Development of a Low-latency, High-precision, Intra-train Beam Feedback System Based on Cavity Beam Position Monitors


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Outline

• Introduction
  – Feedback at a linear collider
  – International Linear Collider
  – Feedback on Nanosecond Timescales
• Experimental setup at Accelerator Test Facility
• Cavity beam position monitor signals
• Modes of feedback operation
• Results
Introduction

Feedback at a Linear Collider

• Successful collision of bunches at a linear collider is critical
• A fast position feedback system is required

Misaligned beams at interaction point (IP) cause beam-beam deflection
Introduction

Feedback at a Linear Collider

• Successful collision of bunches at a linear collider is critical
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![Diagram showing misaligned beams at interaction point (IP) causing beam-beam deflection and measuring deflection on one of outgoing beams using a BPM (beam position monitor).]
Feedback at a Linear Collider

- Successful collision of bunches at a linear collider is critical
- A fast position feedback system is required

Misaligned beams at interaction point (IP) cause beam-beam deflection

Measure deflection on one of outgoing beams

Correct orbit of next bunch (correlated to previous bunch due to short bunch spacing)
Introduction

International Linear Collider (ILC)

- Proposed linear electron-positron collider
- Centre-of-mass energy: 250-1000 GeV
- Vertical beamsize: 5.9 nm
- Bunch separation: 554 ns

(ILC Technical Design Report)
Introduction

Accelerator Test Facility (ATF) at KEK

- Test bed for the International Linear Collider
- Facility located at KEK in Tsukuba, Japan
- Goals:
  - 37 nm vertical spot size at final focus
  - Nanometre level vertical beam stability
Introduction

Accelerator Test Facility (ATF) at KEK

Electron source

90 meters
Introduction

Accelerator Test Facility (ATF) at KEK

1.28 GeV linear accelerator

Electron source

90 meters
Introduction

Accelerator Test Facility (ATF) at KEK

Electron source

1.28 GeV linear accelerator

Damping ring

90 meters
Introduction

Accelerator Test Facility (ATF) at KEK

Final focus
Extraction line
Model interaction point (IP) of a collider
Electron source
Damping ring
1.28 GeV linear accelerator
90 meters
Introduction

Accelerator Test Facility (ATF) at KEK

Feedback system

Final focus

Extraction line

Model interaction point (IP) of a collider

Electron source

1.28 GeV linear accelerator

Damping ring

90 meters
Introduction

Accelerator Test Facility (ATF) at KEK

• ATF can be operated with 2-bunch trains in the extraction line and final focus
• The separation of the bunches is ILC-like (tuneable up to ~300 ns)
• Our prototype feedback system:
  – Measures the position of the first bunch
  – Then corrects the path of the second bunch
• Train extraction frequency: ~3 Hz
• Low-latency, high-precision feedback system
• We have previously demonstrated a system meeting ILC latency, BPM resolution and beam kick requirements
• We have extended the system for use at ATF
• We aim for nanometre level beam stabilisation
Experimental Setup

- 12 cm long strips
- 12 mm radius
- On x and y mover system

Stripline BPM
Experimental Setup

- Analogue: latency 13 ns
- Resolution of 330 nm
- Details in poster TUPME009
Experimental Setup

- C-band: 6.4 GHz in y
- Low Q: decay time < 30 ns
- Resolve 2-bunch trains
Experimental Setup

- Analogue, 2-stage downmixer
- Resolution of < 100 nm
- Developed by Honda et al.

For cavity BPM
Experimental Setup

- 9 ADC channels at 357 MHz
- 2 DAC channels at 179 MHz
- Xilinx Virtex 5 FPGA
Experimental Setup

- IPB
- P3, P2
- Processor, Processor, Amplifier, Amplifier
- Board, Board

Amplifier

- Made by TMD Technologies
- ± 30 A drive current
- 35 ns rise time (90% of peak)
Experimental Setup

- Vertical stripline kicker
- 30 cm long strips for K1 & K2
- 12.5 cm long strips for IPK

Local upstream feedback results presented in poster TUPME009
Cavity BPM Signal Processing

<table>
<thead>
<tr>
<th>IPB(Y)</th>
<th>6426 MHz</th>
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<tbody>
<tr>
<td>Ref(Y)</td>
<td>6426 MHz</td>
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**IPB cavity**
Dipole mode frequency (in y)
~6426 MHz

**Reference cavity**
Monopole mode frequency (in y)
~6426 MHz
The IPB and reference cavity signals are downmixed using a common, external 5712 MHz local oscillator (LO).
The IPB signal is downmixed using the reference cavity signal as LO. The I and Q output signals at baseband are used to obtain the beam position.
Feedforward

• Use position at P2 & P3 to correct position at IPB
• Correction calculated locally, then sent along 60 meters of cable
• Latency: 202 ns
• Effect measured at IPB
FF Off Jitter: 160 ± 10 nm
FF On Jitter: 106 ± 10 nm

FF Off Correlation: 73 %
Feedforward

**IPB**

**FF Off Jitter:** $160 \pm 10$ nm

**FF On Jitter:** $106 \pm 10$ nm

**FF Off Correlation:** 73 %

**FF On Correlation:** 23 %
Feedforward

6 μm incoming beam position scan

First bunch uncorrected

Second bunch corrected
Interaction Point Feedback

- IPB position is used to drive the local kicker IPK
- Latency: 212 ns
- Effect measured at IPB
Interaction Point Feedback

FB Off Jitter: 168 ± 7 nm
FB On Jitter: 98 ± 5 nm

FB Off Correlation: 81 %
Interaction Point Feedback

FB Off Jitter: 168 ± 7 nm
FB On Jitter: 98 ± 5 nm

FB Off Correlation: 81 %
FB On Correlation: -16 %
Interaction Point Feedback

10 μm incoming beam position scan

first bunch uncorrected

second bunch corrected
Conclusion

• Demonstrated low-latency, high-precision, intra-train feedback systems
• Cavity BPM feedback latency: 212 ns
• Achieved beam stabilisation at the ATF IP in 2 modes:
  – Feedforward: ~100 nm
  – IP feedback: ~100 nm
Thank you for your attention!

*We thank the ATF collaboration and the ATF operations team for their support*