BTF observations and simulations for LHC: an update for discussions

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A closer look to the BTF data (1)

Octupole scan at injection (6.5A, $\varepsilon=2.0e-6$, $Q' \sim 4$)

- Data normalized to the analytic amplitude (no calibrated BTF system)
- Sidebands visible at $\pm Qs$ at injection $\rightarrow$
- Height of the sidebands depends on chromaticity value
- How does they appear in the SD?
A closer look to the BTF data (2)

- The loop is visible only to one side (frequency sweep from lower to higher frequencies)
- Why is it placed at $\Delta Q \sim 3e^{-3}$ in measurements?
- Where does this discrepancy come from?
  $\rightarrow$ Normalization factor + collective effects?
SD octupole scan at injection

- The loops (and deformations of it) are always present in measurements
- High octupole current: deformation of the SD and loops —> sidebands included in the transverse spread (see next slide)
Octupole scan at injection: amplitude and phase

- With high octupole current at injection sidebands are included in the transverse spread
Measured SD for pilot bunches

In this case, applying the same normalization the loop is at the position $Q_s$. 
Measured SD at flat top

- The loop (or deformations of it) is present also at flat top energy
- Noisy phase $\rightarrow$ noisy SD
Stability diagram in the presence of resonances

A look at some literature....

Visible loops in correspondence of the excited resonances (in this case by beam-beam)

J. Borer et all. “Information from beam response to longitudinal and transverse excitation”

Case of LEAR in presence of coupling resonance: “Notes on BTF by A. Mosnier”
Observations

• Phase jumps are well visible in the BTF amplitude and phase at ±ΔQs
• The jumps are visible at injection energy and at flat top
• They produces loops in the SD around the position ±ΔQs and the size depend on the chromaticity value
• It is not always easy to recognize them depending on the resolution, chromaticity and tune spread
• Loops are clearly visible only to one side of the SD due to the direction of the frequency sweep (see next slides)
• The position of the loops in the stability diagram is very sensitive to the applied normalization

Can we reproduce the loops by mean of simulations and characterize them?

With COMBI we can study the 6-D motion for different octupole spread and chromaticity

Now we have also access to the phase of the simulate BTF by COMBI and extrapolate the stability diagram
Stability diagram in COMBI

COMBI Simulation, Q’=4, injection energy (octupole current 11.5 A )

Normalization applied as value from PySSD
The normalization of COMBI simulations is still under discussion
Loops appear at +- Qs
Stability diagram in COMBI

Normalization applied as value from PySSD

The normalization of COMBI simulations is still under discussion

Loops appear at \(\pm Q_s\)
Stability diagram in COMBI inverse frequency sweep

COMBI Simulation, Q’=4, injection energy (octupole current 11.5 A)

With the inverse frequency step, the loop better appears on the right side of the SD —> Modify GUI for this feature
Normalization of COMBI SD: open question

From Chao Book and Werner H. on Landau damping, the averaged beam response:

\[ g(u) = \pi \Delta \omega \rho(\omega_x - u \Delta \omega) = \pi \Delta \omega \rho(\Omega) \quad f(u) = \Delta \omega \text{P.V.} \int d\omega \frac{\rho(\omega)}{\omega - \Omega} \]

- excitation amplitude
- size of SD (frequency spread)
- shape of the SD

**COMBI**

- \( A_{ex} = arg \cdot \sigma' \)
- \( \sigma' = \sqrt{\frac{\epsilon}{\gamma \beta^*}} \)
- \( \sigma = \sqrt{\frac{\epsilon \beta^*}{\gamma}} \)

**Theory**

\[ \ddot{x} + \omega^2 x = A \cos \Omega t = f(t) \]

\[ A = \frac{m}{s^2} \quad \omega_x = Q_x \cdot f_{rev} \quad \text{?} \]

\[ A_{norm} = A_{ex} \cdot f_{rev} / \sqrt{\beta^*} \quad \text{?} \]
Normalization of COMBI SD: open question

There is a certain dependency on octupole current

\[ A_{ex} = \arg \cdot \sigma' \]
\[ \sigma' = \sqrt{\frac{\epsilon}{\gamma \beta^*}} \]
\[ \sigma = \sqrt{\frac{\epsilon \beta^*}{\gamma}} \]

\[ A_{norm} = A_{ex} \cdot f_{rev} / \sqrt{\beta^*} \]
Qs scan injection

- The loops are moving with the Qs value as expected (normalized to PySSD)
Increasing the chromaticity the loops appear enlarged (still around $\pm Qs$). Would it be possible to calculate the size of the loops from the chromaticity value?
Bunch length scan at injection

- Not a crucial dependency on the bunch length: the shape/size of the loops slightly changes
Octupole scan at flat top

COMBI Simulation, $Q' = 6$

- Sidebands depend not only on the chromaticity value but also on the value of the octupole current
- Loops increases while reducing the octupoles current
Stability diagrams from SixTrack distribution: injection 6.5A

SixTrack simulation have been launched to study the effect of high octupole current on the distribution and calculate the SD with PySSD.

SixTrack distribution at the first turn (injection, 6.5A octupole current)

Smoothing after weighting with a gaussian-like distribution
Stability diagrams from SixTrack distribution: injection 6.5A

SixTrack distribution after 1e6 turn (injection, 6.5A octupole current)

No substantial changes w.r.t. the 1st turn
Stability diagrams from SixTrack distribution: injection 13A

SixTrack distribution after 1e6 turn (injection, 13A octupole current)

SixTrack distribution after 1st turn (injection, 13A octupole current)
Stability diagrams from SixTrack distribution: injection 13A

SixTrack distribution after 1e6 turn (injection, 13A octupole current)

SixTrack distribution after 1st turn (injection, 13A octupole current)
Stability diagrams from SixTrack distribution: injection 13A

SixTrack distribution after 1e6 turn (injection, 13A octupole current)

SixTrack distribution after 1st turn (injection, 13A octupole current)
Stability diagrams from SixTrack distribution: injection 13A

SixTrack distribution after 1e6 turn (injection, 13A octupole current)

How can we find a good compromise between binning and distribution information after the tracking?
Conclusions and discussion

- Loops in the SD around the position $\pm \Delta Qs$ have been observed in BTF data
- It is not always easy to recognize them depending on the resolution, chromaticity and transverse tune spread
- By computing the stability diagram with COMBI the loops are visible also in simulations and it is possible to characterize them as a function of $qs$ and chromaticity, different longitudinal distributions (to be included in the code)
- The position of the loops in the stability diagram is very sensitive to the applied normalization —> still debated: how can we extrapolate from COMBI a value to obtain the same amplitude as in PySSD?
- More interesting: would it possible to calculate the area of the loops?
- How do the loops change with different longitudinal distributions?
- To save time, SUSSIX has been modified in order to be applied for COMBI post processing
- Stability diagram with SixTrack distribution: there is still a factor missing between PySSD and SixTrack integrated distribution
- SixTrack simulations with 1 million particle at injection to study the effect of high octupole current
- How could the binning dependency be solved?