Status of non-linear dynamics correction studies

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Beam dynamics properties before optimization
Original lattice

Off-momentum particle survived only to 0.1%

Amplitude dependent tune:
- $\varepsilon_{x,N} = 0.35E-6$, $\varepsilon_{y,N} = 0.07E-6$
- $\beta_{x,ip} = 0.1$ m, $\beta_{y,ip} = 0.02$ m
- $\sigma_{x,ip} = 23$ $\mu$m, $\sigma_{y,ip} = 4.6$ $\mu$m

Tune footprint:
- $Q_x = 25.7905$
- $Q_y = 26.2727$

Chromatic tune:
- Poor chromatic property
Beam dynamics properties before optimization
Modified lattice with -I CCB and 60° arcs

Off momentum particle survived up to 0.3 %

Q_x = 28.4105, Q_y = 27.8552

Amplitude dependent tune

Chromatic tune

Large chromatic tune shift
Beam dynamics properties before optimization
Modified lattice with -I CCB and 90° arcs

Amplitude tune

Off momentum particle survived up to 0.4%

Tune footprint

Amplitude dependent tune

Qx = 30.623, Qy = 28.739

Chromatic tune

Large chromatic tune shift
Phase trombone of original lattice

Add $x$ & $y$ phase trombone at both sides of IP to make the IP sextupoles have $-I$ phase to final doublet.

$Q_x = 25.7905, \quad Q_y = 26.2727$

$\xi_x/\xi_y = 0/0, \quad W_{x,IP}/W_{y,IP} = 0/0$

$\beta^*_x = 10 \text{ cm}$

$\beta^*_y = 2 \text{ cm}$

$X_{S-Q \, U} = 2.0141$

$Y_{S-Q \, U} = 3.2843$

$X_{S-Q \, d} = 6.1026$

$Y_{S-Q \, d} = 5.4109$

$K_{SF} = 25.065$

$K_{SD} = -26.888$

$K_{SFIPU} = 5.591$

$K_{SDIPU} = 6.282$

$K_{SFIPD} = 4.983$

$K_{SDIPD} = -5.202$
Original lattice + phase trombone makes $n\pi$ phase advance

Phase Trombone

$\Delta \mu_{X,U} = -0.0141$
$\Delta \mu_{y,U} = 0.2157$
$\Delta \mu_{x,d} = 0.3974$
$\Delta \mu_{y,d} = 0.0891$

$Q_x = 26.557,$
$Q_y = 26.882$

Second order dispersion

$D_x,$ $D_y$

Chromatic tune

$Q_x,$ $Q_y$

Improves chromatic property

W function

$KSF = 5.418$
$KSD = -13.029$
$KSFIPU = 1.194$
$KSDIPU = -1.219$
$KSFIPD = 2.579$
$KSDIPD = -4.746$
Original lattice + phase trombone $n\pi$

MAD8 Lie4 dynamic aperture tracking

Dynamic aperture

- $\Delta p/p = 0.0$
- $\Delta p/p = 0.2\%$
- $\Delta p/p = 0.2\%$
- $\Delta p/p = 0.3\%$
- $\Delta p/p = 0.4\%$
Original lattice + fine tune phase trombone

Phase Trombone
\[ \Delta \mu_{X,U} = -0.0141 - 0.008 \]
\[ \Delta \mu_{Y,U} = 0.2157 - 0.008 \]
\[ \Delta \mu_{X,d} = 0.3974 - 0.008 \]
\[ \Delta \mu_{Y,d} = 0.0891 - 0.008 \]
\[ Q_x = 26.509, \]
\[ Q_y = 26.850 \]

Second order dispersion

Chromatic tune

Improving chromatic property

W function

KSF = 13.497
KSD = -18.878
KSFIPU = 0.501
KSDIPU = -0.747
KSFIPD = 1.904
KSDIPD = -4.895
Phase trombone of Modified lattice with -I CCB and 60° arcs

Add x & y phase trombone at both sides of IP to fine adjust phase of the IP sextupoles and the final doublet.

\[
\begin{aligned}
\beta^*_x &= 10 \text{ cm} \\
\beta^*_y &= 2 \text{ cm} \\
\Delta\mu_{x,y} &= n\pi \\
D_x &= 3.5 \\
D_y &= 2.5 \\
D_{x,S-Q} &= 7.5 \\
D_{y,S-Q} &= 5.0 \\
Q_x &= 28.4105 \\
Q_y &= 27.8552 \\
K_{SF} &= 15.007 \\
K_{SD} &= -19.187 \\
K_{SFIPU} &= 3.166 \\
K_{SDIPU} &= -5.527 \\
K_{SFIPD} &= 8.297 \\
K_{SDIPD} &= -10.747 \\
\xi_x / \xi_y &= 0/0 \\
W_{x,IP} / W_{y,IP} &= 0/0
\end{aligned}
\]
Beam dynamics properties of modified lattice with -I CCB and 60° arcs

Phase Trombone
\[
\Delta \mu_{X,U} := -0.001 \\
\Delta \mu_{Y,U} := -0.011 \\
\Delta \mu_{X,d} := 0.004 \\
\Delta \mu_{Y,d} := -0.01
\]

Qx = 28.417, Qy = 27.813

Second order dispersion

KSF = 19.926, KSD = -25.841, KSFIPU = 2.534, KSDIPU = -4.590, KSFIPD = 7.763, KSDIPD = -10.841

Chromatic tune

The off momentum range is extended but tune diverges more
Phase trombone of Modified lattice with -I CCB and 90° arcs

\[ \beta^*_x = 10 \text{ cm} \]
\[ \beta^*_y = 2 \text{ cm} \]

Add x & y phase trombone at both sides of IP to fine adjust phase of the IP sextupoles and the final doublet.

- SF
- SD

Add x & y phase trombone at both sides of IP.

- \( d\mu_{X,S-Q,U} = 3.5 \)
- \( d\mu_{Y,S-Q,U} = 2.5 \)
- \( d\mu_{X,S-Q,d} = 7.5 \)
- \( d\mu_{Y,S-Q,d} = 5.5 \)

- \( Q_x = 30.623 \)
- \( Q_y = 28.739 \)

- \( KSF = 7.938 \)
- \( KSD = -25.042 \)
- \( KSFIPU = 4.273 \)
- \( KSDIPU = -5.601 \)
- \( KSFIPD = 9.548 \)
- \( KSDIPD = -10.222 \)

- \( \xi_x/\xi_y = 0/0 \)
- \( W_{x,IP}/W_{y,IP} = 0/0 \)
Phase trombones of the original lattice to make $n\pi$ phase advance between final doublets and sextupoles help to reduce the sextupole strengths and improve the chromatic properties of the lattice.

A quick check with MAD8 dynamic aperture tracking agrees with the gain from chromatic tune correction.

The fine tune of the phase trombone around $n\pi$ can help to further optimize the dynamic aperture, it’s still under investigation.