The Injection Chicane of the National Bureau of Standards–Los Alamos Racetrack Microtron

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Abstract—Injection of 5-MeV electrons into the National Bureau of Standards–Los Alamos racetrack microtron (RTM) is accomplished with a dipole magnet on the linac axis. A three-magnet chicane is used to compensate for the unwanted deflection of the recirculating beam by the injection magnet. In order to minimize emittance growth due to power supply noise, the three chicane magnets are driven by two power supplies, with each supply connected in series to two coils in different magnets. This arrangement, together with the tight space available for the chicane, constrains the choice of conductors and leads to very precise and compact low-field magnets. Magnetic field measurements demonstrate that all design goals have been achieved.

INTRODUCTION

INJECTION of 5-MeV electrons into the National Bureau of Standards–Los Alamos racetrack microtron (RTM) [1] is accomplished by deflecting the beam from the injector by 15 degrees into the RTM linac. In Fig. 1, D6 is the dipole magnet used for injection. The 5-MeV beam is then accelerated to 17 MeV by the linac and deflected through 180 degrees by end magnet E1 to reenter the linac at the other end. Dipole magnets D7 and D8 compensate for the displacement of the 17-MeV beam by E1 so that it reenters the linac on axis [2]. The 17-MeV beam is then accelerated to 29 MeV in the opposite direction by the (standing-wave) linac.

The 29-MeV beam encounters the injection chicane, which comprises magnets D6, D9, and D10. It is then deflected 180 degrees by end magnet E2, bypasses the linac in a return line, and is returned to the linac by magnets E1, D8, and D7 for further acceleration. Magnets D8 and D7 give an unwanted parallel displacement Δx to the beam at 29 MeV and above. If this is not corrected, the displacement would cause the beam to reenter the linac off axis. At 29 MeV, Δx is 2.4 cm. Dipole magnets D9 and D10 in the chicane compensate for this effect by displacing the beam by −Δx before it encounters magnets D8 and D7. In addition, magnet D9 compensates for the unwanted deflection of the recirculating beam by magnet D6, a deflection of three degrees at 29 MeV.

MAGNET AND POWER SUPPLY CONFIGURATION

The three chicane magnets are driven by two power supplies, as shown in Fig. 2. The air gaps of all three magnets are equal. The effective lengths of magnets D6 and D10 are equal and are half that of magnet D9. Power supply 1 drives current i1 through the coil of magnet D6; then, in the opposite direction, through a coil in magnet D9. The D9 coil has half as many turns as the D6 coil, so the magnetic field in D9 produced by i1 is half of and anti-parallel to that in D6. The angular deflection of a beam in a magnet is proportional to the magnetic field integrated over the pathlength or “field integral.” The field integrals for magnets D6 and D9 due to power supply 1 are equal in magnitude but opposite in sign. Therefore, the net field integral due to power supply 1 is almost zero. Consequently, power supply 1 imparts a parallel displacement to the beam with little angular deflection. Similarly, power supply 2 drives current i2 through a second coil in magnet D9 in series with the coil in magnet D10 and produces equal and opposite magnetic field integrals in magnets D9 and D10.

The chicane configuration was chosen for several reasons. First, each power supply controls one of the two desired functions of the chicane. Power supply 1 is set to deflect the 5-MeV beam onto the linac axis with magnet D6; power supply 2 is adjusted to give the desired parallel displacement −Δx to the 29-MeV beam with magnets D9 and D10. Second, each power supply produces a parallel displacement of the beam with very little angular deflection. This is essential to minimizing the contribution of magnet power supply noise to emittance growth, especially since the beam makes as many as 14 passes through the chicane. The criterion for negligible emittance growth for a magnet on the linac axis is that the product of the net field integral produced by the power supply and the percent current regulation of the power supply should not exceed 3 G·cm%. This was achieved for both chicane power supplies by designing the magnets carefully to match the field integrals produced by series-connected coils, and by using power supplies having 10⁻⁴ regulation.

Ideally, the chicane as a whole would produce a pure parallel displacement of the beam. In reality, it also produces some small angular deflection, but this can be compensated with steering magnets on the return beam lines. Negligible emittance growth from the available 10⁻³ regulated steering-magnet power supplies is ensured if the chicane field integral is less than 125 G·cm. The measured value is 58 G·cm.

MAGNET DESIGN AND PERFORMANCE

Two-dimensional magnet field calculations were performed using TRIM [3] to design the chicane magnets for the desired magnetic field integrals and field uniformity. To limit emittance growth to an acceptable level, the relative sextupole component ε of RTM dipole magnets must be 7 ⋅ 10⁻⁴ cm⁻².

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or less. The chicane magnets were fabricated of AISI 1006 carbon steel to achieve this degree of field uniformity. Field clamps, shown in Fig. 3, were used to control the effective length of the magnets. The magnets were field-mapped with a Hall-probe apparatus that is described in [2]. All design goals were achieved. Measured properties of the magnets are given in Table I.

The width of magnet D9 is limited by its proximity to magnet D5 in the injection transport line, as shown in Fig. 1. To minimize the width, a picture-frame design is used, and one coil is made of hollow water-cooled conductor, as shown

<table>
<thead>
<tr>
<th>Magnet</th>
<th>Gap (cm)</th>
<th>L (cm)</th>
<th>N (turns)</th>
<th>I (A)</th>
<th>B0 (G)</th>
<th>B0·L (G·cm)</th>
<th>ε (cm⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D6</td>
<td>2.59</td>
<td>12.60</td>
<td>380.0</td>
<td>788.9</td>
<td>4,789</td>
<td>3 × 10⁻⁴</td>
<td></td>
</tr>
<tr>
<td>D9</td>
<td>2.59</td>
<td>12.56</td>
<td>1369.0</td>
<td>-661.8</td>
<td>-16,585</td>
<td>2 × 10⁻⁴</td>
<td></td>
</tr>
<tr>
<td>D10</td>
<td>2.59</td>
<td>12.56</td>
<td>1949.2</td>
<td>943.8</td>
<td>11,855</td>
<td>5 × 10⁻⁴</td>
<td></td>
</tr>
</tbody>
</table>

a L is the effective length.
b N and I are the number of turns and currents in the coil.
c B0 is the central field.
d ε is the relative sextupole field coefficient.
in Fig. 4. In order to limit the number of high-current power supplies, the other coil (the one in series with D6) is made of solid conductor. The solid coil is cooled by conduction to the water-cooled coil and is located inside it to permit a workable lead configuration. The side yoke is as thin as possible without the internal magnetic field exceeding 10 kG. The top- and bottom-yoke thickness was chosen for good field uniformity in design calculations. Calculated and experimental transverse field profiles for magnet D9 are given in Fig. 5.

Magnet D6, shown in Fig. 6, is a picture-frame magnet with the same gap dimension as D9. It contains a solid conductor coil that is powered in series with the solid coil in D9. Cooled by convection only, the D6 coil is made of larger wire to reduce the power density and to limit the operational temperature rise to 30°C. The D6 coil must contain 60 turns to match the field integral produced by the D9 coil in series. Because the wire is larger in D6, ten layers do not fit in the gap as in D9. Instead, eight layers of seven turns plus four extra turns are used. The extra turns are located at the outside of the coil to minimize their effect on the beam. They are located symmetrically in the middle of the half-gaps, the position for which design calculations predicted the best field uniformity. The top and bottom yokes are thicker than in the other magnets to offset the reduced permeability at the lower field of D6.
Fig. 7. Magnetic field $B$ in magnet D6 versus $x$.

Fig. 8. Cross section of magnet D10.

Fig. 9. Magnetic field $B$ in magnet D10 versus $x$.

Calculated and experimental transverse field profiles for magnet D6 are given in Fig. 7.

Magnet D10, shown in Fig. 8, is a picture-frame magnet with the same gap dimension as D9. Its hollow conductor coil has twice the number of turns as the hollow conductor coil in D9 and is powered in series with it. Calculated and experimental transverse field profiles for magnet D10 are given in Fig. 9.

REFERENCES

