Operational Experience on Linear Coupling Correction in the RHIC Interaction Regions

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Two different methods (local interaction region orbit bumps and action jump trajectory analysis) to measure linear coupling errors in the RHIC interaction region (IR) are described. The measurements allow to find the values of the strengths needed in the skew quadrupole corrector elements, located in the IR's, to linearly decouple the accelerator.

1. Introduction

Interaction Regions (IR's) are specially sensitive to quadrupole misaligns. The beta functions in the IR's can be several times bigger than beta functions inany other place in the accelerator. Since the coupling errors are proportional to the root square of the beta function, small quadrupole misaligns can produce significant coupling errors

Corrections to betatron coupling originated from the IR's in RHIC are done using skew quadrupoles located, also, in the IR. RHIC has 2 skew quadrupoles at each IR in each ring which leads to a total of 24 skew quadrupole correctors, all of them independently powered [1].

The strengths that must be applied to the skew quadrupoles can be determined from orbit measurements. Two methods were used to find the appropriate strengths of the skew quadrupoles in this work: closed orbit bumps around the triplets and orbit action jump graphs.

2. Closed Orbit Bump Method (COBM)

The closed orbit bumps based on 3 dipole correctors were applied around the IR triplets. The value of the excited closed orbit rms in the plane opposite to the bump plane is proportional to the bump amplitude and to the value of the coupling error. Since we have the local skew quadrupole corrector inside the IR triplet and the betatron phase advance over the triplet is small, the corrector strength can be calculated to reduce or totally eliminate the orbit excitation in the opposite plane.

The measurements were done in the 3 interaction regions (IR2,IR6,IR8) in both RHIC rings (Blue and Yellow rings). In these IRs we had observed the strong sources of the betatron coupling. Also these are the IRs containing the experiment detectors and the local coupling compensation there should help us to improve the quality of the orbit bumps used to optimize the beam collision and improve the luminosity. The closed orbit bumps with amplitude from 5mm to up to 60mm (at some triplets) were applied and the excited orbit rms in the ring arcs was measured as well as the shift of the betatron tunes. Doing so detailed bump scan we wanted also to get the information about nonlinear field harmonics in the triplets [2].

The presence of coupling errors excites the orbit rms in the plane opposite to the plane in which the bump was applied. Figure 1 shows the measured dependence of the rms orbit excited in the plane opposite to the bump plane versus bump strength for Blue ring (There is a similar figure for Yellow ring). The sign of the rms orbit was chosen by looking at the sign of the orbit measured on the several BPMs in the arcs where according the model simulation we could expect positive orbit measurement in the case if the coupling error produced in the given IR triplet has

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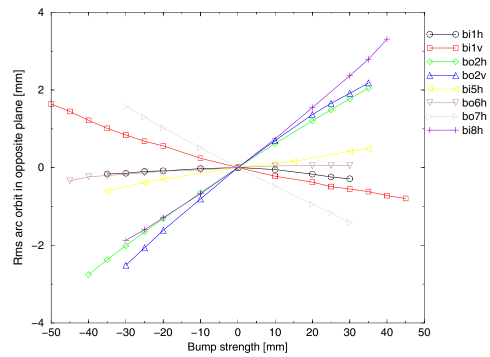

Figure 1: Orbit rms measured in the opposite plane versus the bump strength in Blue ring.

positive sign. The linear slope of the measured curves at the region of the low bump amplitudes is proportional to the value of the coupling error.

Using the calculated slope of the measured curves and beta-functions at the skew quadrupole corrector place we can also extract the corrector strength necessary to put the curve slopes to 0, thus correcting for the coupling effect. The Table I lists the calculated skew corrector strength. The strongest coupling sources are at the Blue ring triplets at IR2 and IR8. The quadrupole rolls to produce the measured coupling effect at these triplets should be few mrad.

Table I Calculated IR skew corrector strengths at Injection.

IR	Triplet Blue/Yellow	Blue corr.str. (10^{-3} 1/m)	Yellow corr.str. (10^{-3} 1/m)
IR2	I1/O1	-0.22 ± 0.16	0.3
	O2/I2	1.23 ± 0.15	0.76 ± 0
IR6	I5/O5	0.39	-0.94 ± 0.08
	O6/I6	0.12	$\pm 0.36 \pm 0.02$
IR8	O7/I7	-0.84	0.36 ± 0.04
	I8/O8	1.32	-1.1

3. Orbit Action Jump Method (OAJM)

First turn difference orbits can give a clear indication of coupling at the interaction regions. This is even more evident if graphs of action vs the longitudinal coordinate s are derived from the first turn difference orbit. Figure 2 shows one of such graphs, obtained from RHIC 2000 run. The graph is roughly constant in the arcs of the ring but there are big jumps of the action between the arcs. These jumps have their origin on linear coupling at the IR's.

Large betatron oscillations are needed in order to perform reliable measurements with this method. The available dipole correctors in the ring are used for this purpose. After the first turn difference orbit is obtained, the action at each point in the ring is calculated from the two nearest BPM measurements.

The strength needed in the quadrupole correctors at any specific IR (Sk_{corr}) can be found by directly extracting the value of the corresponding induced action due to coupling (J_{coup}) from the graphs of action vs s and using:

$$Sk_{\mathrm{corr}} = -\frac{\sqrt{2J_{\mathrm{coup}}}}{y_{\mathrm{corr}}\sqrt{\beta_{\mathrm{corr}}}} \tag{1}$$

where y_{corr} is the beam position in the plane of dipole kick (in this case the vertical plane) at the location of the skew quadrupole corrector and β_{corr} is the beta function at the position of

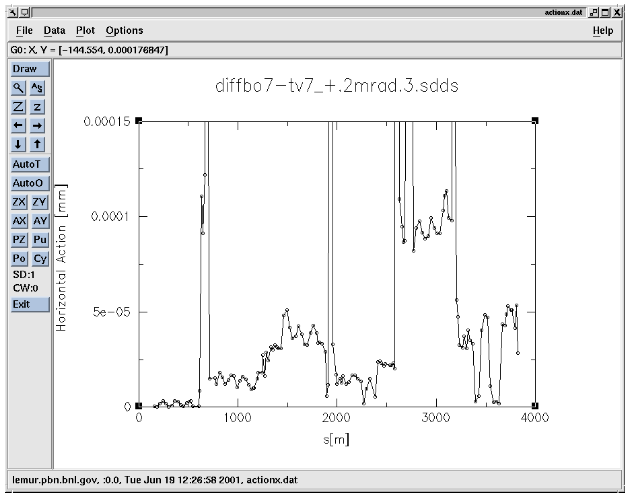

Figure 2: horizontal action of Orbit with kick in vertical plane.

the skew quadrupole corrector. This equation is derived from the fact that the amplitude of the betatron oscillation due to coupling minus the amplitude of the betatron oscillation due to the skew quadrupole corrector must be zero.

More than 40 Difference orbits, taken at injection, were analyzed and the strengths calculated at each IR leading to the following table:

Table II Quadrupole Strengths for Blue Ring at Injection

IR	Measured Sk	Real Settings
	10^{-3}	10^{-3}
IR8	(0.67 ± 0.07)	0.5
IR10	(1.0 ± 0.15)	1
IR12	(0.18 ± 0.026)	0.1
IR2	(0.99 ± 0.14)	1
IR4	(0.63 ± 0.06)	0.64
IR6	(0.6 ± 0.15)	0.5

The third column of Table II shows the values to which the skew quadrupoles were set during 2001 RHIC run. Initially, IR8, IR10, and IR2 correctors were set by trial and error using the IR bump method to test for the effectiveness of the decoupling. The good agreement between the real settings and the measured ones for the mentioned IR's encouraged the IR group of RHIC to do the remaining corrections in 1 step by using directly the measured values of the strengths.

4. Conclusions

COBM and OAJM proved to be reliable in the determination of the strengths needed for correction of linear coupling although there are important differences between the 2 methods. While the COBM can determine the coupling erroe for each triplet of quadrupoles in the IR OAJM can determine only one coupling error for each IR. The advantage of OAJM is that it requires less orbits than COBM. In principle, OAJM needs 2 orbits to find the coupling errors in all IR's in the ring while COBM requires 1 orbit for each triplet of quadrupoles which means a total of 12 orbits to find the coupling errors in the 6 RHIC IR's.

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References

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