Advanced Accelerator Research Department
- Feedback & Dynamics Group -

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Group’s Goal

- Combine Beam dynamics, feedback system, signal processing and electronics hardware skills to conduct R & D to overcome fundamental limits in accelerators related to the beam intensity and luminosity.

1 Accelerating RF station - Beam dynamics interaction
   - Coupled-bunch instabilities
   - RF noise effects on beam distribution
   - Optimal configuration of RF station

2 Intra-bunch Instability: Electron Clouds and Strong Head-Tail Instabilities at SPS
   - Appropriated Modeling of the bunch dynamics for feedback control design
   - Bunch stabilization
   - Limitations in the feedback design due to noise, signal perturbations and hardware.
Group’s Activities

- **Accelerating RF station - Beam dynamics interaction**
  - Study of the Beam-RF station as a unique dynamical system.
  - Beam Stability, RF station stability, RF station noise impact on beam dynamics.
  - RF station configuration tools and diagnostics based on beam performance.

- **Intra-bunch Instability: Electron Clouds and Strong Head-Tail Instabilities at SPS**
  - Simulation Tools including feedback system.
  - Reduced models and System Identification.
  - Data Analysis.
  - Hardware development for machine studies - Kicker design report.

- **Proposals:** Timing & Synchronization, Multi-rate control of linear Accelerators
Coupled-bunch instabilities - Setting of RF stations

- Coupled-bunch instabilities are defined by the impedance and associated circuitry of RF stations.
- Cavity Controller (LLRF) feedback loops are employed to reduce the accelerating fundamental impedance to achieve stable operation.
- Cavity Controller settings are critical for the stability of both the beam and the RF station. Defines level of RF noise and perturbation of the accelerating RF stations.
With LARP/SLAC support and in collaboration with the CERN BE-RF group, SLAC personnel have successfully developed a suite of tools to remotely commission and optimally configure the LHC RF stations.

Remote operation was crucial under the new stricter CERN policies which prevented tunnel access when the magnets are energized.

The tools were essential for the Winter 2010 and 2011 commissioning.

Tools reduced commissioning from 1.5 days/station to 1.5 hours/station, increased consistency and reliability.
RF noise effects on LHC longitudinal beam emittance

- The noise power spectrum of the RF accelerating voltage can strongly affect the longitudinal beam distribution and contribute to beam motion and diffusion.
- A theoretical formalism relating the bunch length growth with beam dynamics, accelerating voltage noise, and RF system configurations was developed at SLAC.
- Studies and measurements were then conducted to estimate the bunch length growth for various operational configurations and to identify the RF components contributing to this effect.
Longitudinal beam emittance - RF noise threshold

- Based on noise studies and measurements a validated relationship between bunch length growth rate and noise in the accelerating RF stations was defined.
- Studies were conducted with proton and ion beams.
- A threshold level for the noise power spectrum was calculated to achieve \[ \frac{d\sigma}{dt} = 2.5\text{ps/hr}. \]
Intra-bunch Instabilities: Electron Clouds / Strong Head-Tail instabilities at SPS

- One of the limits in particle accelerators to increase current is due to intra-bunch instabilities.
  - Large research effort has been conducted to understand and quantify the different instabilities
  - Mitigation for e-clouds induced instabilities have been proposed and tested: Coating, grooves in vacuum chambers, etc.
  - Mitigation for transverse mode coupled instabilities are under study at SPS: Chromaticity

- Our approach is to investigate the feasibility of controlling e-cloud and strong Head-Tail instabilities via feedback. Requires measuring/driving transversally different areas of the bunch (\textit{nsec - psec scale})
Intra-bunch Instabilities: Electron Clouds

Simple Observations from SPS Data

- SPS MDs: June 2009, SPS injection 26GeV, Charge: 1E11p/bunch, separation 25 nsec.,
- Time domain Vertical pick-up signals: SUM and DIFF - Extracted Vertical displacement (Data sampled 20 ps/point)

Two batches: First 72 bunches stable, (e.g. bunch 47), second set of 72 bunches E-cloud instabilities, (e.g. bunch 119). Time span: 2.6 nsec.
Intra-bunch Instabilities: Electron Clouds / Strong Head-Tail instabilities at SPS

R & D goal

- Goal is to have a minimum prototype to fully understand the limitations of feedback techniques to mitigate E-cloud / TMCI effects in SPS.

R & D areas

- Non-Linear Simulation Codes (CMAD-WARP) - Real Feedback Models - Multi-bunch 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 / Multi-particle results
- Study and Development of Hardware Prototypes
MD Plans: Driving the bunch

Next MD, we want to drive the bunch using the existent SPS kicker.

Critical to prove feasibility of driving different areas of the bunch, understand the power level and kicker gain to design the new kicker prototype.

Combine results and studies from different areas of our R & D effort: multi-particle codes, bunch modeling and identification.

Test SLAC hardware - Back-end, Synchronization with SPS machine - Timing

Using a particular signals ($V_C$), drive a beam through the amplifier and Kicker.

Measure the vertical displacement

Based on Input- Output signals, estimate the bunch dynamics and reduced model.
MD Plans: Driving the bunch

Studies using CMAD multi-particle simulation code

- CMAD multi-particle code is being up-dated to include realistic models of the feedback control system.
- Includes frequency response of the real hardware, allows to estimate and quantify the vertical displacement of different areas in the bunch.
- Studies are conducted to analyze the impact of different signals driving the bunch.

![Graphs showing signal applied to the bunch, momentum, Y displacement, and Y - centroid over turns.](image-url)
MD Plans: Driving the bunch

Studies using CMAD multi-particle simulation code

- DAC signal (a.u.) vs. DAC samples and Turns
- Momentum [eV−m/sec] vs. Bunch Slices and Turns
- Number of particles/slice vs. Sample number
- Z displacement vs. Z [m] and sample number
- Charge vs. Turn

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MD Plans: Driving the bunch

Studies using CMAD multi-particle simulation code
MD Plans: Driving the bunch

Hardware Development

- In collaboration SLAC AE Control Electronics Eng. group, development of hardware necessary for MDs and prototypes for evaluation of feedback system performance.

- Development of excitation board: 4 GSamples/sec FPGA + DAC to generate arbitrary signals and synchronize with the SPS ring to drive the bunch.

- Test and pack 100W - 1GHz bandwidth RF power amplifiers

- Development of Matlab interface (GUI) to generate waveforms and commands for the excitation board.
Identification of Internal Bunch Dynamics: Reduced Model

- Inject a random sequence or chirp signal → measure the vertical displacement of different areas of the bunch.
- Comparing the vertical displacement to the input signal we can calculate the reduced model

![Graphs showing measured vs estimated output for different samples](image-url)
Conclusions and future plans

- Combining Beam dynamics, feedback system, signal processing and electronics hardware skills, we conduct R & D to improve machine performance and overcome limits in accelerators related to the beam intensity and luminosity.

- Understand, model and design accelerator units as a complete dynamical system.

  - **Beam Dynamics ↔ Hardware ↔ Perturbations: Stability - Performance**

- Collaborate with CERN LHC RF groups to commission and operate the LHC RF systems at high beam currents. (T. Mastorides - Toohig Fellow)

- R & D on feedback control of intra-bunch instabilities: SPS bunch length feasible for state-of-the-art of current electronic systems.

- Collaborate with SSRL to improve RF station- longitudinal feedback at high current

- Evaluate proposal with LCLS on 1) Timing and Synchronization and 2) Multi-rate feedback systems.
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  - SLAC User: I. Rivetta

- Thanks to the audience....Questions??