Dynamic Aperture with Machine Errors
- a preliminary study -

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Many thanks to T. Charles, T. Raubenheimer, D. Shatilov, R. Tomas, F. Zimmermann
Lattice

- Base lattice: FCCee_z_301_nosol_9 (Jul. 31, 2019)
  - 4 IP with ~CDR parameters
  - Correction: “seed_1” by T. Charles
  - Tunes: (274.26400, 270.52000)
    - corresponding to the bb footprint 4’:

- I have made confusions for a week:
  - Base lattice: FCCee_z_301_nosol_8 (Jul. 29, 2019), which corresponds to the bb footprint 4: tunes = (274.26400, 270.38000).
  - Ignored some corrections on standard quads (QR*) by T. Charles (due to a lack of MADX to SAD full converter).
  - Thanks to R. Tomas, D. Shatilov.

- The tune footprint of beam-beam depends on the perfectness of the periodicity. If there is a perfect periodicity of the system, only the “1 IP” footprint matters as shown in the CDR.
  - If the periodicity violates due to machine errors such as by β-beat and x-y couplings, the effective footprints become larger for 2 IP and 4 IP, as shown above.
  - The footprint 4’ above is an alternative working point for 4 IP to avoid $v_y = 0.5$ resonance, suggested by D. Shatilov.
  - The strength of each resonance line depends on the errors and corrections of the lattice.
The correction by T. Charles looks excellent!

- Tunes are slightly shifted:
  - $\{274.26126, 270.52384\}$ from $\{274.26400, 270.52000\}$.
- Emittances: $(0.275 \text{ nm}, 23.2 \text{ fm})$.

Remarks:
- The spike of $\Delta \beta_y/\beta_y$ at IP. 4 corresponds to a shift of waist.
- If we look at $B_{MAGy}$, there are several locations with high $B_{MAGy}$ esp. at crab sexts (see next page).
- The residual orbit looks much smaller than the misalignment; probably the BPMs are placed on the ideal plane in this case?
High $B_{MAGy}$ at Crab Sexts

- Some peaks of $B_{MAGy}$ are seen at some crab sextupoles around each IP.
- What is its implication? —— may need paying attention.

3.5 The $B_{MAG}$ coefficient

We can consider the spread of the Courant-Snyder invariant $2J_z$ defined by Eq. (42):

$$
\langle 2J_z \rangle = \beta \langle p_z^2 \rangle + 2 \alpha \langle x p_z \rangle + \frac{1 + \alpha^2}{\beta} \langle x^2 \rangle,
$$

which is an invariant along the beam line. Then its ratio to the emittance $2\epsilon_z$ is an invariant, too. The ratio is called $B_{MAG}$. By substituting Eqn. (42) into above, we obtain

$$
B_{MAG} = \frac{\langle 2J_z \rangle}{2\epsilon_z} = \frac{\frac{1}{\beta} \left[ \frac{\beta (1 + \alpha^2)}{\beta_m^2} - 2 \alpha \alpha_m + \frac{1 + \alpha^2}{\beta_m} \right]}{\frac{1}{\beta} \left[ \frac{\beta_m}{\beta} + \frac{(\beta_m - \beta_m \alpha)^2}{\beta \beta_m} \right]}.
$$

Therefore it is easy to see that

\[ B_{MAG} \geq 1, \]

\[ B_{MAG} = 1 \quad \text{if and only if} \quad \alpha = \alpha_m \text{ and } \beta = \beta_m. \]
If we look closely at the crab sext SY2L1, \( B_{MAGy} \) raises through the sext, then reset to 1 by the quadrupole corrector MULTI$305$:

\[
\text{MULT } \text{MULTIKS305=}(K1 = .0003921671 )
\]

As the crab sexts are supposed to be superconducting with dipole/quadrupole correctors incorporated. Thus such a raise of \( B_{MAG} \) does not appear in the reality.

The optics model should handle such an overlapped element, otherwise such an illusion may appear.
Nonlinear resonance

- There is a nonlinear blowup of vertical amplitude associated with a horizontal motion around the closed orbit with the optics 301_9 after errors and corrections. This was first noticed by D. Shatilov.
- At the tune at 301_8, the blowup is small.
- The amplitude maximized exactly on the resonance line $2\nu_x - \nu_y = \text{int}$. 

![Graph showing nonlinear resonance](image-url)
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Nonlinear resonance

\[ 2\nu_x - \nu_y = \text{int}. \]
Even without errors/corrections, the dynamic aperture at 301_9 (above) is worse transversely compared to 301_8 (left).

This can be effects of either $2\nu_x - \nu_y = \text{int }$, or $2\nu_y = \text{int }$.

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Optimizations for 301_9 have not improved the DA.
The dynamic aperture shrinks with the errors and corrections (“seed 1”) as seen in figures above.

The errors/corrections for 301_9 were simplified applied on 301_8. The resulting vertical emittance raised to 0.2 pm.

The corresponding momentum acceptance: ±1.3% (no error) → ±0.8%? (seed_1).

Further optimization of sexts with errors/corrections may improve the DA.
Tentative summary

- After corrections of my mistakes, the nonlinear blowup with 301_9 well agrees with Dmitry’s.
  - The blowup is caused by the $2\nu_x - \nu_y = \text{int}$.
- The DA without errors is worse at 301_9 than 301_8, probably due to the closeness to the resonance lines $2\nu_x - \nu_y = \text{int}$ and $2\nu_y = \text{int}$.
- Errors and corrections for 301_9 applied at 301_8 shrinks the DA significantly.
- For further study we may use:
  - a lattice for the new layout
  - a design tune far from resonances
  - errors and corrections applied at that tune.
  - correctors overlapping on main magnets (crab & arc sexts) should be implemented in lattice model.
Feedbacks on the lattice for the new layout

- The ee beam line is not precisely fit to the layout PA31-1.0 (M. Giovannozzi, T. Risselada): There was a mistake to calculate the shift of the IP from PA31.10!!!

- Tunes are not good at Z to avoid beam-beam instabilities with long. wake (M. Zobov, Y. Zhang, D. Shatilov). (0.565, 0.600) has been suggested by Dmitry.

- RF voltages are too high at H & t̃ (D. Shatilov)

- Possible fine tuning of RF phases for 400/800 MHz at t̃ (T. Raubenheimer).

- Modified lattice and associated parameters will come out by FCCIS…