Facility Report of the Pohang Light Source

S. H. Nam

2nd Workshop on Beam Orbit Stabilization

SPring- 8, Japan

December 4- 6, 2002
Aerial View of PAL
# PLS Linac Parameter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy (GeV)</td>
<td>2</td>
</tr>
<tr>
<td>Beam pulse length (ns)</td>
<td>1, 2, 40</td>
</tr>
<tr>
<td>Pulse beam current (A)</td>
<td>&gt; 2</td>
</tr>
<tr>
<td>Bunch Length (ps)</td>
<td>17 ~ 20</td>
</tr>
<tr>
<td>Number of accelerating columns</td>
<td>44</td>
</tr>
<tr>
<td>Operating mode</td>
<td>2p/3</td>
</tr>
<tr>
<td>Operating frequency (MHz)</td>
<td>2,856</td>
</tr>
<tr>
<td>MW Pulse length (?)</td>
<td>4.0</td>
</tr>
<tr>
<td>Number of klystrons</td>
<td>12</td>
</tr>
<tr>
<td>Klystron output power (MW)</td>
<td>80</td>
</tr>
<tr>
<td>Number of Energy Doublers</td>
<td>11</td>
</tr>
<tr>
<td>Energy Doubler gain factor</td>
<td>1.5 ~ 1.6</td>
</tr>
<tr>
<td>Total length of the linac (m)</td>
<td>~160</td>
</tr>
<tr>
<td>Accelerating column wall temperature (?)</td>
<td>45± 0.2</td>
</tr>
<tr>
<td>Number of quadrupole triplets</td>
<td>6</td>
</tr>
<tr>
<td>Number of steering magnet sets</td>
<td>6</td>
</tr>
<tr>
<td>Number of bending magnets</td>
<td>3</td>
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</table>
## PLS SR Parameter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Designed Value</th>
<th>Achieved Value</th>
<th>Operation Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (GeV)</td>
<td>2 (2.5)</td>
<td>2 (2.5)</td>
<td>2.5</td>
</tr>
<tr>
<td>Stored current (mA)</td>
<td>300 (150)</td>
<td>450 (200)</td>
<td>170</td>
</tr>
<tr>
<td>Emittance (nm rad)</td>
<td>12.1 (18.9)</td>
<td>11 (-)</td>
<td>-</td>
</tr>
<tr>
<td>Lifetime @ 100 mA (hr)</td>
<td></td>
<td>28 1) (30)</td>
<td>30</td>
</tr>
<tr>
<td>Bunch length (mm), 1σ</td>
<td>5</td>
<td>6</td>
<td>5-6</td>
</tr>
<tr>
<td>RF Voltage (MV)</td>
<td></td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Betatron Tunes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Horizontal (νₓ)</td>
<td>14.28</td>
<td>14.23 (14.28)</td>
<td>14.28</td>
</tr>
<tr>
<td>- Vertical (νᵧ)</td>
<td>8.18</td>
<td>8.21 (8.18)</td>
<td>8.18</td>
</tr>
<tr>
<td>Synchrotron Tune</td>
<td>0.0109</td>
<td>0.0109</td>
<td>0.01</td>
</tr>
<tr>
<td>Chromaticities (x/y)</td>
<td>0/ 0</td>
<td>0.7/ 1.1</td>
<td>0.7/1.1</td>
</tr>
<tr>
<td>Linear coupling (%)</td>
<td>&lt;10</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>COD (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Horizontal (rms)</td>
<td></td>
<td>~0.5</td>
<td>0.9</td>
</tr>
<tr>
<td>- Vertical (rms)</td>
<td></td>
<td>~0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Dispersion (x/y) (m)</td>
<td>Max. 0.46</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Injection Time (sec)</td>
<td>-</td>
<td>-</td>
<td>&lt; 600</td>
</tr>
<tr>
<td>Damping Time (x/z) (ms)</td>
<td>16/8</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
# PLS Operation History

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Year</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Energy [GeV]</strong></td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0-2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td><strong>Ave. Current [mA]</strong></td>
<td>121.8</td>
<td>155.6</td>
<td>160.7</td>
<td>157</td>
<td>166.9</td>
<td>164.8</td>
<td>170</td>
</tr>
<tr>
<td><strong>Lifetime @ 100mA[hr]</strong></td>
<td>22.3</td>
<td>18.4</td>
<td>23.6</td>
<td>30.6</td>
<td>37.7</td>
<td>34.4</td>
<td>35</td>
</tr>
<tr>
<td><strong>Linac Operation [hr]</strong></td>
<td>4,810</td>
<td>5,481</td>
<td>5,116</td>
<td>5,224</td>
<td>5,280</td>
<td>5,646.6</td>
<td>5,640</td>
</tr>
<tr>
<td><strong>SR Planned [hr]</strong></td>
<td>3,236</td>
<td>3,960</td>
<td>4,272</td>
<td>4,224</td>
<td>4,272</td>
<td>4,056</td>
<td>4,464</td>
</tr>
<tr>
<td><strong>SR Serviced [hr]</strong></td>
<td>3,034</td>
<td>3,618</td>
<td>3,784</td>
<td>3,831</td>
<td>3,884</td>
<td>3,806</td>
<td>4,129</td>
</tr>
<tr>
<td><strong>Availability(^4) [%]</strong></td>
<td>93.8</td>
<td>91.4</td>
<td>88.6</td>
<td>90.7</td>
<td>90.9</td>
<td>93.8</td>
<td>92.5</td>
</tr>
</tbody>
</table>

1) Three main events: RF Window break, Interlock malfunction, Flooding
2) Operation energy increased from 2.0 GeV to 2.5 GeV. Injection time was increased due to the energy ramping.
3) 2.5 GeV operation.
4) Regular injection time is excluded.
<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Operation Runs:</td>
<td>18</td>
</tr>
<tr>
<td>Days of Operation per Run:</td>
<td>~10 Days</td>
</tr>
<tr>
<td>User Operation:</td>
<td>185 Days (~4,440 Hours)</td>
</tr>
<tr>
<td>Machine Study:</td>
<td>63 Days</td>
</tr>
<tr>
<td>Shut-Down:</td>
<td>117 Days (Maintenance and B/L Construction)</td>
</tr>
<tr>
<td>Operation Mode:</td>
<td>2.5 GeV (170 mA)</td>
</tr>
<tr>
<td>Injection Period:</td>
<td>12 Hours</td>
</tr>
<tr>
<td></td>
<td>(2 injections per a day)</td>
</tr>
</tbody>
</table>
The main objective has been to achieve design parameters. (Especially the stored beam current level)

- **Achieved most of design parameters.**

<table>
<thead>
<tr>
<th>Design</th>
<th>Max. Achieved</th>
<th>Provided</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 GeV 300 mA</td>
<td>2.0 GeV 450 mA</td>
<td>2.0 GeV 190 mA</td>
</tr>
<tr>
<td>2.5 GeV 150 mA</td>
<td>2.5 GeV 200 mA (RF Power Limited)</td>
<td>2.5 GeV 170 mA</td>
</tr>
</tbody>
</table>

- **SR Operation Energy Increase to 2.5 GeV by Ramping:** The PLS SR operation energy has been increased from 2.0 to 2.5 GeV since 1999 (Energy is ramped at the PLS SR).

- **2.5 GeV Full Injection:** Succeeded 2.5 GeV full injection by orbit correction of increased rms COD (5-6 times) due to septum leakage field.
Major Issues of the PLS

† Beam Stability

† Diagnostic Upgrade

† EPICS

† RF Power Budget Upgrade

† Linac Energy Stability

† Next Generation Light Source
Status of the PLS Beam Diagnostic System

Beam Position Monitors
- Total Number: 112 (108 arcBPM’s + 4 IDBPM’s: BERGOZ)
- Resolution: < 5 μm (limited by 12-bit ADC)
  Demonstrated <1 μm resolution in lab test.
  Have plan to upgrade resolution of all BPMs to <1 μm.
- Performance Improvement: Found solution for erratic output signals (483 MHz TE mode excitation) of ID as well as arc BPMs.

PBPM:
- Total Number: 1
- Resolution: < 1 μm

Diagnostic Beam Line:
- Have one visible (with a streak camera) and one x-ray (with Kirkpatrick-Baez mirror) diagnostic beam line.
- X-ray pin hole diagnostic beam line is under construction (<10 μm resolution).
Performance of the PLS BPM

Measurement of 24-hour Orbit Drift

Orbit Excursions during Beam Fill-Ups (2.0 to 2.5 GeV Ramping)

~ 4-μm Resolution

BPM66Y on 6/26/2001
Tunnel Elevation Survey of the PLS SR

SR TUNNEL ELEVATION SURVEY
(DEV From '93.6 To '02.07)

Dev(mm)

Cell No
• Deformation (Hill to valley):
  Total accumulated: 23 mm for 9 years
  Average: 2.5 mm/yr.

• Deformation reduction ratio: 10 %/yr.

• Max. adjustable range of the PLS SR girder: 50 mm
  Still within the adjustable range.

• Current deformation of the PLS SR tunnel is about 2.0 mm/yr.

• This corresponds to 5.5 μm/day (peak-to-peak).

• Under investigation: What is the actual effect on SR orbit drift?
Improvement of LCW and Air Temp. Control

- Air Temperature Control Improved
  - From $< \pm 1.0 \, ^\circ C$
  - To $< \pm 0.1 \, ^\circ C$
  - $\Delta T : \sim 2.6 \, ^\circ C$

- LCW Temperature Control Improved
  - From $< \pm 0.5 \, ^\circ C$
  - To $< \pm 0.1 \, ^\circ C$
  - Feedback Control Period: 5~6 min.
  - Upgrade to $< \pm 0.02 \, ^\circ C$ program is under way.
  - $\Delta T$ during ramping: $\sim 0.7 \, ^\circ C$ (Utility Bldg. Point)

- Beam Orbit Sensitivity Factor
  - Air: $\sim 8 \, \mu m / ^\circ C$ (Need further measurement)
  - LCW (Vacuum Chamber Point): $\sim 50 \, \mu m / ^\circ C$
LCW Inlet Temp. Variation (Ramping)

LCW Inlet (After Upgrade: Ramping_2.0-2.5GeV)

Date | Temperature
--- | ---
10/14/2002 00:00:00 | 24.5°C
10/14/2002 03:57:30 | 24.6°C
10/14/2002 07:55:00 | 24.7°C
10/14/2002 11:53:30 | 24.8°C
10/14/2002 15:51:00 | 24.9°C
10/14/2002 19:48:30 | 25.0°C
10/14/2002 23:46:00 | 25.1°C

Date | Temperature
--- | ---
10/14/2002 00:00:00 | 25.2°C
10/14/2002 03:57:30 | 25.3°C
10/14/2002 07:55:00 | 25.4°C
10/14/2002 11:53:30 | 25.5°C
10/14/2002 15:51:00 | 25.6°C
10/14/2002 19:48:30 | 25.7°C
10/14/2002 23:46:00 | 25.8°C

Date | Temperature
--- | ---
10/14/2002 00:00:00 | 25.9°C
10/14/2002 03:57:30 | 26.0°C
10/14/2002 07:55:00 | 26.1°C
10/14/2002 11:53:30 | 26.2°C
10/14/2002 15:51:00 | 26.3°C
10/14/2002 19:48:30 | 26.4°C
10/14/2002 23:46:00 | 26.5°C

Date | Temperature
--- | ---
10/14/2002 00:00:00 | 26.6°C
10/14/2002 03:57:30 | 26.7°C
10/14/2002 07:55:00 | 26.8°C
10/14/2002 11:53:30 | 26.9°C
10/14/2002 15:51:00 | 27.0°C
10/14/2002 19:48:30 | 27.1°C
10/14/2002 23:46:00 | 27.2°C

Date | Temperature
--- | ---
10/14/2002 00:00:00 | 27.3°C
10/14/2002 03:57:30 | 27.4°C
10/14/2002 07:55:00 | 27.5°C
10/14/2002 11:53:30 | 27.6°C
10/14/2002 15:51:00 | 27.7°C
10/14/2002 19:48:30 | 27.8°C
10/14/2002 23:46:00 | 27.9°C

Date | Temperature
--- | ---
10/14/2002 00:00:00 | 28.0°C
10/14/2002 03:57:30 | 28.1°C
10/14/2002 07:55:00 | 28.2°C
10/14/2002 11:53:30 | 28.3°C
10/14/2002 15:51:00 | 28.4°C
10/14/2002 19:48:30 | 28.5°C
10/14/2002 23:46:00 | 28.6°C

Date | Temperature
--- | ---
10/14/2002 00:00:00 | 28.7°C
10/14/2002 03:57:30 | 28.8°C
10/14/2002 07:55:00 | 28.9°C
10/14/2002 11:53:30 | 29.0°C
10/14/2002 15:51:00 | 29.1°C
10/14/2002 19:48:30 | 29.2°C
10/14/2002 23:46:00 | 29.3°C
LCW Inlet Temp. Variation (2.5GeV)

LCW Inlet (After Upgrade: 2.5GeV Injection)

Temperature

Date (10/25/2002)
Air Temp. Variation

Air Temp. of Cell No. 10 & 11 (After Upgrade)

Date

22.0°C
22.5°C
23.0°C
23.5°C
24.0°C
24.5°C
25.0°C
25.5°C
26.0°C

10/14/2002 00:00:00
10/14/2002 03:57:30
10/14/2002 07:55:00
10/14/2002 11:53:30
10/14/2002 15:51:00
10/14/2002 19:48:30
10/14/2002 23:46:00

Temperature

Supply

Return
Effect of LCW Temp. on Orbit

Sensitivity: ~ 50 μm/°C

10/10/2002

MC#1 LCW Temperatures (°C)

RMS COD delta (mm)

RMS del Y
MC1 LCW return temp.
MC1 LCW supply temp.
RMS del X

Time (hh:mm)

10:00 12:00 14:00 16:00 18:00 20:00 22:00 24:00

10/10/2002
Effect of Outside Temp. on Orbit

- **Average horizontal orbit drift:**
  \(~100 \mu m / 10^\circ C\)
  
  **Sensitivity:** \(~10 \mu m/\circ C\)

- **Vertical orbit drift (r.m.s.):**
  \(~40 \mu m / 10^\circ C\)
  
  **Sensitivity:** \(~4 \mu m/\circ C\)

- **Horizontal orbit drift (r.m.s.):**
  Shows no clear dependence on temperature. The orbit change in the figure is due mostly to the U7 ID gap change.
Effect of ID Gap on Orbit

- **U7 ID Gap Control:**
  - 20 mm to 60 mm

- **Vertical orbit change:**
  - ~ 6 μm

- **Horizontal orbit change:**
  - ~ 17 μm
Effect of MPS Performance on Orbit

**Horizontal BPM**
- BPM8-1 X 100Hz, 4Sec
- ~ 32 μm pk-pk
- MPS Ripple: ~ 18 Hz

**Vertical BPM**
- BPM8-1 Y 100Hz, 4 Sec
- ~ 28 μm pk-pk
- MPS Ripple: ~ 18 Hz

**Before Upgrade:**
- < ± 100 ppm

**After Upgrade:**
- < ± 50 ppm
# PLS MPS Performance Table

<table>
<thead>
<tr>
<th>ITEM</th>
<th>Bending</th>
<th>Q4</th>
<th>Q5</th>
<th>Q6</th>
<th>Q1,2,3</th>
<th>SF</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability (± ppm)</td>
<td>50</td>
<td>30</td>
<td>40</td>
<td>30</td>
<td>30</td>
<td>40</td>
<td>40</td>
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<tr>
<td>Ripple (%)</td>
<td>8.125Hz</td>
<td>0.00097</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>8.75Hz</td>
<td>0.00207</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>11.25Hz</td>
<td>0.0038</td>
<td></td>
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<td>12.87Hz</td>
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<td></td>
<td>13.25Hz</td>
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<td></td>
<td></td>
<td></td>
<td>0.0043</td>
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<td></td>
<td>14.75Hz</td>
<td>0.0017</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>30Hz</td>
<td>0.00081</td>
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<tr>
<td></td>
<td>60Hz</td>
<td>0.0022</td>
<td>0.0067</td>
<td>0.0085</td>
<td>0.0018</td>
<td>0.00143</td>
<td>0.00117</td>
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<tr>
<td></td>
<td>180Hz</td>
<td>0.0044</td>
<td>0.0278</td>
<td>0.0053</td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>540Hz</td>
<td>0.0035</td>
<td>0.0278</td>
<td>0.0052</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>900Hz</td>
<td>0.0035</td>
<td>0.0255</td>
<td>0.0058</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>1.08kHz</td>
<td>0.0035</td>
<td>0.0097</td>
<td>0.0058</td>
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<td></td>
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<tr>
<td></td>
<td>1.262kHz</td>
<td>0.0036</td>
<td>0.021</td>
<td>0.005</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>1.62kHz</td>
<td>0.004</td>
<td>0.025</td>
<td>0.0053</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.972kHz</td>
<td>0.0038</td>
<td>0.0247</td>
<td>0.0035</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>2.344kHz</td>
<td>0.004</td>
<td>0.025</td>
<td>0.0045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.692kHz</td>
<td>0.004</td>
<td>0.0217</td>
<td>0.00037</td>
<td></td>
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</tr>
</tbody>
</table>
• Phase noise amplitude in the range of 30 Hz - 35 kHz are below 60 dB from the main RF signal.

• Detail study of RF noise effect on beam stability is in progress. Preliminary result shows that ID photon intensity fluctuation is not strongly depend on RF noise amplitude.

- BPM Signal Spectrum measured when there exists klystron phase noise in the frequency range to 1 kHz.
• Effect of Stored Current Amplitude on Beam Stability
  ➢ Sorting out the current dependence is difficult.
  ➢ Beam stability is affected more by others than the stored current.

• Effect of Mechanical Vibration on Beam Stability
  ➢ < 40 Hz : No clear evidence found
  ➢ > 40 Hz : Need to be measured.

• Effect of Motions of Mechanical Components on Beam Stability
  ➢ Mechanical components: Girder, Magnet, Vacuum Chamber, BPM
  ➢ Some deformation of magnets are measured with the energy ramping operation mode (2.0 to 2.5 GeV).
  ➢ However, no significant mechanical component motions are measured during the 2.5 GeV direct injection mode.
Horizontal Beam Position Stability of the PLS SR: BPM Signal

- 400Hz
- ~16 μm pk-pk

- 25Hz
- ~5 μm pk-pk
Vertical Beam Position Stability of the PLS SR: BPM Signal

- 400Hz
- ~ 12 μm pk-pk

- 25Hz
- ~ 3.3 μm pk-pk
Vertical Beam Position Stability of the PLS SR: PBPM Signal

- PBPM Bandwidth: several kHz
- Orbit Fluctuation at frequencies > 1 kHz has been observed.
- Sources of the fluctuation are not yet fully explored.
- RF noise may be one kind of the sources.
Example of 10-day Run Operation Data of the PLS SR

2002 16th User Run

mA

Date

mm
Summary of the PLS Beam Orbit Stability

• Vertical orbit:
  ➢ ~ 80 µm/run Drift : Mainly due to outside temperature change.
  ➢ < 20 µm/12-hr Drift (User service hour after injection is normally 12-hr.) : Mainly due to MPS stability, LCW temperature.
  ➢ ~ 15 µm orbit change observed just after injection, even in 2.5 GeV direct injection mode. : Cause is not clear yet. Need further investigation.
  ➢ 50 to 100 µm sudden step change of orbit: Cause is unknown. Need further investigation.

• Horizontal orbit:
  ➢ ~ 30 µm/run Drift : Mainly due to U7 ID gap and outside temperature change.
  ➢ < 10 µm/12-hr Drift : Mainly due to MPS stability, LCW temperature.
<table>
<thead>
<tr>
<th>Source</th>
<th>Sensitivity Factor or Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Item</strong></td>
<td><strong>Range</strong></td>
</tr>
<tr>
<td>Tunnel Air Temp.</td>
<td>$&lt; \pm 0.1 , ^\circ C$</td>
</tr>
<tr>
<td>Magnet cooling water temp.</td>
<td>$&lt; \pm 0.1 , ^\circ C$</td>
</tr>
<tr>
<td>RF cavity cooling water temp.</td>
<td>$&lt; \pm 0.2 , ^\circ C$</td>
</tr>
<tr>
<td>Vacuum chamber cooling water temp.</td>
<td>$&lt; \pm 0.1 , ^\circ C$</td>
</tr>
<tr>
<td>Beam current decay</td>
<td>$\sim 30 \mu m$ (180-100 mA)</td>
</tr>
<tr>
<td>Outside temp.</td>
<td>20 $^\circ C$ Max. Change</td>
</tr>
<tr>
<td>ID Gap Change (U7)</td>
<td>20-60 mm</td>
</tr>
<tr>
<td>MPS</td>
<td>$\leq \pm 50 , ppm$</td>
</tr>
</tbody>
</table>
Future Works to Improve the PLS Beam Stability

- First Step Improvement of the PLS Beam Stability: < 5 µm
- Future Works
  2. RF Frequency Feedback: Under operation (Av. Hor. Orbit < 7 µm)
  3. Beam Based Alignment: Under preparation
  4. LCW Temp. Control Upgrade to < ± 0.02 °C: Under preparation
  5. Upgrade of MPS
     Unipolar 46 Units: Reduce low freq. Ripple (10-20 Hz)
        Stability < ± 10 ppm
     Bipolar 140 Units: Reduce ripple (1.5 kHz Switching)
        12 bit to >16 bit controllability (Currently 1 bit ~ 6.3 µm)
  6. Automatic Girder Mover with Hydrostatic Level System
     Automatic alignment: < 10 µm error
  7. Diagnostic Upgrade (Electron Beam and Photon Beam Diagnostics)
(1) Dr. S. J. Park: “Activities of Source Suppression for Improving Orbit Stability in PLS” 17:05-17:25, Dec. 4

(2) Dr. H. S. Kang: “Sources of Slow Orbit Movement and Orbit Feedback Systems in PLS Storage Ring” 11:30-11:50, Dec. 5

(3) Dr. E. S. Kim: “Orbit Stability in PLS Storage Ring” 15:30-15:50, Dec. 5

Thank you for your attention!!