Tickling C:AQ5

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1. Introduction

The alignment of the quadrupoles in a proton synchrotron is important and the alignment of the low beta quadrupoles in collider mode is even more critical. One of the important considerations is the relationship of the electrical center of the Beam Position Monitors (BPMs) to the magnetic center of quadrupoles. Determining this involves measurements when the elements are not in the tunnel and careful alignment utilizing external reference marks when the BPMs are not physically attached to the quadrupole. Even when the BPM is attached to the quadrupole (and calibrated), systematic offsets can be introduced by cable mismatch or slight imbalances in the monitoring electronics. A method has been implemented at Cern [1,2] to determine this relationship using the beam itself.

TM-1960 described a proof of principle experiment at the Tevatron using one of the individually powered quadrupoles near the B0 interaction region whose ACNET name is C:AQ7. This short note demonstrates that we can perform the same analysis on a set of quadrupoles powered by a single power supply without having to worry about exciting a single quadrupole

2. Principle of k-modulation

If the beam is off center in a quadrupole of length L , located at s_0 , then changing the strength k of the quadrupole will give a local kick to the beam. The kick $\Delta x'$ is proportional to the displacement x of the beam from the magnetic center of the quadrupole:

$$\Delta x'(s_0) = \Delta k * L * x(s_0) \quad (1)$$

The change to the closed orbit at a location s due to this kick is given by:

$$\Delta x(s) = \frac{\sqrt{\beta(s_0) * \beta(s)} * \cos[|\mu(s) - \mu(s_0)| - \pi Q]}{2 * \sin(\pi Q)} * \Delta x'(s_0) \quad (2)$$

where β , μ , and Q are the betatron function, phase advance, and tune in the plane of motion under consideration. Cern has developed the idea of harmonically modulating the strength of the quadrupole at a fixed frequency well below the synchrotron frequency and betatron frequency:

$$\Delta k = \Delta k_0 * \sin(\omega t) \quad (3)$$

3. Experimental Setup

The C:AQ5 power supply was modified as shown in figure 1. A simple KROHN-HITE 5200 signal generator was used to apply a 3.2 Hz signal to the modulation input connector. The peak amplitude of the applied modulation signal was .3% of the nominal current at 150 GeV (415 A).

One of the unique features of the experiment was that we simply used the normal BPM system, taking our signals from the front panel of the R. F. module. We were able to observe the applied modulation by putting the BPM signal directly into an HP3561A signal analyzer. However, to get a cleaner signal we utilized a customized crate which uses the intensity signal from the RF module to trigger a sample and hold on the position signal at the proper time in the position processing. A schematic of the data acquisition system is shown in figure 2. Marv Olson modified the crate so that we could use either coalesced or uncoalesced bunches. This experiment used uncoalesced bunches and TM-1960 used coalesced bunches.

The beta functions of the relevant quads in the B0 region are shown in table 1:

Location	β_x (meters)	β_y (meters)
A4Q5	126.5	13.3
B1Q5	13.2	127.9

Table 1.
Horizontal and Vertical β s

4. Data Acquisition and Analysis

Previous studies [3] have shown a number of low frequencies in BPM spectra arising from various vibrational modes of quadrupoles, and we wish to avoid these frequencies. Another consideration is that the low beta quadrupoles are superconducting and we do not wish to quench them; this implies that we should use as low a frequency as possible. Figure 3 shows the spectrum at HPA42 with our "standard candle" 4.6 Hz and the imposed 3.2 Hz signal.

We chose the C:AQ5 quadrupoles because there are both horizontal and vertical BPMs associated with these quads and it is possible to do a 3 bump at one of the Q5's both horizontally and vertically. From a perusal of the beta functions it is interesting that we were able to succeed as well as we did. The experiment consisted of sequentially three bumping in both planes at both quadrupoles, recording the T39 readings at the BPM of interest and the magnitude of the induced signal at a chosen location. The results are shown in figures 4 through 7. The sensitivities are in accordance with the beta functions. We were even able to make measurements vertically at AQ5 and horizontally at BQ5 (where the beta functions are small), although clearly the data are not as consistent as the other two sets of data. The reason for the small number of data points for the horizontal at BQ5 is that the shift was cut short by a dipole corrector overcurrent trip.

5. Conclusion

We have successfully determined the magnetic center of both of the C:AQ5 quadrupoles with respect to nearby BPMs by modulating (tickling) the current in the quadrupoles without quenching the magnets. The data indicates a large vertical offset at AQ5.

Acknowledgments

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References

- [1] I. Barnett et al, "Dynamic Beam Based Calibration of Orbit Monitors at LEP", to be published in the Proceedings of the Fourth International Workshop on Accelerator Alignment, KEK, Japan, November 14-17, 1995.
- [2] R. Schmidt, "Misalignments from k-modulation", Proceedings of the Third Workshop on LEP Performance, CERN SL/93-19 (DI) 1993, pp. 139.
- [3] C. D. Moore, "Vibrational Analysis of Tevatron Quadrupoles" to be published in the Proceedings of the Fourth International Workshop on Accelerator Alignment, KEK, Japan, November 14-17, 1995. Fermilab TM 1959.

FIGURE 1 A005 current Modulation Circuit

Figure 2.
Data Acquisition System

RANGE: -27 dBV STATUS: PAUSED

A: MAG

-50
dBV

3.2 Hz motion from
C: AQ5 modulation

4.6 Hz motion from
CHL motor vibration

10
dB
/DIV

-130

START: 0 HZ
X: 3.175 HZ

BW: 95.485
Y: -72.64 dBV

Figure 3.
Horizontal Spectrum from HPA42

STOP: 10 HZ

●— HPA42 (mm)

AQ5_2/26/96

$$y = m1 \cdot \text{abs}(M0 - m2)$$

	Value	Error
m1	0.0035263	6.2054e-05
m2	1.2628	0.059348
Chisq	5.2541e-06	NA
R	0.99503	NA

Figure 4.
A Horizontal three bump at AQ5

—●— VPA47 (mm)

;AQ5_2/26/96

$y = m1 \cdot \text{abs}(M0 - m2)$		
	Value	Err
m1	0.0010952	4.8462e-1
m2	2.9632	0.144
Chisq	6.8056e-07	↑
R	0.98728	↑

Figure 5.
A Vertical three bump at AQ5

$$y = m1 \cdot \text{abs}(M0 - m2)$$

	Value	Error
m1	0.00094872	2.7412e-05
m2	0.64836	0.04607
Chisq	1.396e-08	NA
R	0.99685	NA

—●— HPA46 (mm)

Figure 6.
A Horizontal three bump at BQ5

VPA47 (mm)

$$y = m1 \cdot \text{abs}(M0 - m2)$$

AQ5_2/26/96

	Value	Error
m1	0.0037083	0.00017774
m2	-0.43224	0.09718
Chisq	5.8251e-06	NA
R	0.97611	NA

Figure 7.
A Vertical three bump at BQ5