BROAD-BAND TRANSVERSE FEEDBACK AGAINST E-CLOUD OR TMCI: PLAN AND STATUS

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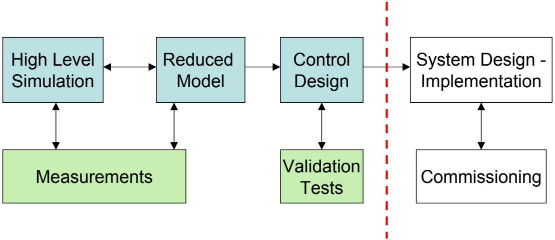
BROAD-BAND TRANSVERSE FEEDBACK SYSTEM - DOE LARP / CERN

- Motivation: Control electron-cloud (ECI) and Transverse Mode Coupled (TMCI) instabilities in SPS and LHC via broad-bandwidth feedback system.
  - Anticipated instabilities at operating currents
  - Complementary to electron-cloud coatings, grooves, etc.
  - Complementary to TMCI mitigation techniques
  - Intrabunch Instability: Requires bandwidth sufficient to sense the vertical position and apply correction fields to multiple sections of a nanosecond-scale bunch.
- US LHC Accelerator Research Program (LARP) has supported a collaboration between US labs (SLAC, LBNL) and CERN
  - Large R & D effort coordinated on:
    - Non-linear Macro-particle simulation codes (LBNL - CERN - SLAC)
    - Dynamics models/feedback models (SLAC - Stanford STAR lab)
    - Machine measurements- SPS MD (CERN - SLAC)
    - Hardware technology development (SLAC)

R & D Areas - Plan

R & D lines

- Goal is to have a minimum prototype to fully understand the limitations of feedback techniques to mitigate ECI & TMCI in SPS.



- R & D areas
  - Study and Development of Hardware Prototypes
  - Non-Linear Simulation Codes - Real Feedback Models - Multibunch behavior
  - Development and Identification of Mathematical Reduced Dynamics Models for the bunch - Control Algorithms
  - MD Coordination - Analysis of MD data - Data Correlation between MD data / Multiparticle results

Feedback Systems

General Requirements

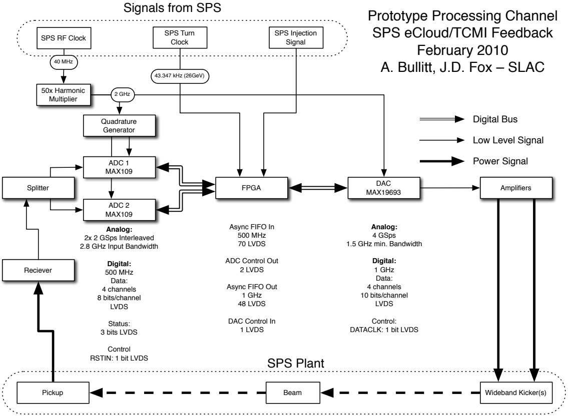
- Original system unstable- Minimum gain for stability
- Delay in control action - Maximum gain limit
- Bunch Dynamics Nonlinear - tunes/growth rates change intrinsically
- Beam Dynamics change with the machine operation
- noise-perturbations rejected or minimized
- Vertical displacement signals has to separated from longitudinal/horizontal signals
- Control up-date time $= T_{revolution}$

Prototype in SPS ring

- Bunch length $\simeq 2.5 - 3.5$ ns
- Sampling frequency $\simeq 4$ G Samples/s

Hardware

Feedback Control Channel - Excitation Prototype

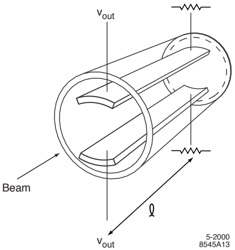


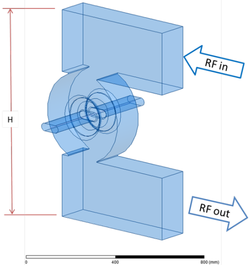
- We are building a proof-of-principle channel for closed loop tests in SPS before the 2013 shutdown, using existing kicker and pick-up.
- 4 GS/sec. digital channel. Flexible reconfigurable processing -

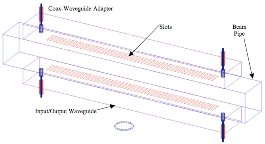
Hardware

Kicker

- LNF-INFN,LBL and SLAC Collaboration. Excellent progress 2012
- Goals - evaluate 3 possible options
  - Stripline (Arrays? Tapered? Staggered in Frequency?)
  - Overdamped Cavity (transverse mode)
  - Slot and meander line (similar to stochastic coooling kickers)
- Based on requirements from feedback simulations, shunt impedance, overall complexity - select path for fab



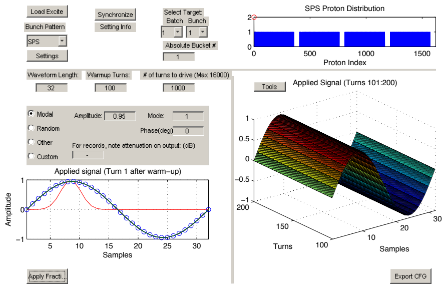


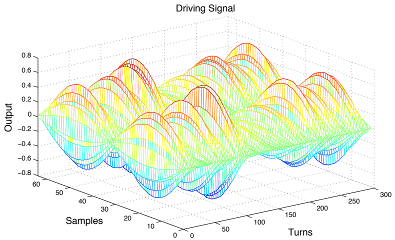


Hardware

Excitation System - Main Features

- Synchronize excitation signal with a selected bunch in the machine.
- 3.2 - 4GS/s programable unit that allows generating arbitrary signals in time (turns) and across the bunch (z-axis).
- Allows driving the bunch with an arbitrary kick signal.
- Able to follow at some level the bunch during acceleration.





Along the turns: Random signal filtered around $f_\beta + f_s$

MD - Results

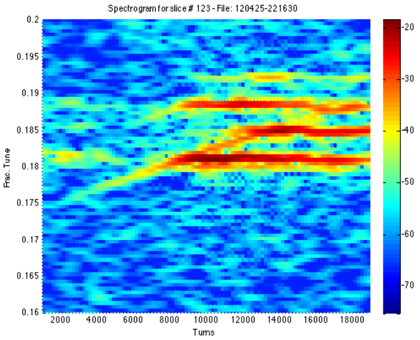
MD Results - Bunch multimode motions

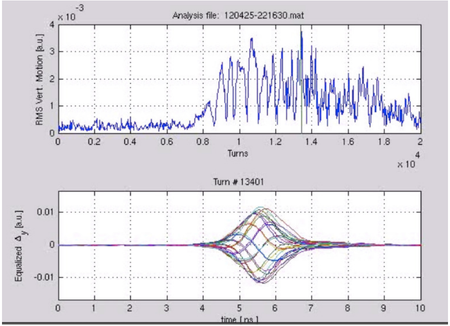
- We drove the beam using a composite AM signal. Along the turns we swept the fractional frequency $F_{Frac}(t)$ of the signal 0.175 to 0.188 in 15K turns
  - $M(z,t) = A(z) sin(\theta(t)); \quad \theta(t) = 2\pi \int F_{Frac}(t) dt \quad z \in [0\, T_b), T_b = 5ns.$
- The frac. betatron tune of the machine was $f_\beta = 0.181$, the frac. synchrotron tune was $f_S \simeq 0.004$
- The SIGMA and DELTA signals in the receiver for 20K turns are equalized (cables, pick-up) to recover the Charge Distribution (Sigma) and Dipole motion (Delta).
- Power spectrum of Dipole motion is calculated using a window of 2K turns.

MD - Results

MD Results - Bunch multimode motions

- Frequency of the driving signal is swept f_{DR}/f_{REV} : 0.175 – 0.188



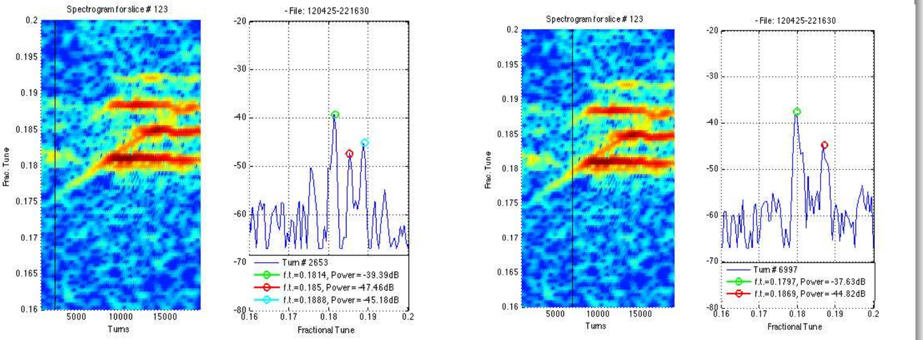


- Spectrum slice 123 (time $\simeq$ 5.8ns) - Delta SIGNAL.
- Delta SIGNAL. Turns 13401-13426

MD - Results

MD Results - Bunch multimode motions

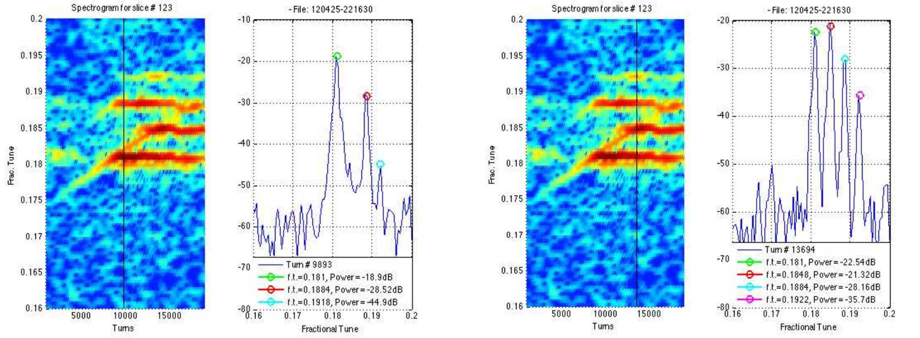
- Spectrum slice 123 - Turns 2653 and 6997. $f_\beta = 0.181$



MD - Results

MD Results - Bunch multimode motions

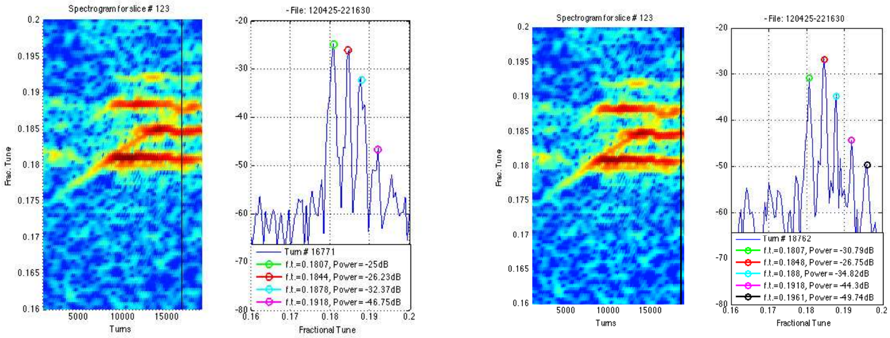
- Spectrum slice 123 - Turns 9893 and 13694 . $f_\beta = 0.181$



MD - Results

MD Results - Bunch multimode motions

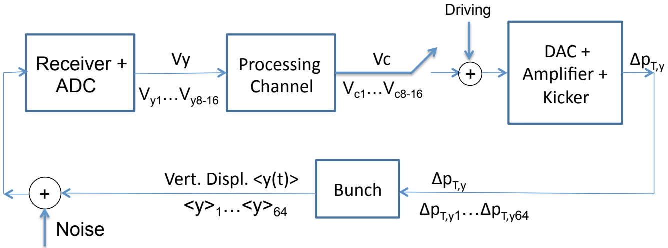
- Spectrum slice 123 - Turns 16771 and 18762. $f_\beta = 0.181$



Macro-Particle Simulation Codes

Realistic feedback channel model (CMAD, HeadTail, WARP)

- Multi-particle simulation codes have been a very useful test-bench for designing MD analysis algorithms and tools.
- Add a model of the feedback channel that includes a realistic representation of the receiver, processing channel, amplifier and kicker hardware.



- Test-bench to check feedback control system design.

Macro - Particle Simulation Codes : Realistic Feedback

Receiver

- Selection to process as input signal the true vertical motion or dipole motion of the bunch.
- The final frequency response of the receiver can include pick-up response, cables, anti-aliasing filters, etc.
- Introduce signal limitations, e.g. ADC
- Add combination of noise and signal perturbations.

Power Stage

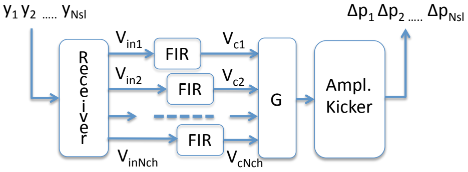
- The final frequency response of the power stage can include kicker-power amplifiers frequency response, cables, etc.
- Introduce signal limitations, e.g. DAC, power amplifiers
- Add noise and perturbation signals or excitation signal in case of open loop simulation

Controller - Processor

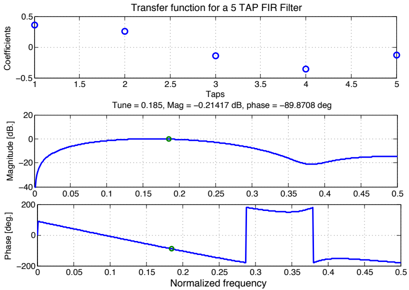
- Up to now, less effort modeling general processing structures.
- Option of FIR-IIR filters processing individual bunch slices (No coupling throw the filter between adjacent bunch slices - Diagonal controllers)
- Requires up-date when there is a better understanding of the system.

Macro - Particle Simulation Codes

Feedback Channel



Simple FIR filter - 5 taps

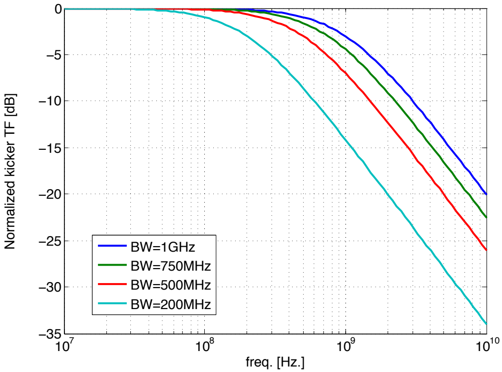


- The overall gain G is used as parameter to set the closed loop response.
- FIR recursive equation - 5 TAPs

$$V_{C_i}(kTs) = C_1 V_{IN_i}((k-1)Ts) + C_2 V_{IN_i}((k-2)Ts) + \cdots + C_5 V_{IN_i}((k-6)Ts)$$

Macro - Particle Simulation Codes

Kicker

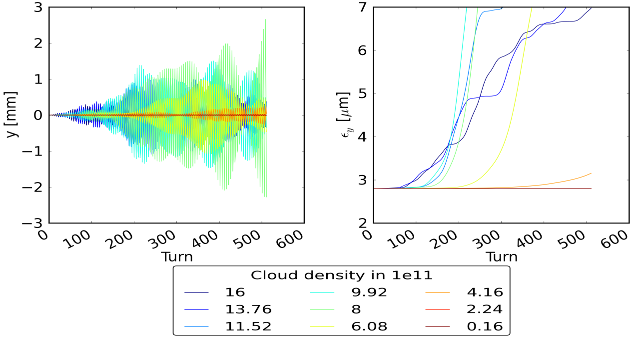


- Normalized kicker transfer functions (TF) used in the simulations
- Similar to the kicker TF installed in SPS ($BW = 180MHz$).

Macro-Particle Simulation Codes

Simulation Results - HeadTail

- Electron cloud interaction with a bunch of 1.1×10^{11} protons in the machine.

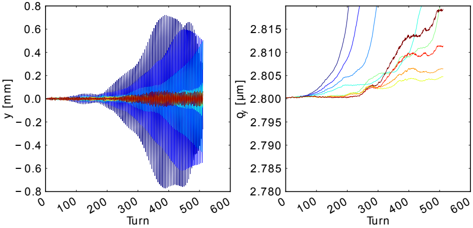


- Evolution of the bunch centroid motion and the normalized emittance for different electron cloud densities.
- The case of cloud density $= 6 \times 10^{11} e/m^3$ will be used for the studies.

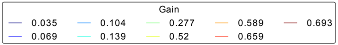
Macro-Particle Simulation Codes

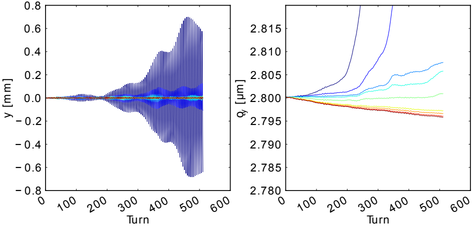
Macro-Particle Simulation Codes - HeadTail

- Electron cloud interaction with a bunch in the machine of 1.1×10^{11} protons.



Kicker $BW = 200$ MHz.





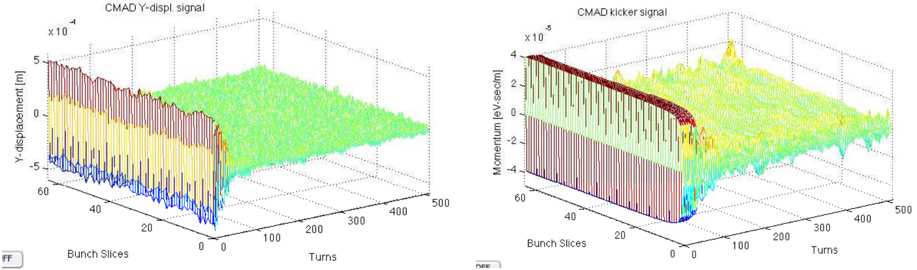
Kicker $BW = 500$ MHz.

- Evolution of the bunch centroid motion and the normalized emittance for different gains G.
- The case of cloud density $= 6 \times 10^{11} e/m^3$ will be used for the studies.

Macro - Particle Simulation Codes

Macro-Particle Simulation Codes - CMAD

- Electron cloud dens.: $6 \times 10^{11} e/m^3$, initial vertical off-set $y_0 = 0.5mm$



- The overall gain is set to $G = 0.5$, the maximum kicker signal $\Delta p_{MAX} = 4 \times 10^{-5}$ eV s/m

Conclusions

Important progress in the different R & D areas of the project during the last year

- Installation in SPS of amplifiers and excitation system. Several MDs driving a single bunch in the machine
- Expansion of multi-particle simulation codes with models of the feedback system. Realistic models including frequency response, limits, noise and spurious signal.
- Development of the hardware to test a simple feedback channel controlling a single bunch in SPS (' proof of principle prototype ')
- Analysis of wideband Kicker options for the feedback channel.
- Getting ready to test the 'proof of principle prototype' before the LS1.

Conclusion

Future Plans

- Conduct MDs in SPS during Oct 2012 - Test hardware
- Install 'proof of principle prototype' in SPS during Nov 2012 - Test simple feedback channel
- Propose kicker structure - End 2012
- Evaluate purchase of new amplifiers during LS1
- Design vacuum devices and install in SPS during LS1
- Develop control algorithms and diagnostic firmware - During LS1
- Be ready to test feedback system mitigating ECI - TMCI - Start after LS1

Thanks to the audience for your attention!!!, ...Questions?