Intra-train Beam-based Feedback Systems

Philip Burrows
Queen Mary, University of London

- System overview
- FONT/NLCTA
- FEATHER/ATF
- Future plans
International Collaboration

- **FONT:**
  Queen Mary: Philip Burrows, Glen White, Tony Hartin, Stephen Molloy, Shah Hussain
  Daresbury Lab: Alexander Kalinine, Roy Barlow, Mike Dufau
  Oxford: Colin Perry, Gerald Myatt, Simon Jolly, Gavin Nesom
  SLAC: Joe Frisch, Tom Markiewicz, Marc Ross, Chris Adolphsen, Keith Jobe, Doug McCormick, Janice Nelson, Tonee Smith, Steve Smith, Mark Woodley

- **FEATHER:**
  KEK: Nicolas Delerue, Toshiaki Tauchi, Hitoshi Hayano
  Tokyo Met. University: Takayuki Sumiyoshi

- **Simulations:** Nick Walker (DESY), Daniel Schulte (CERN)
Intra-train Beam-based Feedback

Intra-train beam feedback is last line of defence against ground motion

Key components:
Beam position monitor (BPM)
Signal processor
Fast driver amplifier
E.M. kicker
Fast FB circuit

Warm: augments active stabilisation
Cold: principal ground-motion correction

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Beam Feedback Luminosity Recovery

G/NLC:
recover > 80% of design luminosity

TESLA:
> 95% feasible

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Feedback on Nanosecond Timescales (FONT) (SLAC/NLCTA)

- 100 micron train-train jitter
- Bunched at X-band (87ps)
- 50% Q variation along train:
  - 170ns long train
  - 1mm size beam
  - Few 100 micron offsets

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3kW tube amplifier:

10/1 position correction
latency of 67 ns
FONT1: expected latency

- Time of flight kicker – BPM: 14ns
- Signal return time BPM – kicker: 18ns
  Irreducible latency: 32ns
- BPM cables + processor: 5ns
- Preamplifier: 5ns
- Charge normalisation/FB circuit: 11ns
- Amplifier: 10ns
- Kicker fill time: 2ns
  Electronics latency: 33ns
- Total latency expected: 65ns
FONT2: outline

Goals of improved FONT2 setup:

• Additional 2 BPMs: independent position monitoring
• Second kicker added: allows solid state amplifiers
• Shorter distance between kickers and FB BPM: irreducible latency now c. 16 ns
• Improved BPM processor: real-time charge normalisation using log amps (slow)
• Expect total latency c. 53 ns: allows 170/53 = 3.2 passes through system
• Added ‘beam flattener’ to remove static beam profile
• Automated DAQ including digitisers and dipole control
FONT2: expected latency

- Time of flight kicker – BPM: 6ns
- Signal return time BPM – kicker: 10ns
  Irreducible latency: 16ns
- BPM processor: 18ns
- FB circuit: 4ns
- Amplifier: 12ns
- Kicker fill time: 3ns
  Electronics latency: 37ns
- Total latency expected: 53ns
FONT2: beamline configuration

Dipole and kickers

New BPMs

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FONT2: BPM signal processing
FONT2: amplifier + beam flattener

FB signal into amplifier:

Beam flattener:

Bandwidth limited (30 MHz)
FONT2 BPM resolution

Residuals:

Resolution 14 microns
FONT2 results: feedback BPM

Beam starting positions

Beam flattener on

Feedback on

Delay loop on
FONT2 results: witness vs. FB BPMs

BPM1 (FB)

BPM2 (witness)
FONT2 results: gain studies

Vary main gain

<table>
<thead>
<tr>
<th>Gain Value</th>
<th>Graphs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td><img src="image1" alt="Graph" /></td>
</tr>
<tr>
<td>0.7</td>
<td><img src="image2" alt="Graph" /></td>
</tr>
<tr>
<td>0.9</td>
<td><img src="image3" alt="Graph" /></td>
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<tr>
<td>1.1</td>
<td><img src="image4" alt="Graph" /></td>
</tr>
<tr>
<td>1.3</td>
<td><img src="image5" alt="Graph" /></td>
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</table>

Main gain –ve (!)

<table>
<thead>
<tr>
<th>Gain Value</th>
<th>Graphs</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.8</td>
<td><img src="image6" alt="Graph" /></td>
</tr>
<tr>
<td>-1.2</td>
<td><img src="image7" alt="Graph" /></td>
</tr>
<tr>
<td>-1.6</td>
<td><img src="image8" alt="Graph" /></td>
</tr>
<tr>
<td>-2.0</td>
<td><img src="image9" alt="Graph" /></td>
</tr>
</tbody>
</table>

Also: delay loop length + gain ...

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FONT2 final results (Jan 22 2004)

Super-fast modified configuration:

Latency 54ns
Correction 14:1
(limited by gain knob resolution)

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FONT2 Simulation

Simulation includes:

- time of flight
- cable delays
- latencies
- bandwidths
- delay loop

Useful tool for LC FB simulations

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Feedback At High Energy Requirements (FEATHER) (KEK/ATF)

**FEATHER (羽)**

**Extraction line layout**

- Feedforward and feedback are possible
- Feedforward uses a cavity BPM + movable electrode kicker
- Feedback uses the new button BPM + kicker

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FEATHER: kicker simulations

**Kicker with a movable electrode**

A kicker with a movable electrode has been designed. (Simulations with POISSON/SUPERFISH)

This allow us to have a small gap between the two electrodes.

**KEK report 2003-6**

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FEATHER: kicker performance

kick vs gap (low frequency)

Commissioning of the movable electrode kicker:
Kick intensity as a function of the gap for both input upstream and downstream.

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FEATHER: latency

Time budget

• The response time of our new amplifier has been measured: 5.6 ns
• There is ~1 meter between our kicker and our BPM
  => Beam flight ~ 4 ns
  => Cable delay ~ 7 ns
• Various electronics delay should be less than 5ns
• Response should come ~20ns after first bunch
• Delay loop needs ~11ns more (Total ~35 ns)
• 20 bunches at 2.8 ns make a 56ns train
  => Should be possible to test our delayed model

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Nicolas Delerue  Nicolas@post.kek.jp
http://acfahep.kek.jp/subg/lr/feather/
FEATHER: beam scan across kicker gap

Scan of the acceptable trajectories
Vertical orbit of the beam has been modified several times to scan the acceptable orbits and thus deduce the position of the kicker's electrodes.

Smallest gap has been found at 13.09/12.49
This correspond to a gap at the windows of ~1.12 mm (electrodes are bent)

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Comparison of NLCTA with ATF

<table>
<thead>
<tr>
<th></th>
<th>NLCTA</th>
<th>ATF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train length</td>
<td>170 ns</td>
<td>300 ns</td>
</tr>
<tr>
<td>Bunch spacing</td>
<td>0.08 ns</td>
<td>2.8 ns</td>
</tr>
<tr>
<td>Beam size (y)</td>
<td>500 mu</td>
<td>5 mu</td>
</tr>
<tr>
<td>Jitter (y)</td>
<td>100 mu</td>
<td>few mu</td>
</tr>
<tr>
<td>Beam energy</td>
<td>65 MeV</td>
<td>1.3 GeV</td>
</tr>
</tbody>
</table>

Stabilising 1 GeV beam @ 1 mu ⇔ 1000 GeV @ 1 nm

For the warm machine:

ATF has ‘right’ bunch spacing and train length, and the beam is smaller and more stable than at NLCTA

-> much better place for fast feedback prototypes

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Future Experimental Programme at ATF

FONT and FEATHER are joining forces!

1. Stabilisation of extracted bunchtrain at 1 micron level:
   low-power (< 100W), high stability amplifier
   stripline or button BPM w. ~ 1 micron resolution
   these are exactly what are needed for the LC!

2. Stabilisation of extracted bunchtrain at 100 nm level:
   requires special (cavity) BPM and signal processing
   useful as part of nanoBPM project

3. Test of intra-train beam-beam scanning system:
   high-stability ramped kicker drive amplifier
   very useful for LC
Future Experimental Programme at SLAC

The SLAC A-line is potentially extremely useful for IP FB system tests:

Train charge, length, bunch spacing ... parameters can be made relevant for warm or cold machine (Woods)

Well instrumented laboratory for BPM tests

High-flux e+e- pairs mimic LC IR environment:
   study impact of pair background on BPM resolution;
   radiation damage issues for feedback components
Other issues for intra-train feedbacks

- Beam angle-jitter:

  warm machine: correction best done near IP with RF crab cavity (needed anyway):
  
  design + prototyping starting in UK

- Ideally, feedback on luminosity:

  bunch-by-bunch luminosity measurement would allow intra-train luminosity feedback