Beam Trip Analysis by Bunch-by-bunch BPM System in BEPCII storage rings

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Outline

- BEPCII storage rings
- Bunch-by-bunch system
- Beam trip analysis results
  - RF trip
  - Magnet power instabilities
  - Beam instabilities
- Summary
Beam trip in BEPCII storage ring

- **Cause of beam trip**
  - Almost every subsystem failure/instabilities
  - ...

- **Result of beam trip**
  - Degrade the operating efficiency
  - Cost troubleshoot time
  - Cause other subsystem trip
  - ...

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**Parameters**

<table>
<thead>
<tr>
<th></th>
<th>Electron ring</th>
<th>Positron ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumference</td>
<td>237.53m</td>
<td>237.53m</td>
</tr>
<tr>
<td>RF frequency</td>
<td>499.8MHz</td>
<td>499.8MHz</td>
</tr>
<tr>
<td>Harmonic number</td>
<td>396</td>
<td>396</td>
</tr>
<tr>
<td>The number of RF cavity</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>MAX beam current</td>
<td>930mA</td>
<td>930mA</td>
</tr>
<tr>
<td>Minimum bunch interval</td>
<td>4ns</td>
<td>4ns</td>
</tr>
<tr>
<td>Revolution frequency</td>
<td>1.2621MHz</td>
<td>1.2621MHz</td>
</tr>
</tbody>
</table>

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Beam trip analysis (post-mortem diagnose): Urgent! Complicated!
Bunch-by-bunch system overview

- Bunch-by-bunch position measurement (BPM) prototype for BEPCII storage ring

Front-end

Digital signal process system: (ADC, FPGA, DDR)

Control and Interface

Computer

Button Beam Position Monitor

Commercial DAQ

Four 14bit 500MHz ADC
FPGA: SX550T
Double 4GB DDR3 memory
Front end and sampling

- Sampling rate: RF frequency (499.8MHz).
- To achieve high isolation between neighbouring sampling: All element in the front end should have large analogue bandwidth to prevent bunch-by-bunch signal coupling.
- The front-end adjust the four signal in the same phase.

Take the case of positron signal

![Diagram of front end and ADC schematic](image)

**Analog Signal form BPM**

- Attenuator phase shifter
- Low pass filter (ADC)
- Sampling clock
- To FPGA

**from accelerator main timing clock**

$f_{rf} = 499.8 MHz$
Front end and sampling

- Sampling clock is from the accelerator main timing source.
- Position ideal sampling schematic: ADC sampling at each top of bunch signal.
- Calculate the bunch position and bunch current.

\[
X = k_x \frac{V_B + V_C - V_A - V_D}{V_A + V_B + V_C + V_D}
\]

\[
Y = k_y \frac{V_A + V_B - V_C - V_D}{V_A + V_B + V_C + V_D}
\]

\[
I_{\text{bunch}} = k_c (V_A + V_B + V_C + V_D)
\]
Digital signal process for beam trip detection

- Write all sampling data to DDR.
- 4GB DDR3 memory (2 second bunch by bunch data).
- Logic in FPGA judge beam trip (Regardless of the oscillation):
  \[ I_{beem} = k \sum_{t_i}^{t_{i+rev}} (a + b + c + d) \]
  system doesn’t need any interlock signal input.
- After beam trip logic lock the DDR data.
- Transport the DDR data to computer
Beam trip research in BEPCII

→ Beam trip events
  → More than 200 beam trip events had been collected and analysis
  → Many contrast experiment

→ Beam trip analysis by bunch-by-bunch system
  → Time domain and frequency domain
  → Bunch-by-bunch (current, position)
  → Tune in three dimensions

→ Some trip events become clear
  → RF trip
  → Magnet power instabilities
  → Beam instabilities
  → ...

[Graphs showing frequency and position data for X, Y, and S dimensions]
RF trip

Fill pattern: three bunch train bunch Interval 4 bucket (8ns)

The bunch current is uniform in the process of trip
RF trip

Trip event

Before beam trip:
No position change, No obvious Instability oscillation
RF trip

- **Sum signal change** and appear negative value
- The signal change should caused by phase shift between beam signal and sampling clock
- **Sampling clock** is from the accelerator main timing system: stably
- Beam signal shift cause this phenomena

The sum signal in the process of beam trip
RF trip

- Sample at the next bunch signal, Bunch interval is 8 ns
- Beam longitudinal phase changed violently (20 ns) in 200 us
- In storage ring, should cause by beam energy change
Conclusion
- The bunch current is uniform
- No obvious Instability oscillation
- No position change
- Longitudinal phase changed $\rightarrow$ Beam energy change
  $\rightarrow$ RF trip!

Confirmatory experiment
- Turn off the RF manually

Almost all the beam trip events in BEPCII storage rings are accompany with RF trip.
RF trip

• Beam trip in the process of injection

RF trip

Kicker
Many double rings RF trip events

- Electron beam trip earlier than positron beam trip about 0.3ms
- The electron beam trip has no affection on the positron beam motion.
- Double RF trip cause double beam trip.
Magnet power instability

- Magnet power failure cause the beam trip is analysis in the right figure.

- Main to analyze the beam trip caused by Magnet power instability.
Magnet power instability: resonance

- In time domain, Beam position oscillation seriously → instabilities
- In frequency domain, the amplitude at 0.5 is very high → resonance
- The bunch current is nonuniform in the process of beam trip
Whole process analysis

Magnet power instabilities (slow process)
→ Beam position changed, Tune shift to half integer
→ Beam resonance, partial beam loss
→ RF trip, all beam loss

Graph:
- Tune x at 0.5
- Lost part of current
- No obvious oscillation
- RF trip, all beam loss

Timeline:
- 0.507
- 360ms
- 160ms
- 400ms
- 25ms
- t
Magnet power instability

Magnet power instabilities (fast process)
→ Position change
→ Partial beam loss
→ RF trip, all beam loss

Position changed, no obvious oscillation

RF trip

20ms
Magnet power instability

- To find the problem magnet, the faster process need faster data
  - Monitor: all magnet power, the monitor system may need as fast as 100Hz.
  - Calculation: form all BPM data in storage ring to find the unstable magnet
Beam instabilities

- BEPCII is running at high beam current condition
- Often change the parameters to get higher luminosity
- Beam instabilities feedback system may work at critical state

Portion current loss
Beam instabilities

Beam oscillation increase along bunch trains, both in vertical and horizontal plane.
The tail bunches at the second bunch train loss firstly cause by oscillation.
Partial beam loss cause the RF trip, and the all beam loss.
**Beam instabilities**

- Solution for beam instabilities trip:
  - Adjustment the parameters of beam instabilities feedback system.
  - Optimize the fill pattern for high current operation.

**Compare beam trip data to the normal beam data:**
- No Position change
- No Bunch tune shift
Summary

- **Advantage**
  - System is very simple and stand alone.
  - Beam based Analysis method: directly and accurately.
  - Good at RF trip and multi-bunch instabilities trip analysis.

- **Turn-by-turn BPM → Bunch-by-bunch BPM**

- **Big data!**
  - What is can we do more from bunch-by-bunch BPM?
  - More powerful for beam trip analysis.
  - ...

Big data!
• Thank you for your attention!