REAL-TIME BETATRON TUNE CONTROL IN RHIC *

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Abstract

Precise control of the betatron tunes is necessary to preserve proton polarization during the RHIC ramp. In addition, control of the tunes during beam deceleration is necessary due to hysteresis in the superconducting magnets. A real-time feedback system to control the betatron tunes during ramping has been developed for use in RHIC. This paper describes this system and presents the results from commissioning the system during the polarized proton run.

1 INTRODUCTION

The real-time tune control system (QLoop) provides controlled and settable tunes during the RHIC ramp. It uses phase-locked loops (PLLs), which track the betatron tunes, as its feedback sensors [1]. Based on the measured tunes it adjusts the main quadrupole magnet currents to keep the betatron tunes equal to the tune setpoint during the ramp. The magnet current corrections are in the form of delta strengths for the horizontal and vertical main quadrupoles. These are sent over the RHIC real-time data link (RTDL) to the waveform generators. The strengths are used to calculate individual magnet currents within the waveform generators. The QLoop is implemented in software running on one of the RHIC front-end computers.

2 SYSTEM DESCRPTION

The QLoop is a multi-input, multi-output (MIMO) control system. There is one system for each ring. Each system has the focussing and defocussing tunes as the multiple inputs, and the focussing and defocussing strengths as its outputs. Figure 1 shows the measured open loop frequency response from strengths to tunes. This graph includes the responses of the PLLs, the power supplies, the magnets, and the beam. The two planes have different frequency responses therefore the error signal from each plane is filtered separately; this allows each plane to be compensated differently to approximately equalize the frequency response of the two branches. Figure 2 shows the Simulink™ block diagram of the QLoop. A PID filter was chosen as the compensation filter. The PID filters are labeled "PIDFilterX" and "PIDFilterY" in the block diagram.

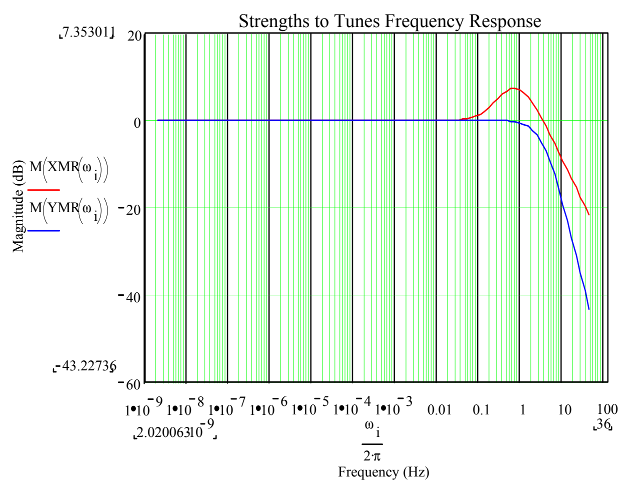
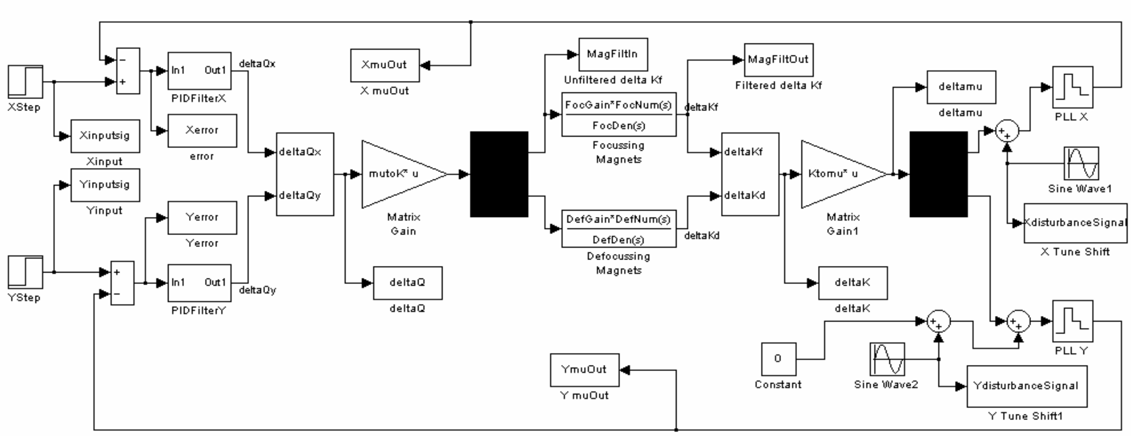


Figure 1 Strengths to Tunes Frequency Response

Figure 2 Simulink Block Diagram of QLoop



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After filtering, the error signals represent the delta tunes from the commanded tunes, they are labeled "deltaQx" and "deltaQy" in the block diagram. The delta strengths are then calculated from the following coupling matrix:

$$\begin{bmatrix} \delta K_F \\ \delta K_D \end{bmatrix} = \begin{bmatrix} 0.003819 & 0.000822 \\ -0.000776 & -0.003930 \end{bmatrix} \begin{bmatrix} \delta \nu_F \\ \delta \nu_D \end{bmatrix}$$

This matrix is labeled "Matrix Gain" in the block diagram. This matrix only includes cross terms between the horizontal and vertical tunes. The expansion of this matrix to a four-by-four to include the horizontal and vertical chromaticities would be necessary to close a real time chromaticity control loop [2]. The coefficients for the PID filters were calculated to equalize, and stabilize, the two branches. The resulting open loop response of the complete system is shown in figure 3.

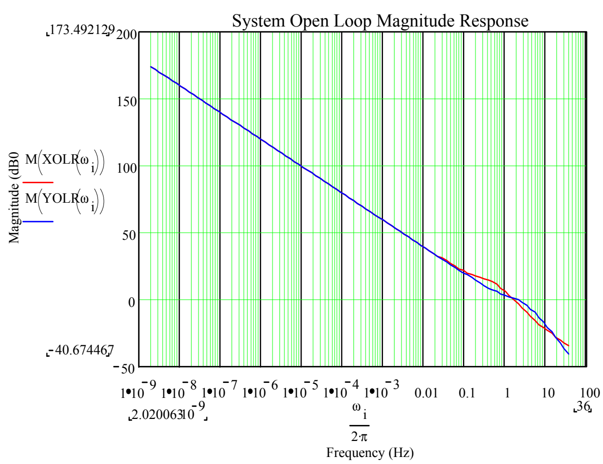

Figure 3 Open Loop Response of QLoop

The resulting closed loop response has a bandwidth of 2 Hz. This bandwidth was sufficient to control the tune variations during the ramp.

3 CONTROL SYSTEM INTERFACE

The control system interface permits an operator to set the operating conditions of the loop and select two modes of operation. The operating parameters are listed in table 1. The first mode is a test mode; the operator can excite either, or both, strengths with sin waves of adjustable amplitude and frequency. This mode is used to measure the open loop response. The second mode is closed loop operation. In this mode the operator can set the desired tune, loop response via the filter gain coefficients, the maximum rate the tune setpoint is allowed to change, and a maximum strength that will be set on the RTDL.

3.1 Automatic Control and Limits

The loop can be closed automatically by the control system by setting a flag. When the state is initially set to run the QLoop reads the measured tune and uses that value for the desired tune. This procedure avoids transients when the loop is first closed. The tune can then be changed to a desired setpoint by the control system. The loop will only allow the setpoint to change at a maximum rate. If this maximum rate is exceeded, the QLoop will ramp the setpoint at the Maximum Tune Slope Parameter until the desired tune in reached. The Maximum Strength is used to limit the corrections the loop will attempt to send on the RTDL. When the Maximum Strength is exceeded the loop "switches off." It begins updating the RTDL with the last strengths sent, this applies to both planes since they are related through the coupling matrix. After this type of incident no attempt is made to close the loops during that particular ramp. These operations are executed within the QLoop software. When the ramp reaches flattop the loop "switches off " after a fixed time period. This keeps the strengths constant on the RTDL. The control system reads the strengths from the RDTL and ramps the strengths to values that set the tunes to the desired value for the flattop.

Table 1 QLoop Operating Parameters

Operating Mode	Operating Parameter	Comment
Closed Loop Operation	Desired Tune	Tune setpoint
	K_p	PID Filter Proportional Gain
	K_I	PID Filter Integral Gain
	K_d	PID Filter Derivative Gain
	Maximum Tune Slope	Maximum Rate the setpoint is allowed to change.
	Max Strength	Maximum delta strength allowed.
Open Loop Operation	Test Frequency	Frequency of sinusoidal excitation.
	Test Amplitude	Amplitude of sinusoidal excitation

4 RESULTS

The QLoop system was tested during the RHIC 2001 polarized proton run. Several acceleration ramps were successful. Deceleration ramps were attempted but none were successful. Figure 4 shows the commanded tunes, the measured tunes, and the delta strengths during a RHIC acceleration ramp. The control effort indicates the largest tune shift correction was approximately 0.019 at 11:53:45 in figure 4. The snapback due to the start of the ramp is clearly visible at the beginning of the ramp. The last vertical line indicates the end of the ramp. The strengths approach zero as the tunes settle after the ramp.

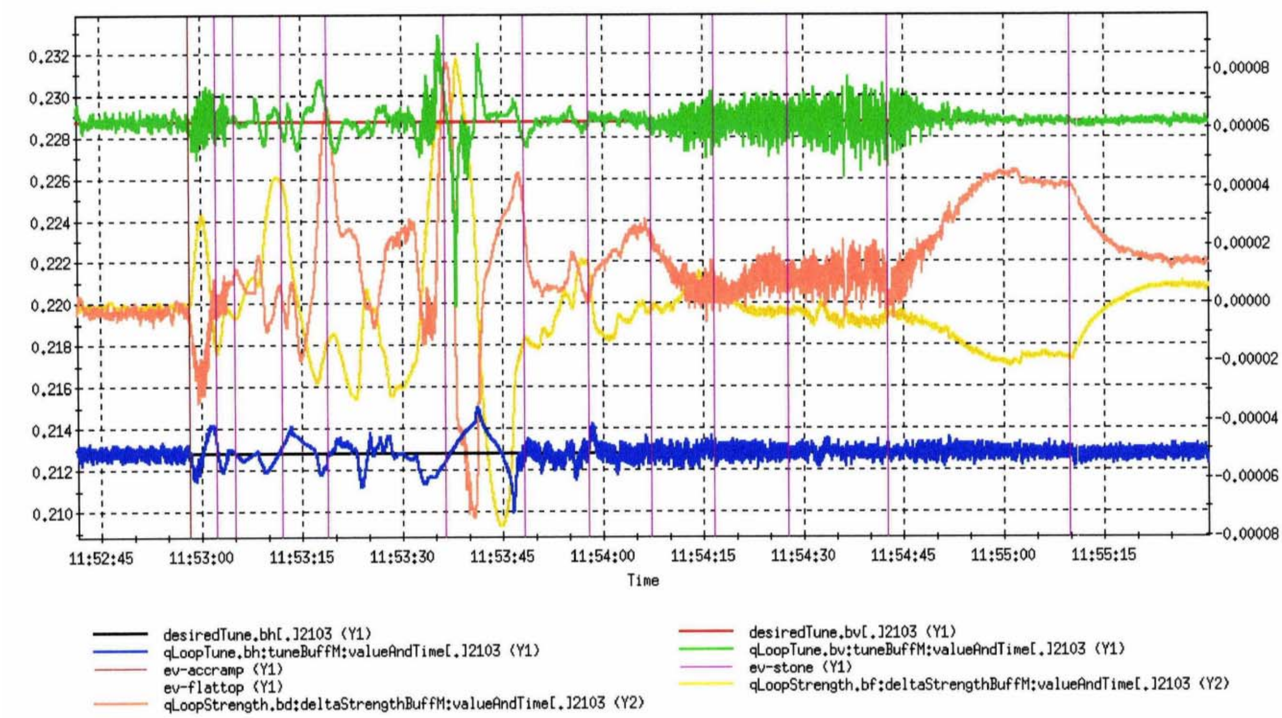

Figure 4 QLoop Signals during a RHIC acceleration ramp. The defocussing strength affects the vertical tune. The focussing strength affects the horizontal tune.

5 REFERENCES

[1] P. Cameron, et al., “PLL Tune Measurement during RHIC 2001,” EPAC’2002, Paris, June 2002

[2] S. Tepikian, et al., “Measuring Chromaticity along the Ramp using the PLL Tune-meter in RHIC,” EPAC’2002, Paris, June 2002