Beam Stabilization in SPring-8 Linac

JASRI Acc Div. Linac Group
H. Hanaki

Beam energy instability of SPring-8 linac is 0.01% rms.
How have we achieved it •••

1 Overview of SPring-8 linac
2 Beam stabilization
   • Stabilization of RF amplitude & phase
   • Synchronization of linac RF with ring RF
   • Energy compression system (ECS)
   • Feedback control
3 Summary

<table>
<thead>
<tr>
<th>Injection beam</th>
<th>Booster synchrotron</th>
<th>NewSUBARU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy</td>
<td>1 GeV</td>
<td>1 GeV</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>1 pps</td>
<td>1 pps</td>
</tr>
<tr>
<td>Pulse width</td>
<td>1 ns</td>
<td>40 ns</td>
</tr>
<tr>
<td>Peak current</td>
<td>2 A</td>
<td>70 mA</td>
</tr>
<tr>
<td>Energy spread</td>
<td>± 0.3 %</td>
<td>± 0.5 %</td>
</tr>
</tbody>
</table>

1-GeV linac
8-GeV booster synchrotron
8-GeV storage ring
NewSUBARU
Beam energy: 1.2 GeV max.
Beam current: 2 A
Beam pulse width: 250 ps, 1 ns, 40 ns
RF frequency: 2856 MHz
Repetition: 60 pps
Klystron: 80 MW x 13
Acc. structure: 3 m x 26
Length of linac: 140 m

Present Linac RF System

PIN Mod. | Amp | PLL-Stabilized Coaxial Line | 80MW Klystron (13 sets)
---|---|---|---
OSC 2856MHz | | Drive Line (90 m) | |
Prebuncher | Buncher | H0 Acc. | H1 Acc. | M18 Acc. | M20 Acc.

ECS | Chicane
Strategy for stabilizing beam energy

1. Stabilization of RF amplitude & phase
   - Investigate variation chains
   - Stabilization of their origins or devices

2. Reduce beam loading fluctuation ➡ No SHB!
   - Synchronization of linac RF with ring RF

3. Compensate accidental energy variation
   - Introduce Energy Compression System (ECS)

4. Reduce residual beam position drift
   - Introduce feedback control
Variation chains in SPring-8 linac

### Long Period Variation Chain
- Room temperature
- Cooling water temperature
- Line voltage

→ RF phase in long transmission line
→ RF phase in low power RF system

→ RF phase in acc. guide
→ Klystron RF phase
→ Klystron RF amplitude

→ Beam energy variation

### Shot-by-Shot Variation Chain
- Phase noise of RF system
- Asynchronosity of beam pulse and linac RF

→ Bunch charge distribution

→ Klystron RF phase
→ RF beam loading

No SHB

---

**Reduction of long-period RF variation**

- **Room temperature stabilization**
  - Readjustment of air conditioners
  - Covering the long drive line with heat jackets
  - Circulating temperature stabilized water inside the jackets

- **Klystron temperature stabilization**
  - Improvement of water cooling system

- **Isolate line voltage variation**
  - Stabilization of Pulse Forming Network (PFN) voltage by improving modulator regulation circuits
Room temperature stabilization

90 m long main drive line
H0 klystron

Phase variation
10 deg. / 4°C
< 1 deg. / 1°C

Klystron temperature stabilization

Phase variation
2.4 deg. / 3°C
< 0.5 deg. / 0.5°C

Calculated temperature coefficient: 0.74 deg. / °C
**Control Induction Voltage Regulator (IVR) to compensate line voltage variation**

- Optimization of de-Q'ing rate
  - 7% → 4%

**PFN voltage**
- 0.3 % (rms)
- 0.03 % (rms)

**Improved beam stability**

- Beam energy
  - 0.4 % (peak to peak)
  - 0.06 % (rms)

- Beam current
  - > 20 %
  - 1.9 % (rms)
  - 0.06 % (rms) (4 h)
  - 0.03 % (rms) (10 min)
Strategy for stabilizing beam energy

1. Stabilization of RF amplitude & phase
   - Investigate variation chains
   - Stabilization of their origins or devices

2. Reduce beam loading fluctuation \(\rightarrow\) No SHB!
   - Synchronization of linac RF with ring RF

3. Compensate accidental energy variation
   - Introduce Energy Compression System (ECS)

4. Reduce residual beam position drift
   - Introduce feedback control

Asynchronous RF issue before 2001

Asynchronous 2856-MHz RF forms two or three bunches along with beam trigger timing referred to the RF phase.

Energy distribution of 1-ns beam (@1.9A)

- Unstable beam energy at high current
- Unstable current of single-bunch beam
A start signal synchronous to 508.58 MHz starts the AWG to generate a **burst wave** of 89.25 MHz.

A narrow band pass filter reduces phase noises.
Strategy for stabilizing beam energy

1. Stabilization of RF amplitude & phase
   - Investigate variation chains and fix their origins

2. Reduce beam loading fluctuation
   - Synchronization of linac RF with ring RF

3. Compensate accidental energy variation
   - Introduce conventional Energy Compression System (ECS)

4. Reduce residual beam position drift
   - Introduce feedback control
**Energy Compression System (ECS)**

- **1 GeV beam**
- **Rectangular type bending magnets**
- **3 m long accelerating structure**

**Chicane expands bunch length along with beam energy.**
**ECS compresses beam energy spread and variation.**
**ECS requires RF phase stability**

---

**ECS requires RF phase stability**

1) **PLL circuit for ECS klystron drive system**

- New synchronous Oscillator
  - Phase variation 0.2 deg. rms

2) **Klystron voltage > 350 kV**

- Phase variation 0.2 deg. rms
- ECS Phase instability: 0.3 deg. rms
- Energy instability: ~ 0.01% rms
ECS compressed beam energy spread

40-ns beam at 350 mA

ECS on

1.4%

ECS off

3.5%

Strategy for stabilizing beam energy

1. Stabilization of RF amplitude & phase
   ➤ Investigate variation chains and fix their origins
2. Reduce beam loading fluctuation
   ➤ Synchronization of linac RF with ring RF
3. Compensate accidental energy variation
   ➤ Introduce conventional Energy Compression System (ECS)
4. Reduce residual beam position drift
   ➤ Introduce feedback control
**Problem:** beam position drift

Beam position drift at the linac upstream
- Small betatron oscillation
- Beam position drift at the injection points

**Solution:** beam position feedback control

Beam position stabilization at BT lines
- Injector part
- Linac end
- Long BT to the NewSUBARU storage ring

Control steering magnets referring to BPM data
- Position window: 60µm
- Response time: a few minutes

Beam Position Feedback Control
Summary

1. Stabilization of RF amplitude & phase
   ➤ Investigate variation chains
     Stabilization of their origins or devices
     ➤ **Energy instability: 0.03% rms**

2. Reduce beam loading fluctuation
   ➤ Synchronization of linac RF with ring RF
     ➤ **Energy instability: < 0.01% rms**

3. Compensate uncontrollable energy variation
   ➤ Introduce Energy Compression System (ECS)
     ➤ **Long and short term stability**
     ➤ **High current injection**

4. Reduce residual beam position drift
   ➤ Introduce feedback control
     ➤ **Position stability: 60 µm**