COUPLING MEASUREMENT AND CORRECTION AT RHIC*

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Abstract

Coupling correction at RHIC has been operationally achieved through a two-step process: using local triplet skew quadrupoles to compensate coupling from rolled low-beta triplet quadrupoles, and minimizing the tune separation and residual coupling with orthogonal global skew quadrupole families. An application has been developed for global correction that allows skew quadrupole tuning and tune display with a choice of different tune measurement techniques, including tune-meter, Schottky and phase lock loop (PLL). Coupling effects have been analysed by using 1024-turn (TBT) information from the beam position monitor (BPM) system. These data allow the reconstruction of the off-diagonal terms of the transfer matrix, a measure of global coupling. At both injection and storage energies, coordination of tune meter kicks with TBT acquisition at 322 BPM’ s in each ring allows the measurement of local coupling at all BPM locations.

1 INTRODUCTION

Coupling correction is essential for the operational performance of an accelerator, and RHIC is no exception. Effective independence of the transverse degrees of freedom makes diagnostics and tune control easier, and it is usually advantageous to operate an accelerator close to the coupling resonance to minimize nearby nonlinear sidebands. In addition, the more RHIC specific requirement of stringent tune control on the ramp (especially for polarized proton operations) demands good control of coupling effects, to ease the operation of the PLL based tune feedback system.

The coupling correction strategy that we used during the Run 2001 is based partly on simulation but primarily on operational experience and data analysis from the RHIC Run 2000. [1] First, we used the independently powered skew quadrupole correctors embedded in the IR triplets to compensate locally the effect of roll alignment errors. The initial local corrector settings, based on the analysis of the Run 2000 data, are applied at injection and ramped. The IR local coupling compensation techniques and the performance during the RHIC 2001 run are described in [2]. After the end of the run, the alignment of selected individual triplet cold masses was revisited and the measured roll errors were found in good agreement (with the roll inferred from the beam based measurements.

The residual coupling in the machine, from arc magnets, experimental magnets (and in addition the Siberian snakes during the polarized proton run) has been corrected with two orthogonal families of skew quadrupoles by minimizing the tune separation, a well established operational technique to correct coupling in the machine.

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This technique was also used during Run 2000. The improvement in 2001 was the development of application scripts to aid the global decoupling operation by taking advantage of both the tune meter and the Schottky detector for tune measurements, and by allowing easier skew quadrupole family setting. The scripts and the performance of the global coupling correction system are discussed in Section 2.

Development work for upgraded coupling correction techniques started during beam experiment time in run 2001 is the basis for new developments planned for the next run. Section 3 discusses the requirements for coupling correction in the upcoming run 2003 and the strategy to fulfill them. Several techniques were presented at the RHIC Retreat (March 2002) with the potential of correcting coupling without moving the tunes, opening the possibility of coupling compensation on the ramp. Most of these techniques are based on analysis of turn-by-turn data of beam position.

The RHIC coupling correction system for the Blue ring is shown in Figure 1. The configuration is equivalent for the Yellow ring.

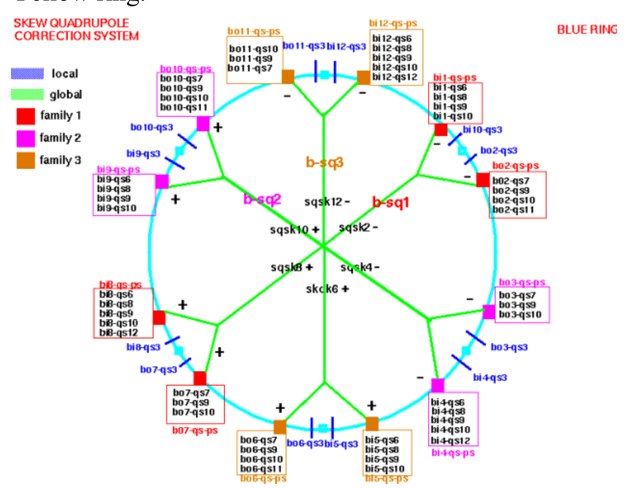

Figure1. The RHIC skew quadrupole correction system.

2 GLOBAL COUPLING CORRECTION

A common operational way to correct global coupling in an accelerator is the minimum tune separation technique. This has been used at a variety of accelerator including RHIC. It can be derived that the minimum achievable separation of the horizontal and vertical tune (ΔQ_{min}) in presence of coupling is given by:

$$\Delta Q_{\min} = \frac{1}{\pi}\frac{\sqrt{\det E}}{\sin 2\pi Q_x + \sin 2\pi Q_y} \approx \frac{1}{2\pi}\frac{\sqrt{\det E}}{\sin 2\pi Q_o}$$

where E is the 2x2 off diagonal coupling matrix of the 4x4 1-turn matrix. For N skew quadrupoles of strength k and length L wired into a family, neglecting beta and phase differences, we can write the following relation:

$$\Delta Q_{\min} \approx \frac{N}{2\pi} kL\sqrt{\beta_x \beta_y}$$

The operational way to correct coupling is to reach the minimum separation via a tune scan to bring the tunes together. At the minimum, a pair of orthogonal skew quadrupole families are varied to reduce the separation, ideally limited only by the resolution of the tune measuring system.

2.1 The global coupling application package

An application package (DQMIN) has been developed for global linear decoupling for Run 2001. It consists of a series of *tcl* scripts, able to interface with the tune measurement systems (Tune Meter, Schottky monitor, and PLL) and the power supply control software (Ramp-Editor) respectively for tune and skew quadrupole families control. In more detail, the script functionality include:

- Setting of the desired tunes
- Monitoring magnet current changes
- Getting measured tunes from the existing tune measurement systems
- Visualization of tune scans vs. set-tunes
- Setting of skew quads family strengths

2.2 Performance during Run 2001

The global coupling correction system has been used during run 2001 almost exclusively to correct the residual coupling in the machine, after the local correction in the IR triplets [2]. The system could correct coupling in the machine to the tune measurement system precision of 0.001-0.0005 using the tune meter and the HF Schottky monitor. Use of the PLL use for decoupling, potentially providing a much higher resolution (~10^{-5}), will be discussed in Section 3. Although the ultimate correction quality in 2001 has been to ΔQ_{min}=0.0005, it has been our experience that for operations the coupling had to be typically controlled to ΔQ_{min}~0.005. Global coupling corrections were performed at injection and flattop. Global coupling readjustment was required after tune changes (as the global correction is valid only in the vicinity of the tunes where the tune scan is performed), and after orbit correction, that generate tune shift.

Table 1. Global decoupling performance Run 2001.

	Blue injection	Blue flattop	Yellow injection	Yellow Flattop
ΔQmin	0.0005	0.006	0.004	0.0005
Skew Quad (kL)	0 0.0006 0	0- 0.0005 0.0001	0 0.0001 0	0.00005 -0.0005 0.0005
Measured tunes	28.2207 29.2202	28.228 29.234	28.208 29.2124	28.2169 29.2164
Tune system	Artus FFT	Artus	Artus FFT	HF Schottky
Date	7/12/01	7/2/01	10/12/01	11/16/01

The global decoupling system performance for the gold run after dedicated tune and family scans are summarized in Table 1. Similar performances were obtained during the polarized proton run.

Coupling correction in run 2001 was done exclusively at injection and flattop, with the injection settings propagated during ramping. The skew quadrupole families settings over the life of run 2001 (both Au and PP) at injection are shown in Figure 2, showing more correction activity at the run start and during polarized protons operations. Figure 3 shows a typical tune scan to bring the tunes together, in this example at flattop in Yellow, during the polarized proton run.

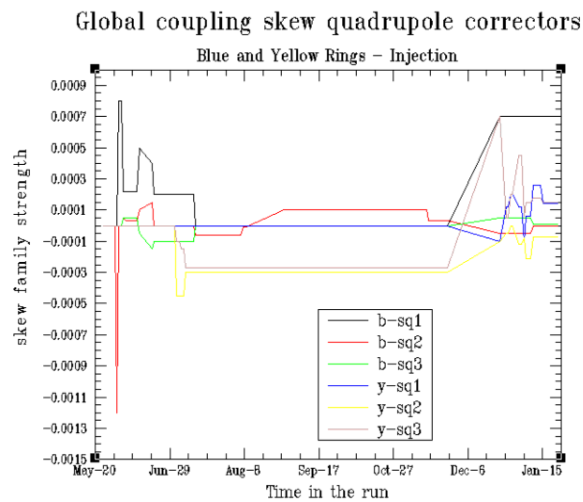

Figure 2. Skew family strengths during Run 2001

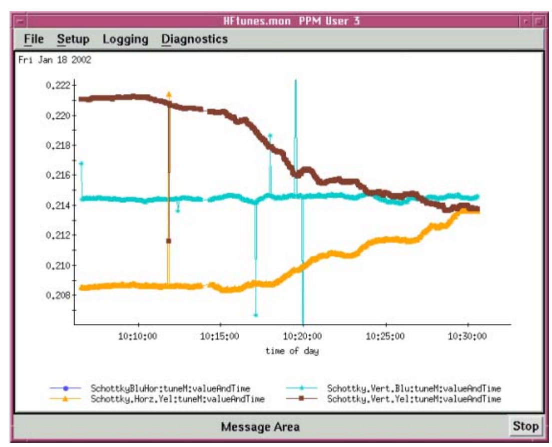

Figure 3. Scan to bring the tune together, Yellow ring, polarized proton operation, High Frequency Schottky

3 DEVELOPMENTS FOR RUN 2003

The planning of the RHIC Run 2003, to start in November 2002, was initiated at the RHIC Retreat in March 2002. Operational experience from 2001 stressed that we need faster coupling correction capabilities, and a library of correction configurations, for example, for every experiment axial and solenoidal magnet settings at flattop, that typically affects the coupling. Faster global

correction with the application can be achieved by speeding up the underlying tune measurements (i.e. faster averaging for the HF Schottky at flattop or use of the PLL for decoupling) and by speeding up the skew quadrupole scans (by providing for knobbing).
Another requirement on coupling correction capabilities comes from tune control on the ramp, to minimize beam losses on resonances in general, and to preserve polarization during proton operations. Tune feedback is required to keep the tunes constant on the ramp, and for optimal PLL performance, coupling must be minimized, to avoid losing the lock. Operationally, during the commissioning of PLL in 2001, we set the tunes artificially apart at injection by ~0.02, and that typically prevented coupling on the ramp to be a problem for the PLL. However, as the plan is to use tune feedback in operations, we have to be able to set the tunes on operational requirements other than coupling minimization. The minimum tune separation technique is obviously not a good candidate, because it is time consuming and changes the tunes, both incompatible with a dynamic situation. Work has started on devising methods to correct coupling that can work on the ramp. Table 2 summarizes the techniques that were discussed at the RHIC Retreat.

Table 2. Coupling correction techniques

METHOD	**meas.**	**corr.**	**ramp**	**global/local**
ΔQmin	indirect	Yes	No	Global
IR bumps	Yes	Yes	No	Local (IR)
Action-Phase jump	Yes	Possible	Yes	Local (IR)
SUSSIX method	Yes	Yes	Yes	Global corr Local meas
N-turn transfer matrix	Yes	Possible	Yes	Global
local decoupling	Yes	Yes	Yes	Local
Schottky line	Yes	Yes	Yes	Global

The first 3 methods in Table 9 were used in operation in run 2001, and we will retain this capability in 2003.

The (SUSSIX) coupling resonance compensation method is based on analysis of turn-by-turn BPM data and has been successfully tried at RHIC in 2001 during Beam Experiments. [3]. The advantage of this method is that it does not require moving the base tunes, so it is a good candidate to allow feed-forward coupling correction on the ramp. The plan for 2003 is to have an application available on line that allows easy acquisition and quick analysis of turn-by-turn data.

Information about the global coupling of the machine can be in principle inferred by the off-diagonal terms of the 1-turn transfer matrix. In practice though the off diagonal terms at RHIC are typically 10^{-4} smaller than the diagonal ones, unfavourable for experimental robust determination. However, it can be demonstrated that for the N-turn map, where N is half the coupling beat period, the off diagonal are the same order than the diagonal terms. Table 3 shows the comparison of the N-turn map for RHIC (Run 2001 data), before and after a global decoupling operation (with the ΔQ_{min} method).

Table 3. . Comparison of N-turn matrices before and after decoupling

0.3935	-1.1215	**-1.4554**	**4.6185**
-0.00406	0.3822	**-0.0837**	**-0.0865**
0.5319	**-13.7945**	0.2947	1.5399
-0.0146	**0.9480**	*-0.0056*	*0.1527*

-0.0676	3.0765	**1.8507**	**2.6660**
-0.0056	0.1656	**0.0834**	**0.3968**
0.0961	**3.0091**	-0.1847	0.9820
-0.0563	**1.0073**	*-0.0137*	*-0.2917*

By modeling the predicted changes of the off diagonal terms of the N-turn matrix, this technique can be used for global coupling corrections.

Another method that has the capability of measuring (and correcting) coupling on the basis of turn-by-turn BPM data is the local decoupling technique. A detailed derivation of the method can be found in [4] and the study of its application to RHIC in [5]. The essence of the method is to use the turn-by-turn signal measured at all double plane BPM 's. After kicking (or exciting) the beam in one plane, it is possible to extract from the turn-by-turn data the ratio between the out of plane and in plane oscillations. From this it is possible to derive the magnitude of the eigen-angles, a measure of coupling, locally, at every double plane BPM. Furthermore, it is possible from the data to build a badness function, function of the skew quadrupole corrector strengths available in machine. Minimization of the badness function gives the skew quadrupole strengths to correct the coupling locally. This method gave excellent results in simulation for RHIC). The plan for run 2003 is to implement local decoupling first in the present RHIC offline model (based on the UAL software package), then make it available to the upgraded online machine model.

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