SPS High Bandwidth Feedback Progress Report

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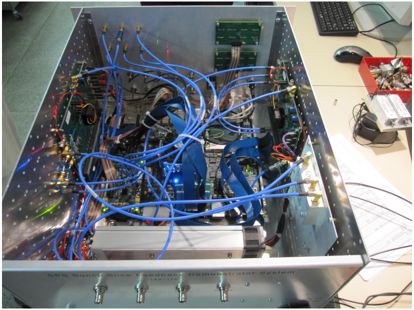
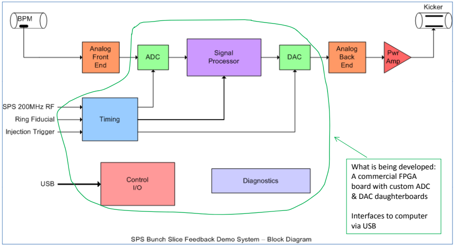
SPS Transverse Intrabunch Feedback Progress Report

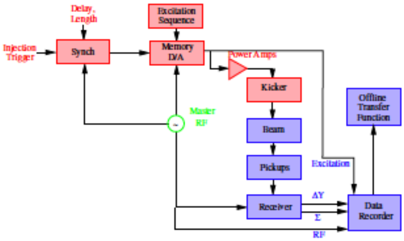
- Technology development, what processing prototypes are at CERN
- Strategies for evaluating control methods
- Recent MD results
- Discussions and ideas for the near term
- Longer range LARP plans and collaboration ideas





LARP Efforts and plan

- Overall Goal - explore wideband feedback methods to control Ecloud/TMCI instabilities
  - Simulation Efforts - nonlinear time domain codes, reduced model control codes
  - Machine measurement program - studies at SPS 2010 - 2013
  - Technology development program (excitation system, Demo feedback channel)



Technology Development for SPS tests

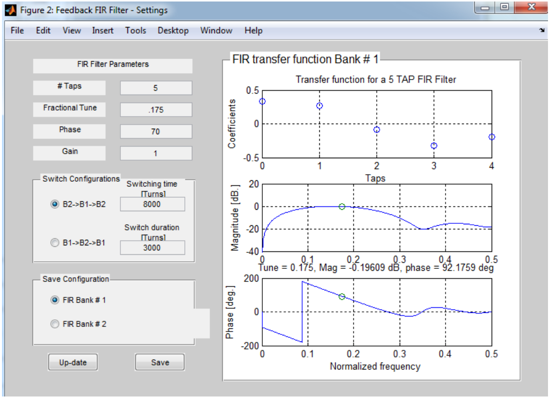
- Timing and synchronization master oscillator
- Beam Motion Receiver (delta/sigma system)
- 4(3.2) GS/sec. Beam excitation system (arbitrary waveform generator, 15K turns)
- 4(3.2) GS/sec. DSP Feedback Demo processor
- Tunnel amplifiers/control for beam excitation (4× 80W 1 GHz)

The goal is to build general purpose testbed components to allow machine measurements, experiments of fundamental control ideas using the SPS

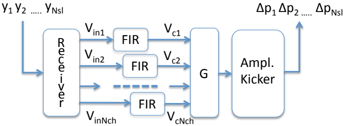
Demonstration 1 bunch processor

- Synchronized DSP processing system, initial 1 bunch controller
- Implements 16 independent control filters for each of 16 bunch "slices"
- Sampling rate 4 GS/sec. (3.2 in SPS tests)
- Each control filter is 16 tap FIR (general purpose)
- A/D and D/A channels
- Two sets of FIR filter coefficients, switchable on the fly
- Control and measurement software to synchronize to injection, manipulate the control filters at selected turns
- Diagnostic memories to study bunch motion, excite beams with arbitrary signals
- Reconfigurable FPGA technology, expand the system for control of multiple bunches
- What's missing? A true wideband kicker. Technology in development. These studies use a 200MHz stripline pickup as a kicker

Feedback Filters



- FIR up to 16 taps
- Designed in Matlab
- Filter phase shift at tune must be adjusted to include overall loop phase shifts and cable delay

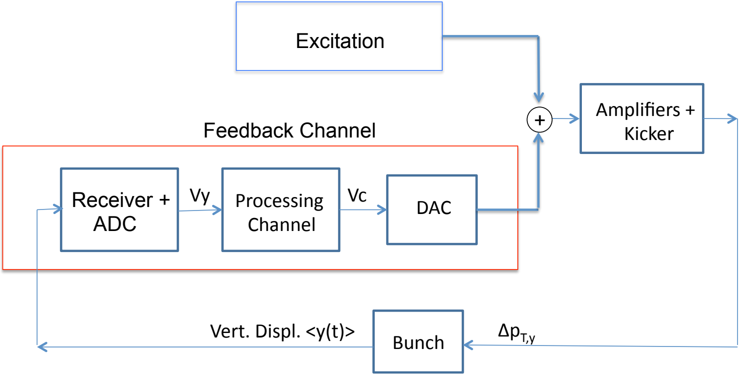


Recent MD Results

- Several MD trials since November, implement one-bunch feedback control
- 5 and 7 Tap FIR filters, $\phi = 90°$, gain variations of 30dB
- Studies of loop stability, maximum and minimum gain
- Driven studies
  - variation in feedback gain, filter paramters
  - multiple studies allow estimation of loop gain vs frequency (look at excitation level of several modes)
  - interesting to look at internal beam modes
- Feedback studies of naturally unstable beams

We are just starting to analyze data, a few examples to stimulate discussion

Measuring the closed loop system - methods

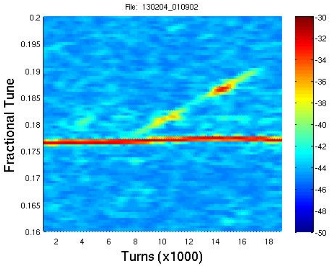


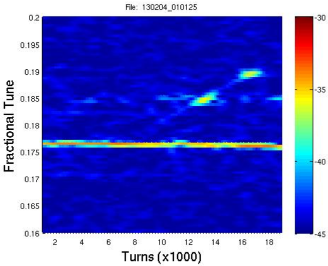
- We want to study stable or unstable beams and understand impact of feedback
- We can vary the feedback gain vs. time, study variation in beam input, output
- We can drive the beam with an external signal, observe response to our drive
- System isn't steady state, tune and dynamics vary
- Excite with chirps that can cross multiple frequencies of interest
- Unstable systems can be studied via Grow-Damp methods, but slow modes hard to measure

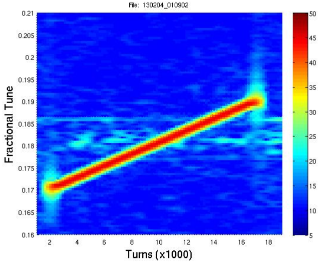
MD measurement -Driven motion studies

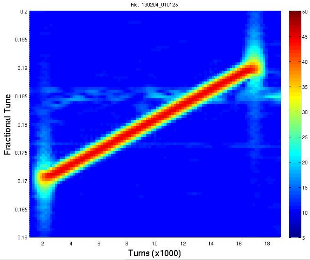
- Drive the beam with chirps or tailored excitations
- Feedback control in various modes (on, off, variable gains, filters, etc.)
- Study changes in dynamics with feedback as change in driven response
- Advantage - applicable to stable beams
- Allows estimation of loop gain vs. frequency in study of driven responses at various modes
- Applicable to unstable beams, too

Driven Motion Studies



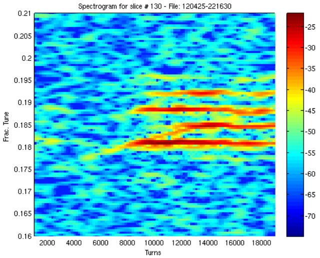






Value of Driven measurements

- We need to characterize the response of the combined beam-feedback system
- Drive the beam using excitation chirps
- Vary the feedback gain and phase.
- Beam response shows effect of feedback on beam dynamics
- Measurements like this will help us quantify the frequency response of our feedback system.



- An example spectrogram of excited beam from the April 2012 MD
- Multiple modes are clearly visible.
- Variation in response at each mode can show frequency response of kicker subsystem

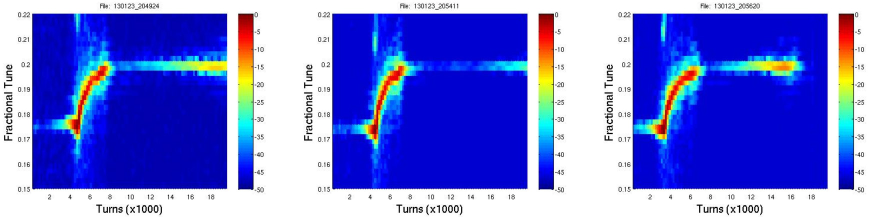
MD Feedback studies on unstable or marginally stable beams

- Manipulate feedback parameters, study free beam responses
- Feedback control as time-varying parameter (on, off, variable gains, filters, Positive/Negative feedback etc.)
- Study changes in dynamics vs. feedback configuration (grow/damp studies)
- Manipulation of feedback filters allows growth of instability from stable controlled state, measurement in small-amplitude conditions
- Easily measures fastest modal growth rates - requires care to measure slow modes in presence of fast modes
- Disadvantage - requires feedback control to do most studies

Example feedback control of unstable beam

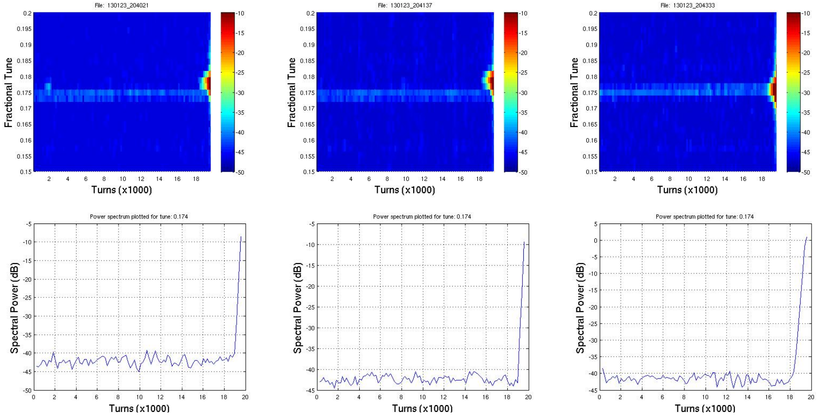
- SPS Cycle with chromaticity sweep to low (zero?) chromaticity after 1 sec into the cycle
- charge 1×10^{11} with slightly negative chromaticity
- With no FB the bunch is mode zero unstable (loses charge, seen in SUM signal and tune shift)
- Feedback was applied to beam after 2k (46 ms) turns, for a duration of 16 k turns
- Similar FIR filter design, $\phi = 90°$, G = 32.
- Stabilization of the dipole mode is clearly shown during the 16k turns when FB is ON
- The beam motion grows when the FB is switched off as shown at the end of the data recording, turns 18k – 20k.

Unstable Beam, Feedback OFF



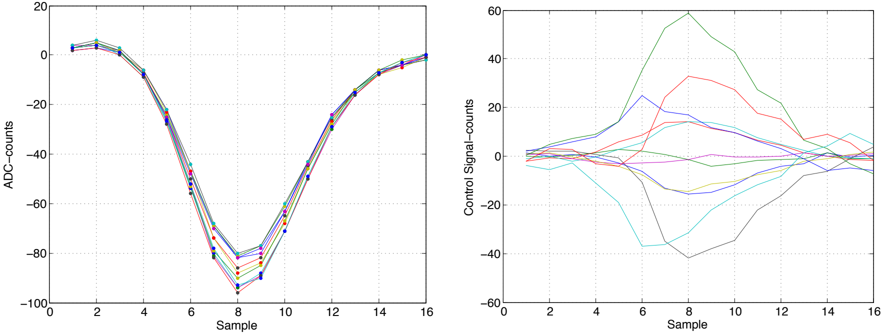
- Spectrograms of bunch motion, nominal tune 0.175
- after chromaticity ramp at turn 4k, bunch begins to lose charge and gets tune shift.
- Bunch is unstable in mode zero (barycentric).

Unstable Beam, Feedback ON



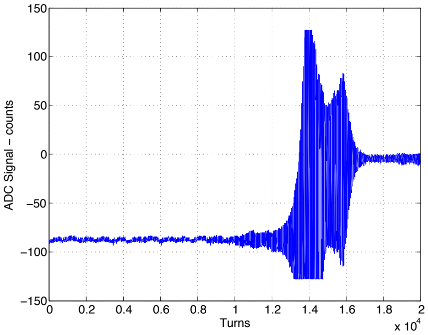
Feedback is switched off at turn 18K, beam then is unstable

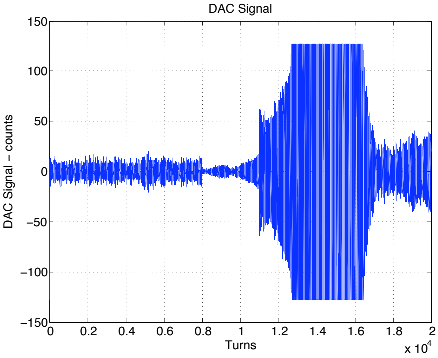
System Input, Output signals via snapshot



- mode zero motion of the bunch
- 25 consecutive turns
- Left equalized pickup, right kicker drive
- note gain of filter and DC suppression

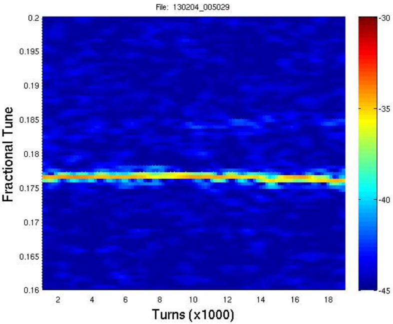
System Input, Output signals via snapshot

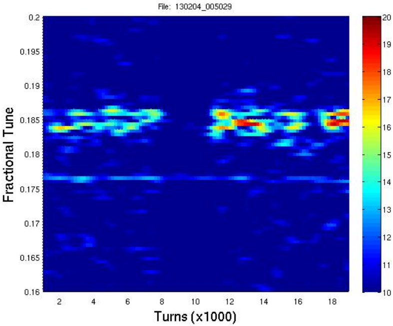




- Example of gain reduction during stable control, loss of control after gain restoration 3k turns later. Transient deserves more complete analysis
- Mode zero unstable beam
- Gain modulated $\times 8$-$\times 2$-$\times 8$ during cycle
- For turns 0-8k, 8k-11k, 11k-end
- Input (left), DSP output (right) Note gain of filter, DC suppression and saturation

Modulation of Feedback Gain Unstable Beam





- Gain modulated from gain $\times 8$-$\times 2$-$\times 8$
- For turns 0-8k, 8k-11k, 11k-end
- Left pickup, right kicker spectrograms

Invitation for Discussion

- We are in process to analyze the recent transients and measurements
- Frequency domain analysis via spectrograms
- Time domain data is filtered, post processed to remove offsets, time-aligned and then presented as movies to help visualize motion
- We are trying to measure effective damping rates (or changes in damping rates)
- We measure noise floors, estimate saturation limits, estimate stability limits
- What new methods might be useful?
- Are there better methods to excite high frequency modes to study?
- Difficulties characterizing unstable system

Future Directions - beam studies

- The Demo platform is a reconfigurable testbed for control techniques
- Provides unique beam diagnostics and opportunities for new measurement methods
- Studies of unstable systems are difficult, control and time varying gain is a useful method (grow-damp techniques)
- To date, unstable beams available have had mode zero instabilities, we want to study higher internal modes
- Complementary methods with driven responses
- We are eager to collaborate on novel beam diagnostics and measurement techniques, analysis methods
- Analysis of recent MD transients will require some time, future talks and discussions

Summary - LARP program directions

- LARP
  - LARP program is transitioning, wideband feedback is proposed as a US deliverable for HL upgrade
  - R&D program necessary to develop full-function prototype
- Plans for next two years
  - Use recent MD data to better simulate beam instablities and feedback system properties
  - Wideband kicker (in conjunction with SLAC/LBL/LNF-INFN) - install at end of LS1
  - Expand Demo prototype to control 16 - 48 bunches, useful for Ecloud/TMCI studies
- Areas of SLAC/CERN LARP activity
  - Beam-Feedback simulations (nonlinear and reduced model)
  - Development of optimal control approaches, use of simulations, fit of models to MD data
  - Hardware development (timing and synchronization methods, beam receiver and offset rejection techniques)

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