Beam Based Alignment of Recycler Chromaticity Sextupoles

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April 1, 2003

Introduction

The natural chromaticity in the Recycler (in the absence of any sextupole field) is approximately -32 units in each plane(actual -32 H and –34 V). The arc gradient magnets were designed to have a sextupole built into the body to correct for the natural chromaticity of the Recycler. These strengths were designed to produce a chromaticity of –2 units in each plane (actual -1.9 H and –2.2 V). The design strengths of the dipole and first two harmonics of the arc gradient magnets are listed in Table 1.

Magnet Type	BL [kG-m]	B1 units	K1 [m-2]	B2 units	K2 [m-3]
Arc f	6.1824	619.74	0.01132	8.69	.01250
Arc d	6.1824	-598.08	-0.01092	-15.05	-.02164
Dis f	4.1216	1275.96	0.02253	0	0
Dis d	4.1216	-1303.08	-0.02301	0	0

The gradient magnets were installed with an offset to the central trajectory to minimize the feeddown from the body sextupole and quadrupole terms.

Initially, the Recycler had 16 horizontal and 8 vertical powered sextupoles recycled from the old Main Ring installed for chromaticity adjustment. These were individually powered and were designed to be able to adjust the chromaticity +/- 5 units. During the October 2001 shutdown 8 horizontal and 14 vertical sextupoles were added. Due to power supply constraints, the sextupole circuits were connected in loops containing 3 or 4 sextupoles per supply.

The sextupoles were installed to keep a (modulo) 90 degree phase advance between sextupoles. This meant that they were installed either in the center or downstream corrector slots. They were to be installed centered on the beampipe, but not surveyed.

If the orbit is not centered through out the powered sextupoles, adjustment of the chromaticity will produce an added tune shift proportional to the displacement in the sextupole due to the feeddown from the sextupole to quadrupole. This observed tune shift, while adjusting the chromaticity, has been noted by Stan on several previous occasions, the latest being February 2003 (logbook entry 46). This implies the sextupoles are not centered on the beam trajectory. Prior to centering the sextupoles on the beam trajectory, we should try to center the trajectory as close to zero (center of beampipe) as possible.

Prior to March of this year, the horizontal orbit, according to the BPM's had a rms of ~7.5mm with a peak oscillation of greater than 10 mm. Subsequently, the horizontal orbit was smoothed to reduce horizontal orbit distortions ***as reported by our BPM system***. This reduced the orbit distortion from 7.5 mm to 3.5 mm rms. Figure 1 shows the smoothed horizontal orbit. This brought the orbit offsets, as reported by the BPM system to an average of –1.3 mm through the powered sextupoles at 112, 114, 116, and 118 which is powered by the S112 circuit.

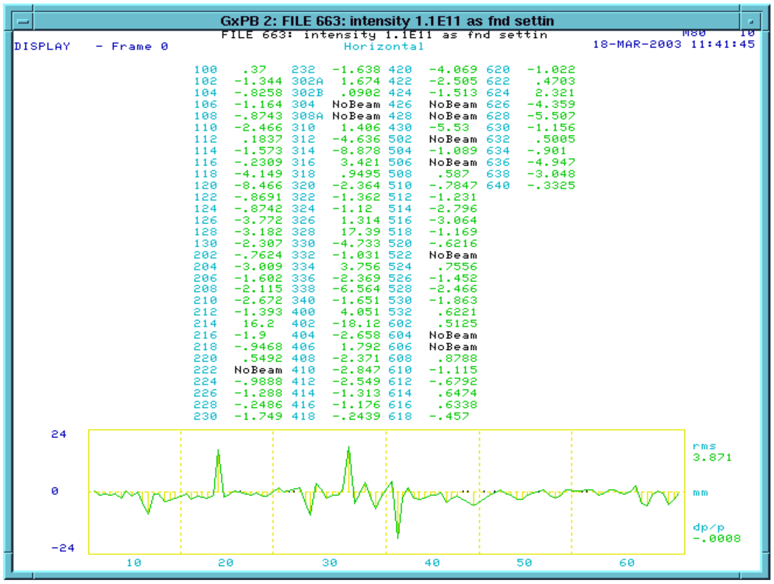

Figure 1: Horizontal orbit after smoothing

Sextupole Feeddown

The feed down from the sextupole field to quad is just

$$k_1 = k_2 * dx,$$

where k_1 and k_2 are the quadrupole ($B'/\beta\rho$) and sextupole ($B''/\beta\rho$) field components and dx is the offset in the sextupole. The tune shift due to a single quad:

$$\Delta\nu = (1/4\pi)\ (\beta/f) \quad \text{where } f = (k_1 L)^{-1} \ \ [\text{m}]$$

If the quad is located at a focusing location, then:

$$\Delta\nu_x = (1/4\pi)\ \beta_x k_1 L \quad \text{and} \quad \Delta\nu_y = -(1/4\pi)\ \beta_y k_1 L$$

Substituting the expression for k_2, the tune shift due to an offset through a sextupole is

$$\Delta\nu_x = (1/4\pi)\ \beta_x k_2 L dx \quad \text{and} \quad \Delta\nu_y = -(1/4\pi)\ \beta_y k_2 L dx$$

The transfer function, K, of the powered recycled MR sextupoles with no spacers, as reported in TM-1412 , is 4.66 kG-m/m^2/A, so $k_2 = I\,K / L(\beta\rho)$ in units of m^{-3}.

Then the tune shift in terms of the current in the sextupoles and the transfer function is,

$$\Delta\nu_x = (1/4\pi)\ \beta_x IKdx/(\beta\rho) \quad \text{and} \quad \Delta\nu_y = -(1/4\pi)\ \beta_y IKdx/(\beta\rho)$$

For multiple sextupoles on a single supply, we just sum over the $\Delta\nu$ contribution at each location.
The average offset through the sextupoles can be calculated by:

$$dx = (+/-)(4\pi)(\beta\rho)\Delta\nu_{x,y} / n\langle\beta_{x,y}\rangle IK$$

where $\Delta\nu_{x,y}$ is the total measured tune shift due to the current, I, in the circuit of n sextupoles, $\langle\beta_{x,y}\rangle$ is the average beta at the sextupole, and n is the number of sextupoles in the circuit. The (+/-) denotes the polarity of on plane/off plane tune shifts.

Machine data

To determine the offset of the beam through the sextupole, all the sextupole correctors were set to zero and the tunes were split so that the horizontal and vertical tune shifts could easily be measured. See Recycler logbook on March 18,2003 for data. This measurement was done during pbar stacking, so the spectrum analyzer, which looks at the 21 Mhz Shcottky detector, was set trigger on a $29 event with a zero offset to eliminate any tune shift from the MI ramp. I averaged over 10 cycles. The tune shift for a +/- 5 Amp change in sextupole current was measured. Figure 2 shows the tune shift/amp for each of the circuits.

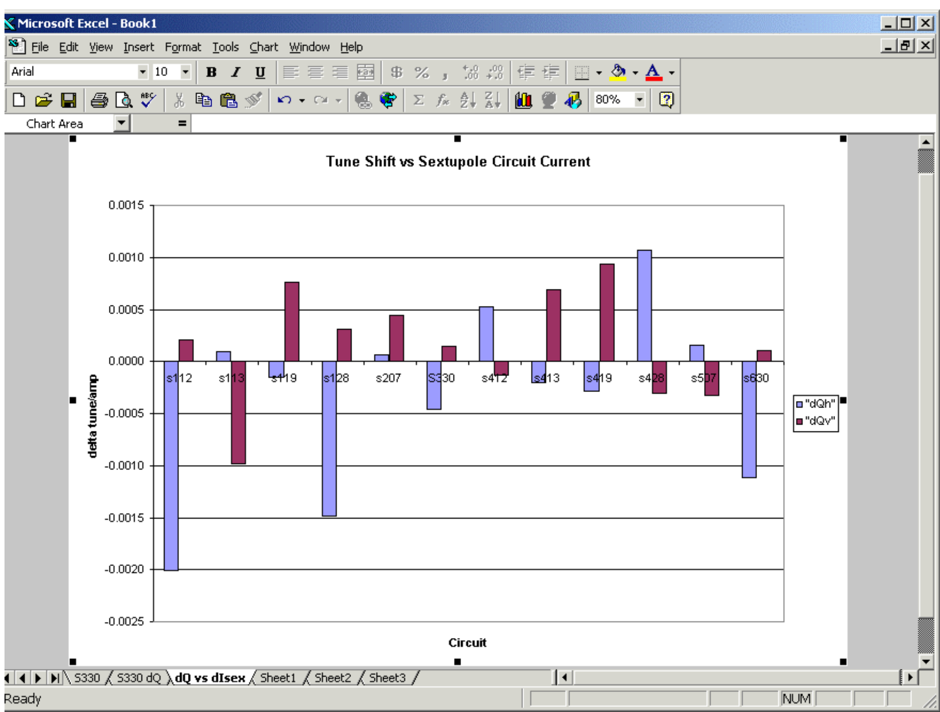

Figure 2: Tune shift corresponding to a 10 amp (total) change in each sextupole circuit independently.

Data Analysis

The largest tune shift observed for the 10 Amp change was in the S112 circuit. Here, the horizontal tune shift in was –0.02 and the vertical tune shift was small at +0.002 for the full 10 Amp range. The direction of the tune shift corresponds to an action of a defocusing quad. To determine the offset of the beam in the sextupole, look at the relative orientation of the beam to the center of the sextupole field.

A diversion on sign. The bend field in the gradient magnets point down. The arc gradient magnets (RGF,RGD) contain dipole, quadrupole, and sextupole fields. Figure 3 shows the general orientation of the *equivalent* fields for dipole, quadrupole and sextupole, rather than the gradient magnet pole face and fields. The powered chromaticity correction sextupoles are installed in the same configuration as the sextupole in the body. A positive current increases the strength of the field in the direction shown.

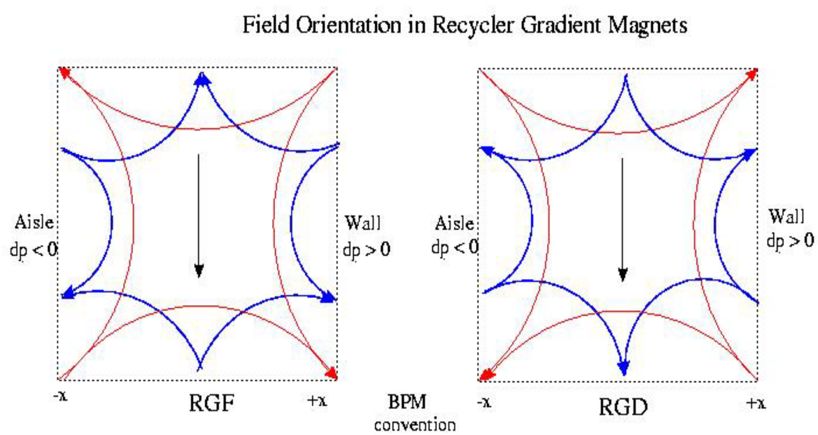

Figure 3: Orientation of the equivalent dipole quadrupole and sextupole fields at focusing and defocusing locations in the Recycler. The black arrow represents the dipole field, red represents the quadrupole field, and the blue represents the sextupole field orientation in the gradient magnet.

Chromatic effects lead to a deficit of focusing/defocusing for higher momenta particles and an excess focusing/defocusing for lower momenta particles. To compensate for this effect, the sextupole field must provide additional focusing/defocusing for the higher momenta and reduced focusing/defocusing for the lower momenta particles.

Based upon this convention a negative horizontal tune shift for an orbit through sextupoles at a focusing location says that the beam is on the aisle side (inside, -x) of the sextupole centerline.

For each circuit, the average horizontal offset through the sextupoles in that circuit was calculated. Tables 2 and 3 show the results of the measured tune shifts (*per amp*) and the calculated displacement to produce the measured tune shift. Table 2, for the horizontal circuits, includes the average offsets at the sextupoles as measured by our BPM system. The measured horizontal position for the vertical circuits are not included since the decommissioning of those BPMs. The tables also show, in the last two columns, the

predicted tune shifts due to the calculated displacement. The design lattice functions at the location at each sextupole were used from a model that included measured fields and feeddown effects.
Looking at the results for S112 in Table 2, the calculated average offset of the beam through the sextupoles was –7.8 mm. The orbit from the BPM's show that the average measured offset <dX> was –1.3 mm. Using this calculated horizontal offset, I recalculate the expected horizontal and vertical tune shifts. These are reported in the last two columns. The horizontal tune shift agrees as expected, but the vertical tune shift generally has the correct sign, but can deviate by up to a factor of 2 or so. This is due to the uncertainty in the vertical orbit through the sextupoles.

If the measured positions from the BPM system are used to calculate the expected tune shift for the S112 circuit, the predicted horizontal tune shift is about a factor 5 smaller than measured.

Table 2: Results for the Horizontal Sextupole circuits

CIR No.	No. sext in circuit	Measured				Calculated		
		dI	dQh/Amp	dQv/Amp	<dX>	dX	dQh/Amp	dQv/Amp
S112	4	9.8	-0.0020	+0.0002	-1.3	-7.8	-0.0020	+0.0005
S128	4	9.8	-0.0015	+0.0003	-2.3	-6.7	-0.0015	+0.0005
S330	4	9.2	-0.0005	+0.0001	-1.1	-2.1	-0.0005	+0.0001
S412	4	9.2	+0.0005	-0.0001	-1.3	+2.1	+0.0005	-0.0001
S428	4	7.8	+0.0011	-0.0003	NA	+6.3	+0.0011	-0.0004
S630	4	9.8	-0.0011	+0.0001	-1.6	-4.5	-0.0011	+0.0003

Table 3: Results for the Vertical Sextupole circuits

CIR No.	No. sext in circuit	Measured			Calculated		
		dI	dQh/Amp	dQv/Amp	dX	dQh/Amp	dQv/Amp
S113	3	9.8	+0.0001	-0.001	+4.98	+0.0002	-0.001
S119	4	9.8	-0.0002	+0.0008	-3.4	-0.0003	+0.0008
S207	4	9.9	+0.0001	+0.0004	-1.8	-0.0001	+0.0004
S413	3	8.6	-0.0002	+0.0007	-4	-0.0002	+0.0007
S419	4	7.8	-0.0003	+0.0009	-4.8	-0.0003	+0.0009
S507	4	9.8	+0.0002	-0.0003	1.3	-0.0003	-0.00001

Conclusions

The results for S112 would suggest that either the orbit should be moved toward the outside of the ring toward the wall, +x, or that the sextupole should be moved to the inside of the ring. Similarly, the sign of the result for dX for the other circuits indicates, the direction of the average beam offset through that circuit, negative for inside and positive for outside. From the comparison of the measured BPM offset and calculated offset from the tune shift, is clear that the results of this measurement do not agree with the reported BPM positions. This difference between these measurements could be taken as the offset from the center of the beampipe. **However, due to the uncertainty of the absolute calibration of the BPM, the sextupoles with the largest offset, namely S112, should initially be shifted by the calculated dX to reduce the tune shift from the offset to the present orbit.** If this test works, we should move the other sextupoles with offsets greater than 4 or 5 mm. It should be noted that as the new BPM's become operational, and the true design orbit is achieved, this procedure should be repeated.