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Power Supply Accuracy Requirements Due to Fluctuations in the Tune

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RHIC PROJECT

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1. Introduction

It is assumed that the goal in setting the power supply accuracy is to keep the variation in the tune to within

$$\Delta\nu \leq 1 \times 10^{-3}$$

This note will consider only the major sources of $\Delta\nu$, of which there are three:

1. I_Q, the current in all the quadrupoles except Q1, Q2, Q3. Errors in I_Q will generate a $\Delta\nu$ according to

$$\Delta\nu_Q = C_Q \left(\frac{\Delta I}{I}\right)_Q$$

2. I_{Q123}, the current in Q1, Q2, Q3

$$\Delta\nu_{Q123} = C_{Q123} \left(\frac{\Delta I}{I}\right)_{Q123}$$

3. I_B, the current in all the dipoles except BC1 which is separately powered

$$\Delta\nu_B = C_B \left(\frac{\Delta I}{I}\right)_B$$

$(\Delta I/I)_B$ causes an orbit displacement, and this displacement at the sextupoles causes a $\Delta\nu$.

It may be shown analytically that C_Q is equal to the chromaticity due to these quadrupoles, C_{Q123} is the equal to the chromaticity due to Q1, Q2, Q3 and C_B is equal to the chromaticity of the sextupoles if the contribution of BC1 to the chromaticity is small, which it is.

Thus if the chromaticity is set to nearly zero, then

$$C_B + C_Q + C_{Q123} \simeq 0 \ .$$

For a First Pass, the $\Delta\nu$ due to all other bypasses and trim and the BC1 power supplies will be neglected. It is assumed that the power supply accuracies can be chosen to make these sources of $\Delta\nu$ relatively small. If this is not always true, one can correct the results on a Second Pass.

It is assumed that in computing the power supply accuracy, the relevant energy swing is 3.33, from $\gamma = 30$ to $\gamma = 100$.

One can compute C_B, C_Q and C_{Q123} and find the results

$$\beta^* = 6 \qquad \begin{aligned} C_Q &= 31 \\ C_{Q123} &= 16 \\ C_B &= -47 \end{aligned}$$

$$\beta^* = 2 \qquad \begin{aligned} C_Q &= 31 \\ C_{Q123} &= 47 \\ C_B &= -78 \end{aligned}$$

These results show that Q1, Q2, Q3 can generate as much $\Delta\nu$ as the arc quadrupoles.

2. Computation of the Power Supply Accuracy

The $\Delta\nu$ due to all 3 sources is given by

$$\Delta\nu = C_B\left(\frac{\Delta I}{I}\right)_B + C_Q\left(\frac{\Delta I}{I}\right)_Q + C_{Q123}\left(\frac{\Delta I}{I}\right)_{Q123} \tag{1}$$

$$C_B + C_Q + C_{Q123} \simeq 0$$

Case 1: Series Connection, one power supply

$$\left(\frac{\Delta I}{I}\right)_B = \left(\frac{\Delta I}{I}\right)_Q = \left(\frac{\Delta I}{I}\right)_{Q123}$$

$$\Delta\nu = (C_B + C_Q + C_{Q123})\left(\frac{\Delta I}{I}\right)_B$$

Because $C_B + C_Q + C_{Q123} \simeq 0$, $\Delta\nu$ does not give a tolerance on $(\Delta I/I)_B$. The tolerance will come from other effects which are not considered here. The accuracy of $(\Delta I/I)_B$ will probably be set at whatever is the best value technically feasible, which is about (G. Cottingham)

$$\left(\frac{\Delta I}{I}\right)_B \lesssim 3 \times 10^{-5}$$

at the lowest current level that is important, which may be at $\gamma = 30$.

Case 2: 3 Power Supplies, $I_{Q123} \neq I_B$

The dipoles are on one power supply which determines I_B. The quadrupoles are on a second power supply that determines I_Q. Q1Q2Q3 have a 2000 Amp bypass that determines I_{Q123}.

The power supply tolerances depend on how these power supplies are set. It is assumed that the I_Q power supply is set by monitoring $I_Q - I_B$, and the I_{Q123} bypass is set by monitoring $I_{Q123} - I_B$.

In the case of the I_{Q123} bypass, one can think of several other current combinations that one might monitor. The above choice tends to make $\Delta\nu_B$ small.

In order to find the current tolerances one has to distribute the allowed $\Delta\nu = 1 \times 10^{-3}$ among the 3 sources. To do this in a reasonable way, one has to rewrite Eq. (1) so that the currents being monitored, $I_Q - I_B$ and $I_{Q123} - I_B$ are obviously displayed. Let us write

$$I_Q = I_B + (I_Q - I_B) \ ,$$

$$I_{Q123} = I_B + (I_{Q123} - I_B) \ .$$

Then

$$\Delta\nu = \left(C_B + C_Q \frac{I_B}{I_Q} + C_{Q123} \frac{I_B}{I_{Q123}} \right) I_B + C_Q \frac{\Delta (I_Q - I_B)}{I_Q} + C_{Q123} \frac{\Delta (I_{Q123} - I_B)}{I_{Q123}}$$

For $\beta^* = 6$

$$\Delta\nu = 11 \left(\frac{\Delta I}{I} \right)_B + 31 \frac{\Delta (I_Q - I_B)}{I_Q} + 16 \frac{\Delta (I_{Q123} - I_B)}{I_{Q123}}$$

We assume the 3 terms are uncorrelated and will add quadratically. We then allow $1/\sqrt{3} \times 10^{-3} = 0.58 \times 10^{-3}$ for each term. This gives the current tolerances at $\gamma = 30$

$$\left(\frac{\Delta I}{I} \right)_B = \frac{0.58 \times 10^{-3}}{11} = 5.3 \times 10^{-5}$$

$$\frac{\Delta (I_Q - I_B)}{I_Q} = \frac{0.58 \times 10^{-3}}{31} = 1.9 \times 10^{-5}$$

$$\frac{\Delta (I_{Q123} - I_B)}{I_Q} = \frac{0.58 \times 10^{-3}}{16} \times \sqrt{6} = 8.9 \times 10^{-5}$$

It has been assumed that the 6 Q1Q2Q3 bypasses are independently powered.

For $\beta^* = 2$

One can compute the $\Delta\nu$ due to each term using the above tolerances. One finds

$$\Delta\nu = 31\left(\frac{\Delta I}{I}\right)_B + 31\frac{\Delta\left(I_Q - I_B\right)}{I_Q} + 47\frac{\Delta\left(I_{Q123} - I_B\right)}{I_Q} \ .$$

Thus at $\gamma = 30$

$$\Delta\nu_B = 1.6 \times 10^{-3}$$

$$\Delta\nu_Q = 0.58 \times 10^{-3}$$

$$\Delta\nu_{Q123} = 1.74 \times 10^{-3}$$

These $\Delta\nu$ are too large, but one can introduce $\beta^* = 2$ at higher energies where these $\Delta\nu$ become smaller. The above $\Delta\nu$ are for 6 $\beta^* = 2$ insertions.

The above analysis can be applied to a new design of Q1Q2Q3 where $I_{Q123} \simeq 5600$. The main change is that $\Delta\nu_B$ becomes smaller. The tolerances on $\Delta\left(I_Q - I_B\right)/I_Q$ and $\Delta\left(I_{Q123} - I_B\right)/I_{Q123}$ are unchanged.

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