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RHIC Run 7 Feedback Ramp Tunes

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THE EFFECT OF MAINS HARMONICS

The RHIC baseband tune measurement system (BBQ) is extremely sensitive, capable of detecting beam motion of the order of 10nm. This sensitivity has revealed the presence of harmonics of the power line frequency in the betatron spectrum [1]. These harmonics are ~30dB above the BBQ noise floor at injection and store, and ~70dB above the noise floor during ramping. The effect of these harmonics must be considered in selecting tunes used for ramps that employ tune and coupling feedback. Two simple examples will give the reader some sense of how strongly these harmonics affect BBQ functioning.

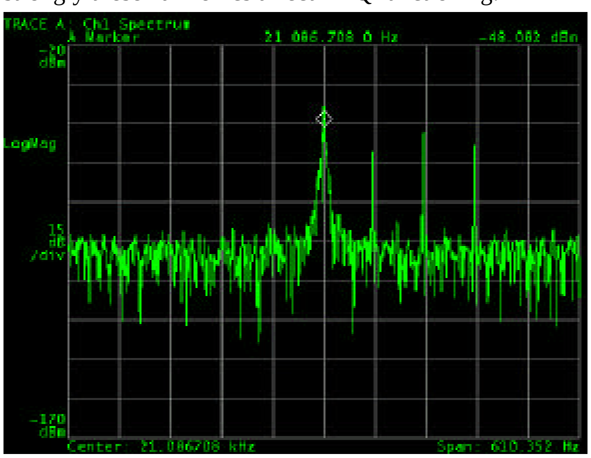


Figure 1: Simulation of mains harmonics

Figures 1 and 2 show data taken during bench testing in preparation for Run 7. In Figure 1, the relatively broad spectral line in the center of the figure results from the BBQ being locked to a test resonator. The three sharp lines to the right come from a signal generator used to simulate the effect of mains harmonics, the carrier being frequency modulated at 60Hz to create the sidebands on either side. The carrier is ~8dB down from the BBQ excitation, and the sidebands are ~15dB down. For the measurements shown in Figures 1 and 2 the resonator was de-Q'd, so that the amplitude of its response to the signal generator remains relatively constant as the generator frequency is varied.

Figure 2 shows the interaction of the BBQ with these simulated mains harmonics as they are swept across the BBQ excitation. Time flows from top to bottom in this figure, with most recent time at the bottom. As the first sideband approaches it captures the BBQ, despite the fact that it is 15dB down, and holds it for ~30Hz of sweep. During this time additional sidebands appear ~10Hz away from the BBQ/mains harmonic line, suggesting that the BBQ is verging on instability. As the 'mains' carrier approaches the BBQ excitation it also appears to 'capture' the BBQ (in some sense of the word), but here it appears to be repelling rather than attracting. In frequency modulation the carrier and sidebands are 180 degrees out of phase. The observed difference in effect of the 'mains' carrier and sideband on the BBQ can probably be understood as a result of this phase shift. Again, the effect of the 'mains harmonic' on the BBQ is strong, despite the fact that the carrier is 8dB down from the BBQ.

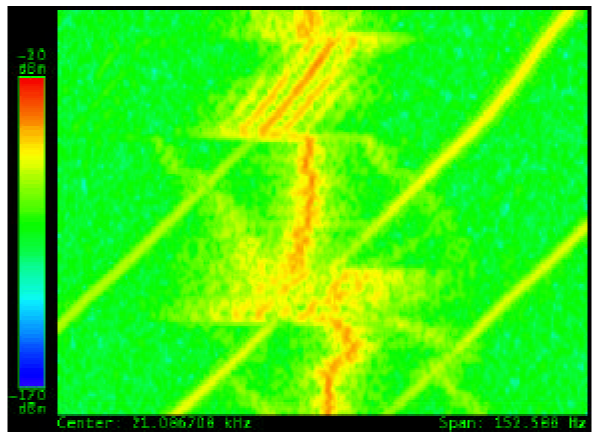


Figure 2: Walking the simulated mains harmonics across the BBQ/test resonator

Figure 3 shows data taken at store during Run 6. Again time flows from top to bottom. At the top of the figure, the BBQ was locked to the betatron line. The BBQ excitation was such that its amplitude was ~30dB stronger than the weak mains harmonics, and ~15dB stronger than the strong mains harmonics. The phase of the lock was zeroed, then swept in increments of 10 degrees. The lock can be seen to jump discretely from one mains harmonic to the next until it is adjacent to a strong harmonic, where it remained pinned by the phase information of the strong harmonic for 50 degrees of phase change. It then jumped 6 harmonics to the next strong harmonic. Dialing the phase back towards zero, the BBQ again preferentially locked in the vicinity of mains harmonics while finding its way back to the starting point. It is useful to keep in mind that this data was taken at store, and that the mains harmonics are ~40dB stronger during ramping.

These examples hopefully make clear the strong effect of mains harmonics on the functioning of the BBQ, as well as the need to carefully select and control tunes during ramping.

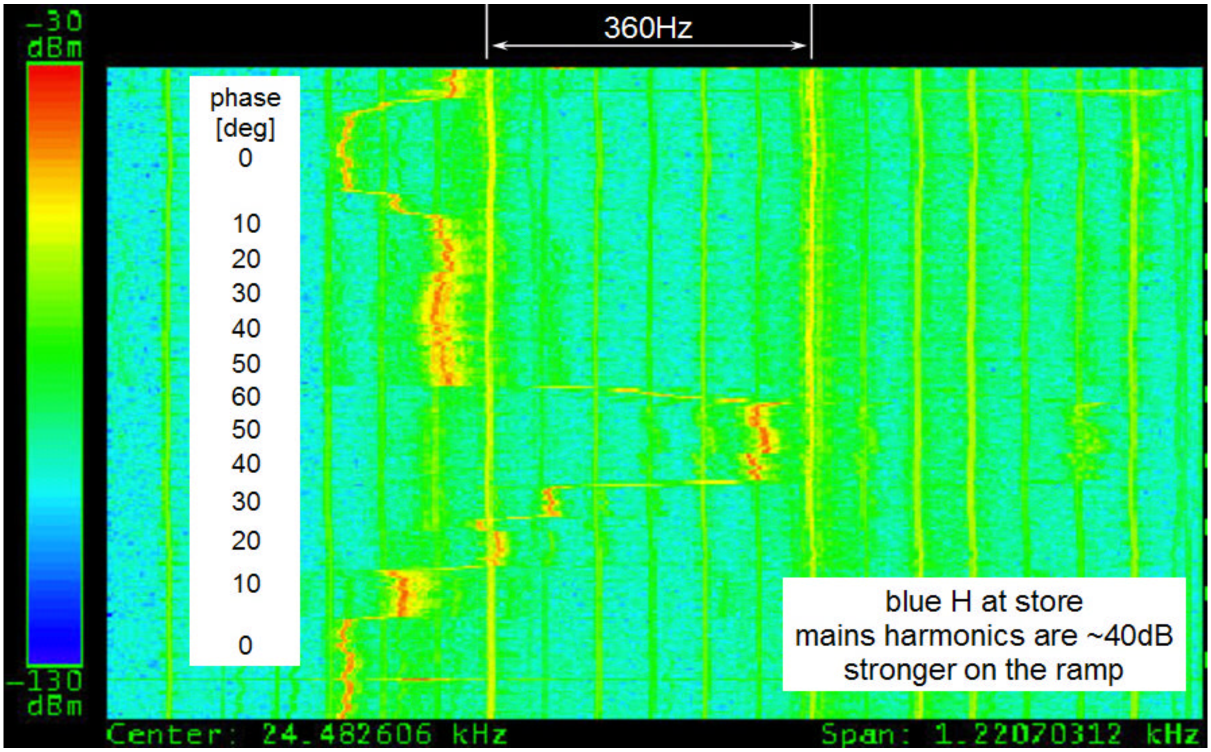


Figure 3: Effect of phase walk at store during Run 6

DESIRED TUNES

During Run 6 (with protons above transition at injection) the frequency swing up the acceleration ramp was small enough to permit closing the tune feedback loop through the ramp without pulling the tunes across mains harmonics. This is not the case for gold beam during Run 7. Frequency swing up the ramp for a horizontal tune of .230 at injection is shown in Figure 4. Rather than maintaining ***constant tunes*** during feedback ramps, it is desirable to maintain ***constant*** tune ***frequencies***, to avoid pulling the tunes across the ~constant frequency mains harmonics. This can be accomplished by calculating desired ramp tunes from Bρ.

The nominal desired Run 7 tunes are .230, .215. Figure 5 shows the location of strong mains harmonics from Run 6. Due to the tunes used for proton running, data is available only down to a tune of ~.22, which is above the desired vertical tune of ~.215. However, experience has shown that mains harmonics are not strong in the vertical plane when RHIC is well decoupled, which should be the case during feedback ramps. Assuming that the same mains harmonics will be strong for Run 7 (not necessarily so, but probably the best guess), desired tunes at store for Run 7 are also shown in Figure 5. This note proposes that store tunes of .22905, .21524 be used for Run 7 feedback ramps.

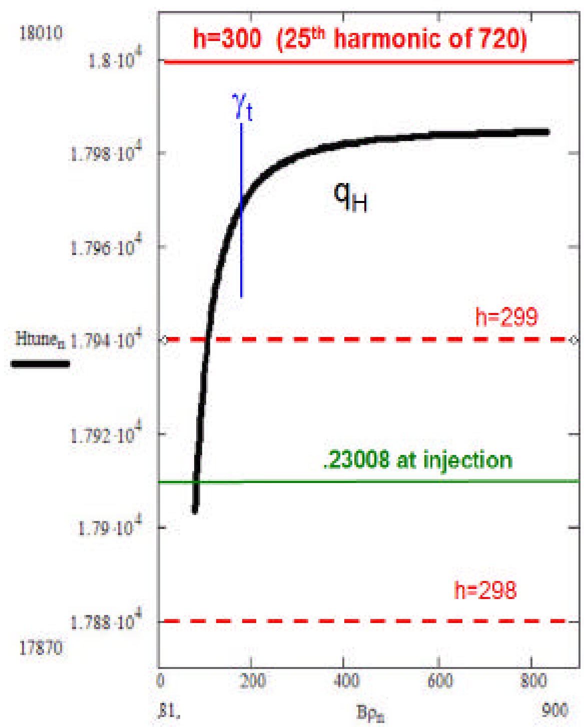


Figure 4: Tune swing up the Au ramp

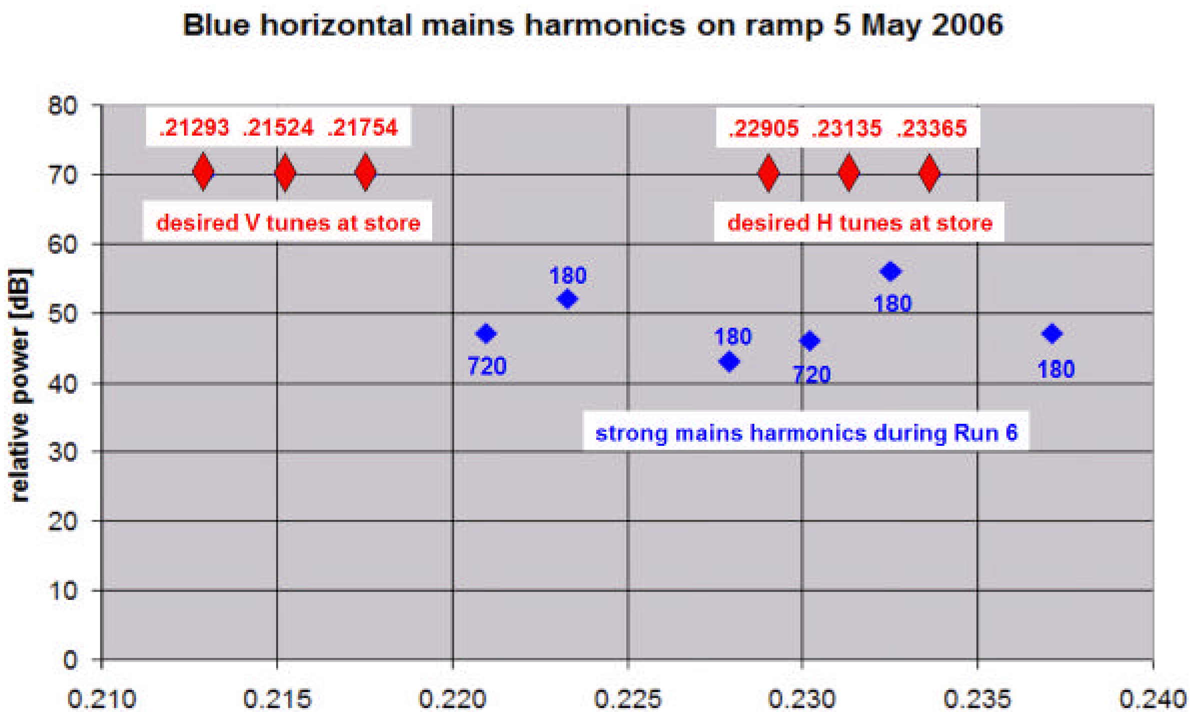


Figure 5: Strong mains harmonics during Run 6, and desired tunes for Run 7

DESIRED TUNE CALCULATION

Table 1 shows relevant machine and beam parameters [2] used for the desired tune calculation.

parameter	symbol	value
Au charge [q]	Q	79
Au mass [GeV]	m	183.43312
RHIC radius [m]	R	610.17538
Injection Bρ [T-m]	Bρinj	81.11378
Store Bρ [T-m]	Bρsto	839.5

Table 1: Machine and beam parameters

The maximum revolution frequency in RHIC is

$$Frev_{\max} = \frac{c}{2pR}$$

or 78196.3Hz. For a given Bρ, the revolution frequency [3] is

$$Frev = Frev_{\max} \sqrt{1 - \frac{1}{\left(\frac{Q \cdot Br \cdot c}{m}\right)^2 + 1}} \qquad (1)$$

which gives revolution frequencies of 77842.2Hz at injection and 78193Hz at store. To maintain constant tune frequencies, the desired tunes along the ramp are then

$$n_{ramp} = \frac{n_{store} \cdot Frev_{store}}{Frev}$$

which for the .22905, .21524 store tunes (shown below on Waldo's resonance diagram) gives

$$n_{rampH} = \frac{17910\,Hz}{Frev} \qquad n_{rampV} = \frac{16830\,Hz}{Frev}$$

where Frev is calculated as shown in eqn (1). Injection tunes would then be .23008, .21621.

ACKNOWLEDGEMENTS

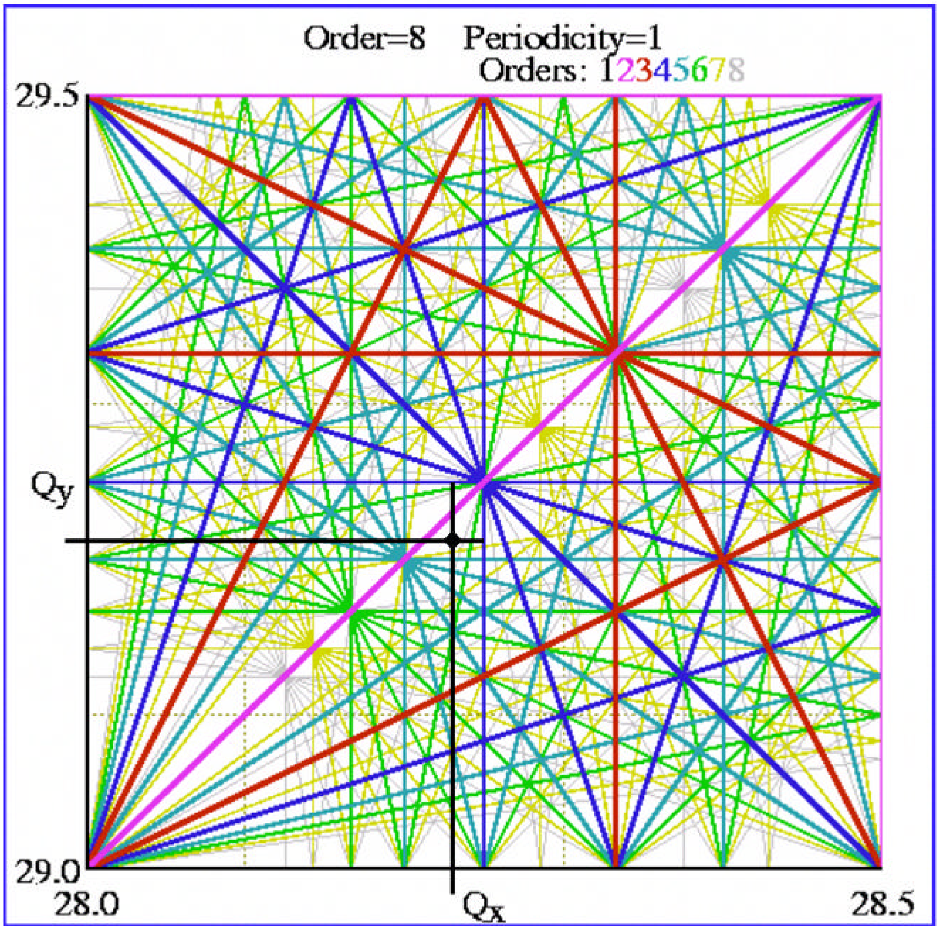
Thanks to Al Dellapenna for setting up and taking the data shown in Figures 1 and 2, and to Larry Hoff for a helpful conversation regarding referencing tunes to the revolution frequency at store, rather than injection.

REFERENCES

[1] P. Cameron et al, "Observations of Direct Excitation of the Betatron Spectrum by Mains Harmonics in RHIC", C-AD AP Note 253, September 2006, available at
http://www.rhichome.bnl.gov/AP/ap_notes/cad_ap_index.html

[2] RHIC Design Manual, available at
http://www.rhichome.bnl.gov/NT-share/rhicdm/index.html

[3] J. DeLong, private communication



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