Beam Stabilization in SPring-8 Linac

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></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>
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</table>

**Diagram:**
- **NewSUBARU**
- **8-GeV booster synchrotron**
- **1-GeV linac**
- **8-GeV storage ring**
Thermionic electron gun
Bunching section
Accelerating structure
Linac synchrotron beam transport line
80 MW klystron
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

OSC 2856MHz

PIN Mod.  Amp

PLL-Stabilized Coaxial Line
Drive Line (90 m)

Attenuator Phase Shifter

80MW Klystron (13 sets)

ECS
Chicane

GUN  Prebuncher  Buncher  H0 Acc.  H1 Acc.  M18 Acc.  M20 Acc.
Beam Injection Instability in 1998

WCM-M20@1 GeV straight line

9.0% (rms)

WCM-LS@LSBT
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
- PFN voltage of modulator
- RF phase in acc. guide
- Klystron RF phase
- Klystron RF amplitude
- Beam energy variation

Shot-by-Shot Variation Chain

- Phase noise of RF system
- Asynchrononuity of beam pulse and linac RF
- Bunch charge distribution
- Klystron RF phase
- RF beam loading

No SHB
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

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%
**Improved beam stability**

- **Beam energy**
  - $> 1\%$ (10 h)
  - $0.06\%$ (rms) (4 h)
  - $0.03\%$ (rms) (10 min)

- **Beam current**
  - $> 20\%$
  - $1.9\%$ (rms)
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
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.
Single-bunch current stability

Beam pulse width: 250 ps

Beam current after electron gun

Beam current after bunching section

Instability caused in bunching section

Beam Current (A)

0 0.2 0.4 0.6 0.8 1.0 1.2

Time (min)

0 20 40 60 80 100 120

Synchronous Asynchronous
Beam energy stability at high current

1-ns beam energy at 1.4 A

Asynchronous

0.03% rms

Synchronous

0.009% rms
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
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

- Phase variation: 0.2 deg. rms
- 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%

Injection enhancement
Strategy for stabilizing beam energy

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

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   - Introduce feedback control
Feedback control of beam trajectory

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

Chicane Magnets

Feedback Control

NewSUBARU

Synchrotron

Horizontal Steering Magnet [A]

Time [week]

0 1 2 3

Horizontal Beam Position [mm]

0 0.2 0.4 0.6 0.8 1

Window 60µm

Stabilized Beam Position

Automatic Steering Control

Horizontal Steering Magnets [A]

Time [week]

0 1 2 3

-10 -8 -6 -4 -2 0 0.2 0.4 0.6 0.8 1
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