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The Warm Iron Geometry of the "Average" RHIC Dipole

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Introduction

The code RAPIDEAL [1], maintained by RAP, is used by the surveyors to place RHIC arc dipoles (and other magnets) into exactly the right location in the tunnel, prior to their connection to neighboring magnets. Although RAPIDEAL accounts for the individual idiosyncrasies of particular dipoles, it nonetheless incorporates a model iron geometry of a nominal dipole. Until recently, the model of a "theoretical" dipole was assumed. This note describes the derivation and parameters of an "average" dipole model, based purely on data available from as many as 159 DRG magnets. Now that RAPIDEAL uses this new model, the systematic error in the offset of beam tubes (and other piping) is greatly reduced, from about 100 mils to about 20 mils.

Having established the iron geometry of the average RHIC dipole, this note goes on to advocate an intentional 50 mil radial offset of the dipoles (and tubes and pipes). With this intentional offset, injected beam is closer to the magnetic center of the dipole, optimizing the field quality seen by the beam.

Fitting the average sagitta data

The eight data points in Figure 1 are derived from measurements taken on every dipole at Northrop-Grumman, information stored in the "magbase" Sybase database. Error bars correspond to the standard deviation for the distribution of 159 dipoles, for which data were available in late June, 1995. The end data points (at approximately 5 and 375 inches) are not quite at the extreme ends of the iron, and so the "total iron sagitta", shown as a single data point on the vertical axis, is slightly larger than the mid-arc maximum.

The solid line shows the best fit possible when a constant radius arc is constrained to go through the outer data points. Note that the adjacent data

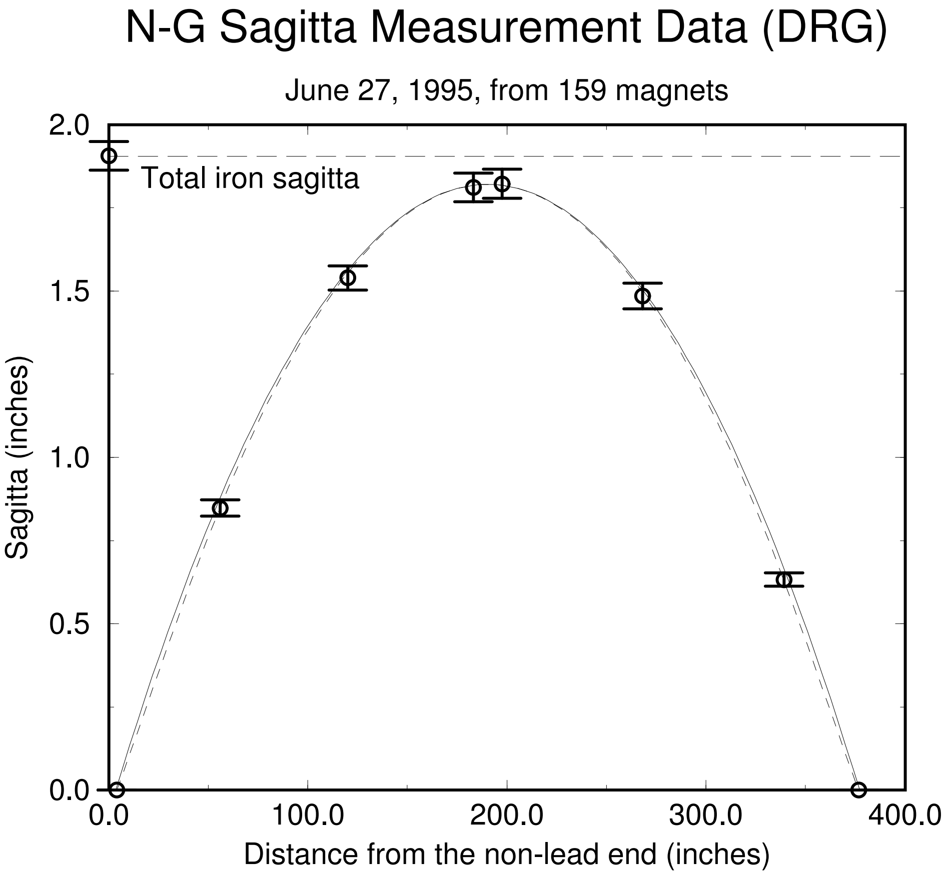

Figure 1: Single arc (solid line) and arc plus straight ends (dashed line) fits to measurements of the iron profile.

points (at approximately 50 and 330 inches) are not well fit. By contrast, the dashed line gives an excellent fit to these points. In this case the iron geometry is modeled as a constant radius arc in the center, with straight sections 0.85 meters long at both ends of the dipole iron. This composite geometric model is physically plausible, given the procedure by which Northrop-Grumman bend an originally straight magnet.

Quantity	Units	Design value	Model value
Iron arc length	[m]	9.7282	9.7165
Iron total sagitta	[in]	1.91 ± .03	1.906
Iron end straight length	[m]	0.0	0.85
Iron radius	[m]	(243.834)	(236.297)
Iron arc HALF angle	[rad]	(.019948)	(.016963)
Radial fiducial offset	[in]	4.8	4.804
Tangential fiducial offset	[in]	5.0	4.912
Tangential beam tube offset	[in]	14.875	14.646
Mechanical pivot radial offset	[in]	.0	.050

Table 1: Mechanical parameters that were directly measured from, or were adjusted to best fit, the average dipole, according to "magstat" and "qaf" data. Dependent values (in parentheses) are derived from the three independent parameters directly above them in the table.

The first three rows in Table 1 are the primary variables in the iron geometry model. The *iron arc length* and the *iron total sagitta* are simply the averages of Northrop-Grumman data recorded in "magbase", while the *iron end straight length* has been adjusted to best fit the data in Figure 1. As the straight length increases, both the iron radius and the iron arc angle are constrained to decrease. This is shown in the (output) parameters also listed in the table, as derived by the code DRG_GEOM [2].

Note that if the fit curves are extrapolated in a straight line beyond the ends of the iron, the dashed line is radially outside the solid line. This explains why the old "theoretical" iron geometry model causes the dipoles ends to be systematically displaced, outwards.

Fitting the average cold mass fiducial data

The second part of constructing the average iron geometry concerns the cold mass fiducials, M1, M5, M6 and M10. In principle, these fiducials are 5.0 inches in from the iron ends, and ±4.8 inches radially displaced. In practice, and as listed in Table 1, the optimum values for these parameters are slightly different.

These values were obtained by matching the "qaf" data recorded by the survey group for every dipole. These data will soon be available in the "quality" table of the "survbase" Sybase database. After the data have been averaged over all available DRG dipoles [3], their locations are symmetrised [4]. This enables the four model fiducial locations to be described by the two offsets recorded in Table 1, instead of the eight parameters that would be necessary if each fiducial was allowed to float independently.

A similar "average and symmetrise" procedure is followed for the tangential beam tube offsets at each end. Note that the beam tubes are not allowed any nominal radial offset.

Object	x [inches]	y [inches]
M1 fiducial	0.000	0.000
M5 fiducial	0.000	372.529
M6 fiducial	−9.607	−0.163
M10 fiducial	−9.607	372.692
Lead end beam tube	−4.472	392.166
Non lead end beam tube	−4.472	−19.637

Table 2: Location of the averaged and symmetrised cold mass fiducials, and the beam tubes, according to the average dipole model. In the local "mancat" frame the x-axis points radially inwards, while the y-axis points clockwise (looking down).

Table 2 lists the model locations of fiducials and beam tubes, in the local "mancat" frame that is used by the surveyors to record the "qaf" or "quality" measurements.

Optical consequences, and optimization

So far, no mention has been made of the vital relationship between the warm iron geometry and the particle optics and dynamics. Since the beam size is largest at injection, when the dipole nonlinearities dominate the linear and dynamic apertures, it is mainly injection conditions that are a concern. Table 3 lists the measured values for the magnetic length of the dipoles, at injection and at storage, as derived from the "magbase" data. Since the optical bend angle is immutable - the beam MUST bend by 2π radians in one turn - this leads directly to the optical radii of the design trajectories, also listed in Table 3. These radii differ by about 6 meters from the iron radius listed in Table 1.

Quantity	Units	Nominal value	Measured value
FULL optical bend angle	[rad]	.038924026	
Dipole magnetic length, injection	[m]	9.440656	$9.4238 \pm .0038$
Dipole magnetic length, storage	[m]	9.440656	$9.4416 \pm .0030$
Optical radius, injection	[m]	242.5406	242.108
Optical radius, storage	[m]	242.5406	242.565

Table 3: Optical parameters, according to the nominal RHIC92.0.5 lattice design, and according to "magstat" measured data.

The consequence of having different optical and iron radii is that the injected beam is displaced from the center of the iron (and the field), by an amount that varies along the length of a dipole. Since the injection design orbit is a fixed object in space (for a given optical radius), while the dipole can be deliberately offset radially, it is convenient to discuss the radial displacement of the iron center from the injection orbit. This is what the curves in Figure 2 show, for the average dipole.

The dashed curve corresponds to a dipole aligned so that its ends - the beam tubes - lie exactly on the injection orbit. This is the optimum position for connection to the neighboring CQS magnets. However, the field center is consistently a millimeter or two on the inside of the injection trajectory, leading to physical and linear aperture degradation, and multipole feedown. The solid line represents an average dipole intentionally displaced radially outwards by 50 mils. In this case the injection trajectory is always within a millimeter of the field center. Moreover, the displacement is approximately zero at the ends of the rectangular box, where the lead end and non lead end multipoles give the beam a discrete kick.

Although the solid line configuration is preferred for dynamical reasons, it assumes that a 50 mil systematic offset of the beam tubes and cryogenic piping is acceptable.

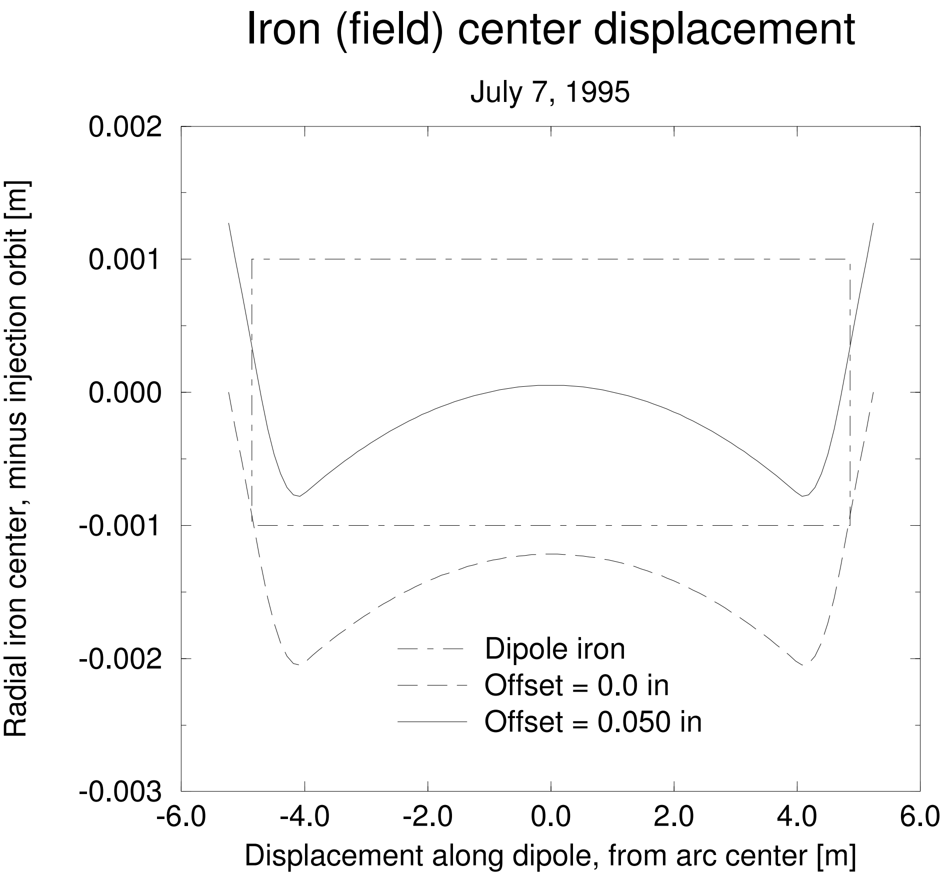

Figure 2: The radial displacement of the iron center line, relative to the injection trajectory, for dipole placement with the recommended radial offset of 50 mils (solid line), and no offset (dashed line). A positive radial displacement means that the magnet is moved away from the ring center. The end points of the curves are the "beam tubes" referred to in Tables 1 and 2.

Conclusions

The arc dipoles, as constructed, are well modeled by an iron geometry with a central arc of radius 236.297 m, and straight ends approximately 0.85 m long. These parameters, derived from a fit to the Northrop-Grumman sagitta data, explain almost all of the systematic 100 mil beam tube offset observed when RAPIDEAL has a "theoretical" iron geometry.

RAPIDEAL now uses the composite arc "average" iron geometry, and incorporates the RAP request for a deliberate offset of 50 mils, radially outwards, at the dipole ends. This is the optimum offset for beam dynamics at injection, with a reasonable burden on magnet connection procedures. It is half the 100 mil systematic offset erroneously introduced by assuming a "theoretical" iron geometry.

Only a *warm* iron geometry model has been considered, in part because there is essentially no information on the cold iron geometry, beyond the observation that a dipole shrinks by $\Delta L/L \approx 0.0031$, longitudinally. Under the naive assumption that the iron shrinks isotropically, about its center post, the curves shown in Figure 2 are in error by, at most, 2 or 3 mils (transversely). This is better than the accuracy of the iron geometry model of the average dipole, and much smaller than the statistical spread of the dipole iron parameters.

References

[1] The RAPIDEAL code, written and maintained by Steve Tepikian, can be found in the $HORST/rapideal directory.

[2] The DRG_GEOM code was written, and is maintained, by Steve Peggs. See the $HORST/drg_geom directory.

[3] The code RAP_AVERAGE, written and maintained by Steve Tepikian, was used to average the fiducial and beam tube locations. It can be found in the $HORST/rapideal directory.

[4] The code SYMM, written and maintained by Steve Peggs, was used to perform the symmetrisation. See $HORST/drg_geom.