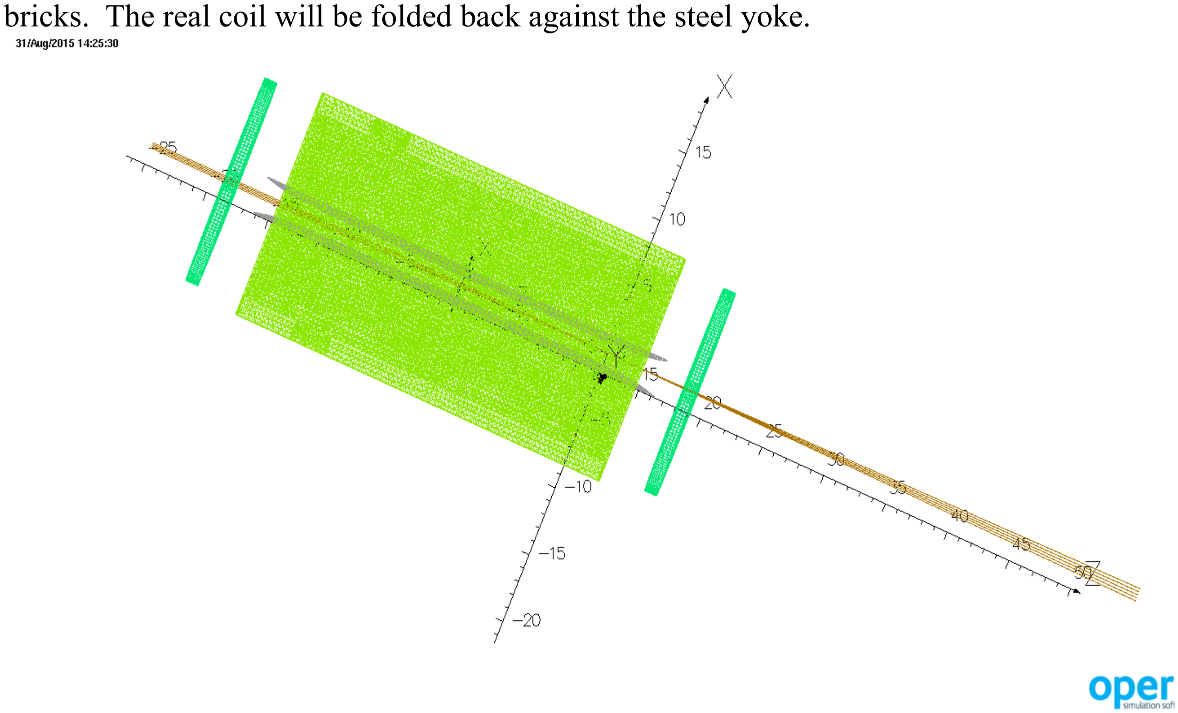


Figure 3. One sees here a 4 mm square array of twenty-five 200 keV electrons propagating through the Wien filter set for 100 degrees of precession. Horizontal focus is just before the beam leaves the steel (green). The coils aren't seen because this is view is of the electric field model and OPERA automatically drops coils when computing electric fields. I imported the magnetic fields from a magnetic field calculation with identical mesh so I could use both E and B fields in calculating particle trajectories as shown.

Note: (placed here because it fits). The hole in the nickel plate is 15 mm diameter, the same as the electrode spacing. The beam tube is presumably smaller.

fixed precession at 100 degrees, variable BdL, B, V

KE (keV)	beta	BdL(T-m)	B(T)_step_fu	V/m	Vapp +-	Current(26T)	beta_ratio
100	0.5482	2.33E-03	0.0076	-1.25E+06	9347	8.64	0.7885
130	0.6037	2.82E-03	0.0092	-1.66E+06	12476	10.47	0.8683
200	0.6953	4.00E-03	0.0130	-2.71E+06	20360	14.84	1.0000
225	0.7197	4.44E-03	0.0144	-3.12E+06	23374	16.45	1.0351
250	0.7410	4.88E-03	0.0159	-3.53E+06	26491	18.11	1.0657
275	0.7598	5.34E-03	0.0174	-3.96E+06	29713	19.81	1.0928
300	0.7765	5.81E-03	0.0189	-4.41E+06	33039	21.56	1.1168
325	0.7914	6.29E-03	0.0205	-4.86E+06	36469	23.35	1.1383
350	0.8048	6.79E-03	0.0221	-5.33E+06	40004	25.18	1.1575

The table above shows the BdL required for 100 degrees precession at the indicated kinetic energy. The effective length (BdL/B(0,0,0)) of the magnet is 0.30714 m, resulting in B(T)_step_function in the next column. This is in turn used to calculate the E field required for a straight orbit through the Wien filter assuming equally perfect and square-ends in E, V/m. Vapp is the voltage which must be applied to the electrodes, separated by 0.015m, to achieve the needed V/m. The current needed to achieve the BdL with 26 turns is shown next. The last column gives the ratio of beta to 200 keV so one has an idea of much span one might have in entering the new quarter-cryomodule or copper capture cavity. Actual orbits through the model require that the electric field be reduced by 1.0% from that shown in the table for all energies. This is acceptable accuracy given that step-function B and E fields are assumed. Since the magnetic field is low and the E fields high, I reduced the E field to adjust the orbit.

The 275 keV line catches my eye. A 20A trim supply would work given that the Wien will rarely be set above 90 degrees. 30 kV feedthroughs may be used, although if a 35 kV unit which fits can be found it would be better. Current density is high for an air-cooled conductor, 5.8 A/mm^2 in the copper, but it is in good thermal contact with steel core and so should be OK. The power dissipation at 90 degree precession for 275 keV is about a third higher than with the present coil at 130 keV. Test required.

The internal Macor electrode supports will be fine even with 40 kV applied to electrodes if clean.

The coils will be about 0.32 ohms so a water-cooled series resistor may be required to raise the voltage to a better point on the 20A/75V power supply's operation line. The leads going to the service building might suffice to raise impedance.

The only other change which may be required AFAIK is reducing the lengths of the 1/4" bolts which hold the Wien filter to its stand so as to keep the bolt ends away from the slightly thicker coil. One could change to 1/4-28 and jam nuts to increase the distance. One could even tap the mounting tabs on the Wien 5/16-24 and drill out the mounting stands to match, using jam nuts as lock-nuts to hold everything tight. This last option would provide the largest gap to the coil surface.

Conclusion

The changes required to adapt the existing Wien filters to beam energies up to 275 keV are modest: new magnet coils and 30 kV electrical feedthroughs mounted on CF flanges. Higher energies are possible but coil heating and external space for electrical feedthroughs would have to be checked.