The Present Performance and Future Upgrade of the KEKB Electron Linac

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Introduction, KEK e⁻ Linac

- KEKB Asymmetric Collider Complex and Belle Detector for CP-Violation Study
- Stable and Robust Operation of Linac for Higher Experiment Efficiency
- Many Active Operation Parameters at Microwave Systems, etc.
- Frequent Switching between
  - KEKB e⁻ 8 GeV 1.28 nC Single Bunch
  - KEKB e⁺ 3.5 GeV 0.64 nC Single/Dual Bunch
    (Primary e⁻ 10 nC)
  - PF e⁻ 2.5 GeV 0.2 nC Multibunch
  - PFAR e⁻ 2.5/3.0 GeV 0.2 nC Multibunch
## Regular Operation Statistics

### Basic Operation Performance

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>KEKB e−</td>
<td>1.28</td>
<td>8.0</td>
<td>~14/18</td>
<td>~1.5</td>
</tr>
<tr>
<td>KEKB e+(1)</td>
<td>0.64 x 1</td>
<td>3.5</td>
<td>~14</td>
<td>~8 (single bunch)</td>
</tr>
<tr>
<td>KEKB e+(2)</td>
<td>0.64 x 2</td>
<td>3.5</td>
<td>~18</td>
<td>~4 (double bunch)</td>
</tr>
<tr>
<td>PF e−</td>
<td>0.2</td>
<td>2.5</td>
<td>1</td>
<td>~5</td>
</tr>
<tr>
<td>PFAR e−</td>
<td>0.2</td>
<td>2.5/3.0</td>
<td>12</td>
<td>~4</td>
</tr>
</tbody>
</table>

### Operation Hours

<table>
<thead>
<tr>
<th></th>
<th>FY1999</th>
<th>FY2000</th>
<th>FY2001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Operation Time</td>
<td>7297</td>
<td>7203</td>
<td>7239</td>
</tr>
<tr>
<td>Machine Down Time</td>
<td>768 (10.5%)</td>
<td>601 (8.3%)</td>
<td>385 (5.3%)</td>
</tr>
<tr>
<td>Beam Loss Time</td>
<td>74 (1.0%)</td>
<td>54 (0.8%)</td>
<td>22 (0.3%)</td>
</tr>
</tbody>
</table>

Machine Down: Machine was not ready. (including rf-trip, 10-minute maintenance, etc)
Beam Loss: Machine was not ready when an injection was requested.
Beam Quality Control

- **rf System Optimization**
  [Routine Monitoring of Beam/Machine Parameters]

- **Emittance and Matching Condition**

- **rf Phasing**
Advanced Injection for KEKB (1)

- Double Bunch Injection
  Positron Double Bunch in one rf Pulse

- Doubled the Injection Rate
  Luminosity Increase ~8%
  (Bunch Pattern Restriction)
  Already 4-week Experience
Advanced Injection for KEKB (2)

- **Continuous Injection During Experiment**
  - Detector Veto
  - Beam Pipe Heating
  - Switch to PFAR

  Luminosity Increase ~20%

- Both “Double-Bunch Injection” and “Continuous Injection” in the upcoming Autumn Operation
Linac / Ring Upgrade for SuperKEKB

◆ for Precise Measurement of $B$-meson System Parameters and Search for New Physics (ex. SUSY)

SuperKEKB : Luminosity of $10^{35}$ cm$^{-2}$ s$^{-1}$

with Major Upgrade of Linac and Ring

◆ Luminosity Increase
  (1) Squeezing Beta at Interaction Region (by factor of 3.3)
  (2) Increasing e$^-$ and e$^+$ Beam Current (by factor of 3.3)
  (3) Exchanging Energies of e$^-$ and e$^+$ (to cure e$^-$ cloud issues)

◆ for Linac
  (3) is the Major Challenge, as well as (2)
Two Schemes are Considered
  (a) Higher Gradient with C-band Structures
  (b) Recirculation of Positron
**Linac Energy Upgrade with C-Band**

- **e⁺ 8.0 GeV with Doubling the Acceleration Gradient**
  
  **C-Band Structures**: 21 → 42 MeV/m, 320 MeV/unit, 24 Units

- **Lower Emittance with e⁺ Damping Ring**
  
  (1) for Smaller Aperture of the C-Band Structures
  (2) for Design of the Interaction Region at the Ring

- **Overview of the Scheme**  *(Green Part is New/Upgrade)*
C-Band (5712MHz) Components R & D

- Being Designed for KEKB Linac, Based on the Development by JLC C-Band Group
- C-Band Klystron: 50MW from Toshiba
- Pulse Modulator: Compact Type, First Version under Production
- Driver Klystron: Modified 40kW, Designing
- Pulse Compressor: TE038 LIPS Type, Designing
- Acceleration Structure: $2\pi/3$-mode, under Fabrication
- rf Components: Designing
- High-Power/Acceleration Test at Spring 2003
Linac Energy Upgrade with Recirculation (Backup)

- No Major Change in Acceleration Components
  Damping Ring to Keep Positron for the Next Pulse

- Slightly Complicated Operation Scheme
  Return Line, Bypass Lines at Arc and Target
  Multi-Bunch Acceleration with Very Different Characteristics
  Before/After the Target

- Overview of the Scheme
Linac Beam-Current Enhancement

◆ $e^-$ Beam Charge:
  
  \[ \begin{align*}
  3 \text{ mA} / \text{s} & \rightarrow 15 \text{ mA} / \text{s} \quad \text{(Injection Rate)} \\
  1 \text{ nC} / \text{pulse} & \rightarrow 5 \text{ nC} / \text{pulse} \quad (3.5 \text{ GeV})
  \end{align*} \]
  
  Already Achieved for Primary Beam for $e^+$ Generation
  Emittance Control May be Necessary

◆ $e^+$ Beam Charge:
  
  \[ \begin{align*}
  1.5 \text{ mA} / \text{s} & \rightarrow 3 \text{ mA} / \text{s} \quad \text{(Injection Rate)} \\
  0.6 \text{ nC} / \text{pulse} & \rightarrow 1.2 \text{ nC} / \text{pulse} \quad (8.0 \text{ GeV})
  \end{align*} \]
  
  Flux Concentrator for Energy Acceptance (Planning)
  Double Bunch Acceleration and Damping Ring (?)

◆ Continuous Injection
  Already Achieved

◆ Simultaneous $e^-$ and $e^+$ and Injection
  Transport Line Lengths, Injection Timing (?)
Linac Beam Measurement and Quality Control

- **Beam Measurement**
  Between Injections → During Continuous Injection

- **Stealth Bunch Measurement** Possibility
  Between Injection Bunches
  Fast Kicker, To Prevent Dirty Beam Injection
  Fast Actuator Installation
  ex. Fast Phase Shifter is under Development
  Synchronous Data Acquisition Improvement
  Timing System Modification

- **Fast (50Hz) Data Acquisition**
  Under Development for BPM with Fast Digitizer
  Need to Measure Dual Bunch Simultaneously

- **Need More Beam Quality Control**
Conclusions

◆ Linac Operates Well with Low Down Rate
   Contributes to KEKB/Belle Achievement

◆ Beam/Machine Quality Control, Dual-Bunch Injection,
   Continuous Injection are Improving
   Enhance Integrated Luminosity

◆ Linac Upgrade Design for SuperKEKB
   Energy Exchange (8-GeV e+) is the Major Challenge
   With C-Band Technology at First
   R & D Started This Year, and First Test at Spring 2003

◆ Miscellaneous Improvements are Planned
   Considering for SuperKEKB
Layout of KEKB Linac

- 600m Linac with 59 S-band rf Stations, 56 of them have SLED with Gain of 160MeV
- Double (114MHz, 571MHz) Sub-Harmonic Buncher to Achieve 10ps Pulse Width and 10nC
## Design Beam and Achieved Performance

<table>
<thead>
<tr>
<th></th>
<th>8-GeV electron</th>
<th>3.5-GeV positron</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Goal</td>
<td>Achieved</td>
</tr>
<tr>
<td><strong>(1) Gun</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>keV</td>
<td></td>
</tr>
<tr>
<td>Intensity</td>
<td>nC/pulse</td>
<td></td>
</tr>
<tr>
<td>Pulse width</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td><strong>(2) Buncher</strong></td>
<td></td>
<td></td>
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<tr>
<td>Energy</td>
<td>MeV</td>
<td></td>
</tr>
<tr>
<td>Energy spread (σ)</td>
<td>MeV</td>
<td></td>
</tr>
<tr>
<td>Intensity</td>
<td>nC/pulse</td>
<td></td>
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<tr>
<td>Efficiency</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Emittance γβε (σ)</td>
<td>mm</td>
<td></td>
</tr>
<tr>
<td>Bunch width</td>
<td>ps</td>
<td></td>
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<tr>
<td><strong>(3) Arc</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>GeV</td>
<td></td>
</tr>
<tr>
<td>Energy spread (σ)</td>
<td>MeV</td>
<td></td>
</tr>
<tr>
<td>Jitters (p-p)</td>
<td></td>
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<tr>
<td>Drift (with feedback)</td>
<td>&lt;0.2%/h</td>
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<tr>
<td>Emittance γβε (σ)</td>
<td>mm</td>
<td></td>
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<tr>
<td>Transmission</td>
<td></td>
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</tr>
<tr>
<td><strong>(4) e+ target</strong></td>
<td></td>
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</tr>
<tr>
<td>Energy</td>
<td>GeV</td>
<td></td>
</tr>
<tr>
<td>Intensity</td>
<td>nC/pulse</td>
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<tr>
<td>Transmission</td>
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<tr>
<td><strong>(5) e+ Solenoid exit</strong></td>
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<tr>
<td>Intensity</td>
<td>nC/pulse</td>
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<tr>
<td>Specific yield</td>
<td>e+/e-GeV</td>
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<td><strong>(6) Linac end</strong></td>
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<tr>
<td>Energy</td>
<td>GeV</td>
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<tr>
<td>Energy spread (σ)</td>
<td>MeV</td>
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<tr>
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<tr>
<td>Emittance γβε (σ)</td>
<td>mm</td>
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</tr>
<tr>
<td>Pulse repetition</td>
<td>pps</td>
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