BNL-105179-2014-TECH

Booster Technical Note No. 135;BNL-105179-2014-IR

QUADRUPOLE CORRECTORS FOR THE HALF-INTEGER STOPBANDS IN THE BOOSTER

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January 1989

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U.S. Department of Energy

USDOE Office of Science (SC)

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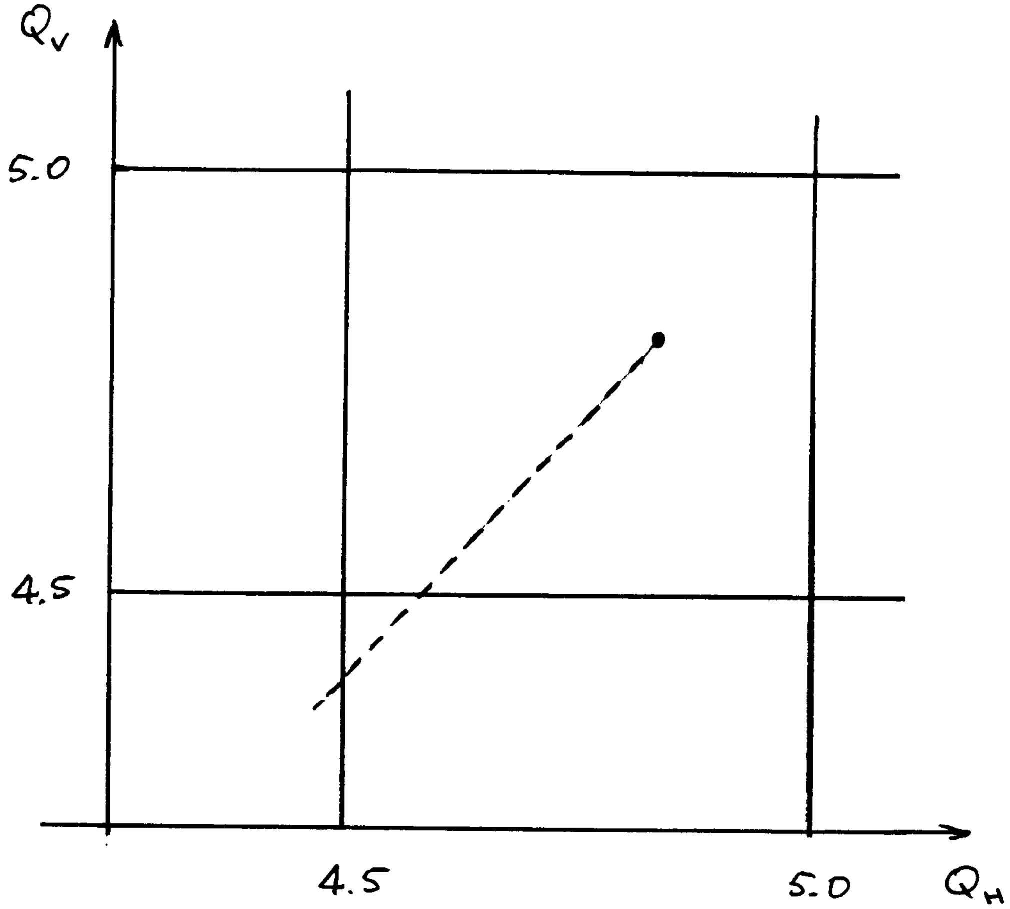

Half-Integer Stopbands

$$\begin{cases} 2Q_H = 9 \\ 2Q_H = 10 \end{cases} \quad \text{and} \quad \begin{cases} 2Q_V = 9 \\ 2Q_V = 10 \end{cases}$$

Driving Terms $(K = B'/B\rho)$

$$J = \frac{1}{2\pi} \oint \beta(s)\, K(s)\, e^{ip\phi(s)}\, ds$$

H and V $\qquad p = 9$ and 10

Expectation Values of the Stopbands

* Booster TN # 112 (Feb. 1988)

Assume $(\Delta k/k)_{rms} = 10^{-3}$ then the rms values of the stopband width are

$$\delta\nu_H = 0.0035 \qquad \delta\nu_V = 0.0038$$

* Similar contribution is expected from the product

sextupoles × uncorrected closed orbit

Booster TN # 107

* Once the closed orbit is corrected, the corresponding contribution is about 10 times smaller.

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* It is not possible to know in advance the errors and the stopbands they cause.

The correction scheme should be capable to generate a set of driving terms with selected amplitudes and phases

There are 8 conditions:

$$\sum_s \beta_{H_s} K_s \cos 9\phi_{H_s} = \frac{2\pi}{L} |J_{H9}| \cos \psi_{H9}$$

$$\sum_s \beta_{H_s} K_s \sin 9\phi_{H_s} = \frac{2\pi}{L} |J_{H9}| \sin \psi_{H9}$$

$$\sum_s \beta_{H_s} K_s \cos 10\phi_{H_s} = \frac{2\pi}{L} |J_{H10}| \cos \psi_{H10}$$

$$\sum_s \beta_{H_s} K_s \sin 10\phi_{H_s} = \frac{2\pi}{L} |J_{H10}| \sin \psi_{H10}$$

$$\sum_s \beta_{V_s} K_s \cos 9\phi_{V_s} = -\frac{2\pi}{L} |J_{V9}| \cos \psi_{V9}$$

$$\sum_s \beta_{V_s} K_s \sin 9\phi_{V_s} = -\frac{2\pi}{L} |J_{V9}| \sin \psi_{V9}$$

$$\sum_s \beta_{V_s} K_s \cos 10\phi_{V_s} = -\frac{2\pi}{L} |J_{V10}| \cos \psi_{V10}$$

$$\sum_s \beta_{V_s} K_s \sin 10\phi_{V_s} = -\frac{2\pi}{L} |J_{V10}| \sin \psi_{V10}$$

Moreover, we require that the betatron tunes do not change, that is

$$\sum_s \beta_{H_s} K_s = 0$$

$$\sum_s \beta_{V_s} K_s = 0$$

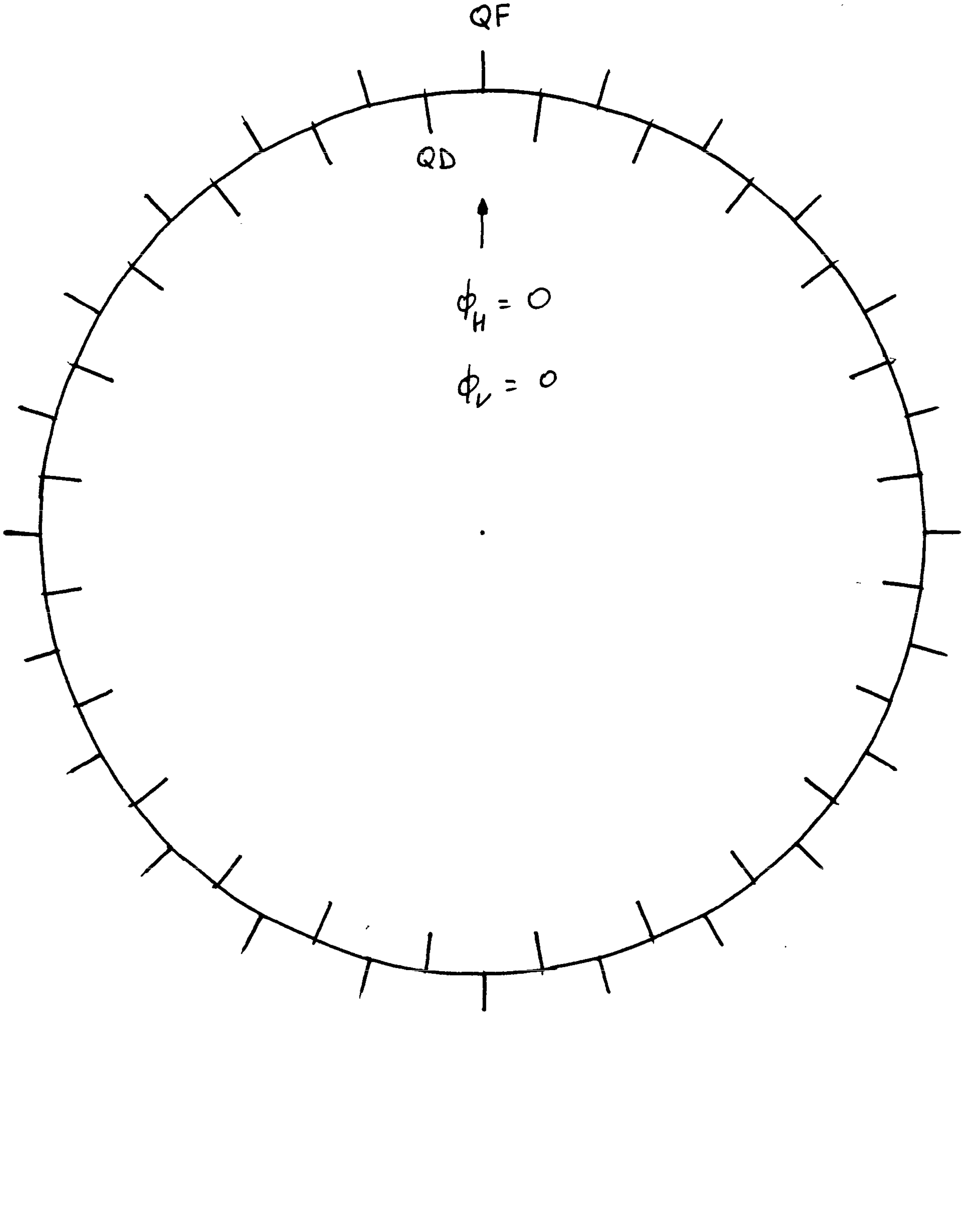
QF, focussing horizontally $\beta_H = 13.5\,m$ $\beta_V = 3.5\,m$
QD, focussing vertically $\beta_H = 3.5\,m$ $\beta_V = 13.5\,m$

Define the origin of ϕ_H and ϕ_V at the location of any QF.

Because of the symmetry build-up in the lattice

$$\phi_{Hs} = \phi_{Vs} = \frac{2\pi}{48}(s-1)$$

$s = 1, 2, \ldots, 48$


QF
QD
$\phi_H = 0$
$\phi_V = 0$

Corrector $\kappa_{j\ell}$

$$\vec{K}_\ell = L\left(\kappa_{1\ell},\ \kappa_{2\ell},\ \kappa_{3\ell},\ \kappa_{4\ell},\ \dots,\ \kappa_{8\ell}\right)$$

QF_1 QD_1 QF_2 QD_2 .... QD_4

$\ell = 1, 2, \dots 6$

$$\vec{K}_\ell = \vec{K}_1 \cos \frac{\pi}{5}(\ell - 1)$$

This will make $\Delta Q_H = \Delta Q_V = 0$

Thus we are concerned only with the calculation of the components of the vector $\vec{K}_1$

$$M \vec{K}_1 = \vec{J}$$

$$\vec{K}_1 = M^{-1} \vec{J}$$

$$M^{-1}$$

$$\begin{bmatrix} -0.3533 & -0.0000 & 0.4217 & -0.0175 & 0.0916 & 0.0000 & -0.1093 & 0.0045 \\ 0.0351 & 0.0846 & -0.0327 & -0.1044 & -0.1352 & -0.3264 & 0.1260 & 0.4028 \\ -0.8619 & -0.2499 & 0.9703 & 0.1710 & 0.2234 & 0.0648 & -0.2515 & -0.0443 \\ 0.0257 & 0.2312 & -0.0223 & -0.2544 & -0.0990 & -0.8919 & 0.0860 & 0.9814 \\ -0.7861 & -0.4328 & 0.9505 & 0.2593 & 0.2038 & 0.1122 & -0.2464 & -0.0672 \\ -0.0257 & 0.2312 & 0.0012 & -0.2554 & 0.0990 & -0.8919 & -0.0044 & 0.9852 \\ -0.2499 & -0.2499 & 0.3739 & 0.1957 & 0.0648 & 0.0648 & -0.0969 & -0.0507 \\ -0.0351 & 0.0846 & 0.0239 & -0.1068 & 0.1352 & -0.3264 & -0.0923 & 0.4118 \end{bmatrix}$$

$$\vec{J} = \begin{bmatrix} J_{H9} \cos \psi_{H9} \\ J_{H9} \sin \psi_{H9} \\ J_{H10} \cos \psi_{H10} \\ J_{H10} \sin \psi_{H10} \\ -J_{V9} \cos \psi_{V9} \\ -J_{V9} \sin \psi_{V9} \\ -J_{V10} \cos \psi_{V10} \\ -J_{V10} \sin \psi_{V10} \end{bmatrix}$$

$|J| = 0.01$

$2Q_H = 9$

ψ: 0°	30°	60°	90°	120°	150°
-0.02220	-0.01923	-0.01110	-0.00000	0.01110	0.01923
0.00220	0.00457	0.00571	0.00532	0.00350	0.00075
-0.05415	-0.05475	-0.04067	-0.01570	0.01348	0.03905
0.00161	0.00866	0.01339	0.01453	0.01178	0.00587
-0.04939	-0.05637	-0.04824	-0.02719	0.00115	0.02918
-0.00161	0.00587	0.01178	0.01453	0.01339	0.00866
-0.01570	-0.02144	-0.02144	-0.01570	-0.00575	0.00575
-0.00220	0.00075	0.00350	0.00532	0.00571	0.00457

$2Q_H = 10$

0°	30°	60°	90°	120°	150°
0.02649	0.02240	0.01230	-0.00110	-0.01420	-0.02349
-0.00205	-0.00506	-0.00671	-0.00656	-0.00466	-0.00150
0.06096	0.05817	0.03979	0.01074	-0.02118	-0.04742
-0.00140	-0.00921	-0.01455	-0.01599	-0.01315	-0.00678
0.05972	0.05986	0.04397	0.01629	-0.01575	-0.04357
0.00007	-0.00796	-0.01386	-0.01605	-0.01393	-0.00809
0.02349	0.02649	0.02240	0.01230	-0.00110	-0.01420
0.00150	-0.00205	-0.00506	-0.00671	-0.00656	-0.00466

$2Q_V = 9$

0°	30°	60°	90°	120°	150°
0.00576	0.00498	0.00288	0.00000	-0.00288	-0.00498
-0.00850	-0.01761	-0.02201	-0.02051	-0.01352	-0.00290
0.01404	0.01419	0.01054	0.00407	-0.00349	-0.01012
-0.00622	-0.03341	-0.05164	-0.05604	-0.04542	-0.02263
0.01281	0.01461	0.01251	0.00705	-0.00030	-0.00756
0.00622	-0.02263	-0.04542	-0.05604	-0.05164	-0.03341
0.00407	0.00556	0.00556	0.00407	0.00149	-0.00149
0.00850	-0.00290	-0.01352	-0.02051	-0.02201	-0.01761

$2Q_V = 10$

0°	30°	60°	90°	120°	150°
-0.00687	-0.00581	-0.00319	0.00028	0.00368	0.00609
0.00792	0.01951	0.02588	0.02531	0.01796	0.00580
-0.01581	-0.01508	-0.01031	-0.00279	0.00549	0.01230
0.00540	0.03551	0.05611	0.06167	0.05070	0.02616
-0.01548	-0.01552	-0.01140	-0.00422	0.00408	0.01130
-0.00028	0.03071	0.05347	0.06190	0.05375	0.03119
-0.00609	-0.00687	-0.00581	-0.00319	0.00028	0.00368
-0.00580	0.00792	0.01951	0.02588	0.02531	0.01796

At Injection

$$B\rho = 2.15 \ T\cdot m$$

$$\frac{B'L}{B\rho} < 0.1 \ m^{-1} \qquad L = 0.5 \ m$$

$$B' < 43 \ G/cm$$

Pole Tip Radius = 8.255 cm

(a) Pole Tip Field < 355 Gauss

(b) Maximum Pole Tip Field = 8.3 KG

$$(a)/(b) < \frac{0.355}{8.3} = 4.3\,\%$$

*) Eliminate the zero-tune-shift conditions

still require <u>8</u> conditions for a total of <u>4</u> stopbands

$$\vec{K}_\ell = \vec{K}_1 \cos \frac{\pi}{2}(\ell-1)$$

$\ell = 1, 2, \dots 6$

$$\frac{K}{K_{max}} \sim 1.8\%$$

Small tune-shift ~ 0.02

(*) Only <u>Four</u> conditions for

- $2 Q_H = 9$
  $2 Q_V = 9$ stopbands

$$\vec{K}_\ell = \vec{K}_1 \cos \pi(\ell - 1) \qquad \ell = 1, 2, \ldots 6$$

$$\frac{K}{K_{max}} \sim 0.3 \%$$

No tune-shift

(*) Only Four conditions for

$$2\,Q_H = 10$$
$$2\,Q_V = 10$$

stop bands

$$\vec{K}_\ell = \vec{K}_1 \cos\frac{\pi}{3}(\ell-1) \qquad \ell = 1, 2, \dots 6$$

$$\frac{K}{K_{max}} \sim 0.45\ \%$$

No tune-drift