Proposal of a Diamond-based Beam Halo Monitor for an Energy Recovery Linac

Hideki Aoyagi, T. Bizen, T. Itoga, N. Nariyama
JASRI / SPring-8

Y. Asano, T. Tanaka, H. Kitamura
RIKEN / SPring-8

OUTLINES

1. Introduction
   *Purpose of the halo monitor, Required detection limit*
   *Principle verification tests of diamond detector*

2. Feasibility tests using a prototype of the halo monitor

3. Adoption of RF fingers to the halo monitor

4. Operational Experience at SACLA

5. Summary
**Table 1 Main Design Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Target Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy (GeV)</td>
<td>4–8</td>
</tr>
<tr>
<td>Bunch compression ratio</td>
<td>&gt; 3000</td>
</tr>
<tr>
<td>Peak current (kA)</td>
<td>3–4</td>
</tr>
<tr>
<td>Repetition rate (Hz)</td>
<td>Max. 60</td>
</tr>
<tr>
<td>Normalized slice emittance (π μmrad)</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Shortest SASE laser wavelength (Angstrom)</td>
<td>0.6</td>
</tr>
<tr>
<td>Laser power (GW)</td>
<td>20–30</td>
</tr>
<tr>
<td>K-value setting range</td>
<td>1.1–2.2</td>
</tr>
<tr>
<td>Undulator period length (mm)</td>
<td>18</td>
</tr>
<tr>
<td>Number of undulator periods</td>
<td>277</td>
</tr>
<tr>
<td>Number of undulator segments</td>
<td>18</td>
</tr>
</tbody>
</table>

**Figure 1:** Aerial photo of SACLA.

**Figure 3:** Picture of the SACLA injector section.

**Figure 5:** C-band acceleration system in the tunnel.

**Figure 7:** Vertically streaked profile of the fully compressed bunch.

**Figure 8:** SASE laser spectrum at 10 keV.
In order to protect the undulator permanent magnets against radiation damage, **Beam Halo Monitor** has been installed in front of the in-vacuum undulators.

*Beam will be stopped, when beam halo exceed the threshold*
Tolerance of demagnetization rate of undulator magnets

1 % / 10 year

→ Tolerance of incident electron on the magnets

$4 \times 10^{14} \text{e}^- / \text{10 year}$ (based on the experimental results)

→ Required detection limit $< 2 \times 10^4 \text{e}^- / \text{pulse}$

( $60\text{Hz} \times 24\text{hrs} \times 365\text{day} \times 10\text{ year} \Rightarrow 1.9 \times 10^{10} \text{pulse}$ )

→ Tolerance of electron loss rate $< 10^{-5}$

cf. Number of electron through undulators

$2 \times 10^9 \text{e}^- / \text{pulse (0.3nC/pulse)}$
How to measure?

**Ideally**
Measure a differential of charge between before and after undulators.

Required resolution must be less than $10^{-6}$.

**Realistically**
Measure a beam halo in front of undulator permanent magnets.

Direct measurement in the beam duct

We adopted this type.
Configuration of sensors?

A single large detector with a hole in center.

- Bulk diamond crystal
- Active area
- Side edge of magnet array

- Wide active area
- Fixed aperture
- Longer time constant, $\tau = RC$

A pair of detectors with separate actuators

- Active area
- Side edge of magnet array

- Small active area
- Variable aperture
- Short time constant
- Easy to fabricate (small crystal)

We adopted this type.
Diamond detector as semi-conductor detector

**Advantages of diamond:**
- High radiation hardness (durable)
- Good heat resistance (bakable)
- High insulation resistance (low dark current)

**Active area**

5 mm²

**Beam core passes through between diamond detectors.**

**Clamp area**

**Active area seen from on the axis**

Manufactured by Kobelco
Principle verification tests of diamond detector

Carried out at 8GeV booster synchrotron

Diamond detector
- Bias voltage = +100V

Si PIN photodiode
- (for calibration of incidence)

8GeV electron beam
- From booster
- (beam size 0.4 x 0.1)

Check of pulse shape
- Unipolar pulse
- FWHM = 0.33 nsec
- One shot measurement

Linearity check
- Wide dynamic range
- Required detection limit

Practical detection limit is $2 \times 10^3$ e$^-$ /pulse.
- Definition: $10\sigma$ of noise signal level
2. Photographs of the Prototype

Installed at 250MeV SCSS Test Accelerator

Kapton coaxial cable
SMA connectors

Seen from on the axis
The effect of Wake Field and their suppression

**Measured at SCSS Test Accelerator**

The active area of the diamond detector was irradiated directly with weak beam core \((3 \times 10^4 \text{ e})\).

The strong beam core passes through near the edge of diamond detectors.

Charge of core part : 0.02nC

The effect of induction current can be smeared by using Low Pass Filters, so the net signal from e-h pairs that is created by the halo part of the electron beam can be measured.

Net signal from diamond

The unipolar pulse shape can be observed clearly.
Profile measurement of the beam halo

Scanning in the vertical direction

Signal charge (pC) vs. Vertical beam profile (mm)

Slit width = 10mm, 4mm, 2mm

Images of OTR screen just after beam halo monitor

Measured at SCSS Test Accelerator

Spatial slit after 50 MeV Injector
Stability Tests of the Halo Monitor at the SCSS

Diamond Detectors in Halo Monitor

Signal from upper blade
Signal from lower blade

Halo Monitor Amp (differential output)
H. Maesaka et al.

Event-synchronized Data-acquisition System
M. Yamaga et al.

(a) The output signal from the diamond detector
(b) The output signal from the pre-amplifier.
(C) The waveform stored at data base.

Current signal (V/50Ω)
Time (nsec)

Current signal (V/50Ω)
Time (nsec)

238 MS/sec (4.2 nsec period)
0 – 2047 ch (≈ 8 μsec)

Signal from upper blade
Signal from lower blade

Time (210 nsec/div)
Result of stability tests during user operation during machine study

Measured at SCSS Test Accelerator

during machine study

during user operation

Power of FEL

Intensity of electron beam

Signal from upper blade

Signal from lower blade

9am 7pm

9am 7pm
3. Adoption of RF Fingers

Finger type 0
(no fingers)

Finger type 1
(not covered)

Finger type 2
(fully covered)

In the configuration of type 1, the active areas of the diamond detectors project from between RF fingers.

In the configuration of type 2, the RF fingers are connected without bumps.

→ We need to know,
if the fingers can reduce induced current, and
if the signal blows up by radiation from the finger material.
Reduction of induced current at SCSS Test Accelerator

Finger type 0 (no fingers)

Finger type 1 (not covered)

Finger type 2 (fully covered)

The high frequency component is drastically decreased.
Purpose of this measurement is to evaluate a variation of the detective efficiency caused by secondary electrons and bremsstrahlung that are generated in the finger material.

**Experimental conditions**

<table>
<thead>
<tr>
<th>Finger type</th>
<th>Material</th>
<th>Thickness</th>
<th>Pass length</th>
</tr>
</thead>
<tbody>
<tr>
<td>no finger</td>
<td>none</td>
<td>0 mm</td>
<td>0 mm</td>
</tr>
<tr>
<td>Al window</td>
<td>Al</td>
<td>0.1mm</td>
<td>0.3mm</td>
</tr>
<tr>
<td>BeCu x 1</td>
<td>BeCu</td>
<td>0.2mm</td>
<td>0.6mm</td>
</tr>
<tr>
<td>BeCu x 3</td>
<td>BeCu</td>
<td>0.6mm</td>
<td>1.8mm</td>
</tr>
</tbody>
</table>

Carried out at 8GeV booster synchrotron
The experimental results and the simulation results are in good agreement within the measurement errors. RF finger with Al window can be used for our purpose.
4. Installation at **SACLA**

T. Hara et al.

The geomagnetic shield box (blue box) is for beam based alignment.
Suppression of residual induced current

Measured at SACLA

without Low Pass Filter

with Low Pass Filter

fc = 117 MHz & 300 MHz

Vert = + 2.9 mm

Vert = - 1.7 mm

Vert = + 2.4 mm

Vert = - 1.2 mm

Signal (500 mV/div)

Signal (50 mV/div)

Signal (200 mV/div)

Signal (2 mV/div)

Time (5 ns / div)

Time (5 ns / div)

Time (5 ns / div)

Time (5 ns / div)

Ave _10 folds

Ave _10 folds
The laser power did not receive a significant change even at the minimum gap. We conclude that this is an effect of reducing the wake field by the RF fingers.
We succeeded in achieving the required detection limit at SACLA.

Notice: When the edge of the RF finger is near the beam core, the output signals of diamond detectors blow up because of scattering.
5. Summary

1. Purpose of this work
   - to protect undulator magnets against radiation damage
   - using the beam halo monitor equipped with the diamond detectors
   - adopting pulse measurement for enhancing S/N ratio

2. Performances of the Halo Monitor
   - Practical detection limit is about $2 \times 10^3$ e/pulse. (1ppm of 0.3nC)
   - Dynamic range is 4 orders. ($2 \times 10^3$ to $10^7$ e/pulse)
   - Feasibility had been demonstrated.
   - RF fingers with Al windows were adopted.
   - Commissioning of the Halo Monitor at SACLA has been successfully carried out.

3. Things to do toward a versatile equipment,
   - Improvement of lower/upper detection limit.
   - Refinement of RF finger structure (reduce gap between a finger and a detector)
   - Equipment with a cooling mechanism.