First Simultaneous Top-up Operation of Three Different Rings in KEK Injector Linac

Masanori Satoh (Acc. Lab., KEK) for the injector upgrade group
Overview of Linac Beam Operation
Simultaneous Top-up for three rings in KEK

Accelerator Complex in KEK Tsukuba Campus

- **Linac**
  - 600-m-long e-/e+ injector
  - 50 Hz

- **Two Rings** for High Energy Physics
  - KEKB
    - 8 GeV e- 1 nC x2 bunch
    - 3.5 GeV e+ 1 nC x2
    - (10 nC primary e–)

- **Two Light Sources:**
  - PF 2.5 GeV e- 0.1 nC
  - PF-AR 3 GeV e- 0.2 nC
Accelerator Complex in KEK Tsukuba Campus

- **Linac**
  - 600-m-long e-/e+ injector
  - 50 Hz

- **Two Rings** for High Energy Physics

  Four independent rings share only one injector.

- **Two Light Sources:**
  - PF 2.5 GeV e- 0.1 nC
  - PF-AR 3 GeV e- 0.2 nC
Linac Parameters

• Linac parameters should be changed to a optimized one for each beam injection.
  – Timing (trigger/delay)
  – RF phase
  – Magnet settings
  – Positron Target Insertion/Extraction
  – etc.
Simultaneous Top-up for three rings in KEK

Linac Parameter Switch for KEKB e-

Linac Parameters: KEKB e-

GUN #1

GUN #2

Positron target W

PF

KEKB e-

PF-AR

KEKB e+

e- 1 nC
Simultaneous Top-up for three rings in KEK

Original Beam Operation for KEKB e−/e+, PF

- KEKB e−/e+ : every 90 min.
- PF (PF-AR) : twice daily
Simultaneous Top-up for three rings in KEK

Improvement of Integrate Luminosity at KEKB

- Continuous Injection Mode (CIM)
  - Quasi Top-up Injection
- Linac Parameters are frequently switched

CIM Mode

KEKB e- mode
1 min.

Linac Bema-Mode Change
30 sec.

KEKB e+ mode
4 min.
More Improvement

• Much higher current stability is required for KEKB.

At the same time,

• PF Top-up is also strongly required.
Linac Upgrade: Simultaneous 3-rings Top-up
Operation Scheme for Simultaneous Top-up (Multi-energy Linac Scheme)

• Common DC Magnet Setting
• Several Pulsed Magnets
• Fast Beam Energy Control
  – Fast Low-Level RF Phase Control
  – Fast High Power Klystron Timing Control
Simultaneous Top-up for three rings in KEK

Fast Switching of 3 different beams

Timing switching

RF pulse

Beam
- KEKB 8 GeV e-
- KEKB 3.5 GeV e+
- KEKB 2.5 GeV e-

20 ms (50 Hz)
Simultaneous Top-up for three rings in KEK

Beam Energy along linac for each Injection Beam

Beam energy (GeV) vs s (m) and W_{target}

- KEKB e- (8 GeV)
- KEKB e+ (3.5 GeV)
- PF (2.5 GeV)

GUN #1, GUN #2, 600
Beam Energy along linac for each Injection Beam

Common energy region

Beam energy (GeV)

s (m) $W_{\text{target}}$

0 2.5 3.5 8

GUN #1 KEKB e- KEKB e+ PF

deceleration
Fast Timing Control - Event Based System -
Event System: MRF230 EVG/EVR

• One EVG x1, EVR x21 (on EPICS/VxWorks)
• To change ~100 parameters in every 20 ms.
  • Trigger/delay for Klystron, Pulsed magnet, Gun, etc.
  • Low-Level RF Phase
Simultaneous Top-up for three rings in KEK

Event Generator

Central

Injection

ARC

e⁻ Gun

Cont-ABC

KL_B5/B6

SB_B

SH_A1

SB_A

e⁺ Target

Cont-1

Cont-2

Cont-3

Cont-4

Cont-5

SB_C

SB_1

SB_2

SB_3

SB_4

SB_5

KL_51/52

e⁻ BT (PF: 2.5GeV, 0.1nC)

e⁺ BT (KEKB: 3.5GeV, 2nC)

e⁻ BT (KEKB: 8GeV, 2nC, PFAR: 3.0GeV, 0.1nC)
Simultaneous Top-up for three rings in KEK

Set Event Code for KEKB e-

Event Generator

Central

KL_B5/B6  SB_B  SH_A1  SB_A

ARC

Cont-ABC  SB_C  SB_1  SB_2  SB_3  SB_4  SB_5  KL_51/52

e\^- Gun

Cont-1  Cont-2  Cont-3  Cont-4  Cont-5

e\^+ Target

Event Receivers

Injection

e\^- BT (PF: 2.5GeV, 0.1nC)
e\^+ BT (KEKB: 3.5GeV, 2nC)
e\^- BT (KEKB: 8GeV, 2nC, PFAR: 3.0GeV, 0.1nC)
Set Event Code for KEKB $e^+$

Event Generator

Central

Injection

$e^-$ Gun

$e^-$ BT (PF: 2.5GeV, 0.1nC)

$e^+$ BT (KEKB: 3.5GeV, 2nC)

$e^-$ BT (KEKB: 8GeV, 2nC, PFAR: 3.0GeV, 0.1nC)

Event Receivers

KL_B5/B6
SB_B
SH_A1
SB_A

Cont-ABC
SB_C
SB_1
SB_2
SB_3
SB_4
SB_5

Cont-1
Cont-2
Cont-3
Cont-4
Cont-5
Set Event Code for **PF**

Simultaneous Top-up for three rings in KEK

**Event Generator**

- **Central**
- **Injection**

**Event Receivers**

- **e⁻ Gun**
  - **e⁻ BT (PF: 2.5GeV, 0.1nC)**
- **e+ Target**
- **e+ BT (KEKB: 3.5GeV, 2nC)**
- **e⁻ BT (KEKB: 8GeV, 2nC, PFAR: 3.0GeV, 0.1nC)**

- **KL_B5/B6**
- **SB_B**
- **SB_A**
- **SH_A1**
- **Cont-ABC**
- **SB_C**
- **SB_1**
- **SB_2**
- **SB_3**
- **SB_4**
- **SB_5**
- **KL_51/52**

**2010/9/16**

M. Satoh/ KEK Linac Control
Simultaneous Top-up for three rings in KEK

New PF-BT
Simultaneous Top-up for three rings in KEK

Original PF-BT

Beam switchyard

KEKB e-/e+ Injection
ECS ON

KEKB e+ (3.5 GeV)

KEKB e- (8 GeV)
Simultaneous Top-up for three rings in KEK

Original PF-BT

Beam switchyard

PF Injection
Switching ECS Bends #1 and #6

Switching Bend ON

Original PF-BT

PF
Construction of New PF-BT

Beam switchyard

Simultaneous Top-up
ECS ON
Pulsed Switching Bent

New PF-BT

ECS

Pulsed Bend

PF

KEKB e+ (3.5 GeV)
KEKB e- (8 GeV)
## Pulsed Bend and Power Supply

<table>
<thead>
<tr>
<th><strong>Pulsed bend:</strong></th>
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<tbody>
<tr>
<td>Beam bending angle:</td>
<td>7 deg. (up to 3 GeV)</td>
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<tr>
<td>Max. magnetic field:</td>
<td>1.36 T</td>
</tr>
<tr>
<td>Gap:</td>
<td>157 x 30 mm (W x H)</td>
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<tr>
<td>Coil:</td>
<td>1 turn</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Power supply:</strong></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Max. current:</td>
<td>32 kA (12.5 Hz)</td>
</tr>
<tr>
<td></td>
<td>27 kA (25 Hz)</td>
</tr>
<tr>
<td>Pulse width:</td>
<td>200 μs (half-sinusoidal)</td>
</tr>
<tr>
<td>Stability:</td>
<td>0.1%</td>
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</table>

<table>
<thead>
<tr>
<th><strong>Ceramic chamber:</strong></th>
<th></th>
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<tbody>
<tr>
<td>Length:</td>
<td>1200 mm</td>
</tr>
<tr>
<td>Coating:</td>
<td>Ti (1 μm)</td>
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</tbody>
</table>
Fast Switching Between e- and e+ Operation
Photograph of New Target

W target (φ5 mm)

Hole (φ5 mm) for e-
Fast Switching e-/e+ Scheme

- e- 10 nC
- e+ 1 nC
  (KEKB e+)

**e+ operation**

- Pulsed steering magnet
- Hole
- e+ target
- Pulsed steering magnet
Simultaneous Top-up for three rings in KEK

Fast Switching e-/e+ Scheme

- e- 1 nC
  (KEKB e-)

\[ \text{e- operation} \]

- Pulsed steering magnet
- B
- Hole
- W
- e+ target
- Pulsed steering magnet

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Simultaneous Top-up for three rings in KEK

Result of Beam Study

Old scheme

w/o e+ target
(normal operation)

X [mm]

Y [mm]

I [nC]

New scheme

w/ e+ target

X [mm]

Y [mm]

I [nC]
Fast Beam Position Measurement
BPM-DAQ System Upgrade:

- **Old System:**
  - 5 GSa/s, 8 bits, 1 GHz Analogue BW
  - GPIB control
  - Measurement performance: up to 1 Hz

- **New System:**
  - 10 GSa/s, 8 bits, 1 GHz Analogue BW
  - 100 Mbps/GbE Network
  - DAQ Speed: more than 50 Hz
  - Twenty four systems have been installed.

Old System
(VME + Oscilloscope with GPIB)

New system
EPICS embedded IOC
SIMULTANEOUS TOP-UP OPERATION OF KEKB e-/e+ and PF
Simultaneous Top-up Operation

- Beam current stability in Original Operation
  - KEKB: 300 mA (~ 50 %)
  - PF: 240 mA (~ 53 %)
Simultaneous Top-up Operation

- Beam current stability since Apr. 2009
  - KEKB: 1 mA (~ 0.05%) : e-: 12.5 Hz, e+: 25 Hz
  - PF: 0.05 mA (~ 0.01%) : 0.5 Hz
Simultaneous Top-up for three rings in KEK

Remaining Problem: PF-AR Injection

- AR-BT and KEKB-BT share the long part of beam line.
- AR-BT: \(~3.1\) GeV
- Tight tunnel space

BT dedicated for PF-AR

Common BT for KEKB and PF-AR

AR

KEKB-BT

AR South Exp. Hall

Linac end

Beam switchyard
Toward SuperKEKB Operation

• Beam lifetime $\sim 10$ minutes.

• PF-AR injection will be a crucial problem
  – Interrupt top-up injection (15 min. twice daily)

• In SuperKEKB operation, Beam Energy will be changed.
  – $e^{-}$: 8 GeV $\Rightarrow$ 7 GeV
  – $e^{+}$: 3.5 GeV $\Rightarrow$ 4 GeV

• $e^{+}$ beam with 4 GeV will be available for PF-AR injection.
  • AR-BT Upgrade
  • Pulsed Bend switching between AR-BT and KEKB-BT
Summary and Future Plan

• **Simultaneous Top-up for KEKB e-/e+, and PF was achieved successfully.**
  
  – Beams with different energy and charge (0.1 nC to 10nC)
    
    • 2.5 GeV (PF), 3.5 GeV (KEKB e+), 8 GeV (KEKB e-)
  
  – Development of Many Subsystems and Many Beam Studies.
  
  – Many People's Contributions and Efforts

  – **Great Improvement of Experimental Efficiency at both of KEKB and PF**

• Towards SuperKEKB:
  
  – We are planning the simultaneous injection including PF-AR.
  
  – Simultaneous top-up (SKB e-/e+, PF) and PF-AR 4 GeV e+
Thank you for your attention!