BNL-102268-2014-TECH

RHIC/AP/164;BNL-102268-2013-IR

The AC Quadrupole in RHIC

W. Ficsher

February 1999

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

DISCLAIMER

RHIC/AP/164

The AC Quadrupole in RHIC

W. Fischer, A. Jain and D. Trbojevic

February 25, 1999

1 Introduction

An AC quadrupole has been installed in RHIC, at a position very close to IP4. Both, the quadrupole and its power supply have been used earlier in the Tevatron at Fermilab. The quadrupole will be common to both rings and will be able to provide a tune modulation of $\Delta Q_{x/y} = 1.48 \times 10^{-3}$ at injection, and $\Delta Q_{x/y} = 1.73 \times 10^{-4}$ at storage energy, with a modulation frequency of up to 2 kHz.

This note describes the mechanical and magnetic properties of the AC quadrupole, its power supply and its effect on the beam. The note is intended as a reference document.

2 Mechanical Design and Alignment

The AC quadrupole has a mechanical length of 1.56 m. It has a ceramic beam pipe with an elliptical cross section. The minor half axis of the elliptical cross section is 19 mm long, the major half axis is 32 mm long. The minor half axis is in the vertical direction. The quadrupole field is provided by a coil on a support frame with a cylindrical cross section. Since essentially no magnetic material is used, the magnetic field inside the coil is proportional to the current. The whole assembly is potted in RTV [1].

Table 1: β-functions at the AC quadrupole location in the rhic99 optics.

	injection		storage	
	Blue	Yellow	Blue	Yellow
β_x[m]	10.0	10.0	10.2	9.7
β_y[m]	10.0	10.0	10.2	9.8

The particle amplitude a for a particle at one σ of the beam emittance is given by

$$a_{x/y} = \sqrt{\frac{\beta_{x/y}}{6}\frac{\epsilon_N}{(\beta\gamma)}} \qquad (1)$$

where $\beta_{x/y}$ denotes the lattice β-function, ϵ_N the 95% normalized emittance and $(\beta\gamma)$ the relativistic functions of the beam. With the β-functions in Tab. 1, a minor half axis of 19 mm, a 95% normalized emittance of 20 μm for gold beam at injection, and a relativistic γ of 12 at injection, only 11.5 σ of the beam can be accommodated vertically, given a perfectly aligned beam pipe. 19.3 σ fit into the beam pipe horizontally.

The alignment requirements for the AC quadrupole are more relaxed than for other magnets in RHIC. The transverse position of the the quadrupole has been aligned such that the center of the beam pipe is aligned to the beam axis and the minor half axis vertically.

3 Magnetic Measurements

The AC quadrupole has been measured at 15A DC. The transfer function and harmonics were measured with a 1 meter long mole from the SSC program. Due to the small beam pipe the measuring coil radius is only 12 mm, and the calibration is not as precise as for the other RHIC coils.

The measuring coil, when centered in the magnet, does not cover the ends completely. As a result, two types of measurements were made. One with the measuring coil centered, and another with only one half of the magnet measured at a time and then adding the two measurements to get the integral over a total length of 2 meters. The integral transfer function measured with the coil centered (integration over only one meter length) is 3.446 T/kA. The integral transfer function obtained by adding measurements in two halves (integral over 2 m) is 3.638 T/kA. The error in locating the mole in the two positions is less than 5 mm and causes a less than 1% error in the integral transfer function. The calibration error can be up to 2%.

The harmonics at 1.0 cm radius up to a_5 and b_5, with b_2 denoting a normal sextupole, are given in Tab. 2. The higher harmonics go to zero rapidly since the reference radius is small compared to the magnetic coil aperture.

Table 2: Coefficients of magnetic field harmonics at 1.0 cm reference radius.

order n	normal harmonic b_n	skew harmonic a_n
2	36.7	−9.5
3	−13.6	5.5
4	−2.0	0.8
5	7.4	0.1

4 The Power Supply

The magnet is seen by the power supply as 125 μH in series with 0.05 Ω. The power supply is designed to deliver $\pm$50 A to this load at frequencies of up to 2 kHz [2].

The power supply has a three phase bridge raw supply powered from 480 V AC which delivers ±75 V at 70 A RMS. The output of the raw supply is fed into two amplifiers, A1 and A2. A1 supplies current in only the positive direction and A2 supplies current only in the negative direction. A switching amplifier A3 triggers the use of either A1 or A2 thus delivering the AC output. Both amplifiers, A1 and A2, have 16 hexfets in parallel on a water cooled heat sink [2].

5 Optical Effects

The AC quadrupole starts at 36 cm from IP4 towards IP6. Its site wide name is g4-qacx. The quadrupole is common to both rings. The β-functions at the quadrupole's location are given in Tab. 1.

The tune change is given by

$$\Delta Q = \frac{1}{4\pi}\int_l \frac{\beta(s)B'(s)}{(B\rho)}ds. \tag{2}$$

With the β-functions in Tab. 1, $\int_l B'(s)ds = 3.638$ T/kA, I=50 A, $(B\rho)_{inj} = 97.5$ Tm and $(B\rho)_{sto} = 839.5$ Tm [3], we get

$$\begin{aligned}\Delta Q_{x/y} &= 1.48\times 10^{-3} \quad \text{at injection,}\\ \Delta Q_{x/y} &= 1.73\times 10^{-4} \quad \text{at storage.}\end{aligned}$$

These are the maximum achievable numbers at 2 kHz modulation frequency. The AC quadrupole thus allows to study tune modulational effects that have been previously investigated in simulations [4].

6 Acknowledgments

We are thankful to M. Harrison for information on the AC quadrupole which he designed and built for the Tevatron, to D. Hsueh and his group for preparing the magnet for installation, and to F. Karl and his group for the surveying and alignment.

References

[1] M. Harrison, private communication (1999).

[2] J. Biggs and J. Dinkel, "Bucker quad power supply", private note, 16 May 1991.

[3] RHIC Design Manual, revised April 1998.

[4] W. Fischer and T. Satogata, "A simulation study on tune modulation effects in RHIC", RHIC/AP/109 (1996).