TRIUMF Beam Physics Note
TRI-BN-10-03
Sept, 2010

Magnetic field compensation for E-Linac

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Abstract: The 4-wire scheme of creating a region of relatively uniform magnetic field is described and applied to that required to compensate the 3 gauss ambient field at the location intended for the electron linac.

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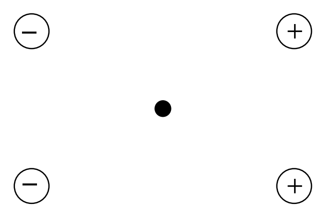
1 Geometry

Circular coils arranged as Helmholtz, with their separation equal to their radius, create a region of uniform field appropriate for cancelling a uniform ambient field. The region of uniformity can be extended by elongating the coils in one direction. This is the configuration required for creating a uniform field along a straight line. Instead of the 2:1 ratio between coil width and separation, the ratio is $\sqrt{3} : 1$.

The configuration is therefore as follows. In a cross section plane through and perpendicular to the beamline, with the beam axis at the origin, $+y$ is up, x is horizontal. There are 4 currents: two positive currents at $(\sqrt{3}/2, 1/2)$ and $(\sqrt{3}/2, -1/2)$, and two negative currents at $(-\sqrt{3}/2, 1/2)$ $(-\sqrt{3}/2, -1/2)$. The coordinates are in units of h, the vertical separation of the currents. See figure below.



The field magnitude is plotted in Fig. 1. For a current $\pm I$ in the 4 wires, the magnetic field

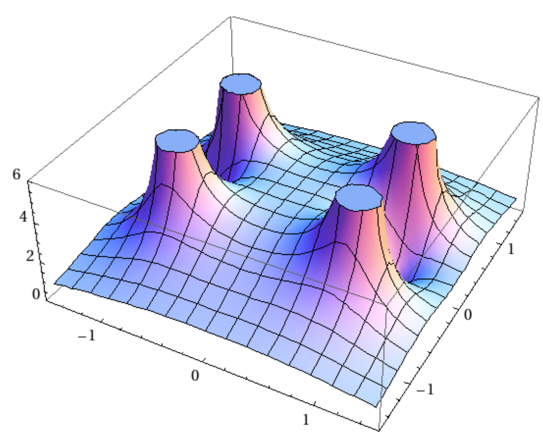


Figure 1:

at the beam axis is

$$B_0 = 2\sqrt{3}\,\frac{\mu_0 I}{2\pi h} \tag{1}$$

The following expansion applies for magnetic field near the axis:

$$\frac{B_x}{B_0} = 4xy(x^2 - y^2) \tag{2}$$

$$\frac{B_y}{B_0} = 1 - x^4 - y^4 + 6x^2y^2 \tag{3}$$

Thus even for distances as large as $h/2$ from the axis, the field is still well within 10% of the on-axis field.

2 Application to E-linac

Refer to the layout Fig. 2. The fields found from a survey March 12, 2010[1] taken with cyclotron magnet powered and before the hall had been emptied of old steel are roughly in the range (3 ± 0.6) gauss, and dominantly in the vertical direction. It is expected that the field will be more uniform once the SASP and MRS steel have been removed, so once compensated, the field variation will be no larger than about 0.3 gauss.

The most sensitive area is the electron gun and the 300 keV transport. However, it is also desirable to reduce the fields in the cryostats as the usual thin shielding of μ-metal would saturate at 3 gauss. It may therefore be best to split the field compensation into two parts as shown in black in Fig. 2. Each part would have a length of roughly 10 m.

The horizontal distance between wires is $h\sqrt{3}$. For the E-linac, this ideally accommodates the 2 m diameter pressure vessel (see Fig. 2), so $h = 2/\sqrt{3}\,\text{m} = 1.15\,\text{m}$. To compensate the average field of 3 gauss, we have:

$$3\,\text{gauss} = 2\sqrt{3}\,\frac{\mu_0 I}{2\pi(2/\sqrt{3}\text{m})},\ \text{or}\ I = 500\,\text{Amps} \tag{4}$$

This can be divided among any number of turns.

Assuming four copper ($\rho = 1.7\,\mu\Omega$-cm) current carriers 10 m long, we have a resistance of $0.0068\,\Omega\text{cm}^2/A$ where A is the total cross-sectional area of the turns. The power is thus $1700\,\text{Watt-cm}^2/A$. If we take an area of $10\,\text{cm}^2$, the power is 170 Watts; quite reasonable. For a round number, say 100 turns, this would require 5 Amps at 34 Volts, and a turn would be 10 mm^2. This would not require water-cooling.

ISAC Polarizer Loops: The current loops around the ISAC LEBT polarizer are very similar to our requirements: they achieve 10 Gauss over a similar volume, but in the logitudinal direction. There are 8 loops and each loop is 90 cm dia. 180 turns of copper wire about $8\,\text{cm}^2$ in cross section, each turn is $3.38 \times 1.27\,\text{mm}^2$ flat section enameled copper wire. Loops are powered in series with a 60 V, 10 A Xantrex PS. The turns are stacked in a simple welded aluminum structure, U-shaped in cross section; sides, bottom composed of 1/8” thick plate. It is sufficiently rigid for our purposes. They are warm to the touch[2] at 8 Amps (1440 A-t), so at 500 A-t, should be no cooling required, as calculated above.

References

[1] Andy Hurst: private communication.

[2] Phil Levy: private communication.

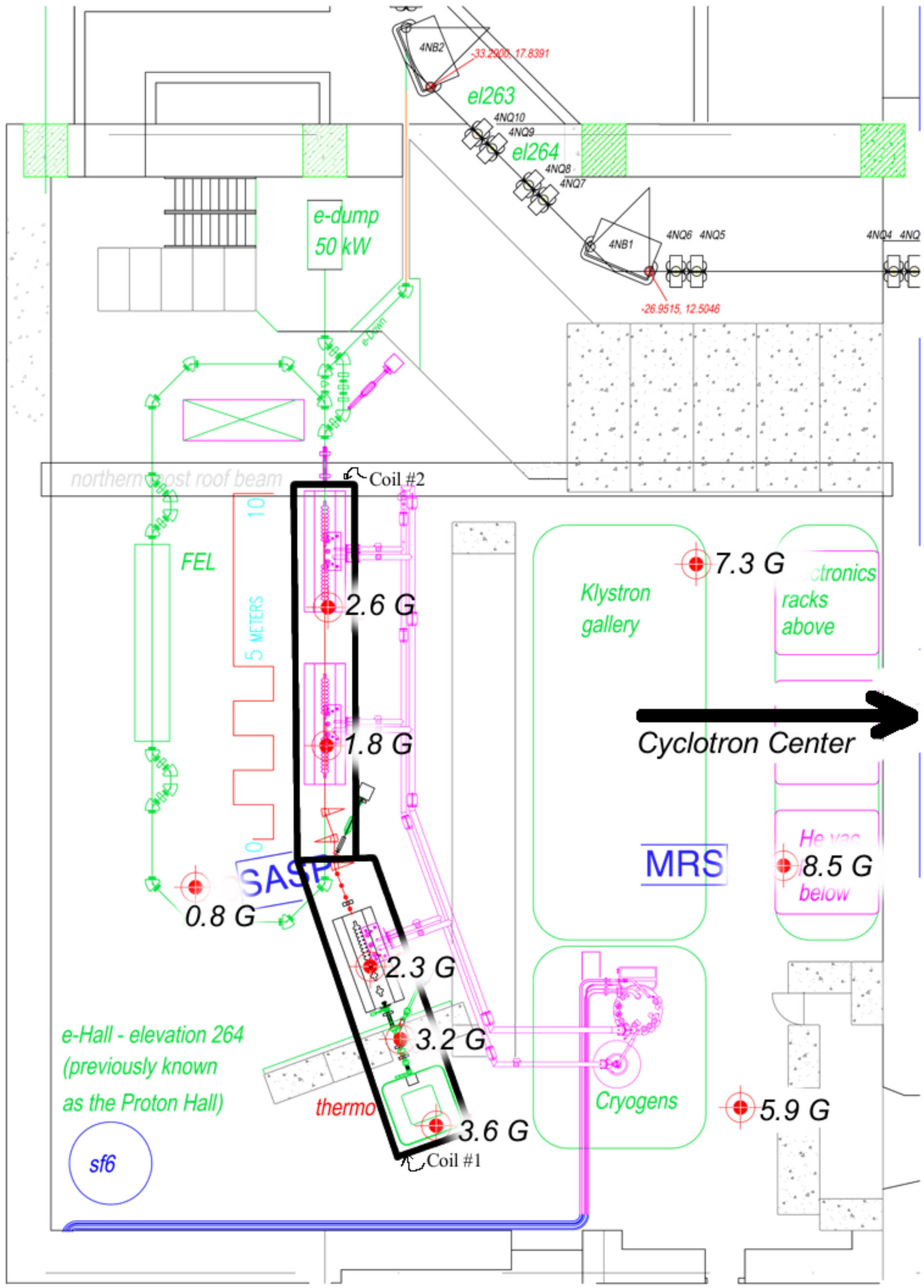


Figure 2: E-linac layout.