RHIC/AP/110

Preliminary Tracking Results with Helical Magnets in RHIC

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Abstract

Helical magnets, used to manipulate the spin direction in particle accelerators, are nonlinear elements which influence the particle motion. Their effect on tune, linear coupling and amplitude dependent tune shift is estimated through computer simulations. In these simulations, helical magnets are represented as nonlinear maps which can be included in element-by-element tracking by the object-oriented version of the tracking program TEAPOT [1, 2].

1 Introduction

Siberian snakes and spin rotators in RHIC consist of superconducting helical dipole magnets. Even perfect helical dipoles are nonlinear elements which also have, off-axis, a longitudinal field component. In addition to their intrinsic nonlinearity, the magnetic fields inside helical dipoles can be further disturbed by multipole errors.

The BNL magnet design with two coil layers can have a helical sextupole component $\tilde{b}_2$ as large as -116 when both layers are powered in series. The damaging effect of this error needs to be evaluated to decide if the two layers have to be powered independently thus requiring additional power supplies.

Helical dipoles lead, among other things, to orbit distortions, tune shifts, chromaticity changes, linear coupling and amplitude dependent tune shifts. These effects are estimated analytically in references [3–5]. Here, the results of computer simulations are presented for which new features of the tracking code TEAPOT [1,2] are used. In these simulations helical dipoles are represented by higher order nonlinear maps which are included in element-by-element tracking.

2 Simulated Machine Conditions

A lattice of the RHIC Blue Ring (in which particles travel clockwise) at the proton injection energy (relativistic $\gamma = 27$) is used. The closed orbit distortions have rms values of 0.15 mm and 0.19 mm in the horizontal and vertical plane respectively. Tunes are set to $(\nu_x, \nu_y) = (18.19, 19.18)$. The chromaticities $\Delta\nu/(\Delta p/p)$ are adjusted to +2 in both planes. Multipole errors are introduced as random numbers with the expected standard

Table 1: Position and configuration of Siberian snakes and spin rotators in the RHIC Blue Ring at injection energy. "r" stands for right-handed helicity and "l" for left-handed helicity. The order of the magnets follows the beam direction.

sector	type	magnet 1		magnet 2		magnet 3		magnet 4	
		hel.	field [T]	hel.	field [T]	hel.	field [T]	hel.	field [T]
4	snake	r	−1.191	r	+3.863	r	−3.863	r	+1.191
6	rotator	r	−1.924	l	−2.352	r	−2.352	l	−1.924
7	rotator	r	+1.924	l	+2.352	r	+2.352	l	+1.924
8	rotator	r	−1.924	l	−2.352	r	−2.352	l	−1.924
9	rotator	r	+1.924	l	+2.352	r	+2.352	l	+1.924
10	snake	r	+1.191	r	−3.863	r	+3.863	r	−1.191

deviations and a cut at 3 σ. The RF voltage is set to zero. Momentum deviations $\Delta p/p$ up to 0.001 are considered.

The lattice includes 2 Siberian snakes and 4 spin rotators. Each of these elements contains 4 helical dipole magnets the configuration of which is shown in Tab. 1 (Ref. [6]). Multipole errors of the helical dipoles can be parameterized in terms of coefficients $(\tilde{a}_n, \tilde{b}_n)$, analog to the coefficients (a_n, b_n) for straight magnets [7]. In Tab. 2 the expected numbers for the helical multipole coefficients are given for the BNL design with two coil layers [8]. For those numbers it is assumed that both coil layers are powered in series by a common power supply. By far the largest error is a helical sextupole component. This error can be reduced when 2 power supplies can be used for the 2 coil layers. No fringe fields are considered in this study.

The object-oriented version of the tracking code TEAPOT allows to represent elements in the lattice by nonlinear maps [1,2]. In these simulations snakes and spin rotators are represented by maps of order 5 in the phase space variables $(x, p_x, y, p_y, -ct, \delta)$ [1]. These maps are obtained by integrating through the helical fields which includes the errors. For snakes and spin rotators, the field error coefficients at 2.0 T are used for the two outer magnets and the coefficients at 3.8 T for the two inner magnets. For the integration a fourth order Runge-Kutta algorithm is used, resulting in a non-symplectic map [2]. Therefore, investigations with those maps are restricted to limited turn numbers. For long-term studies it would be necessary to symplectify them.

Simulations are performed without snakes and rotators, with snakes only and with snakes and rotators.

3 Simulation Results

All investigations in this study are based on tune measurements. Particles are tracked for 1000 turns to obtain the tune from the averaged phase advance per turn. In the presence of strong coupling this method can not be used and particles are tracked for up to 16384

Table 2: Expected helical field error coefficients for the BNL design with two coil layers powered in series. All $\tilde{a}_n$ are assumed to be zero. The reference radius is $r_0 = 31$ mm.

	$B_0 = 2.0$ T	$B_0 = 3.8$ T
$\tilde{b}_0$	0.0	0.0
$\tilde{b}_1$	0.0	0.0
$\tilde{b}_2$	-63.7	-116.0
$\tilde{b}_3$	0.0	0.0
$\tilde{b}_4$	7.7	0.7
$\tilde{b}_5$	0.0	0.0
$\tilde{b}_6$	0.3	1.3
$\tilde{b}_7$	0.0	0.0
$\tilde{b}_8$	-7.5	-7.5
$\tilde{b}_9$	0.0	0.0
$\tilde{b}_{10}$	2.9	2.9

turns to obtain the eigentunes from a Fourier analysis.

The new TEAPOT version had no tuning or correction capability at the time of the study. Tuning and correction procedures were performed with the old program version and the trimmed lattice was used with the new tracking engine. Therefore, there was no possibility to correct the closed orbit, adjust the tunes or linearly decouple the lattice in the presence of the helical magnets.

The tune shifts introduced by snakes without field errors, by snakes only and by snakes and rotators are shown in Tab. 3. Those tune shift can be easily corrected in RHIC. They agree qualitatively with the analytically computed tune shift in Ref. [4]. The effect of the field errors in the snake dipoles is of the same order of magnitude as the effect of perfect helical dipoles.

The closest tune approach was determined to estimate the linear coupling introduced by the helical magnets. However, tunes could not be changed in the presence of the helical magnets. Therefore, they were preadjusted with the old program version (using the obtained tune shift introduced by the helical dipoles) such that the resulting horizontal and vertical tunes have both a fractional part of 0.185. Since this procedure is not very

Table 3: Tune shifts due to helical magnets.

	$\Delta\nu_x$	$\Delta\nu_y$
snakes only (no field errors)	$+0.01$	$+0.03$
snakes only	-0.04	$+0.06$
snakes and rotators	$+0.03$	$+0.05$

Table 4: Coupling induced by helical magnets.

	$\lvert\nu_x - \nu_y\rvert_{min}$
bare machine	< 0.001
snakes only (no coupling corr.)	0.013
snakes and rotators (no coupling corr.)	0.013

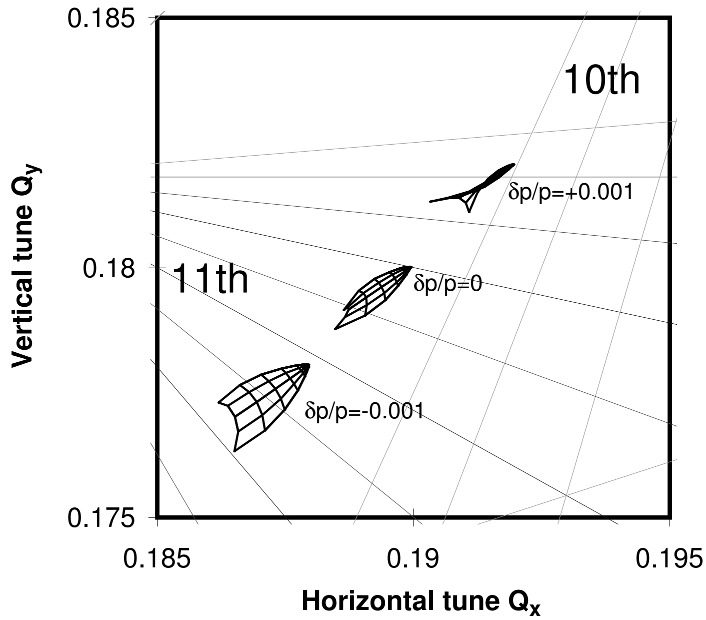

Figure 1: Covered tune space with no helical dipoles

accurate, the results may have a relatively large error. The obtained minimum tune distances are shown in Tab. 4. The distance obtained with snakes only is approximately 5 times larger than the one in Ref. [5] which was computed without field errors. The spin rotators do not seem to introduce significant further coupling.

To obtain the amplitude dependent tunes, amplitudes from 1 to 6 σ, in steps of 1 σ, and 5 different amplitude ratios were tested. A σ of 2.24 mm at $\beta = 50$ m, the maximum value for the beta function in the arcs, is assumed for both planes. The result is shown in Fig. 1 in the form of "tune leafs" for the bare machine and three different momenta. For the chosen working point no resonances below order 10 are relevant. The tune leafs are clearly distorted when the snakes are included in the lattice (see Fig. 2). The covered tune space is somewhat larger, in particular for large positive momentum deviations. With snakes and rotators, the covered tune space is almost as large as without any helical magnets.

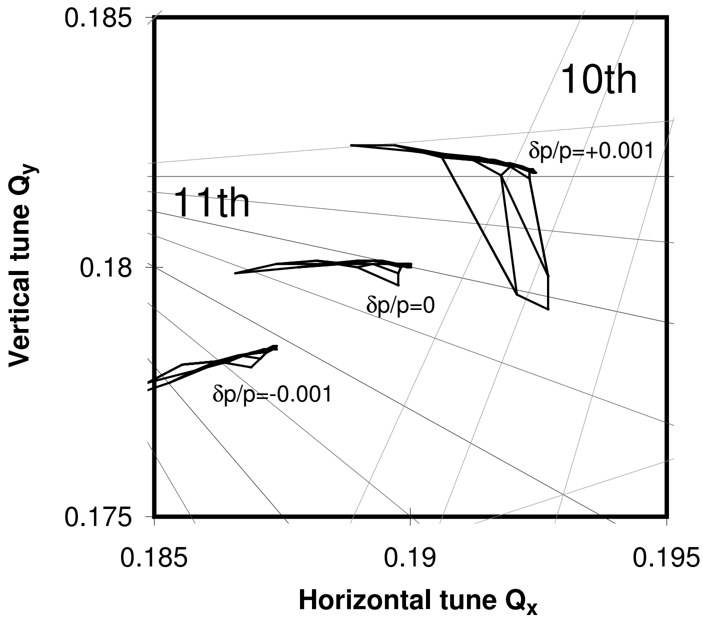

Figure 2: Covered tune space with Siberian snakes only.

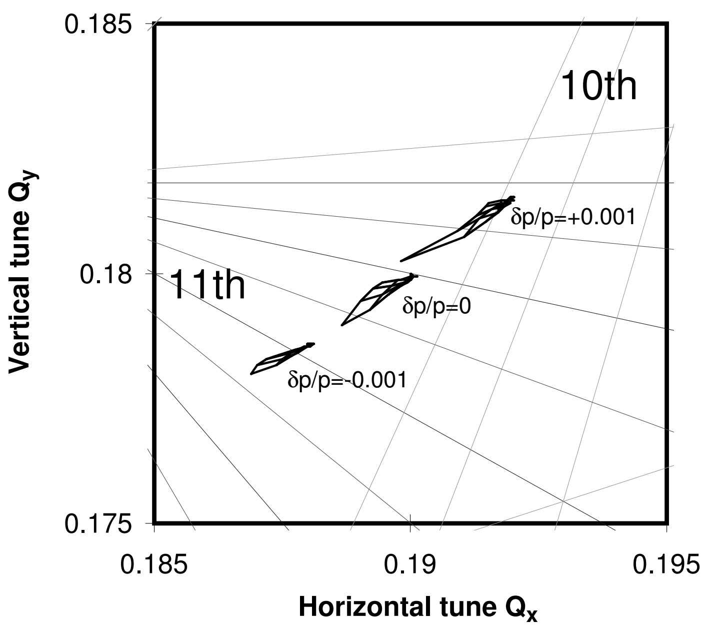

Figure 3: Covered tune space with snakes and rotators.

4 Conclusion

The results of particle tracking with helical magnets are in qualitative agreement with analytical estimates. Whereas the absolute tune shift is no problem for the RHIC correction system, the coupling needs further investigation. This will be possible with tuning capabilities in the new TEAPOT. Although the amplitude dependent tune shift does not change much by the introduction of helical dipoles it is desirable to obtain loss and chaotic borders with long-term tracking. Thus, changes in the dynamic aperture can be estimated.

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