Simulated Performance of an FIR-Based Feedback System to Control the Electron Cloud Single-Bunch Transverse Instabilities in the CERN SPS

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Outline

- The problem
- Modeling
- Control System
- Future Works
- Conclusions
The Problem

- Transverse instabilities observed in SPS beams due to electron clouds, see presentation by C. Rivetta et al. (SLAC) and J. L. Vay et al. (LBNL)

- Interaction between e-cloud and beam leads to large transverse oscillations

- Possible solution: **Feedback System** to control beam transverse motion, (see J.L.Vay et al. Proceedings of IPAC 2010, [1]).

- Use of the Particle-In-Cell framework **Warp-Posinst**
Feedback Model

Scheme of the overall system:

Amplifier + Kicker → Beam → Receiver

CONTROL
Processing Channel
WARP quasistatic model similar to HEADTAIL, QuickPIC. (see presentation by J.L.Vay. et al.)

Option of using POSINST to get secondary emission of electrons; Uniform Ecloud density distribution used in our runs.
Comparison with SPS Data - I

Observation of SPS June 2009 measurements:

- Instabilities within bunches due to Electron Cloud. Head and Tail splitting. (see J. Fox et al. Proceedings of IPAC 2010 [2])

- Frequencies within bunch and estimated bandwidth of instability signal.

![Graph showing comparison between Experiment and Warp-Posinst data](image)
Open Loop simulation shows tuneshift, SPS nominal $\beta_y = 0.185$

Open Loop simulation, FFT window of the bunch displacement plot for each turn

Tune Video: Open Loop - 20 stall - window= 100 turns - step = 1 turns - frame at turn : 1

Fractional Tune

TAIL

HEAD

Bunch slices
Goal of the Feedback System: stabilize the bunch due to the e-cloud induced instability ideally for all the operation conditions of the machine.

Key parameters for the Feedback Design:

- Minimum Gain required for stability
- Delay in the Control Action
- Achievable Bandwidth
- Frequency Response of the Pick-up, Power Amplifier and Kicker
- Minimize noise injected by the feedback to the beam
Use of a Digital Filter

Characteristics of Digital Filters:

- **Programmable**, i.e. its operation is determined by a program stored in the processor's memory
- Very much **versatile** in their ability to adapt to changes in the characteristics of the signal
- Fast DSP processors can handle complex combinations of filters in parallel, making the hardware requirements relatively simple and compact
Filter Choice

Filter Requirements:

- Remove static orbit offset
- Remove out of band signals
- Phase shift

A Finite Impulse Response (FIR) filter is non recursive, while an Infinite Impulse Response (IIR) filter is recursive.

$y_0, y_1 \ldots y_n \xrightarrow{\text{FIR}} z_0, z_1 \ldots z_n$

$y_0, y_1 \ldots y_n \xrightarrow{\text{IIR}} z_0, z_1 \ldots z_n$

Time $t$ is equal to $t = nh$, where $n$ is a positive integer and $h$ is the sampling interval.
The FIR Filter has **5 taps** to process bunch slices.

Each measurement $y_i(k)$ is processed following the algorithm:

$$z_i(k) = a_1 y_i(k-1) + a_2 y_i(k-2) + \ldots + a_n y_i(k-N)$$

Where $y$ = vertical displacement, $i$ = slices, $k$ = turns, $N = 5$.

If the Amplifier/kicker/cable are ideal (no bandwidth limitation), the complete feedback system with gain $G$ can be modeled as:

$$C_i(k) = G z_i(k)$$

Where $C_i(k)$ is the kick signal applied at the $i^{th}$ slice at turn $k$.

Using **64 slices** of the bunch. Applying kick with **1 turn delay**
Filter Bode Plot

Transfer function for a 5 TAP FIR Filter

Coefficients

Magnitude [dB]

Fractional Tune

Phase [deg]

Tune = 0.185, Mag = -0.22387 dB, phase = 89.275 deg
All simulations were run at Injection Energy $E = 26$ GeV and with a uniform electron distribution of $D_e = 10^{12}$ electrons, using a single bunch of $1.1 \times 10^{11}$ protons.
Closed Loop results with **No Limit** on the Kick applied on the bunch

**Single Slice vertical displacement in the TAIL**

![Graph showing single slice vertical displacement in the TAIL]

**Single Slice vertical displacement in the HEAD**

![Graph showing single slice vertical displacement in the HEAD]
Limiting the Electric Field in the Kicker reduces the possibility of stabilizing the bunch via feedback system.

Max Electric Field of the Kicker limited at **300 kV/m**

Single Slice vertical displacement in the TAIL

![Graph showing vertical displacement in the TAIL](image)

Vertical position [μm] vs. turns

Tune from turn 1 to turn = 2000

Normalized power [a.u.]

Fractional Tune

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Single Slice vertical displacement in the HEAD

![Graph showing vertical displacement in the HEAD](image)

Vertical position [μm] vs. turns

Tune from turn 1 to turn = 2000

Normalized power [a.u.]

Fractional Tune
Comparison between Open Loop emittance growth and Closed Loop with Kick Limitation at 100 kV/m and 300 kV/m, 500 kV/m and with No Limitation:

What Limit on the kick can we tolerate to keep controlling bunch instabilities considering higher e-cloud densities?
Develop the Feedback System model, making it more realistic:

- Amplifier + Kicker
- Beam
- Receiver
- CONTROL
- FIR Filter
- Noise

Can we still control the single-bunch instability using a reduced number of samples? Pick up sampling rate of 4 Gsamples/sec. Rms Bunch Length: 1 ns.

Introduce noise in the Feedback chain.
Future Plans

- Improve the Feedback Model, adding all the components that are necessary in order to understand the limits and requirements for the Design of the System

- Apply the model to Multibunch simulations

- Analysis of experimental data took at CERN in 2010 and planning of new MDs
Conclusions

- Transverse single-bunch instabilities observed in the SPS at CERN due to e-cloud effect.

- A Feedback Control System is a possible solution

- Use of WARP/POSINST framework to simulate the e-cloud effect in the SPS incorporating it with the model of a Feedback using an FIR filter as a first approach to represent the processing channel

- Future developments will lead to a more realistic system and understanding of limit parameters and requirements of the System