Comments on the $a_1$, $b_1$ Correction System

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1. $a_1$ Correction System

$\nu$-Shift Effect

Coupling introduces normal modes $\nu_1, \nu_2$.

Before Correction

$|\nu_1 - \nu_2|_{max} = 228 \times 10^{-3} \quad \beta^* = 2$

$|\nu_1 - \nu_2|_{max} = 80 \times 10^{-3} \quad \beta^* = 6$

(G. Parzen, AD/RHIC-AP-81, 1989.)

Global Correction System

$a_1$ correctors in insertions at Q2 and Q5. Two families for each $\beta^*$. Q2 and Q5 for $\beta^* = 6$. Q2 for $\beta^* = 2$.

After Correction (Residual $\Delta \nu$)

$\Delta \nu_{11}$ Stopband = 0 (Correct to make stopband = 0)

$|\nu_1 - \nu_2|_{max} = 15 \times 10^{-3} \quad \beta^* = 6$

$|\nu_1 - \nu_2|_{max} = 20 \times 10^{-3} \quad \beta^* = 2$

Empirical Correction (Correct to minimize $|\nu_1 - \nu_2|$)

$|\nu_1 - \nu_2| = 7 \times 10^{-3} \quad \beta^* = 6$

$|\nu_1 - \nu_2| = 12 \times 10^{-3} \quad \beta^* = 2$

Some additional $a_1$ correctors needed to reduce $|\nu_1 - \nu_2|$.

Note the advantage of setting correctors empirically, rather than setting them to cancel the $\nu_x = \nu_y$ stopband.
Betatron Distortion due to Random $a_1$

Indicated by large $\beta_1, \beta_2 - \Delta \beta / \beta \approx 60\%$ found.

Betatron distortion measured by coupling distribution factor, CDF

$$CDF = \frac{X_{max}(s)}{X_{max}(s)_{a_1=0}} \text{ for given } x_0, x'_0, y_0, y'_0$$

Usual assumption, $CDF \simeq 1.4$ for $\epsilon_{x,0} = \epsilon_{y,0}$. Computer study gives

$$(CDF)_{max} \simeq 2$$

Consequences of Large CDF – Aperture Loss

a) **Linear Aperture Loss**

Calculations of aperture required, e.g. the extraction magnet, can be off by 40%.

b) **Dynamic Aperture Loss** ($A_{SL}$ loss)

At some QF, $A_{SL}$ can be reduced by 40%. Average loss $A_{SL}$ about 15%. (G. Parzen, AD/RHIC-AP-80, 1989.)

Residual $|\nu_1 - \nu_2|$ and CDF Correction

**Proposal:** Separately excited $a_1$ near each high $\beta$ quad in the insertions. Twelve separately excited $a_1$ near Q2.

This was also suggested by Correction System Review Committee.

This may correct both residual $|\nu_1 - \nu_2|$ and the CDF.

$a_1$ correctors near QD in arc may also be helpful but may not be necessary.

The above 3 effects, (1) the residual $|\nu_1 - \nu_2|$, (2) the high CDF and (3) the loss in $A_{SL}$, deserve careful consideration before giving up the $a_1$ correctors in the arcs.

The $a_1$ at Q2 are excited in two families to generate the cos and sin of the $\nu_x + \nu_y$ harmonic. This gives a total of 4 knobs in the $a_1$ correction system to control $|\nu_1 - \nu_2|$ and the CDF.

Note that again the Q2 correctors are set empirically to reduce the CDF and the residual $|\nu_1 - \nu_2|$. They are not set to cancel out a $|\nu_x + \nu_y|$ stopband.

Are two knobs sufficient to control the CDF and the residual $|\nu_1 - \nu_2|$? Some judgment is needed as to what level of correction is sufficient.
2. The \( b_1 \) Correction System

\( \Delta \beta/\beta \) Effects of Random \( b_1 \)

\[
\beta^* = 6 \quad (\Delta \beta/\beta)_{max} = 0.36
\]

\[
\beta^* = 2 \quad (\Delta \beta/\beta)_{max} = 0.90
\]

\( (\Delta \beta/\beta)_{max} = 0.20 \) comes from the arcs. Largest effect from Q1, Q2, Q3, \( \beta^* = 2 \). (G. Parzen, AD/RHIC–AP–71, 1988.)

Above is a large effect and needs correction. Most of this effect can be corrected using \( b_1 \) corrections in the insertion quads.

Proposal: Use the \( b_1 \) corrections in the insertion quads to also correct the 20% effect due the arc magnets, as well as the large effect due to Q1, Q2, Q3.

Note that the \( a_1 \) effects and \( b_1 \) effects are similar and of the same order. The \( b_1 \) effects only appear smaller because of the availability of correction coils that are already there for other reasons. Both \( a_1 \) and \( b_1 \) produce a \( \nu \)-shift, a betatron distortion, and a loss in dynamic aperture.

Using the \( b_1 \) coils in the insertions makes the \( b_1 \) correction system and the \( a_1 \) correction look similar.

Proposal: Use 4 knobs in the Q2, Q3 magnets to control the effects of the \( 2\nu_x \) and \( 2\nu_y \) resonances on \( \Delta \beta_x/\beta_x \) and \( \Delta \beta_y/\beta_y \). This will produce a certain level of correction which may be sufficient. More knobs could be added, but would be difficult to use.

Why Correct \( b_1 \)?

\( b_1 \) effects may be larger than expected because of

a) difficulty in correcting Q1, Q2, Q3
b) closed orbit errors in sextupoles
c) other various sources
d) operating near the integer \( \nu \)-value.

3. Dispersion Correction

\[
\frac{\Delta X_p}{X_p} = 0.25 \text{ at QF}
\]

\[
\frac{\Delta Y_{p,max}}{Y_p} = 0.31 \text{ at QD}
\]

Mostly from arc magnets. (G. Parzen, AD/RHIC–AP–71, 1988.)
Reasons for Correcting $X_p, Y_p$

1) Effect on beam–beam interaction
2) To be able to operate near integer, $\nu \simeq 29$, where effect maybe about 3 times larger.

Proposal:

1) Use $a_1$ correctors at QD in arcs to correct $Y_p$. Possible $a_1$ corrector near Q9 as a back-up correction.

2) Use $b_1$ correctors at QF in arcs and $b_1$ in insertion quads to correct $X_p$.

The only new correctors required by the proposals in this note are the $a_1$ correctors at each Q2 in the insertions.