CHROMATICITY MEASUREMENT OF THE APS BOOSTER*

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Abstract

Chromaticity plays an important role in the beam dynamics of circular accelerators and storage rings. The APS booster synchrotron has a natural x- and y-chromaticity of -7.15 and -21.1, respectively. There is also an eddy-current-induced sextupole effect in the dipole vacuum chamber [1] that complicates the chromatic correction. Due to the current variation of ramp supplies and the resultant tune changes, we have not been able to measure chromaticity of the booster with sufficient accuracy. Recent improvement in ramp correction and reduction of harmonic ripples [2] has reduced the tune variation substantially. We measured booster chromaticity by the conventional rf frequency ramp method. In this paper we report the measurement method, the result and our analysis.

TUNE PEAK DETECTION WITH FPGA PROCESSOR

The booster tune measurement system is a FPGA-based pinging-and-acquisition system [3]. The system pings the beam via a high voltage pulse supply and a stripline pinger at an interval of around 1.5 ms. After each pinging pulse the tune measurement system acquires a turn-by-turn beam position history record with 1024 data points.

CHROMATICITY MEASUREMENT

With the tune peak waveform record, chromaticity measurement is straightforward. We ramp the rf frequency over a 10-kHz range in 10 steps with `experimentDesigner` [4]. At each step the application waits for the injection control process [5] to stabilize the beam trajectory and then acquires multiple tune waveforms. Due to reconfiguration of the ID sections of APS storage ring and subsequent increase of frequency of the rf source, the booster is running off-momentum. Its operation frequency is higher than the nominal frequency by about 10 kHz. In order to maintain injection efficiency throughout the frequency ramp we had to offset the center frequency by 5 kHz. Figure 1 shows a plot of raw data of a recent measurement.

To process the data we first filter out any outlier data points. Averaging is performed on the waveforms for each frequency step and time interval. A linear fitting is performed on the combined data. Figure 2 shows a plot of the result. From this result we concluded that: (1) booster chromaticity for the APS operational lattice is between 2.0 and 4.5. (2) The shapes of the x-chrom and y-chrom versus time curve are mainly determined by the linear-ramp character of the magnet ramp waveform. (3) The measurement at injection time is not reliable due to the high rate of change in tunes at low energy, which needs improvement.

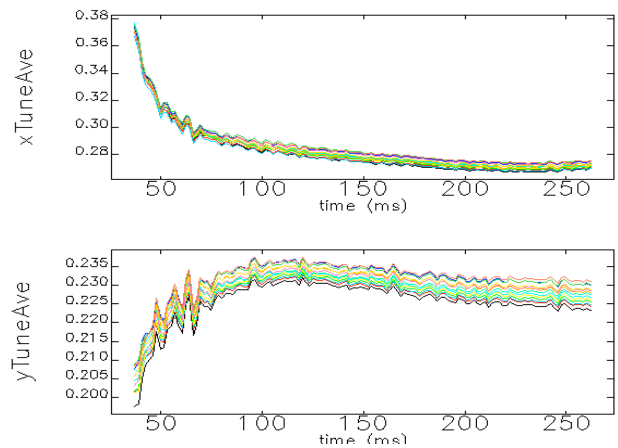

Figure 1: Raw data of booster chromaticity measurement. Horizontal axis represents time in a ramping cycle.

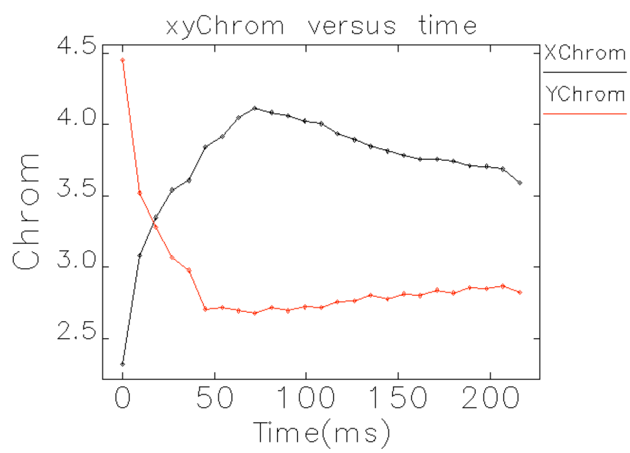

Figure 2: Plot of processed chromaticity data of booster current operational lattice. Black: x-chrom, red: y-chrom.

FITTING CHROMATICITY DATA

During the course of the past year or so we have adjusted chromatic corrections in order to optimize beam performances. Figure 3 shows a history of measured chromaticity data during this period. We performed analysis and fitting in order to understand the relationship between the chromaticity time variation and magnet current waveforms.

Time-variation of chromaticity of a booster synchrotron can be decomposed into several components [6]:

(1) a natural chromaticity due to quadrupole strength change with beam energy:

$$\xi_{x,y}^{nat} = -\frac{1}{4\pi} \sum \beta_{x,y} k_{x,y} L_{quad} \quad ,$$

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where $k_{x,y}$ and L_{quad} are strength and length of the quadupole magnets, respectively;

(2) sextupole chromaticity correction:

$$\xi_x = \frac{1}{4\pi}\sum_{SF} S_h(t)\eta_x\beta_x L_{sext} - \frac{1}{4\pi}\sum_{SD} S_v(t)\eta_x\beta_x L_{sext} ,$$

where $S_{h,v}$ and L_{sext} are geometric strength and length of the sexupoles magnets, respectively, and a similar expression for y-chromaticity.

(3) eddy-current-produced sextupole field in the vacuum chamber due to dipole ramping:

$$\xi_x^{eddy} = \frac{1}{4\pi}\sum S^{eddy}(s,t)\eta(s)\beta_x L_{BM} ,$$

where S_{eddy} is the strength of the sextupole field of eddy current effect in the dipole vacuum chamber, and L_{BM} is the length of the dipole magnet;

(4) And a contribution from orbit offset at sextupole magnets:

$$\Delta\xi_x^{off} = \frac{1}{4\pi}\sum_{SF} S_h\beta_x\Delta x L_{sext} - \frac{1}{4\pi}\sum_{SD} S_v\beta_y\Delta x L_{sext} ,$$

and similarly for y-chromaticity.

x- and y-tune variations of the booster can also be expressed similarly into contribution from the strength variation of the quads and sextupoles.

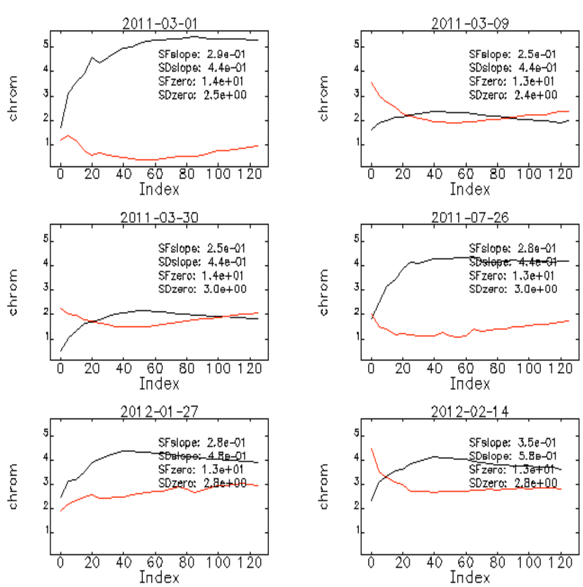

Figure 3: History of booster chromaticity in the last year. Black: x-chrom and red: y-chrom. The legend lists slope and zero (zero crossing) of sextupole ramps.

For the APS booster we use a linear ramp and adjust the quads and sextupoles with amplitude slope and time shift. So the chromaticity from the quads, sextupoles, and the eddy-current-produced chromaticity can all be characterized with a combination of a constant and a 1/t function. Figure 4 shows the k1 and k2 waveforms for quads and sextupoles derived from the magnet current waveforms.

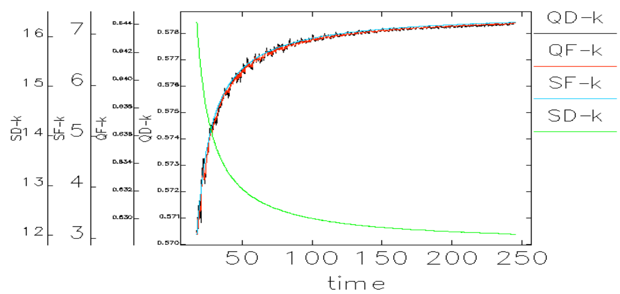

Figure 4: The k1 and k2 waveforms of the quads and sextupoles.

We used `sddsgenericfit` [7], a general fitting program, and `elegant` [8] to fit the measured tunes and chromaticity waveforms. Initial input data to `elegant` are measured magnet strength waveforms derived from ramp currents. Fit variables are teh rate and offset of quads, sextupoles, and dipole-eddy-current-induced sextupoles. An additional dipole k1 term is added to cover orbit offset in the dipole. Figure 5 shows a plot of the tune and chromaticity fit and measured data. The fit result value of variables are listed in Table 1.

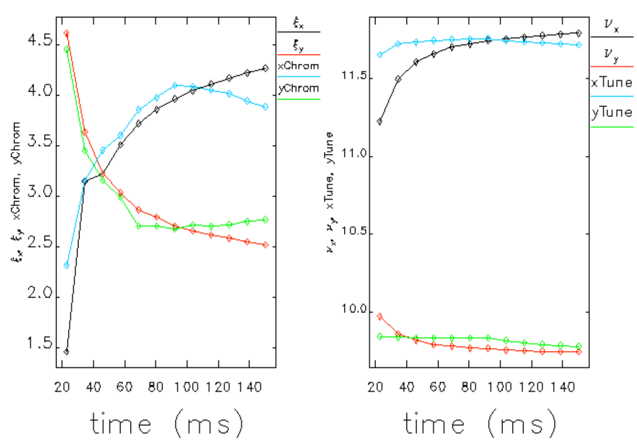

Figure 5: Fit and measured of tunes (right) and chromaticities (left) of the booster operation lattice. Black,Red: fit curve. Blue,Green: measured.

Table 1: Rate and Offset Values from Generic Fit.

Parameter	Value	Parameter	Value
QD rate	9.966e-01	QD offset	9.385e-06
QF rate	9.982e-01	QF offset	-3.036e-04
SD rate	9.807e-01	SD offset	6.276e-03
SF rate	9.824e-01	SF offset	4.993e-02
BM rate	1.016e+00	BM offset	-4.509e-3
BMk1 rate	-1.08e-01	BMk1 offset	8.134e-04

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TUNING OF BOOSTER LOW EMITTANCE LATTICE

The results and method have aided the development of the low-emittance lattice of the booster. The low-emittance lattice has an emittance of 92 nm and a nominal x-tune of 13.75 and y-tune of 5.80. The natural chromaticities are 7.0 and 22.0 in the x and y planes, respectively.

Due to the higher vertical natural chromaticity, the lattice requires more chromatic compensation. Due to the original specification, the SD magnet supply has reached its maximum current. Considering beam instability is stronger at the injection end of a ramp cycle, we shifted the SD ramp earlier and thus increased the defocusing sextupole strength at injection. This tuning scheme would hurt the extraction end of a ramp cycle. However, radiation damping time at 7 GeV is short enough to overcome beam instability so this is not a problem.

Figure 6 shows the recently measured tunes and chromaticities of the low-emittance lattice with fit result. Except for injection time x-chromaticity is mostly negative, and y-chromacity is also negative for a brief period. This explains why the lattice is very sensitive and beam is only stable below ~2.3 nC. Simulation based on these data indicated 4.1% and 18.0% increase in SD and SF current, respectively, is necessary to bring both chromaticities to positive values.

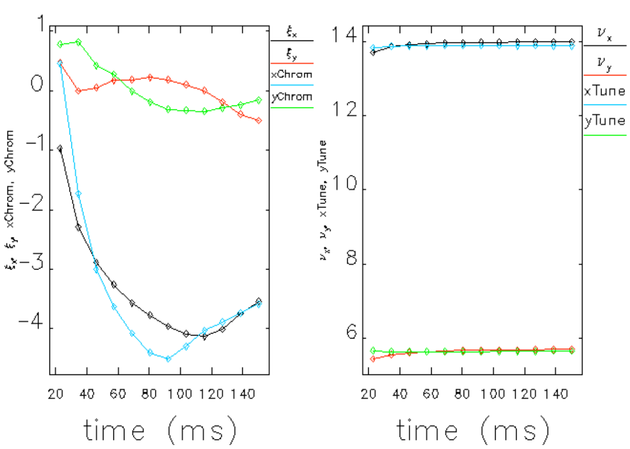

Figure 6: Fit and measured tunes (right) and chromaticities (left) of the booster low-emittance lattice.

CONCLUSIONS

The FFT tune peak detection works well in detecting booster tunes during a ramping cycle. The booster x- and y-chromaticities of the APS operations lattice are between 2 and 4, which agrees with our expectation. The measurement indicates that tune variation at injection is many times higher than at extraction, which agrees with the measurement results of ramping power supply current fluctuations. Generic fitting of the time variation of measured chromaticity and ramp supply currents has shown good agreement. The results have helped the optimization of the booster low-emittance lattice.

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