Measurement and Data Acquisition for Accelerator Controls at KEK

(Beam Position Monitor at Linac)

Kazuro Furukawa

< kazuro.furukawa@kek.jp >

For Linac and KEKB Control Groups

KEK:
Accelerator Facilities for Particle & Nuclear Physics, Material Structure Science
Accelerator Improvement and Nobel Prize

- May.2000
  - Continuous Injections
  - Dual Bunch e^+

- Apr.2003
  - Crab Cavities and Quasi-simultaneous Injection

- Dec.2008
  - Flexible Upgrades for Accelerator Operation
Simultaneous Injection Requirements

◆ Linac clients
  ❖ KEKB
    8-GeV e− 1nC x2
    3.5-GeV e+ 1nC x2
    (with 10nC primary e−)
  ❖ PF 2.5-GeV e− 0.1nC
  ❖ (PF-AR 3-GeV e− 0.2nC)

◆ At first, simultaneous top-up injections to three rings at KEKB and PF
  ❖ Switching beams at 50Hz
  ❖ For stable operation and higher quality exp. results
Beam Instrumentations at Linac

◆ Diagnosis for High-stability (for high luminosity at KEKB ring)
  - Wider dynamic range (0.1nC ~ 12nC)
  - Reasonable resolution

◆ Transverse wake-field suppression
  - Beam position tolerance (0.1mm ~ 0.3mm) against center of quads, otherwise leads to emittance growth

◆ Beam monitors
  - Beam position monitor (Stripline): ~100
  - Streak camera: 2
  - Wire scanner: 14
  - Compact Screen monitor: ~100
  - Wall-current monitor: (~50)
BPM, one of most important Beam Instrumentation

- ~100 monitors (~100 more at beam transport line)
- Resolution down to ~100 µm
- Simultaneous orbit acquisition along the 600m linac
- Simultaneous dual-bunch measurement in a pulse (96ns apart)
- Dynamic range of 0.1nC~12.5nC
- Repetition of 50Hz
- Limited electrode length, fast signal of 10ps - 1ns
- Limited budget
- Limited construction/maintenance man-power
BPM Design

- Strip-line, 50ohm, attached to a quad

Stripline-Type Electrode with a Thickness of $t$

Angular Width $\alpha$

$V_2(\theta=\pi/2)$

$V_3(\theta=\pi)$

$V_4(\theta=3\pi/2)$

$V_1(\theta=0)$

200 mV/div

1 ns/div
Measurement and Data Acquisition

◆ Originally much efforts to develop detectors, shaping amplifiers
  ❖ No budget for all BPMs
◆ Switched to direct waveform acquisition
  ❖ Minimized active components, then minimized calibration tasks, maintenance
  ❖ Equal-length cables
  ❖ One oscilloscope covers about 5 BPMs, or combined 20 (or 40) waveforms
  ❖ 5 - 10Gs/s (with additional interpolation)
  ❖ Possible to measure dual bunches
  ❖ Solved many issues at once!
  ❖ Extract each signal, apply calibration factors, send to upper layer at 50Hz
Database and Calibration Factors

- Pulse **timing** value for each electrode, each monitor, each of four beam modes
- Dynamic **range** (voltage) for each beam mode
- Mapping information up to 3rd order polynomial
- Cable loss for each electrode, combiner loss, charge conversions for single/multi-bunch beams
- About 40 coefficients for each BPM
- Processed on one of 24 DPO7104s in the framework of EPICS software then served directly to clients at 50Hz

Old system served at 1Hz

- 100 BPMs 24 x DPO7104 Clients
- 100 BPMs 19 x TDS680B 19 VMEs ~5 Unix Clients
Evaluation

- Linear position relation between 3 BPMs on changing correctors → deviation ~0.1mm

- Alignment against accompanying quad, changing corrector/quad – offset measurement – every BPM

- Beam based recalibration of BPMs with many measurements (use of fourth information other than x, y, charge)

- Charge calibration was carried with Faraday cup (energy at ~250MeV)
Orbit Stabilization

◆ Simple orbit feedback

❖ Monitor

 обяз Type 1: Two BPM (~90 degree phase apart)
 обяз Type 2: Weighed average of BPMs over a betatron wave length

❖ Actuator: Two steerings
## Orbit Fluctuations and Stabilizations

**At the beginning of the commissioning, both stabilized well**

- Daily change, peak at 6 O’clock, caused by SB_C
- 40-minute changes in A sector
- Later attributed to SHB

### Graphs

<table>
<thead>
<tr>
<th>2XY e- KEKB Orbit</th>
<th>A1 Orbit</th>
<th>A2 Orbit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drag Button-1 to Zoom Graph</td>
<td>Clear Data</td>
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EPICS Meeting, NSRRC, Taiwan

Dual-bunch Energy Equalize, and Feedback

.energy equalization is important for stable operation

Measurement at Bunching section after equalization

First Bunch

Energy at A1_B8 : 15.5378002/3662.22 MeV

\[ a = 1.23249 \pm 0.0077 \quad b = 0.0312 \pm 0.0017 \]

Second Bunch

Energy at A1_B8 : 15.7688654/3682.655 MeV

\[ a = 1.23249 \pm 0.0077 \quad b = 0.0312 \pm 0.0017 \]

Stabilization at R0 Arc

Beam Fluctuation

Read Beam Position (x and dx) at Reference Points BPM BPM

Convert into Timings

Klystron Klystron

Beam Positions of 2-Bunches

- Beam Fluctuation
- Convert into Energy Difference
- Average (Integration)
- x Gain – Offset

Energy Difference Feedback

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Achromatic and Isochronous Arc

◆ Optics correction by quadrupoles and sextupoles using BPM and streak camera
Beam Mode Pattern Generators

◆ There are several versions
  ❖ Because we were commissioning new pulsed hardware equipment, the beam optics schemes, event system itself, etc, since autumn 2008
  ❖ One of them is mostly used, remote or human controllable, automatic- prioritized arbitrated, etc

Remote controlled automatic pattern arbitrator

Manual pattern generator

❖ Typical operation in Apr.2009.
  ✷ ~25Hz for KEKB LER
  ✷ ~12.5Hz for KEKB HER
  ✷ ~0.5Hz for PF
BPM DAQ

- Tektronix DPO7104 can acquire data at >50Hz.
  - With embedded EPICS
- Beam modes are recognized by events through CA network.
- Clients can monitor data of an interested beam mode.
- 26 oscilloscopes are installed.
- 100 BPMs are synchronized. (100 BPMs at BT as well soon)
Other EPICS Development Activities at KEK

◆ By A. Akiyama, et al
  ❖ Embedded IOC on FPGA-based controller

◆ By M. Satoh, et al
  ❖ Embedded IOC on oscilloscopes

◆ By A. Kazakov, et al
  ❖ Redundant IOC (RIOC with OSI supports)
  ❖ Redundant caGateway
  ❖ ATCA IOC with HPI/SAF support for RIOC
    -Encoding ATCA for STF/ILC-LLRF and μTCA for cERL-LLRF
  ❖ Automatic test system environment

◆ By K. Zagar, et al
  ❖ Wireshark protocol analyzer for CA

◆ By K. Furukawa, et al
  ❖ Event-based fast control system
Summary

- DPO7104 (firmware v1.03 2 years ago) can acquire enough data at ~200Hz.
- All of the BPM requirements (for now) are satisfied, with high availability (because of less active components).
  - Waveform data acquisition has much more possibility in particle accelerator applications.
- For the future, faster and more precise processing is necessary.
  - ERL at 1.3GHz-continuous and ILC at 10MHz-10Hz, with precision of <1 micro-m.
Summary 2

❖ Oscilloscope

❖ Not a simple measurement instrument

❖ But a data acquisition station
  ✤ With embedded application software
    • EPICS framework in our case

❖ And a data processing system
  ✤ With direct networking capability
    • Preferable with Linux, but acceptable with Windows
Thank you