FAST AUTOMATED DECOUPLING AT RHIC*

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Abstract

Coupling correction is essential for the operational performance of RHIC. The independence of the transverse degrees of freedom makes diagnostics and tune control easier, and it is advantageous to operate an accelerator close to the coupling resonance to minimize nearby nonlinear sidebands. An automated coupling correction application has been developed for RHIC routine operations. The application decouples RHIC globally by minimizing the tune separation through finding the optimal settings of two orthogonal skew quadrupole families. The program provides options of automatic, semi-automatic and manual decoupling operations. It accesses tune information from all RHIC tune measurement systems: the PLL (phase lock loop), the high frequency Schottky system, and the tune meter. It also supplies tune and skew quadrupole scans, finding the minimum tune separation, display the real time results and interface with the RHIC control system. We summarize the capabilities of the coupling correction application, and discuss the operational protections incorporated in the program.

INTRODUCTION

The coupling correction strategy adapted during RHIC operation has two steps. First, locally compensate the effect of roll alignment errors with the independently powered skew quadrupole correctors embedded in the IR triplets. Then, globally correct the residual transverse coupling caused by the arc magnets, experiment magnets and rotators (during polarized proton run) with skew quadrupole correctors. In both RHIC Blue ring and Yellow ring, skew quadrupole correctors are grouped into three families with phase advances of approximately 120 degrees. Each family consists of 16 skew quadrupoles powered by 4 independent power supplies that are set at the same strength in the software at the RampEditor level. Figure 1 shows the schematic of the skew quadrupole families in the RHIC Blue ring. The configuration in the Yellow ring is the same. Ideally, the global coupling correction can be performed with any one of the three orthogonal pairs: [Family#1, (Family#2-Family#3)], [Family#2, (Family#3-Family#1)] and [Family#3, (Family#1-Family#2)].

An application "DQmin" has been developed to aid the RHIC routine coupling correction operations. The application "DQmin" decouples RHIC globally with the minimum tune separation technique.

METHOD OF COUPLING CORRECTION

In the presence of transverse coupling, if the split of fractional tunes are fairly small as in RHIC, the minimum achievable separation of the horizontal and vertical tune ΔQ_{min} can be derived as [1]:

$$\Delta Q_{\min} = \frac{\sqrt{\det H_0}}{\pi(\sin 2\pi Q_x + \sin 2\pi Q_y)} \qquad (1)$$

or

$$\Delta Q_{\min} = \frac{\sqrt{\det H_0}}{2\pi \sin 2\pi Q_0} \qquad (2)$$

where $Q_x = Q_0 + \Delta Q/2$, $Q_y = Q_0 - \Delta Q/2$ and H_0 is the 2x2 off-diagonal coupling matrix of the 4x4 one-turn matrix. For a family of N skew quadrupoles of strength k and length L, neglecting beta and phase differences, we have:

$$\Delta Q_{\min} \approx \frac{N}{2\pi} kL\sqrt{\beta_x \beta_y}. \qquad (3)$$

The procedure of the global coupling correction is to reach the minimum tune separation, first by a tune scan, then by scan a pair of orthogonal skew quatrupole families. Ideally, the limitation of the minimum tune separation is limited only by the resolution of the tune measurement system.

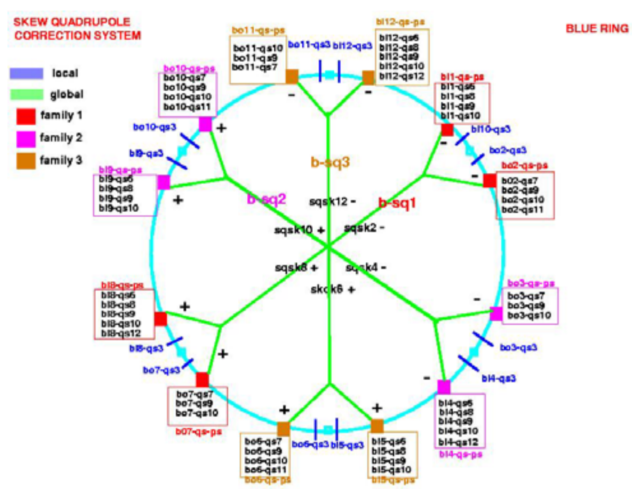

Figure 1: the schematics of the skew quadrupole families in the RHIC Blue ring. The configuration in the yellow ring is the same.

FEATURES OF THE COUPLING CORRECTION APPLICATION

The coupling correction application "DQmin" is available for operation of both Blue ring and Yellow ring of RHIC. Its capabilities are defined in the following list of functions:

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Manual Operations and General Monitoring

1. Setting desired tunes;
2. Setting desired three skew quads family strengths;
3. Monitoring WFG main bus for magnet current changes;
4. Monitoring measured tunes from the RHIC tune measurement instrumentation, including PLL, high frequency Schottky and the tune meter;
1. Option exists for "Record live Settings" and "Load recorded settings";
2. Option exists for "Restore original tune" and "Restore Original Skew Quad Families".

S*emi-automatic Operations*

1. Option exists for scanning horizontal tune Qx or vertical tune Qy independently or simultaneously;
2. Option exists for scanning 1st or 2nd or 3rd family of skew quadrupole correctors;
3. Option exists for scanning any one of the three orthogonal pairs of skew quadrupole families;
4. Input scan ranges ("start point" and "end point") and number of steps for tune scan and skew quadrupole family scans;
5. Start from "start point", at each step, automatically:
   (a) Set the tunes or skew quadrupole values;
   (b) Wait for the current in the magnets to stabilize;
   (c) Measure the tunes with user's choice of PLL, high frequency Schottky or the tune meter;
   (d) Store and display the data point in the graphs;
   (e) Go to the next step until the "end point" is reached.

Automatic Operations and Advanced Features

The following advanced features are available for automatic and semi-automatic operations only:

1. One-touch activation for "auto scan" with a smart button (see figure 2 for the flow chart of this button);
2. One-touch activation to abort scan;
3. Parabolic curve-fit around minimum of ΔQ;
4. Automatically calculate ΔQ_{min} from the scan result;
5. At ΔQ_{min} record and display tune and skew quads settings;
6. After each scan, option exists for "Go to DQmin Settings" or "Go to Pre-scan Settings" or toggle between the two buttons.

Visualization and Graphical Display

1. Visualization of tune scans vs. set-tunes with separate displays for horizontal and vertical;
2. Visualization of tune scans vs. skew quadrupole strengths of all the three families;
3. Continuous update and display the tunes from the RHIC tune measurement instrumentation, including: PLL, high frequency Schottky and the tune meter;
4. For each graph of scan, displays scan choice, tool choice and the current scan status;
5. For each graph of scan, option exists for auto-scale, zoom-in, auto-axis-texts, add or clear data points;

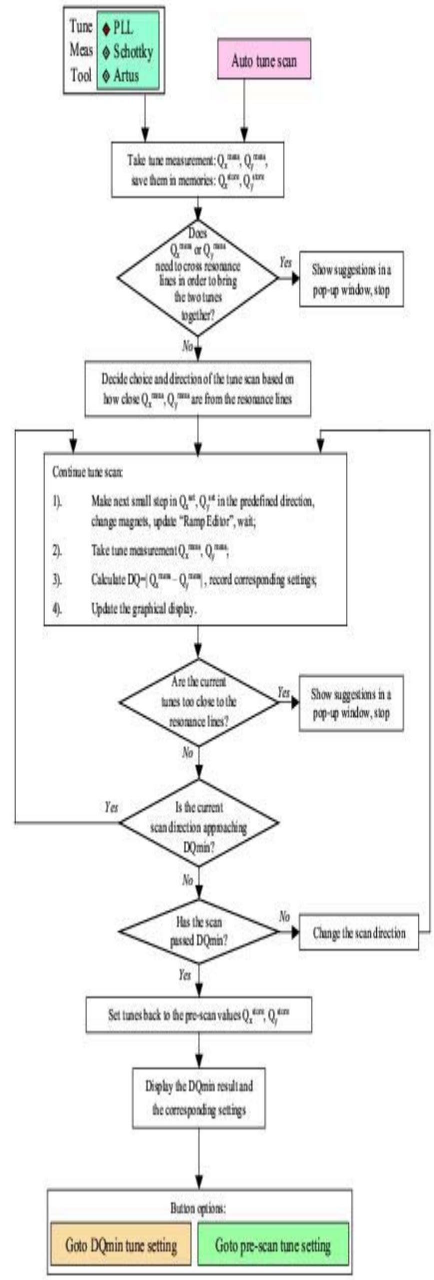

Figure 2: The flow chart of the one-touch activation for "auto scan" with a smart button.

OPERATIONAL PROTECTION

The following operations are disallowed by the "DQmin" application in order to prevent beam loss during the coupling correction operation (A warning window pops up with suggestions):

1. To change any magnet after the LiveStone change;2. To set tune with integer part differ from design value;
3. To set tune too close to resonance lines;

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4. To specify a scan range so that tune has to cross resonance line in order to complete the scan;
5. To specify a scan range too far away from the present setting or the step size is too large for stable machine operation;
6. To set or scan skew quadrupole families with too high (> 0.001) or too low (< -0.001) strength values;
7. To specify a scan range too far away from the present setting or the step size is too large for stable machine operation;
8. To choose a tune instrument (PLL, high frequency Schottky or the tune meter) that is not working;

Other operational protections:

1. Suggested (Default) scan parameters based on present settings;
2. Slow factor set/retrieve before and after each magnet change;
3. Button able/disable based on the operational status;
4. Automatically return to the original settings after finishing/aborting each scan.

PERFORMANCE OF THE APPLICATION

As an example, Figure 3 is the graphical user interface of the "DQmin" application recorded in the RHIC e-log on December 3, 2004 during a coupling correction operation in the RHIC Blue ring. The lower three graphs from left to right show the tune scans vs. skew quadrupole strengths of Family #2, #1 and #3, respectively. The upper two graphs show the tune scans vs. vertical set tunes. This operation successfully reduced the tune separation from 0.02 to 0.001. The earlier performance and achievement of the "DQmin" application was reported in Reference [2].

REFERENCES

[1] S. Peggs, "Coupling and Decoupling in Storage Rings", IEEE Transactions on Nuclear Science, Vol. NS-30, No. 4, 1983.

[2] F. Pilat, J. Beebe-Wang, W. Fischer, V. Ptitsyn and T. Satogata, "Coupling Measurement and Correction at RHIC", Proceedings of EPAC 2002, Paris, France.

Figure 3: The graphical user interface of the "DQmin" application recorded in the RHIC e-log on December 3, 2004 during a coupling correction operation in the RHIC Blue ring. This operation successfully reduced the tune separation from 0.02 to 0.001.