Development of Gated Turn-by-Turn Position Monitor System for the Optics Measurement During Collision of SuperKEKB

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Abstract
Gated turn-by-turn monitor system to measure optics functions using non-colliding bunch has been developed for SuperKEKB accelerators. With the fast, glitch canceling beam switch, beam position of the target bunch will be measured without affecting the fine COD measurement using narrow-band detectors. The gate timing and the bunch position detection are controlled by the Spartan-6 FPGA. The performance of the system, such as the gate timing jitter, data transfer speed from the system to EPICS IOC and the noise effect to the downstream narrow-band detector are reported.

Introduction
SuperKEKB Collider
40 times larger luminosity (8×10^{35}cm^{−2}s) by
• Reducing vertical beam size at IP
• Double beam currents [Nano-beam scheme]
• Low emittance (few nm mrad)
• Low X-Y coupling (less than 0.3%)
• Low vertical dispersion

Gated turn-by-turn BPM
• Should not disturb the measurements of normal narrowband BPM. Switching noise should be suppressed.
• Rise and fall time of the gate should be short enough with the nominal bunch separation of 40μsec.
• Enough isolation for turn-by-turn channel, much better than 70dB.
• Compact, all-in-one, (relatively) cheap system.

Gate timing jitter
Use histogram function of sampling scope (20GHz)
Jitter 3.2ps in STD
Mean timings of all the delay setting stay within
20ps

Optics measurements
KEKB
• Excite one of steering magnets and measure COD response (Single kick method). Several steering magnets with different phase advance are used.
• Betatron functions, X-Y couplings
• Shift RF frequency
Dispersion functions
Low current (~30mA), single beam (without collision) multi bunched beam.
Not safe for large beam current nor colliding beam
Beam-beam tune shift
Strong bunch-by-bunch feedback
SuperKEKB
• Initial optics correction with similar methods used in KEKB (single kick, dispersion)
• New optics measurement using gated turn-by-turn beam position monitors (TbT).

Gated turn-by-turn BPM:
Optics measurement (and correction) with colliding huge beam current.

Main parameters of SuperKEKB rings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>HER</th>
<th>LER</th>
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</thead>
<tbody>
<tr>
<td>Energy (GeV)</td>
<td>7</td>
<td>4</td>
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<tr>
<td>Circumference (m)</td>
<td>3016</td>
<td></td>
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<tr>
<td>Max. beam current (A)</td>
<td>2.6</td>
<td>3.6</td>
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<tr>
<td>Number of bunches</td>
<td>2500</td>
<td></td>
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<tr>
<td>Single bunch current (mA)</td>
<td>1.04</td>
<td>1.44</td>
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<tr>
<td>Bunch separation (ns)</td>
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<tr>
<td>Bunch length (mm)</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>RF frequency (MHz)</td>
<td>508.887</td>
<td></td>
</tr>
<tr>
<td>Harmonic number</td>
<td>5120</td>
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</tr>
<tr>
<td>Revolution frequency (kHz)</td>
<td>99.39</td>
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<tr>
<td>β* at IP H/V (mm)</td>
<td>25/0.30</td>
<td>32/0.27</td>
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<tr>
<td>Horizontal emittance (mm)</td>
<td>4.6</td>
<td>3.2</td>
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<tr>
<td>X/Y coupling (%)</td>
<td>0.28</td>
<td>0.27</td>
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<tr>
<td>Vertical beam size at IP (mm)</td>
<td>59</td>
<td>48</td>
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<tr>
<td>Rad. damping time (μs)</td>
<td>58/29</td>
<td>43/22</td>
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<tr>
<td>Number of BPMs</td>
<td>446</td>
<td>444</td>
</tr>
<tr>
<td>Number of TbT monitors</td>
<td>135</td>
<td>135</td>
</tr>
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</table>

Optics measurement (and correction) with colliding huge beam current.

Fast Gate Switch
Hittite HMC232LP4
Switching noise cancel
Better isolation for TbT channel

Excellent performance
Ultra-low SW noise
Fast rise/fall time (~0.6ns)
Good isolation (~8dB)

Linearity, Dynamic Range, position error
PF-AR ring
508MHz BPF
Wideband (BW24MHz)
Narrowband (BW5MHz)
20dB LNA

Standard deviation of ADC from -50dBm to -10dBm ~ corresponds roughly 30μm of position jitter

Board control and data transfer
GTe(Gigabit Ethernet connection) by MicroBlaze
Status monitors (RF, Fid, temperatures, voltage)
RAW and calculated data on DDR3 SDRAM
EPICS R314.12.1 + ASYN4-21 + Seq
GbE(Gigabit Ethernet connection) by MicroBlaze
Board control and data transfer
SiTCP for much faster data transfer (~900M/s)

Noise to narrowband detector
SW noise - negligibly small
Radiation (amplifiers, RF distributors etc.): much lower than most of the NIM modules.
However...
More RF shield, separate rack etc...

Future development (in progress)
SiTCP for much faster data transfer (~900M/s)
Automatic record parameters on EPEPROM
Firmware update through Ethernet

Summary
• Developed and tested turn-by-turn BPM detector with fast gate switch
• SW noise has been successfully suppressed
• Timing control using FPGA
• Data transfer checked. Trying to speed up by SiTCP

The technology of fast gate switch with noise cancelling has been developed by Prof. T. Naito and Prof. T. Ieiri. We would like to express our sincere application to Prof. T. Obina for the support on the EPICS system and SiTCP system. We thank our colleague of SuperKEKB beam instrumentation for numerous support on the development.