RHIC Tracking Studies with Real Magnets in Real Places *

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Abstract

Results from RHIC tracking studies in which measured magnetic field errors are used in all arc magnets are reported. The dependence of betatron tunes on initial amplitudes, aspect ratio, and momentum are reported and are not significantly different from measured tune dependences when randomly generated magnetic field errors are used in all magnets. Survival plots at injection and storage are also consistent with previous determinations.

1 INTRODUCTION

Magnet installation in RHIC has progressed to the point where all arc dipoles and 60% of arc quadrupoles and sextupoles have been installed in the tunnel. It is of interest to test the quality of these magnets by particle tracking when real magnetic field errors are used in locations where magnets have been installed. In past tracking studies, files with magnetic field errors, generated randomly around expected systematic values using a Gaussian distribution truncated at $\pm 3\sigma$, have been used in all elements. The same approach is used as the starting point when magnetic field errors for actual magnets are used. A file having randomly generated multipoles is read by the filter program, and a new file is written that has measured field errors in slots where magnets have been installed or assigned and randomly generated errors in all other elements. To date, magnet installation has been confined to the arc magnets in both blue (clockwise) and yellow (counterclockwise) rings of RHIC. All arc dipoles have been installed.

2 IMPLEMENTATION

Data from magnet measurements is stored in the MAGBASE database, and the program MAGSTAT is used to query MAGBASE for a particular class of magnets, such as DRG for 8 cm arc dipoles or QRG for arc quadrupoles. In addition to generating a file containing the statistics for the specified magnet type, individual files are written for each magnet. Using DRG as an example, the file DRG540 contains data for magnet DRG540. A "location" file has been compiled for each of the magnet types. The files d8_blue, q8_blue, and sx_blue contain a sequential list of all arc dipoles, arc quadrupoles, and sextupoles, respectively, in the blue ring. One line of the file is devoted to each magnet slot and contains the magnet name, orientation, $+1$ or -1, and four fields for the currents at which the magnet may have been measured. Currents of 30, 660, 1450, and 5000 correspond to room temperature, injection, transition, and storage, respectively for arc dipoles. However, most magnets have been measured at room temperature only. If no magnet has been assigned to a particular slot, the name "EMPTY" is listed in the "location" file.

TEAPOT generates a fort.7 file that is a thin lens description of RHIC. Of the twelve lines used to describe each element, four contain multipole information. The filter program reads the fort.7 file sequentially, and tests the name of each lattice element. When names are encountered, such as rfcavity, that are not listed in the magnet location files, the filter program reads the lines associated with that element and writes them to the new file. When a generic name, such as d , is encountered, the next entry in the d8_blue file is tested to determine if that magnet has been installed. If the magnet name is "EMPTY", the lines describing that element are read and written directly to the new thin lens file. Otherwise the magnet file for the specified magnet is opened and measured multipoles are read. If measurments were made only a room temperature, the measured multipoles are corrected using a warm-cold correlatiion determined from magnets that have been measured both warm and cold.

$$b_n = b_n(w) + (< b_n(c) > - < b_n(w) >)$$

$$a_n = a_n(w) + (< a_n(c) > - < a_n(w) >)$$

where $< b_n(c) >$ and $< a_n(c) >$ are average values from cold measurements and $< b_n(w) >$ and $< a_n(w) >$ are average values from warm measurements.

3 ORIENTATION

The horizontal axis in the beam reference frame is oriented so x increases outward from the centerpoint of RHIC. When magnets are installed with the horizontal axis used for magnet measurements rotated by π radians relative to the beam reference frame, some multipole coefficients must change sign if expansion is performed in the beam reference frame. These magnets are said to have negative orientation. All 8 cm dipoles in both rings of RHIC have positive orientation. However, for considerations of symmentry, the CQS assemblies containing the correctors, quadrupoles, and sextupoles are rotated by π radians in every other sector. In addition, the DX and D0 dipoles are always oriented with their lead ends facing away from

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the interaction region, and the Q1, Q2, Q4, Q5, Q6, and Q8 quadrupoles in the insertions always have leads facing away from the interation region, while Q3, Q7, and Q9 quadrupoles have leads facing towards the interaction region. Hence, all arc dipoles have positive orientation, while half of the arc quadrupoles, insertion quadrupoles, DX and D0 dipoles have negative orientation. In order to make multipole expansions using particle coordinates, the sign of b_n with n odd and a_n with n even in dipoles, and b_n with n even and a_n with n odd in quadrupoles, are changed for magnets that have negative orientation. The orientation of each magnet is specified in the location file.

4 SCALING

The multipole coefficients used in TEAPOT are kick amplitudes - the magnet multipoles have to be multiplied by factors of L/ρ in dipoles, kLr_0 in quadrupoles, and Sr_0^2 in sextupoles, where r_0 is the reference radius and S has the value SF or SD depending on whether the sextupole is focusing or defocusing . The measured multipoles are written to the new fort.7 file. However, the values of b_0 for dipoles, the b_1 for quadrupoles, and the b_2 for sextupoles are the stengths of these elements; the values from the original fort.7 file are written to the new fort.7 file.

5 STUDIES AND RESULTS

The dependence of tunes on initial action J_{tot}, on the aspect ratio J_x/J_y, and on the momentum error $dp/p = 0, \pm\sqrt{6}\sigma_p/p$ has been determined by tracking five particles of fixed J_{tot} when J_x/J_{tot} = 0.96, 0.75, 0.50, 0.25, and 0.04 as $J_{tot} = (n\sigma)^2/(2\beta)$ when n=0.5, 2, 4, and 6 at injection and n=0.5, 2, and 4 at storage. The tunes are usually determined with the program TEALEAF that measures the average phase advance per turn. However for cases where nearly all the action is in one plane, J_x/J_{tot} = 0.96 or 0.04, TEALEAF is sometimes confused. Such cases can often be resolved by using an FFT analysis, but even then there is sometimes a question of which peak corresponds to the second eigentune. Tune determination at injection when all multipoles are generated randomly is shown in Figure 1, and tune determinations when measured multipoles are used where magnets have been installed are displayed in Figures 2 for injection and Figure 4 for storage. The present studies differ from previous ones in that no use is made of correctors in the triplets for b_3, b_4, and b_5 between Q1 and Q2 and following Q3 or of the skew quadrupole corrector between Q2 and Q3. There is a small change in the tune spread at injection when the RMRP filter is used, but this is considered of no consequence. The tune determinations at storage show a spread that is reduced when the correctors mentioned above are used.

Another study concerns the effect of a 1.7 mradian roll of the sextupoles that is a consequence of installing the CQS assemblies to compensate for a rotation of the field of the arc quadrupoles by the quadrupole leads. Leafprints were generated when sextupoles were assumed to be perfectly aligned, $a'_2 = 0.0$, and when they were rotated by 1.7 mradians, $a'_2 = 51x10^{-4}$. There was no difference between the two leafprints, and it is concluded that the roll of the sextupoles is not harmful.

Survival plots were generated using tracking runs of 30K turns at $dp/p = 0.0\%$ with synchrotron motion included. This corresponds to nearly 40 synchrotron periods at injection and 155 synchrotron periods at storage. The results are shown in Figure 3 for injection and Figure 5 for storage. The upper edge of the survival plot at injection is 10σ where $\sigma = 1.138$ mm when $\beta^* = 10$m, $\epsilon_N = 10\pi$ mm mradian, and the kinetic energy is 12 Gev/u. The upper edge of the survival plot at storage is 5.5σ with $\sigma = 0.248$ mm when $\beta^* = 1$m, $\epsilon_N = 40\pi$ mm mradian, and the kinetic energy is 100 GeV/u. The upper edges of the survival plots are completely consistent with previous determinations.

6 REFERENCES

[1] G.F. Dell and S. Peggs, Proc. 1995 IEEE Particle Accelerator Conference, May 1995, Dallas, p. 2237.

[2] Jie Wei, "Error Compensation in Insertion-Region Magnets, Accepted for publication in Particle Accelerators.

[3] Jie Wei etal, "Misalignment Evaluation of Superconducting Magnets in the Relativistic Heavy Ion Collider", This proceedings.

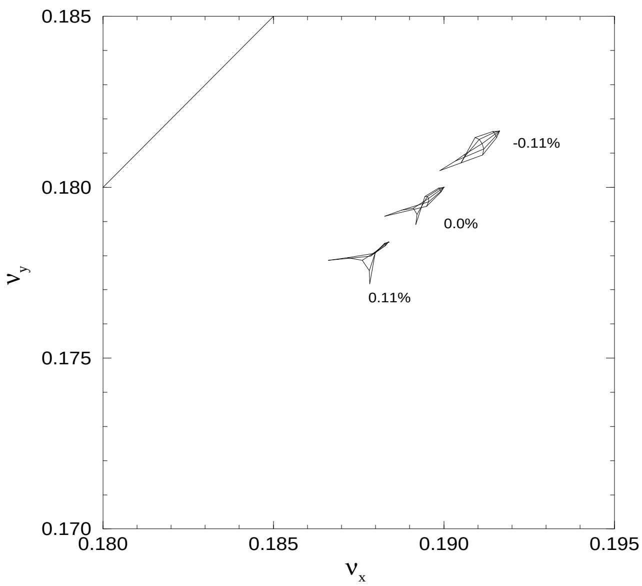

Figure 1: Leafprint at injection when randomly generated multipoles are present in all magnetic elements.

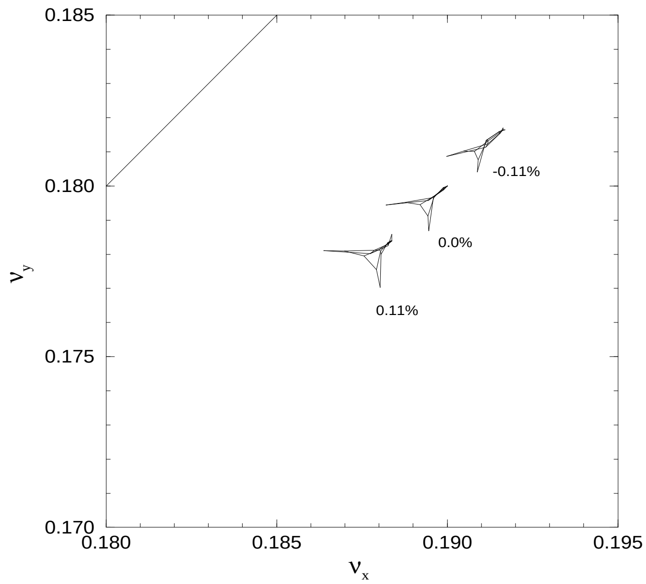

Figure 2: Leafprint at injection with measured multipoles where magnets have been installed.

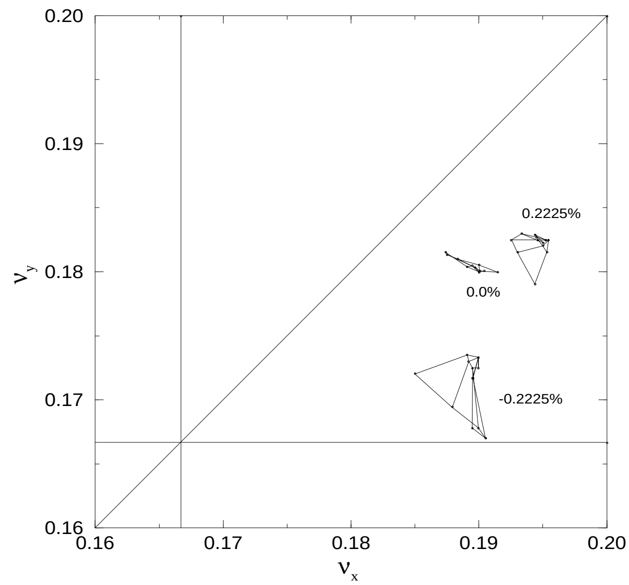

Figure 4: Leafprint at storage with measured multipoles where magnets have been installed.

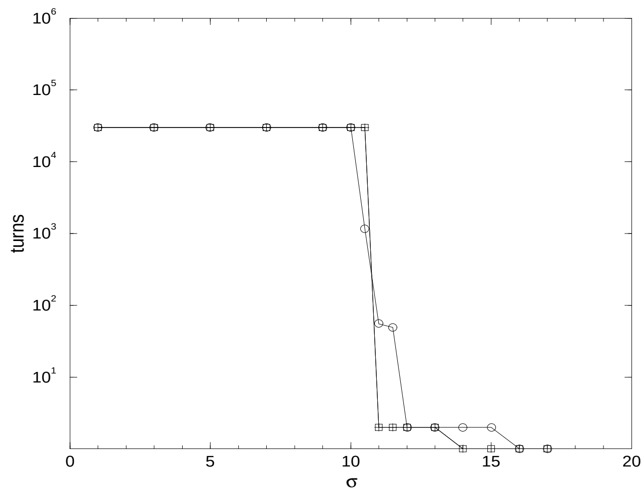

Figure 3: Survival plot at injection when measured multipoles are used in three randomly generated files.

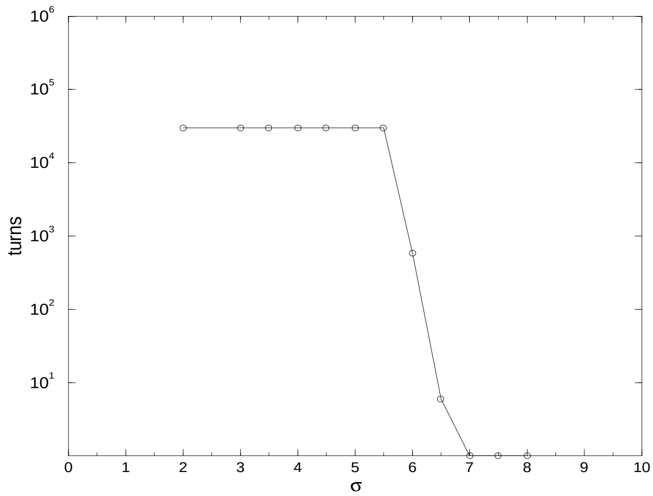

Figure 5: Survival plot at storage when measued multipoles are used in a randomly generated file.