DESIGN OF A PULSED FLUX CONCENTRATOR FOR THE ILC POSITRON SOURCE*

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Abstract

The Positron Source for the International Linear Collider requires an optical matching device after the target to increase the capture efficiency for positrons. Pulsed flux concentrators have been used by previous machines to improve the capture efficiency but the ILC has a 1 ms long pulse train which is too long for a standard flux concentrator. A pulsed flux concentrator with a 40 ms flat top was created for a hyperon experiment in 1965 [1] which used liquid nitrogen cooling to reduce the resistance of the concentrating plates and extend the lifetime of the pulse. We report on a design for a 1 ms device based on this concept.

BRECHNA DESIGN

We have created a simulation of a pulsed flux concentrator based on the Brechna [1] design as shown in Figure 1. Energizing coils are driven with a current 100 kA each with a 1 ms pulse. Concentrating plates in between the coils concentrate the magnetic field. The entire assembly is cooled by liquid nitrogen in order to reduce the resistance of the concentrating plates and increase the lifetime of the peak magnetic field. Table 1 shows the difference in operating parameters between the built and operated Brechna magnet and the desired ILC magnet.

Table 1: The Variation of Key Parameters from Brechna to the ILC

Parameter	Brechna	ILC
Field Strength (T)	10	4
Pulse Length (ms)	40	1
Repetition Rate (Hz)	1/3	5

The magnetic field and pulse length are smaller for the ILC magnet but the repetition rate is larger. A rough scaling would predict lower average power in the ILC magnet but the higher repetition rate will mean that cycling and fatigue should be a larger issue for the ILC magnet. The Brechna device was successfully operated for 400,000 pulses. That is one days running for the ILC magnet which is expected to run 24/7 for one year before replacement.

A fully superconducting magnet was considered but the radiation backgrounds in the positron target area preclude that option due to the heat deposition from stray particles.

* This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

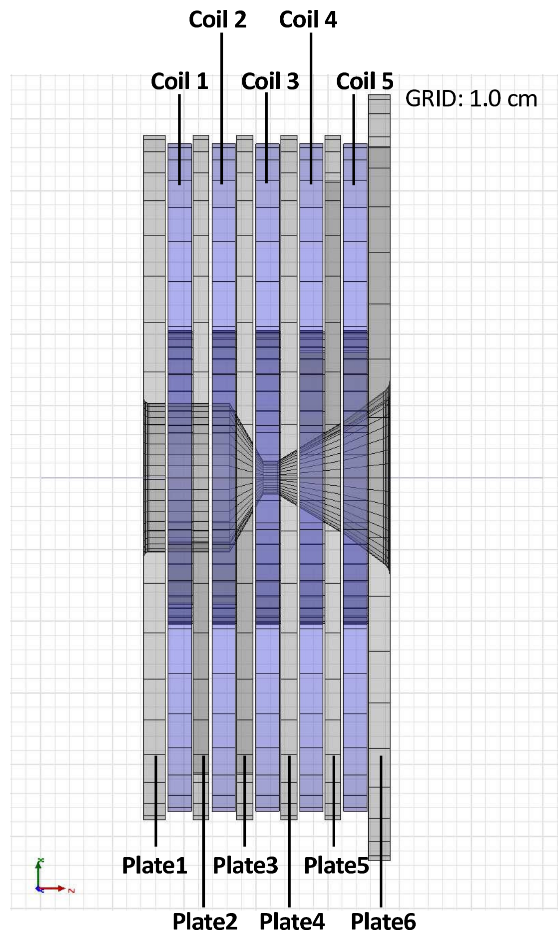

Figure 1: The layout of energizing coils and concentrating plates used in the simulation.

SIMULATION RESULTS

Ansoft Maxwell 3D transient solver is used to generate the magnetic field diagrams for the configuration studied. The plates and coils are assumed to be made of OFHC copper with an electrical resistivity of 0.28 $\mu\Omega - \mathrm{cm}$. The energizing coils are 1.64 cm thick with an inner diameter of 20.5 cm and an outer diameter of 46.4 cm. There is a 1.42 cm gap between each coil. The coils are sandwiched by concentrating plates which fill the volume out to the outer diameter and also fill the inner bore in order to create the shaped field. Each plate contains a slit of width 0.2 cm from the inner bore to the outer diameter which forces the current in the plate to concentrate the magnetic field at the bore. The slit in each plate is offset by 60° from it's neighbor. A total integrated current in each coil of 100 kA injected as a top hat pulse of 1 ms is assumed.

Currents and Magnet Field

The current density can be seen in Figure 2, with the magnetic field presented in Figure 3. The peaks of the field and current density can be seen near the bore of the magnet and along the slits in the plates.

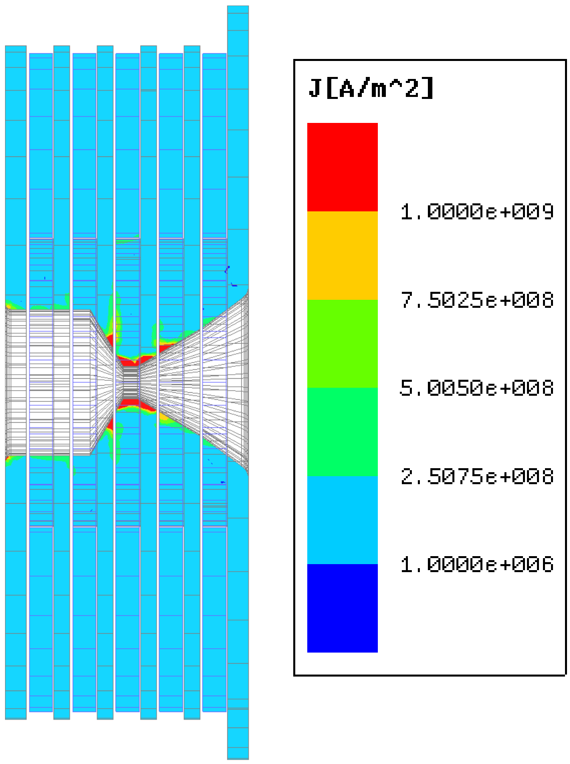

Figure 2: The current density in the plates and coils at time 0.5 ms in Amps/meter^2.

Figure 4 shows the magnitude of the magnetic field along the center line at the middle of the pulse (0.5 ms). The outer edges of the device occur at 70 and 240 mm on this plot.

Heat Dissipation and Cooling

The cooling from the liquid nitrogen flow is calculated using the CFdesign program. Figure 5 shows a Pro/Mechanica simulation of temperatures in the concentrating plates where the calculated volumetric heating is modeled as a surface flux of the appropriate magnitude at the bore and slit. The largest currents flow around the inner bore and along the slit, this is where the maximum heating occurs. At 5 Hz operation the average power loss will be 10 kW which will be absorbed by the liquid nitrogen. The maximum temperature change in the simulation is 6°C, in order to avoid boiling of the liquid nitrogen and associated shocks we propose to provide liquid nitrogen from a cryocooler operating at a temperature cooler than 6°C below the boiling point of nitrogen. The stress from thermal deformation is estimated to be 10 MPa.

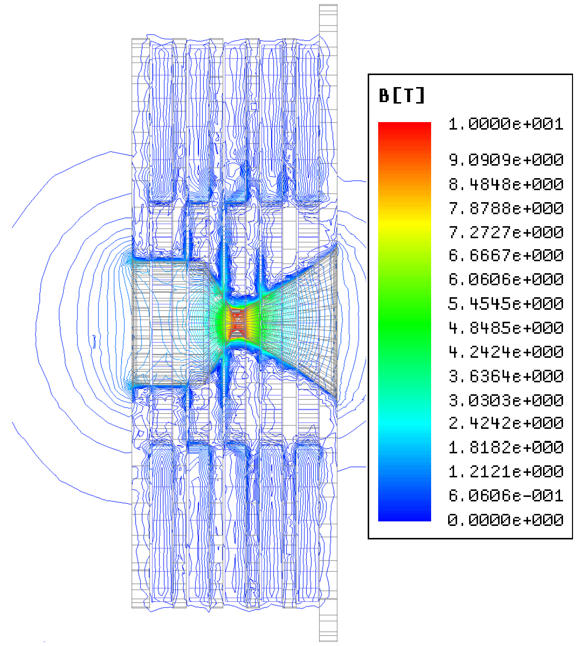

Figure 3: The absolute magnitude of the magnetic field in the device at time 0.5 ms in Tesla.

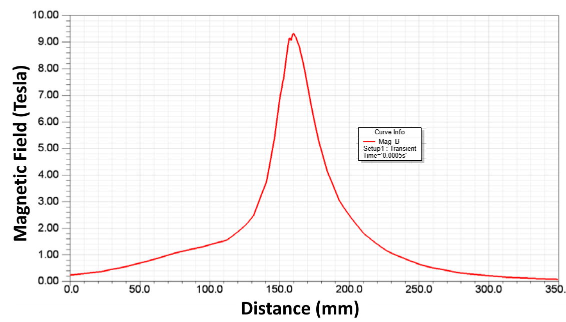

Figure 4: The magnitude of the magnetic field along the center line of the bore at the middle of the pulse (0.5 ms).

Stresses on the Device

The interaction of the currents in the device cause it to want to come apart. The peak volume integrated force occurs between coil 3 and plate 4, see Figure 1, and is approximately 72 kN. Since the speed of sound in copper is $\sim$ 400 cm/ms transient force effects should translate into stresses provided displacements are small. The currents circulating within the concentrating plate will apply a force in the direction of widening the gap. We estimate the stress field from this force, as shown in Figure 6, by taking the volume integrated force and applying it as a pressure to the inner surface of the bore and slit. The peak von Mises stress is on the order of 150 MPa. The yield stress of best OFC copper at 77 K is about 375 MPa [2]. Our best estimate of the fatigue limit for cryogenic copper at 77°K is about 160 MPa, given a value of 115 MPa [3] at room temperature for 10^8 cycles, therefore the model is at the limit for 10 T but will have a better safety margin for the field level

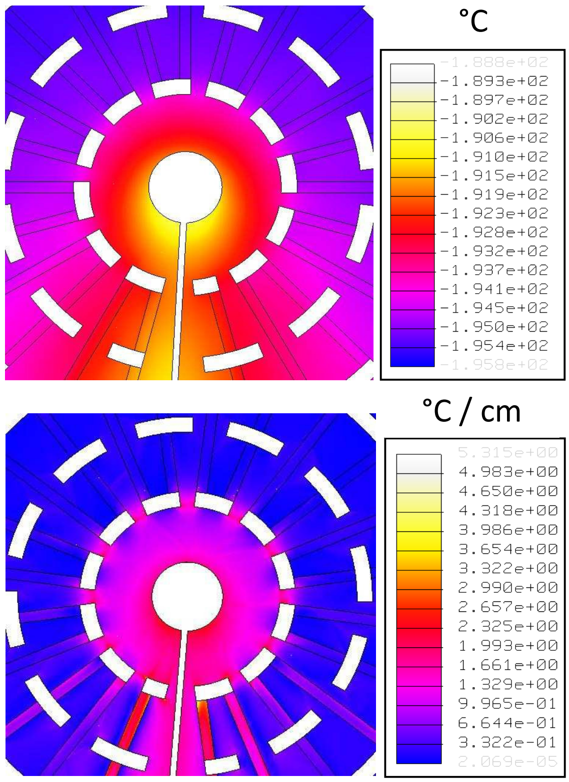

Figure 5: Top: The temperature distribution at the end of the pulse. Bottom: The temperature gradient. The white spaces are the liquid nitrogen flow cooling channels.

needed by the ILC.

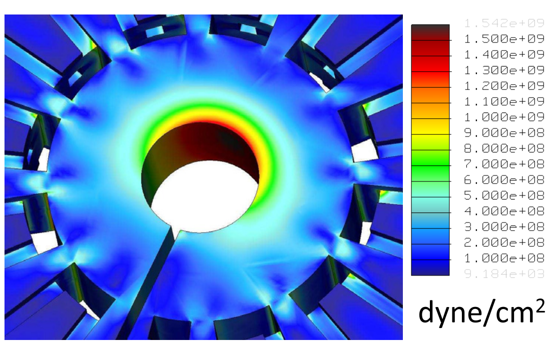

Figure 6: Peak stresses in the concentrating plate.

ANCILLARY HARDWARE

The device will require a pulse forming network to drive the currents which we have estimated would have a capital cost of about \$500K. Given the average ohmic heating load of 10 kW a significant liquid nitrogen cryocooling plant will be required. Commercially available crycoolers can remove 1 kW with 4% efficiency at a capital cost of 100 \$/W. Therefore it will require a \$1M capital cost and \$330K/year in electrical power, assuming 0.15 \$/kW-hr, to provide cooling for the device.

FUTURE WORK

The initial simulations were done using the Brechna configuration at 10 T peak field which is higher than the ILC specification of 4 T. We will proceed to optimize the design at 4 T to maximize the capture efficiency for positrons in the ILC target while maximizing the safety margin for stresses and cycling fatigue.

REFERENCES

[1] H. Brechna, D. A. Hill and B. M. Bailey, Rev. Sci. Instrum. **36**, 1529 (1965).

[2] http://www.copper.org

[3] "Copper and copper alloys", ed. J. R. Davis, ASM International, ISBN: 0-87170-726-8, p454.