Injector linac upgrade and new RF gun development for SuperKEKB

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KEK
Contents

• Injector linac in KEK and upgrade for SuperKEKB
• RF gun development
• Phase1 commissioning in RF gun
• Conclusion
Mission of electron/positron Injector in SuperKEKB

- 40-times higher Luminosity
  - 20-times higher collision rate with nano-beam scheme
    - Low-emittance even at first turn → Low-emittance beam from Linac
    - Shorter storage lifetime
  - Twice larger storage beam → Higher beam current from Linac

- Linac challenges
  - Low emittance e-
    - with high-charge RF-gun
  - Low emittance e+
    - with damping ring
  - Higher e+ beam current
    - with new capture section
  - Emittance preservation
    - with precise beam control
  - 4+1 ring simultaneous injection
# Required injector beam parameters for SuperKEKB

<table>
<thead>
<tr>
<th></th>
<th>KEKB obtained (e+ / e-)</th>
<th>SuperKEKB required (e+ / e-)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy</strong></td>
<td>3.5 GeV / 8.0 GeV</td>
<td>4.0 GeV / 7.0 GeV</td>
</tr>
<tr>
<td><strong>Charge</strong></td>
<td>e- → e+ / e-</td>
<td>e- → e+ / e-</td>
</tr>
<tr>
<td></td>
<td>10 → 1.0 nC / 1.0 nC</td>
<td>10 → 4.0 nC / 5.0 nC</td>
</tr>
<tr>
<td><strong>Emittance [mm-mrad]</strong></td>
<td>2100 / 300</td>
<td>20 / 20</td>
</tr>
</tbody>
</table>

**Diagram:**
- **3.5 GeV**
  - 10nC x 2 (prim. e-)
  - 5nC x 2 (inj. e-)

- **5.0 Hz (e+ or e-) pulse-by-pulse mode switching**
- **S-band linac**
  - **Bunch Compressor**
  - **RF gun**
  - **DC gun**

- **1.1 GeV Damping Ring circ. 136 m**
- **ECS**

- **50 Hz (e+ or e-)**
- **PF 2.5 GeV e- 0.1nC x 1**
- **LER, AR 6.5 GeV e- 3T**
- **AR (later)**
  - **HER 4.0 GeV e+ 4nC x 2**
  - **HER 7.0 GeV e- 5nC x 2**
  - **HER ECS**

- **RF gun**
- **E+ target & LAS capture section**
- **low emittance RF gun and DC gun**
4 ring injection and Virtual Accelerator (VA)

We have to inject to different 4 rings with one beam line, simultaneous injection.

<table>
<thead>
<tr>
<th></th>
<th>Particle</th>
<th>Energy [GeV]</th>
<th>Charge [nC]</th>
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<tbody>
<tr>
<td>SuperKEKB HER</td>
<td>Electron</td>
<td>7</td>
<td>5 x 2</td>
</tr>
<tr>
<td>SuperKEKB LER</td>
<td>Positron</td>
<td>4</td>
<td>4 x 2</td>
</tr>
<tr>
<td>PF</td>
<td>Electron</td>
<td>2.5</td>
<td>0.3 x 1</td>
</tr>
<tr>
<td>PF-AR</td>
<td>Electron</td>
<td>6.5</td>
<td>5 x 1</td>
</tr>
</tbody>
</table>

50 Hz pulse-to-pulse control system is required. Developing pulse magnets and pulse to pulse LLRF control system.
Flux concentrator (FC)

The positron bunch intensity is boosted from 1 nC to 4 nC by efficient FC capture. This FC based on the SLAC-IHEP model design. Primary beam: 3.3 GeV 10 nC e-. Emittance will be reduce by using the new damping ring.
Emittance Preservation

- Linac is 600 m. Misalignment can not avoid
- Transverse kick due to wakefield increases slice emittance
- Offset injection may solve the issue
- Orbit have to be maintained precisely
- Misalignment should be <0.1mm locally, <0.3mm globally

Mis-alignment leads to Emittance blow-up

Orbit manipulation compensates it

Sugimoto et al.
Double electron gun system

This thermionic gun was used for Phase1 positron primary beam and normal operation. RF gun beam line was used for study in Phase1.
RF gun development
Why we need advanced RF gun?

Normal RF gun does not have focusing E-field.
5 nC beam charge has much higher space charge.
We need advanced RF gun.

5 nC beam tracking simulation.
Beam size will be too large for our use.
normal cavity

cavity

focus: Weak

E-field on-axis

accelerate

focus

E-field, Er/r

z

devolved cavity

focus: Strong

E-field on-axis

accelerate

focus

E-field, Er/r

z

Beam

Effectve E-field on-axis

accelerate

focus

E-field, Er/r

z

Beam

Effective E-field on-axis

accelerate

focus

E-field, Er/r

z

Beam
Annular coupling cavities makes narrow accelerating gap

The close nose makes focus field. Side coupled cavity can be made the close nose. But, long drift space is problem. One solution is to use tow standing wave cavity.
Normal side coupled cavities

Quasi traveling wave side coupled cavities
Whole cavities design

This RF gun has total of seven acceleration cavities. These are divided into two standing wave structure of 3 and 4 side coupled cavities respectively.

First cavity (Cathode cell)
Maximum E-field at surface: 120 MV/m

Regular cell
Maximum E-field at surface: 100 MV/m

Emittance: 5.5 mm-mrad @ 5 nC

This RF gun can generate 10 nC beam
Beam tracking simulation result (5 nC)

- Emittance 5.5 mm-mrad
- Gun Exit: Size 0.4 mm
- Energy spread 0.6%
- Bunch shape

5 nC 11.5 MeV parallel beam
3D design

coupling cavities

accelerating cavity

beam

cathode

RF

90 deg hybrid
Installed RF gun at A1

- RF gun
- Cathode
- 90 deg Hybrid
- Laser port
Layout for 25 Hz Yb:YAG Laser system

- Synchronization system
  - 51.9 MHz and 2856 MHz LLRF
- Yb-doped fiber oscillator with Transmission grating
  - 51.9 MHz
  - 0.2 nJ @ 1037 nm
- Yb-doped fiber pre amplifier
- Transmission grating pair stretcher
- Yb-doped fiber pre amplifier
- Yb:YAG thin-disk multipass amplifier
  - >μJ @ 1037 nm
- Yb-doped fiber main amplifier
  - 25 Hz
  - Single or Double bunch
- Pulse picker
- Yb-doped fiber main amplifier
- SHG (BBO)
  - 517 nm
- FHG (BBO)
  - 259 nm
- RF GUN
Layout for 25 Hz Yb:YAG Laser system

Yb Fiber Oscillator

Yb Fiber Pre-Amplifier

Stretcher

Yb Fiber Main-Amplifier

Multi-pass Amplifier

Frequency doubling

Yb:YAG thin disk
Laser injection component near the RF gun.
Laser pulse is transported as 2\textsuperscript{nd} harmonics, and convert to 4\textsuperscript{th} harmonics by BBO. Injection angle is adjusted with remote control mirror to angled laser port.
Phase 1 commissioning in RF gun
Beam charge stability

• Target of RF gun study in Phase 1 was HER injection at 1 nC.
• Charge stability is most important point.

7 hours beam charge stability. (5/19)

1.724 +/- 0.07 nC

We achieve 5% charge stability at 1 nC.
Laser and beam profile stability

Laser profile should be improved.
Position jitter is also one of problem. (Horizontal 0.5 mm, Vertical 0.2 mm)
Emittance measurement by using Q scan method

1 nC beam

<table>
<thead>
<tr>
<th></th>
<th>Horizontal (projection)</th>
<th>Vertical (projection)</th>
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<tbody>
<tr>
<td>A1 chicane</td>
<td>28.3 (31.8)</td>
<td>26.4 (29.4)</td>
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<tr>
<td>A1 M</td>
<td>20.3 (20.8)</td>
<td>17.7 (18.3)</td>
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<tr>
<td>B sector dump</td>
<td>48.5 (52.7)</td>
<td>21.7 (22.2) mm-mrad</td>
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</table>

Measurement emittance is larger than simulated emittance. Due to laser pulse quality.
A1 chicane Q scan

**Horizontal**

Emittance 28.3 (31.8) mm-mrad

\[ a = 1.284 \pm 0.034, \ b = 1.649 \pm 0.008, \ \text{Nemt: 28.3 (31.8) mm-mrad at 32.55 MeV} \]

**Vertical**

Emittance 26.4 (29.4) mm-mrad

\[ a = 1.688 \pm 0.029, \ b = 5.122 \pm 0.710, \ \text{Nemt: 26.4 (29.4) mm-mrad at 32.25 MeV} \]
HER injection with RF gun

We achieved HER injection with RF gun.
It was continuous 10 days injection.
Beam quality and stability are almost same as thermionic gun.

Efficiency is almost 100%
Conclusion

- In KEK injector, several upgrade was carried out.
- Thermionic gun was used for Phase1. Charge of electron beam is 1 nC. Charge of positron beam is 1 nC with FC.
- We achieved charge of 1 nC beam generation by using the new RF gun.
- Laser power stability is acceptable. (charge stability : 5%)
- Position stability is still not so good at RF gun.
- Emittance is approximately 20 mm-mrad.
- SuperKEKB HER Ring injection test was succeeded with the RF gun. We achieved 10 days stable injection.
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**Linac Schedule Overview**

**RF-Gun e-beam commissioning at A,B-sector**
- e- commiss. at A,B,J,C,1
- e+ commiss. at 1,2 sector (FC, DCS, Qe- 50%)
- e- commiss. at 1,2,3,4,5 sector
- non damped e+ commiss. at A→5 sectors

**Phase 1**: high emittance beam for vacuum scrub
**Phase 2,3**: low emittance beam for collision

**Phase 1**
- Beam Licenses in steps
- Low Emittance Beams
- 4+1 Ring Injections

**Phase 2**
- Without Top-up
- Direct PFA/AR BT

**Phase 3**
- damped e+ 4-th stage
- with VXD 5-th stage

**Initial**
- 1 nC
- Phase 1

**Improved**
- 2 nC
- Phase 2
- 4 nC
- Phase 3

**Low Emittance**
- Beams in steps

**High Emittance**
- Beam Licenses

**Electron**
- 

**Positron**
- 

**Low current electron**
- 

29

2014

2015

2016

2017

2018
Thank you for your attention