Suppression of emittance growth and beam stability estimates with the ADT and a head-tail feedback

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Introduction

➢ To mitigate the emittance growth driven by amplitude noise in the crab cavities, a feedback based on ‘A synchronous I/Q demod of PU signal at 2x400 MHz’ was proposed*
  - The kicker is the crab cavities themselves

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Existing ADT with 10 turns damping time
Requires a suppression by a factor 4-5 to reach the specification of 2%/h (total)

*P. Baudrenghien, WP2/WP4 meeting 23.03.2021
Introduction

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Existing ADT with 10 turns damping time

Requires a suppression by a factor 4-5 to reach the specification of 2%/h (total)

➢ A similar ‘head-tail feedback’ was proposed by V. Lebedev to improve the beam stability (MCBI workshop, Zermatt, 2019)

- The crab cavities do not feature a bandwidth sufficient to obtain the beneficial impact that V. Lebedev contemplated for single bunch stability

*P. Baudrenghien, WP2/WP4 meeting 23.03.2021
ADT requirements

CC phase noise only

Rel. emit. growth rate [1/h]

Gain
ADT requirements

CC phase noise only

Current baseline (50 turns)
ADT requirements

To reach ~1%/h from the CC phase noise, the ADT needs to be operated with a gain of 10 to 15 turns instead of the current baseline (50 turns).
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CC phase noise only

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‘machine noise’ only

- 1μm
- 0.5μm
- 0.1μm
- 0.3μm
ADT requirements

CC phase noise only

To reach ~1%/h from the CC phase noise, the ADT needs to be operated with a gain of 10 to 15 turns instead of the current baseline (50 turns).

‘machine noise’ only

To bring the contribution of the machine noise below 2%/h, an effective pickup resolution of 0.2 μm is required.
ADT requirements

→ Experimental validation in Run 3: High gain vs tune acceptance with beam-beam (CERN-ACC-NOTE-2019-0008) and performance of the new ADT pickups
Head-tail damper (HTD) model

- Implementation based on an asymmetric I/Q demodulation* with $f_d = 801.6$ MHz
  - Symmetric I/Q demodulation was already implemented and tested in BimBim and COMBI**

\[
I_\Sigma = \int_{\text{slot}} \cos(2\pi f_d \frac{s}{c}) \lambda(s) \, ds
\]

\[
I_\Delta = \int_{\text{slot}} \cos(2\pi f_d \frac{s}{c}) x(s) \lambda(s) \, ds
\]

\[
Q_\Sigma = \int_{\text{slot}} \sin(2\pi f_d \frac{s}{c}) \lambda(t) \, ds
\]

\[
Q_\Delta = \int_{\text{slot}} \sin(2\pi f_d \frac{s}{c}) x(s) \lambda(s) \, ds
\]

\[
\Delta x \propto -G_{HTD} \frac{Q_\Delta I_\Sigma - I_\Delta Q_\Sigma}{I_\Sigma^2 + Q_\Sigma^2}
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*G. Kotzian @ HSC meeting, 22-01-2014
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➢ The gain is calibrated to obtain the corresponding damping rate of mode ±1 at low gain, \( Q' = 0 \) and no impedance

*G. Kotzian @ HSC meeting, 22-01-2014
https://edms.cern.ch/document/1404633/1
Head-tail mode spectrum

$Q' = 0$

$Q' = 22$
Is the HTD efficiency against CC amplitude noise driven emittance growth maintained for non-zero chromaticity?
➢ Is the HTD efficiency against CC amplitude noise driven emittance growth maintained for non-zero chromaticity?

➢ Does the HTD affect the beam stability by measuring multiple modes and feeding their signal to the CCs?
Suppression of the emittance growth driven by CC amplitude noise

- A significant emittance growth suppression can be achieved with a gain in the order of 0.02 / turn
Suppression of the emittance growth driven by CC amplitude noise

➢ A significant emittance growth suppression can be achieved with a gain in the order of 0.02 / turn

➢ The efficiency is maintained for high chromaticities
The HTD alone can generate weak instabilities
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In combination with the machine impedance and the ADT, the HTD with high gain can drive fast instabilities
- At low gain the beneficial impact found by V. Lebedev is recovered (at least qualitatively)
HTD driven instabilities

HTD only, $Q' = 5$
HTD driven instabilities

- The HTD leads to a significant tune shift for mode ±1, leading to coupling
  - No instability associated thanks to the active damping
HTD driven instabilities

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- Modes ±2 are excited by the HTD
HTD driven instabilities

➢ The HTD leads to a significant tune shift for mode ±1, leading to coupling
  - No instability associated thanks to the active damping

➢ Modes ±2 are excited by the HTD
  - The unstable modes also feature a frequency shift
The combination of the HTD the ADT (10 turns) and the impedance leads to a strong instability.
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- The growth rate is ~40 larger than without the HTD
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- The growth rate is ~40 larger than without the HTD
- The associated real tune shift is positive
In collision, the head-on tune spread remains sufficient to stabilise the beam.
Conclusion

➢ To meet the requirements in terms of emittance growth caused by the CC noise
  - The ADT gain has to be increased towards 10 turns
  - The effective ADT pickup resolution should be in the order of 0.2μm
  - A HTD has to be introduced, having a significant impact on collective beam dynamics

➢ The HTD with a gain sufficient to suppress the emittance growth can increase the growth rate of instabilities by a factor 40
  - This seems acceptable in collision, but not on non-colliding beams
  - The impact on witness bunches is not clear, given the low bandwidth of the CCs
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Requires experimental validation during Run 3
The HTD is more efficient without ADT, but the ADT is needed to stabilise the coupled bunch modes (not included here).

In combination with the ADT, the HTD can be beneficial.