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RADIATION LIMITS ON PERMANENT MAGNETS IN CBETA

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Abstract

The Cornell Brookhaven Energy Recovery Linac Test Accelerator (CBETA) [1], under construction at Cornell, uses Fixed Field Alternating Gradient (FFAG) Halbach magnets made from grade N35EH NdFeB. To reduce the 1% level magnetization errors in fabricated blocks to magnets with better than 0.001 field accuracy, iron wire shimming is necessary. This also limits magnetization changes by external influences to the 1% level. The ambient radiation field present during CBETA operation can induce permanent magnet demagnetization. The radiation field arises from electrons in the beam halo hitting the vacuum chamber, electrons colliding with the residual gas and Touschek (intra-beam) scattering. The radiation dose rate due to electrons striking the vacuum chamber of a 4 cell straight section of CBETA FFAG magnets was calculated using the many particle Monte Carlo radiation code MCNP6.2 [2]. Calculations show that electron losses have to be a few tens of pA per magnet in order to keep the dose rates at an acceptable level during the accelerator lifetime.

INTRODUCTION

The Cornell Brookhaven Energy Recovery Linac Test Accelerator (CBETA) [1], under construction at Cornell, uses Fixed Field Alternating Gradient (FFAG) Halbach permanent magnets (PMs) made from grade N35EH NdFeB. CBETA consists of two FFAG arcs, each containing 16 cells, two arc to straight section transitions with 24 cells each, and two straight sections, one with 14, and the other with 13 cells. A cell consists of a doublet, containing a focusing quadrupole (QF magnet) and a combined function magnet with a dipole and de-focusing quadrupole component (BD magnet). Altogether there are 214 Halbach magnets.

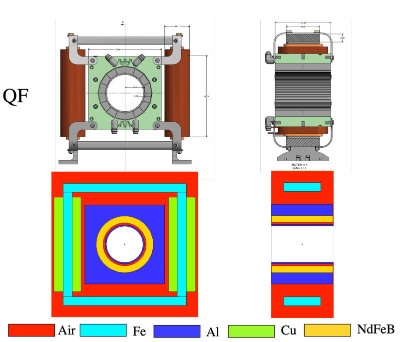

Figure 1: CBETA focusing quadrupole QF magnet and MCNP6 geometry.

It is well known that radiation affects permanent magnet material. (For a recent review of radiation-induced demagnetization of permanent magnets see [3].) The ambient radiation field present during CBETA operation can therefore induce permanent magnet demagnetization. This radiation field arises from electrons in the beam halo hitting the vacuum chamber wall, from electrons colliding with residual gas and Touschek (intra-beam) scattering. The locations along the ring where one would expect the greatest losses are not known at this time. Accordingly, the radiation dose rate due to electrons striking the vacuum chamber wall of a 4 cell straight section in the center of QF and BD magnets at 10° were calculated at 42 and 150 MeV using the many particle Monte Carlo radiation code MCNP6.2.

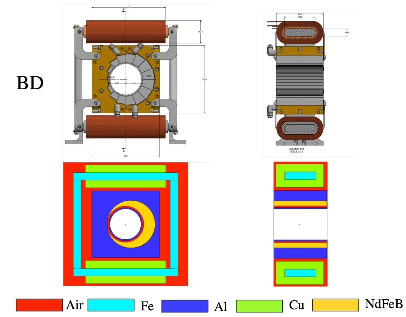

Figure 2: CBETA combined function BD magnet with a dipole and defocusing quadrupole component. For simplicity, the different PM blocks were approximated by smooth curves.

MCNP6 INPUT GEOMETRY

The input geometry for the QF and BD type magnets is shown in Figures 1 and 2. Figure 3 shows a photo of a straight section 4 cell girder and its MCNP6 geometry. In the calculations, electrons hit magnets BD2 and QF3.

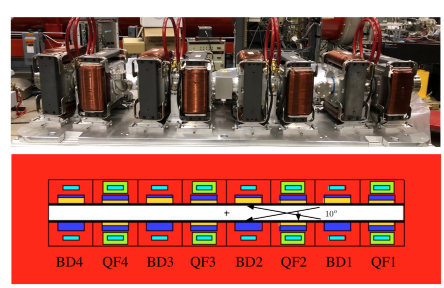

Figure 3: A 4 cell girder, made up of magnets QF and BD and its MCNP6 geometry representation.

RESULTS

MCNP6.2 has a number of tallies that can be used to calculate the radiation dose. There is the track-length heating

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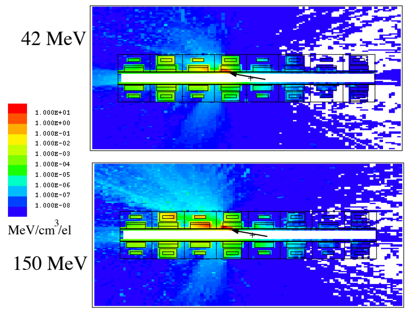

Figure 4: Radiation dose pattern in the yz-plane produced by 42 and 150 MeV electrons hitting the vacuum at the center of magnet BD2 at an angle of 10° in Figure 3.

F6 tally associated with any particle or combination of particles. In addition there is the collision heating, +F6 tally, which contains energy deposition from all particles in the problem. A third type, a mesh tally, scores energy deposition data in which the energy deposited per unit volume from all particles is included. This can be due to the slowing down of a charged particle, the recoil of a nucleus or the energy deposited locally by particles born but not tracked. Since mesh tallies score energy deposition within a mesh of a cell that may contain more than one material, normalization is per unit volume. The units of this tally are MeV/cm^3/source-particle. For the F6 tally, material density is available for the selected cells, and normalization is MeV/gm/source-particle.

Figure 4 shows the radiation pattern produced by 42 and 150 MeV electrons incident on one of the BD magnets in the 4-cell girder at 10°. The pattern is in the yz-plane of the electron beam. The area of interest can be examined using the type 3 mesh as shown in Figure 5. In this case the yzx mesh size is 2 mm × 2 mm × 2mm.

Similarly, Figure 6 shows the radiation pattern produced by 42 and 150 MeV electrons incident on one of the QF magnets in the 4-cell girder at 10°. The area of interest is shown in more detail in Figure 7. The $yz\theta$ mesh size in this case is 1 mm × 5 mm × 22.5°.

At 42 MeV, the total dose from the +F6 tally to the QF magnet is 4.024×10^{-3} MeV/g/el, or 6.449×10^{-13} Gy/el. At 150 MeV, it is 1.652×10^{-2} MeV/g/el or 2.646×10^{-12} Gy/el. The corresponding doses to the BD magnet are 5.087×10^{-3} MeV/g/el or 8.150×10^{-13} Gy/el at 42 MeV, and 1.757×10^{-2} MeV/g/el or 2.814×10^{-12} Gy/el at 150 MeV.

Assuming that the magnets may tolerate a total dose of 10^3 Gy, the corresponding electron losses to QF and BD magnets to accumulate this dose are $1.22 - 1.55 \times 10^{15}$ Gy/el at 42 MeV, and $3.55 - 3.74 \times 10^{14}$ Gy/el at 150 MeV. For a 100 pA electron loss, the 1000 Gy dose in the PM magnets is accumulated in 2.2×10^6 s, or 25.5 d at 42 MeV, and 5.84×10^5 s or 6.76 d at 150 MeV.

Finally, it should be mentioned that the doses calculated are averaged over the entire volume of the PMs. From Figures 5 and 7 there are small regions where the dose rate is around 100 MeV/cm^3/el. Accordingly, the dose rate is

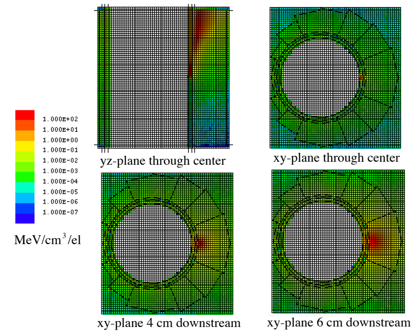

Figure 5: Mesh used and radiation dose pattern around the BD magnet in the xy-plane.

740 MeV/g/el (taking the density of NdBFe as 7.4 g/cm^3), or 1.186×10^{-7} Gy/el, a much higher value.

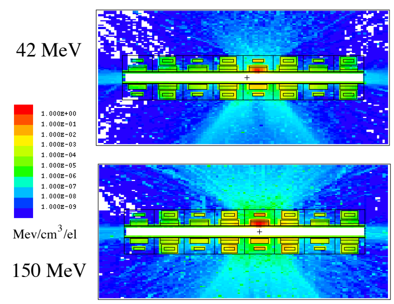

Figure 6: Radiation dose pattern in the yz-plane produced by 42 and 150 MeV electrons hitting the vacuum at the center of magnet QF3 at an angle of 10° in Figure 3

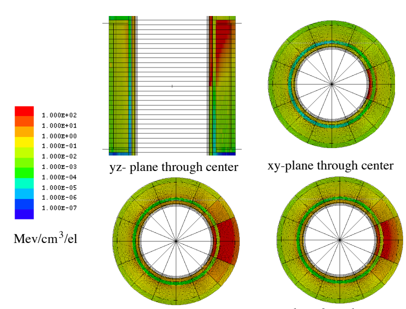

Figure 7: Meshing used and resulting radiation dose pattern around the QF magnet in the xy-plane.

ACKNOWLEDGEMENTS

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