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, $\phi = 90^\circ$, gain variations of 30dB
- Studies of loop stability, maximum and minimum gain
- Driven studies
  - variation in feedback gain, filter parameters
  - 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

Driven chirp Pickup spectrogram (left gain x16, right gain x8)

Driven Chirp Kicker spectrogram

Chirp tune 0.17 – 0.19 turns 2K – 7K
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 $1 \times 10^{11}$ 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, $\phi = 90^\circ$, $G = 32$.
- 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.
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
mode zero motion of the bunch
25 consecutive turns
Left equalized pickup, right kicker drive
note gain of filter and DC suppression
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
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 instabilities 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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