DISCLAIMER

SRC Technical Notes are informal memos intended for internal communication and documentation of work in progress. These notes are not necessarily definitive and have not undergone a pre-publication review. If you rely on this note for purposes other than its intended use, you assume all risk associated with such use.
The "Daresbury" multipole magnets at SRC are 12-pole magnets which may be wired for various multipole fields including dipole, quadrupole, skew-quadrupole, sextupole, octupole, and decapole. In this report, we describe measurements of the skew-quadrupole and dipole fields.

With the magnet oriented so that the sextupole connections are away from the observer, there are poles at 1 o’clock, 2 o’clock, ... 12 o’clock, with minimum radii of 1-5/8" and longitudinal extent of 10 cm. The poles are attached to the inside of an annular yoke, with multipole coil windings circling the yoke midway between the poles. The transverse coordinate, \( x \), increases to the left, the vertical coordinate, \( y \), increases upward, while the longitudinal coordinate, \( z \), increases away from the observer; the point \((x,y,z) = (0,0,0)\) is within \(-1\) mm of the magnet center in the transverse and vertical directions, and within several mm of the magnet center longitudinally.

For traditional skew-quadrupole operation, the multipole windings at 12:30, 2:30, 6:30, and 8:30 carry current inside of the yoke away from the observer, while the windings at 3:30, 5:30, 9:30, and 11:30 carry current inside of the yoke toward the observer. Data were obtained by rotating the magnet 45 degrees counterclockwise and measuring the vertical magnetic field in the horizontal plane containing the magnet center (the \( y = 0 \) plane), using a Group 3 MPT-141 Hall probe and DTM-141D digital teslometer. At \( x \)-values of \(-\frac{1}{4}''\), \(-\frac{1}{4}''\), \(-\frac{1}{8}''\), \( 0 \), \( \frac{1}{8}''\), \( \frac{1}{4}''\), and \( \frac{1}{2}''\), the probe was scanned through the \( z \)-coordinate with measurements taken at \( \frac{1}{4} \) cm intervals.

In Figure 1(a), magnetic field measurements are graphed for a skewquad coil current of 1 Amp, provided by powering 8 windings in series with a voltage of 4.4 volts. For each value of \( x \), the measured data was summed to obtain the magnetic field integral, \( \int B_z dz \), which is plotted in Figure 1(b). The average slope of Figure 1(b) for \( bx < \frac{1}{4}'' \) is 156 G/cm/cm, giving a calibration of \( \frac{d(B_z dz)}{dx} = 156 \text{ G/Amp} \). For \( \frac{1}{4}'' < bx < \frac{1}{2}'' \), the average slope is 14% lower: 135 G/cm/cm, giving a calibration of \( \frac{d(B_z dz)}{dx} = 135 \text{ G/Amp} \). For each value of \( x \), the effective length, \( l \), was determined by dividing the magnetic field integral by the peak value of \( B \). For \( bx > \frac{1}{8}'' \), the values of \( l \) varied between 14.3 and 14.6 cm, with an average effective length of 14.4 cm.

At the location \((x,y,z) = (\frac{1}{4}'' , 0, 0)\), the magnetic field was measured over the current range 0 - 4.5 Amps. The results, shown in Figure 1(c), indicate a linear response over this current range. Before taking this data, the measured field at this location was 0.0 G with zero magnet current. After taking this data, a remnant field of 1 Gauss was observed at the same location with zero magnet current, presumably a result of applying the 4.5 A current.
An alternative wiring scheme for skewquad operation uses all 12 of the multipole windings. The windings at 12:30, 1:30, 2:30, 6:30, 7:30, and 8:30 carry current inside of the yoke away from the observer, while the remaining windings (at 3:30, 4:30, 5:30, 9:30, 10:30, and 11:30) carry current inside of the yoke toward the observer. For a magnet with a constant permeability in the yoke and poles, symmetry considerations indicate that the alternative wiring scheme will produce twice as much skew-quadrupole field and one-half as much 12-pole field for a given coil current. Because a high constant-permeability yoke and pole material produces similar magnetic fields in the air as would be produced by the actual magnet material, these results are expected to describe the Daresbury multipole.

In Figure 2(a), magnetic field measurements are graphed for a rewired skewquad coil current of 2 Amp, provided by powering 12 windings in series with a voltage of 13.2 volts. For each value of \( x \), the measured data was summed to obtain the magnetic field integral, \( \int B_y(x) \, dz \), which is plotted in Figure 2(b). The average slope of Figure 2(b) for \( |x| < \frac{1}{3}\pi \) gives a calibration of \( \frac{d(\int B_y \, dz)}{dx} |I = 305 \, G/Amp. \) For \( \frac{1}{3}\pi < |x| < \frac{2}{3}\pi \), the average slope is 3.7% lower, giving a calibration of \( \frac{d(\int B_y \, dz)}{dx} |I = 294 \, G/Amp. \) As expected, the alternative wiring produces twice as much skew-quadrupole strength for a given coil current, with less deviation from a pure skew-quadrupole field. For each value of \( x \), the effective length, \( l \), was determined by dividing the magnetic field integral by the peak value of \( B \). For \( |x| > \frac{1}{8}\pi \), the values of \( l \) varied between 14.2 and 14.4 cm, with an average effective length of 14.3 cm.

At the location \( (x,y,z) = \left( \frac{1}{2}\pi, 0, 0 \right) \), the magnetic field was measured over the current range 0 - 3 Amps. The results, shown in Figure 2(c), indicate a linear response over this current range. A remnant field of 5.5 G was observed before and after raising the current to 3 Amps.

Dipole operation was studied with the magnet in upright position, again using the Group 3 MPT-141 Hall probe and DTM-141D digital teslameter to measure the vertical magnetic field. The multipole windings at 1:30, 2:30, 3:30, and 4:30 carry current inside of the yoke away from the observer, while the windings at 7:30, 8:30, 9:30, and 10:30 carry current inside of the yoke towards the observer. In Figure 3(a), magnetic field measurements along the \( z \)-axis \( (x = y = 0) \) are graphed for dipole coil currents of 1 and 2 Amperes. For the 1 Amp case, the peak field was 72.05 G; the remnant field at the same location was 4.95 G. For the 2 Amp case, the peak field was 140.72 G; the remnant field at the same location was 5.25 G. For each value of current, the measured data was summed to obtain the magnetic field integral, \( \int B_y(x) \, dz \), with results of 1410 G-cm at 1 Amp and 2770 G-cm at 2 Amps. The average value of field-integral divided by current is: \( \frac{\int B_y(x) \, dz}{I} = 1398 \, G-cm/Amp \). The calculated values of effective length for the currents of 1 and 2 Amps are 19.57 and 19.69 cm, giving an average of 19.63 cm effective length.

In Figure 3(b), magnetic field measurements along the \( x \)-axis \( (y = z = 0) \) are graphed for dipole currents of 1 and 2 Amperes. For \( |x| < \frac{1}{3}\pi \), the field is quite uniform. In Figure 3(c), the magnetic field at the origin \( (x,y,z) = (0,0,0) \) is plotted versus current over the range 0 - 4.5 Amps. The results indicate a linear response over this current range.
Before taking this data, the remnant field was 5.95 G; after applying the 4.5 A current, the remnant field was 8.4 G.

We then measured the expected shielding of the Daresbury dipole field from the nearby quadrupole magnets in the Aladdin lattice. The quadrupole magnet poles are separated by 11 cm from the Daresbury magnet iron, corresponding to a location at z = -16 cm in the coordinates used here. To model this effect, a 3-1/4" hole was drilled in the center of an 11" square piece of 1/8" magnetic steel, which was then placed with its closest surface 11 cm upstream of the Daresbury magnet iron, at z = -16 cm. With 2 A coil current, the peak field was measured to be 145 G; a remnant field of 8.2 G was observed at the same location. Magnetic field measurements taken with a current of 2 A are graphed in Figure 4; measurements taken without a shield are shown for comparison. The discrepancy between the magnetic field values in the center of the magnet may be primarily attributed to the larger remnant field in the shielded case. The magnetic field integral is 2681 G-cm; the field-integral divided by current is \( \frac{\Delta B_r(z)dz}{\Delta I} = 1340 \) G-cm/Amp. This is 4.1% lower than measured without a shield. The effective length of the shielded magnet is 18.5 cm, 1.1 cm (5.8%) shorter than without a shield.

Because the dipole remnant fields are not negligible, their effect may be included in the computed calibrations. Assuming the remnant field has the same distribution as the measured field, the calibrations may be corrected by multiplying by \((B_{max} - B_{remnant})/B_{max}\). Including this correction, the 1 A unshielded dipole measurements give \( \Delta B_r(z)dz/\Delta I = 1315 \) G-cm/Amp, while the 2 A unshielded measurements give \( \Delta B_r(z)dz/\Delta I = 1333 \) G-cm/Amp. The average value is 1323 G-cm/A for unshielded dipole operation. Including the remnant field correction for the shielded dipole case gives \( \Delta B_r(z)dz/\Delta I = 1264 \) G-cm/Amp, which is 4.5% lower than the unshielded value. The unshielded and shielded measurements both give higher calibrations than the existing value of 1200 G-cm/Amp.²

For use as a steering magnet, an integrated field of 3330 G-cm is required for a 1 mrad deflection at an electron beam energy of 1 GeV. The unshielded dipole measurements, corrected for the remnant field, give a calibration of 0.397 mrad/A at 1 GeV and 0.497 mrad/A at 800 MeV. For the shielded magnet, the calibration (corrected for the remnant field) is 0.380 mrad/A at 1 GeV and 0.474 mrad/A at 800 MeV.

In summary, the traditional skewquad wiring was characterized by an effective length of 14.4 cm and quadrupole calibration (when rotated 45 degrees counterclockwise) of \( [d(dB_rdz)/dx]/I = 156 \) G/Amp. The alternative skewquad wiring gives an effective length of 14.3 cm and quadrupole calibration (when rotated 45 degrees counterclockwise) of \( [d(dB_rdz)/dx]/I = 305 \) G/Amp. As expected, the alternative wiring doubles the skew-quadpole strength for a given coil current.

The dipole configuration was characterized by an effective length of 19.6 cm and dipole calibration of \( \Delta B_r(z)dz/\Delta I = 1323 \) G-cm/Amp. With the inclusion of a magnetic shield to model the adjacent quadrupole, the shielded dipole configuration was characterized by an effective length of 18.5 cm and calibration of \( \Delta B_r(z)dz/\Delta I = 1264 \) G-cm/Amp. For use as a steerer at 800 MeV, the unshielded Daresbury dipole has
calibration of 0.497 mrad/A; shielding by the nearby quadrupole is expected to lower the 800 MeV calibration to 0.474 mrad/A.


Daresbury skewquad measurements (4/22-25/96), I = 1 Amp

Figure 1(a)
Daresbury skewquad measurements (4/22-25/96), I = 1 Amp

Figure 1(b)
Figure 1(c)
Rewired skewquad measurements (5/13, 5/15/96), I = 2 Amp
Rewired skewquad measurements (5/13/5/1596), 1 = 2 Amp

Figure 2(b)
Rewired skewquad measurements (5/13,5/15/96), Magnetic field vs. current at \((x,y,z)=(1/2'',0,0)\)

![Graph showing magnetic field vs. current relationship](image-url)
Figure 3(a)
Daresbury multipole measurements 4/29/96 Dipole field versus x for y = z = 0.

Figure 3(h)
Daresbury multipole measurements (4/29/96) Dipole field vs. current at (x,y,z)=(0,0,0)

Figure 3(c)