LINEAR OPTICS MEASUREMENTS AND CORRECTIONS USING AC DIPOLE IN RHIC*

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Abstract

We report recent experimental results on linear optics measurements and corrections using ac dipole. In RHIC 2009 run, the concept of the SVD correction algorithm is tested at injection energy for both identifying the artificial gradient errors and correcting it using the trim quadrupoles. The measured phase beatings were reduced by 30% and 40% respectively for two dedicated experiments. In RHIC 2010 run, ac dipole is used to measure β* and chromatic β function. For the 0.65m β* lattice, we observed a factor of 3 discrepancy between model and measured chromatic β function in the yellow ring.

INTRODUCTION

Due to its uniqueness of exciting beam transverse oscillation non-destructively in high energy, ac dipole becomes an important tool for optics measurement and diagnostics in RHIC, Tevatron and LHC[1-3].

The measured phase beating in RHIC is about 5% at injection and above 10% at store. In order to correct the phase beating, a technique based on SVD algorithm has been developed[4]. As RHIC has more quadrupoles than bpms, it is difficult to identify the global gradient errors from a single phase beating measurement. Our concept is to use 36 trim quads as knobs to minimize the measured phase beating based on the phase response matrix. In RHIC 2009 run, we tested the technique at injection energy by setting a gradient error to one trim quad, identifying it using the SVD algorithm and then minimizing the artificial phase-beating by adjusing the other 35 trim quads.

In 2010 run, RHIC collided Au ion at 100 GeV with 0.65 meter and 0.8 meter β* in IP6 and IP8. Ac dipole was used to measure the β* and chromatic β function. While the β* measurement agreed reasonablely well with what predicted by the model and measured by gradient variation method, the measured chromatic β function in the yellow ring was about 3 times larger than what the model predicted. The discrepancy co-existed with the observation that there was more severe beam loss in the yellow ring than in the blue ring.

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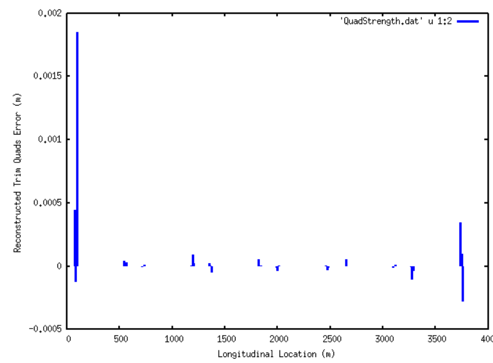
LINEAR OPTICS CORRECTION



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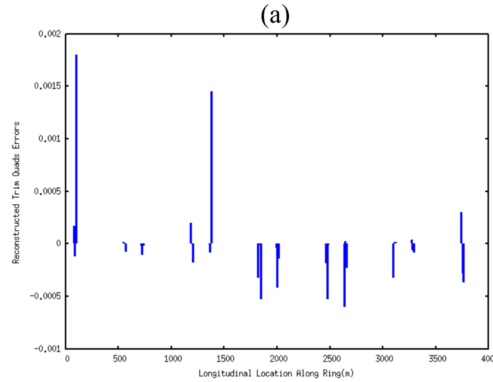

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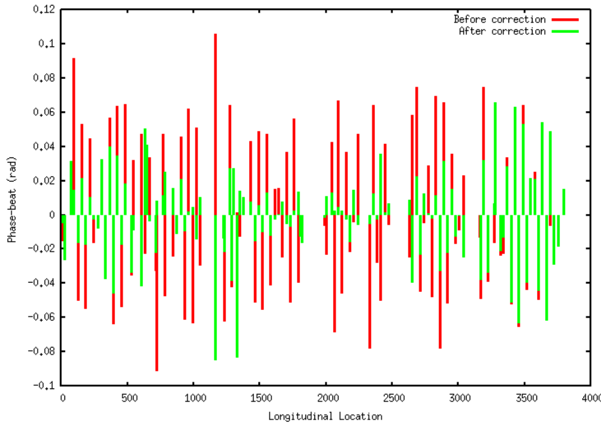
Figure 1: Reconstructed pre-set gradient errors from the SVD algorithm. (a) Artificial integrated gradient error of 0.002 m^{-1} is set in a trim quad, 'bo6-tq6', located at 96 meters. (b) Artificial integrated gradient errors of 0.002 m^{-1} are set in trim quads 'bo6-tq6' and 'bo10-tq6', located at 96 meters and 1374 meters respectively.

In RHIC 2009 run, three accelerator physics experiment sessions were devoted to test the linear optics correction technique. The first session was used to repeat and confirm the previous experiment results[4]. During this session, we set artificial gradient errors to the trim quads and use the SVD algorithm to identify them from the measured phase beating. Figure 1 shows the SVD results for two sets of artificial errors. It is worth noting that identifying the gradient errors from a single phase beating measurement can be difficult if the number of quadrupoles is more than the number of bpms. However, it is possible to minimize the phase beating by adjusing a set of correctors, which, in the case of RHIC, are 36 trim quadrupoles. In the last two sessions, we tested the concept by set an artificial gradient errors to one of the 36



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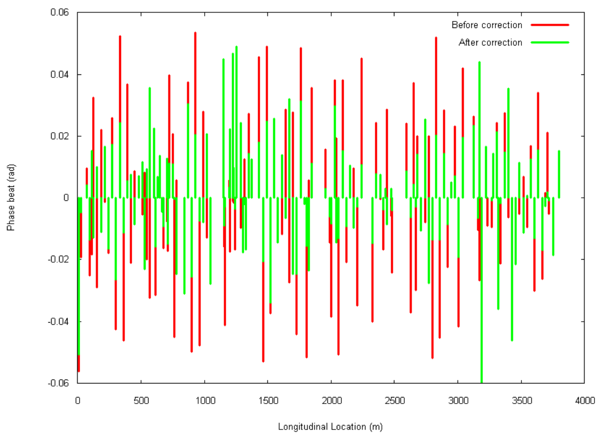

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Figure 2: Minimizing artificial phase beating using 35 trim quads as knobs. The red lines are measured phase beating induced by the artificial gradient error and the green lines are measured phase beating after applying the corrections. (a) The gradient error was set in trim quad 'bo6-tq6' with the integrated strength of 0.002 m^{-1}. The artificial rms phase beating was reduced from 2.6 degree to 1.6 degree. (b) The gradient error was set in trim quad 'bo10-tq6' with the integrated strength of 0.002 m^{-1}. The artificial rms phase beating was reduced from 1.6 degree to 1.1 degree.

trim quads and use other 35 trim quads to minimize the measured phase beating. As shown in figure 2, the artificially introduced phase beating was reduced by 40% for the preset 'bo6-tq6' error and 30% for the preset 'bo10-tq6' error. RHIC has more quadrupoles than bpms. As the quadrupoles with gradient errors are not necessarily degenerate with the knobs that were used, precise identification and complete correction are only possible by including all quadrupoles as corrector, making multiple measurements and then searching with an iterating process, i.e. techniques such as the orbit response matrix. Development of such a technique in RHIC is work in progresses.

OPTICS MEASUREMENT

Ac dipole is the major tool to measure β* in RHIC. In run 10, the initial lattice after β-squeeze has 0.65 meter designed β* in IP6 and IP8. In order to reveal the actually achieved β*, linear optics was firstly measured using ac dipole and then with the gradient variation method for confirmation. Table 1 shows the comparison of the measured β* by the ac dipole and by the gradient variation method. While some discrepancies between the two methods in the horizontal plane are over 15%, the measurements in the vertical plane agrees extremely well.

Table 1: β* in IP6 and IP8 measured with the ac dipole and with the gradient variation methods (in courtesy of V. Ptitsyn). The error bar is 4cm for the ac dipole measurement and 1cm for the gradient variation method.

		IP6		IP8	
		β_H (m)	β_V (m)	β_H(m)	β_V(m)
Ac dipole	Blue	0.62	0.65	0.70	0.63
	Yellow	0.65	0.83	0.87	0.84
Gradient Variation	Blue	0.76	0.69	0.65	0.63
	Yellow	0.72	0.84	0.71	0.84

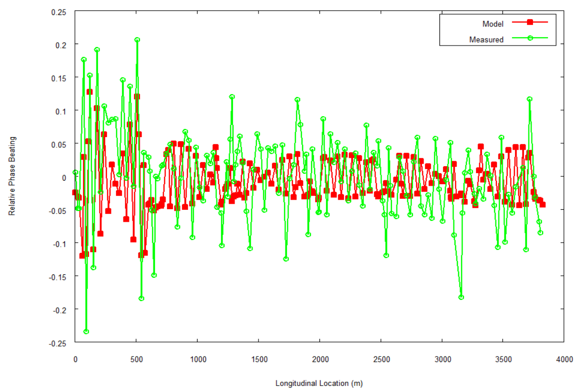
Due to the limited dynamic aperture with the 0.65m β* lattice, RHIC experienced substantial beam losses during re-bucketing[5]. In addition, the beam losses in the yellow ring were more severe than what were observed in the blue ring. For the beam diagnostics, ac dipole was used to measure the chromatic β function. In order to avoid losing exceeding amount of the beam and pulling permit, only -0.3mm radial shift was introduced, corresponding to relative energy deviation of 0.02%. Figure 3 shows the relative β beating defined as

$$\frac{\delta\beta}{\beta} \equiv \frac{\beta_{off} - \beta_{on}}{\beta_{on}}, \qquad (1)$$

where β_{on} is the on-momentum beta function and β_{off} is the beta function measured with beam energy deviation. While the measured chromatic β beating exceeds the model prediction in both rings, the discrepancy in the yellow ring is much worse than that in the blue ring. Further studies are needed to understand whether the unexpectedly large chromatic beating in the yellow ring is related to its worse beam losses.

SUMMARY

The technique of linear optics correction based on the degeneracy of quadrupole elements has been demonstrated in RHIC by correcting artificial gradient errors with 36 trim quads used as knobs. For two sets of gradient errors, the artificial phase beating were reduced by 40% and 30% respectively in a single correction. Further improvements involves correcting in iterations,



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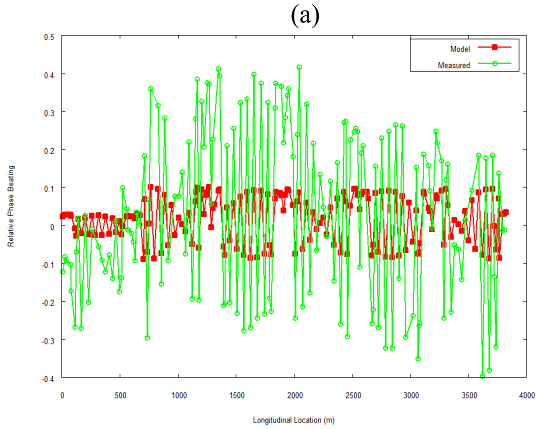

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Figure 3: Chromatic β beating with -0.3mm radial shift. The abscissa is the longitudinal location along the ring and the ordinate is the relative β beating defined in equation. The red square-line is the chromatic β beating calculated from model and the green dot-line is the measurement.

systematic studies of the degeneracy among elements with gradient field and developing automated application. Due to the smaller number of bpms than quadrupoles in RHIC, global identification of gradient errors and complete corrections requires techniques based on multiple measurements such as the orbit response matrix. Ac dipole had also played an import role during RHIC run 10 beam set up and beam diagnostics. The β* measured by ac dipole agrees reasonablely well with the model and the measurement using gradient variation method. In the process of resolving the dynamic aperture issue, chromatic β beating has been found 3 times larger than he model prediction in the yellow ring, which co-exists with the worse beam losses observed in the yellow ring.

ACKNOWLEDGEMENT

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