Pulsed magnet control system using COTS PXIE devices and LabVIEW

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1. Introduction
2. Overview of the system
3. PXI / PXI express devices
4. Software
5. Evaluation and Operation
6. Summary

Key words: Event Timing System, EPICS, LabVIEW, PXI / PXI express
Accelerator complex in KEK Tsukuba

Beam from Injector and Storage Current

- **SuperKEKB**: 7 GeV e- 2600 mA
- 4 GeV e+ 3600 mA
- **PF**: 2.5 GeV e- 450 mA
- **PF-AR**: 6.5 GeV e- 60 mA

**SuperKEKB**
3 km

**PF**
2.5 GeV

**HER**
6.5 GeV

**LER**
4 GeV

**Belle II**

**PF-AR**
6.5 GeV

**2x beam current**

**40x Luminosity**
4 rings and 1 linac
- Two light source rings
  - PF, PF-AR
- Two collider rings
  - SuperKEKB LER, HER

Parallel configuration
- No booster ring

All storage rings
- Full energy injection
- Top-up injection
- Two electron guns
  - RF gun for low emittance injection to SuperKEKB HER
  - Thermionic gun for high charge (10 nC) to produce large number of positrons

Positron injection to LER
Accelerator complex in KEK Tsukuba

<table>
<thead>
<tr>
<th></th>
<th>KEKB</th>
<th>SuperKEKB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>e⁻</td>
<td>e⁺</td>
</tr>
<tr>
<td>Life time (min.)</td>
<td>200</td>
<td>150</td>
</tr>
<tr>
<td>Emittance (μm)</td>
<td>310</td>
<td>1400</td>
</tr>
<tr>
<td>(H/V)</td>
<td>100/15</td>
<td>40/20 (H/V)</td>
</tr>
<tr>
<td>Bunch charge (nC)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

- very short life time
  - a few min. interruption of injection is not acceptable.
- small emittance and high bunch charge requirements
  - common parameter operation is no longer valid.

Simultaneous (shot by shot) injection with different magnet parameter at 50 Hz is necessary.
Beam energy and structure of our linac

- 600 m long, 8 sectors
- Maximize common energy section to use DC magnets as much as possible
- Install pulsed magnets mainly in sector 3 to sector 5

<table>
<thead>
<tr>
<th>Beam energy</th>
<th>2</th>
</tr>
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<tbody>
<tr>
<td>PF (2.5 GeV)</td>
<td></td>
</tr>
<tr>
<td>LER (4 GeV)</td>
<td></td>
</tr>
<tr>
<td>PF-AR (6.5 GeV)</td>
<td></td>
</tr>
<tr>
<td>HER (7 GeV)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bend</td>
<td>2</td>
</tr>
<tr>
<td>Quadrupole</td>
<td>32</td>
</tr>
<tr>
<td>Steering</td>
<td>58</td>
</tr>
</tbody>
</table>
How to realize?

- Requirements
  - Low cost and high reliability
    - We need 100 unit
  - Flexible setting
    - On / off control is not enough
  - Small size
    - Compatible with old DC power supply
  - High efficiency
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  - MRF Event Timing System
    - Compatible with existent timing system
  - EPICS
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  - Limited time and human resources for development
    - That is why I write software….
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  - Use LabVIEW for programming language
  - Use standard windows PC for CPU
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<table>
<thead>
<tr>
<th>Suitable System scale</th>
<th>Full custom</th>
<th>Catalog product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development costs</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Development time</td>
<td>Long</td>
<td>Short</td>
</tr>
<tr>
<td>flexibility</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>
System configuration of the pulsed power supplies

Standard power supply unit (4 x quad + 4 x steering)

- DC power supply
- Pulse driver (for quad)
- Pulse driver (for steering)
- PXI express
- cRIO (interlock and data logging)
- Operater’s machine

CSS archiver
NAS

PC

DC power supply controller server

PXI express (fast control)

Event signal

Pulse driver
Magnet

EPICS CA
LXI ver 1.3
NI network shared variable

Standard unit
 Timing and fast control

- PXI express system is adopted for fast control of the power supplies (8GB/s).
- All of the intelligent functions are processed by PXI express unit
  - Pulse driver works as a kind of power amplifier
  - Separation of control and power section makes it possible for us to flexible installation of different capacity of power supplies.
- MRF (Micro-Research Finland) event receiver with PXI form factor is used for timing control
  - MRF event timing system is used as a master timing system of our linac.
- Mode and shot ID information are sent to the event receiver via optical fiber
  - Mode determine the destination of the beam.
  - Shot ID is used for tagging the data.
EPICS and LabVIEW

- Declare PVs
  - Dynamic declaration is possible only by LabVIEW running on Windows
- Get/put value
- Process by value change event

https://www.ni.com/ja-jp/innovations/white-papers/12/introduction-to-epics.html
Data flow in main program
DAC output control

- Slew rate is limited by voltage of the power supply
- Beam timing $t_3$ is fixed 3 ms after trigger pulse.
- Flat top width $t_2$ is fixed 0.5 ms before $t_3$
- $V_1$ is always 10 V
- $V_2$ is determined by value of output current
- $t_1$ is calculated from other parameters
- DAC output is determined from these parameters

Minimize energy consumption
Data flow in main program
Data flow in main program
Data flow in main program

Point data (8 ch x 1 point @ beam timing) is extracted from ADC data array (8 ch x waveform) and stored in the PV with appropriate mode name.
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Prefix: magnet name: type: mode
LiMag:PF_32_4::IREAD_R::KBE
LiMag:PF_32_4::IREAD_R::KBP
LiMag:PF_32_4::IREAD_R::PFE
Data in log files

Mode number = destination of the beam

<table>
<thead>
<tr>
<th>Current read back</th>
<th>Current setting</th>
</tr>
</thead>
<tbody>
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<td></td>
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</table>

Each low contains information about each pulse.

A new file is created when the size of previous one is larger than 10 MB. Data size is about 3 TB / year in total.
Trigger dropping rate

- A few drops per day for one unit
- $50 \text{ Hz} \times 24 \text{ hour} \times 3600 \text{ sec} = 4.32 \text{ million}
- Dropping rate is less than 1 ppm

Even though Windows is not a real-time OS, practically it works as we want. This is a kind of brute-force solution. Machine power and careful software writing is important.

Difference of shot ID between adjacent pulses from log data for one day.
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Not perfect but acceptable
There are many devices which is less stable than this one....
Summary

- About 100 pulsed magnets were installed to realize simultaneous top-up injection to 4 different storage rings.
- Setting current and destination can be changed every 20 ms.
- COTS devices are used for control system to reduce development cost and time.
- PXI / PXI express with MRF's Event Timing System is adopted.
- Software is written by LabVIEW with EPICS modules.
- Real-timeliness and long-term stability are not perfect but acceptable for present operation.
members

- K. Furukawa
  - Adviser, management of the project, timing system
- T. Kamitani
  - Magnet design
- F. Miyahara
  - Timing system
- T. Natsui
  - Energy recovery pulse driver
- M. Satoh
  - Timing and control system, software
- K. Yokoyama
  - Magnet design
- M. Yoshida
  - Energy recovery pulse driver
- S. Ushimoto
  - cRIO interlock and data acquisition system
- H. Satome
  - Device driver for event receiver

Thank you for your attention!