NON-LINEAR EFFECTS IN THE RHIC INTERACTION REGIONS: MEASUREMENT AND CORRECTION*

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Abstract

A technique for measuring and correcting locally non-linear effects arising from field errors and feed-down from the interaction region (IR) triplets has been developed at RHIC. After a brief review of the method, we will compare measurements taken with different IR optics configurations, with beta at the interaction point ranging from 3 to 1m. The beam data are compared with results from a realistic RHIC model, which includes measured field errors in the magnets, and simulates operational effects and corrections. A control room application has been developed for the RHIC run 2003 that allows faster measurements of non-linear effects, online plotting and fitting of non-linear terms from measurements of tune shift as a function of orbit bump amplitude. Results for local non-linear correction during run 2003 are presented.

INTRODUCTION

The IR bump method allows the determination and correction of triplet errors from beam data by measuring rms orbit and tune shift as a function of the amplitude of closed orbit bumps centred on the IR triplets [1]. This technique has been used during RHIC run 2000 to correct the triplet linear coupling effects [2]. Refinement of linear corrections and test of non-linear corrections were achieved during run 2001 [3].

During the RHIC run 2003, ended in May, a control room application has been developed that speeds up data taking and facilitates the online data analysis and setting of the correctors. That allowed the systematic correction of sextupole effects at all low beta IR's, for optics with β^*=2m (d-Au run) and β^*=1 with (polarized p run). We also tested octupole correction in IR8 and the use of the application for measuring the beam-beam tune shift vs. crossing angle in IR6. In Section 4 we will address the comparison of beam data with model predictions. Finally we will draw conclusions and discuss planning for the next RHIC run.

THE IR BUMP APPLICATION

The IR bump application interface is shown in Figure 1.

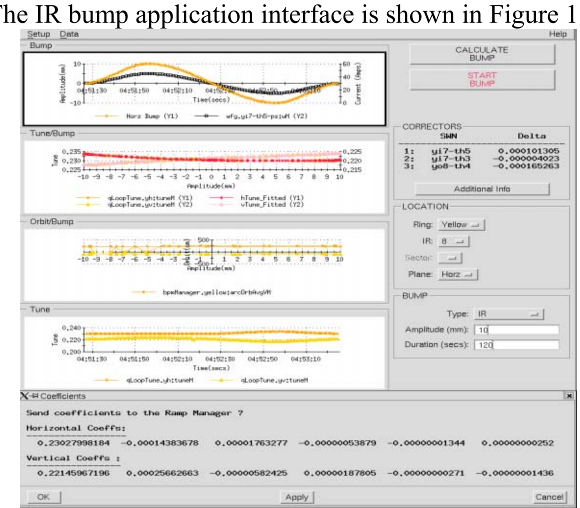

Figure 1. IR bump application interface and functionality.

The application allows us to select, calculate and set orbit bumps centred on a single triplet or spanning the entire IR. Bumps are ramped from zero to the chosen maximum amplitude in a set amount of time, typically 1-2 minutes. Tune values and dipole corrector power supply currents are monitored on the bump. Tunes and rms orbits are plotted as a function of bump amplitude and polynomial fitting up to 5th order is available to quickly quantify the non-linear effects and to aid in the determination of corrector settings.

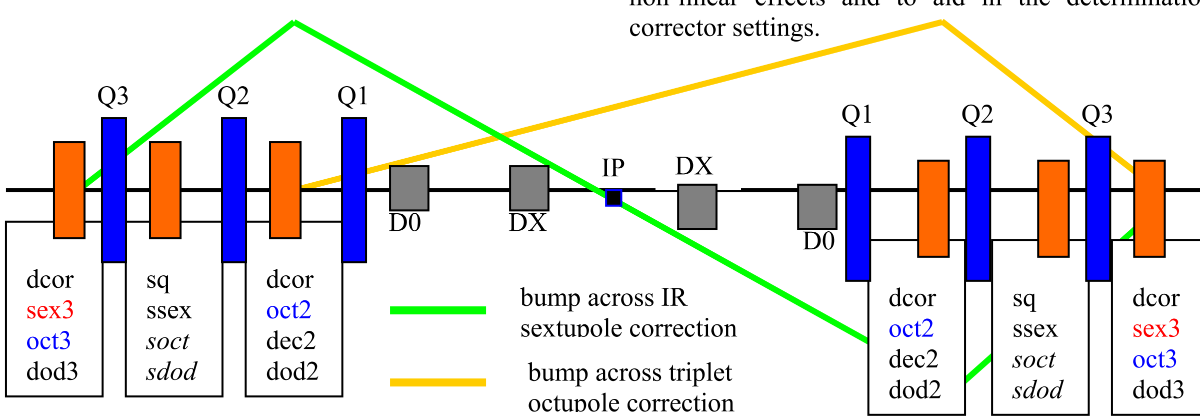

Figure 2. Schematics of a RHIC IR, with the IR correction system and IR bumps used for the correction

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Orbit data proved valuable for linear correction. The feasibility of measuring accurately non-linear effects however resides in the high resolution (~10^{-5}) of the PLL (Phase Lock Loop)[4] tune measurement system used for this application in its highest resolution mode. The application greatly enhanced the speed of non-linear IR measurements and allowed the operational correction of low order non-linear effects.

MEASUREMENT AND CORRECTION

The RHIC IR's are schematically described Figure 2. The beams are horizontally separated first, so there are 2 triplets per ring at every crossing. Nested in each triplet there are 3 multi-layer correction packages, hosting correctors from dipole to dodecapole. Dipole and skew quadrupoles are powered at every IR, while power supplies for non-linear correctors are presently available only at the IR's designed as low β* (IR6 and IR8). Local coupling correction at all triplets was accomplished in run 2000 and 2001. The goal for 2003 was the operational correction of low-order non-linear effects in IR6 and IR8. The motivation is 2 folded: simulation evidence that correction of triplet field errors increases the dynamic aperture at store from 3.5 to ~5σ, and operational. IR sextupole errors cause the IP orbit and angle bumps used for collision steering not to be perfectly closed, thus operationally coupling IP's.

Prerequisite for non-linear measurements and correction is a well corrected machine: good overall orbit correction (rms < 2mm), with beams well centred in the triplets (<2mm); chromaticity adjusted, coupling corrected to ΔQ_{min} <0.002 with enough tune separation (>0.006) to insure independence of horizontal and vertical dynamics; beams anti-cogged by 3 buckets to insure no interference from beam-beam effects.

Sextupole corrections at β=2m IR's*

In each IR there are 2 sextupole correctors (sx3 in Figure 2) at high β_x and β_y locations given the anti-symmetry of the IR optics.

IR	pl	sextupole BC	sextupole AC	octupole BC	octupole AC
Yir8	H	0.22209	0.01347	0.00535	0.00093
	V	-0.33559	0.00595	-0.00388	0.00119
Yir6	H	-0.23338	-0.02673	-0.00968	-0.00051
	V	0.41028	-0.00042	-0.00745	-0.00251
Bir8	H	-0.03204	no correct.	-0.00557	-0.00557
	V	0.07865	no correct.	0.00646	0.00646
Bir6	H	-0.06853	0.02713	0.00536	-0.01491
	V	0.12877	0.01121	-0.00176	0.00015

Table 1. Sextupole and octupole coefficients (in units of 10^{-3}) of the tune vs. bump amplitude, before (BC) and after (AC) local sextupole correction, β*=2m optics.

For sextupole correction we used a horizontal 10mm bump spanning the 2 triplets. The 2 sextupole correctors are independently adjusted on the basis of the fitted sextupole coefficients. Before and after correction tune dependence at all IR's is summarized in Table 1. Since the effect in Blue IR8 was small, it has been left uncorrected. Figure 3 shows the tune dependence vs. bump amplitude before and after sextupole correction at IR8 in the yellow ring.

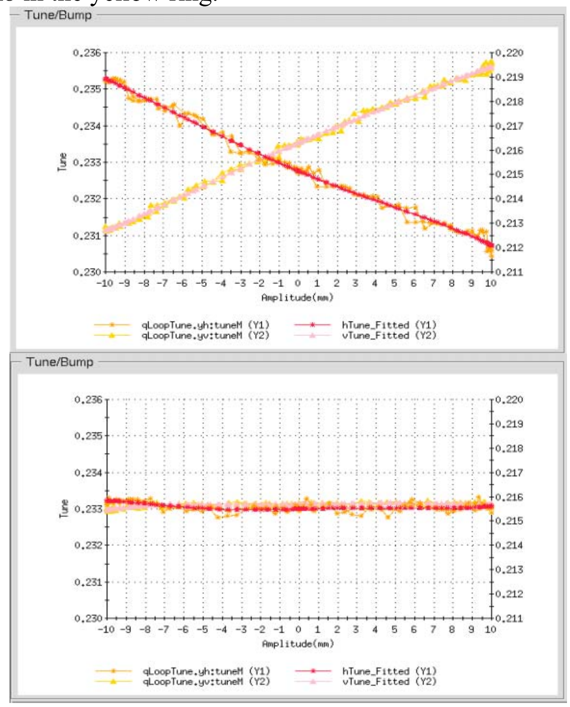

Figure 3. Tune dependence vs. bump amplitude before and after correction, IR8, β*=2m optics.

Sextupole corrections at the β=1m IR's*

In the d-Au run IR8a and IR6 have been operated at β*=2m, while the optics has been squeezed at the same IP's to β*=1m in the polarized proton run. Measurements and sextupole correction were repeated in the new configuration. Results are summarized in Table 2 and displayed in Figure 4.

IR	pl	sextupole BC	sextupole AC	octupole BC	octupole AC
Yir8	H	-0.09225	-0.00717	0.00714	0.00187
	V	0.19926	-0.00351	0.00013	0.00228
Yir6	H	-0.00446	0.09622	-0.00080	-0.00713
	V	0.19372	0.08155	0.00666	0.00634
Bir8	H	-0.03177	-0.00343	-0.00444	-0.00669
	V	0.17317	-0.00344	-0.00076	0.00043
Bir6	H	-0.10395	-0.00241	0.00044	0.00057
	V	0.10728	0.00399	- 0.00514	-0.00461

Table 2. Coefficients (in units of 10^{-3}), before (BC) and after (AC) local sextupole correction, β*=1m optics.

The measured tune shift vs. bump amplitude are on average larger for the β*=2m configuration than for β*=1m. This counter-intuitive result is explained by the fact that for d-Au (1m optics) the magnets were ramped to 4500A (Au 100 GeV/u, d 250 GeV), while for pp to 1800A (p at 100 GeV) and the dependence of field errors on the current offsets the β* dependence.

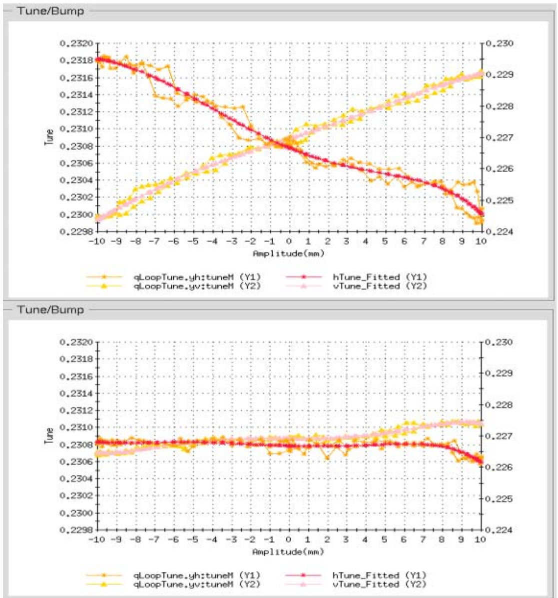

Figure 4. Tune dependence vs. bump amplitude before and after correction, IR8, β*=1m optics.

Octupole correction at IR8

Local octupole correction has been tested in yellow IR8. Since we have 2 octupoles correctors per triplet, we used horizontal 3-bump centred at the individual triplets. Results are summarized in Table 3.

triplet	bump	Octupole BC	Octupole AC
Yi7	10mm	0.00750	0.00153
		-0.00867	-0.00059
Yo8	7 mm	0.00399	-0.00397
		-0.00941	-0.00188

Table 3. Octupole coefficients (units 10^{-3}) before and after correction at the IR8 triplets, yellow ring, β*=2m.

The octupole correction was not retained for operations since feed-down from octupoles degraded the pre-existing sextupole correction. Conceptually, octupole correction should be performed first followed by sextupole, to avoid feed-down, but sextupole correction had higher priority.

Measurements at the β=3m IR's*

IR	bump	plan e	sextupole	octupole	decapole
Yir10	10 H	H	-0.04798	-0.00829	0.00059
		V	0.04262	-0.00092	-0.00111
Yir10	10 V	H	-0.03633	0.00121	0.00085
		V	-0.02066	0.00159	0.00060
Yir2	10 H	H	-0.09138	-0.00856	0.00133
		V	0.13084	0.00553	-0.00116
Yir2	10 V	H	-0.03863	0.00137	-0.00013
		V	0.20178	0.00656	0.00656

Table 4. Measurements at β*=3m interaction regions.

Measurements were taken at the experimental high β IR's (3m) to explore the possibility of further β-squeeze in these locations, where we do not have non-linear correctors. At 3m the effects are large, especially in IR2, not surprisingly since the high field quality triplets were installed in IR6 and IR8 (low β* IR's)

Test measure of beam-beam effects at IR6

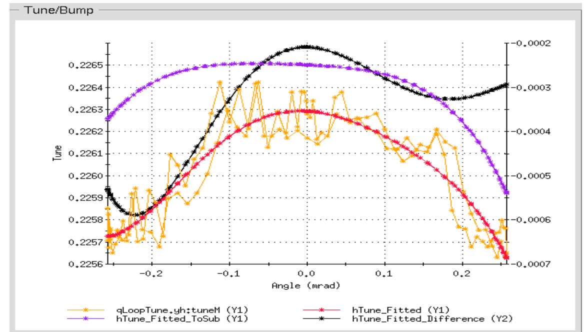

Figure 5. Tune shift vs. crossing angle: difference between cogged and un-cogged beam.

The bump amplitude is proportional to the crossing angle at the IP. By comparing data with colliding beam (cogged) and not colliding (un-cogged) the IR bump application has been tested to determine the tune shift due to the beam-beam effect as a function of crossing angle [5], an interesting operational beam-beam parameter.

COMPARISON WITH THE MODEL

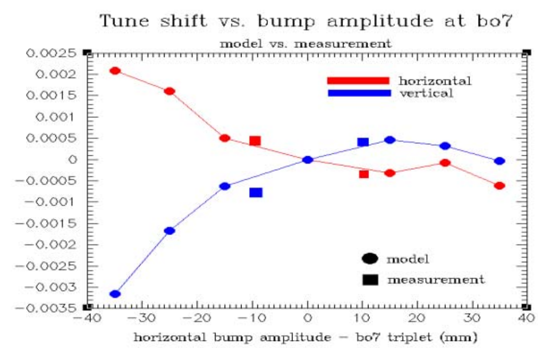

Figure 5. Comparison of model and measurement at bo7

Realistic modelling of the IR bumps with individual measured field and alignment errors in the triplet cold masses has started. Preliminary results for IR8 show good correlation between measured and simulated tune shifts.

CONCLUSIONS AND PLANS FOR 2004

The development of the IR bump application enabled the operational correction of local IR sextupole effects in run 2003, for β*=2m and β*=1 optics, and to prove the feasibility of octupole correction. The plan for 2004 is to make the octupole correction operational, and to more precisely correlate, via measurements and modelling, machine performance to the quality of IR corrections.

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