Status of SCSS & X-ray FEL Project in Japan

Presented by T. Shintake, RIKEN/SPring-8

Representing JASRI+RIKEN Joint Team

- Status of 8 GeV XFEL/SPring-8 Construction
- What we learned from SCSS Test Accelerator
JASRI+RIKEN Joint Construction Team (88)
XFEL/SPring-8 Project (CG)

8 GeV Linear Accelerator (400 m)

Experimental Hall

Undulator Hall (150 m)

8 GeV SPring-8 (existing)

SCSS Test Accelerator (250MeV, 60 m) 2005~
### SCSS & X-ray FEL Beam Parameter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Prototype</th>
<th>X-ray FEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Energy</td>
<td>(E)</td>
<td>0.25</td>
</tr>
<tr>
<td>X-ray Wavelength</td>
<td>(\lambda)</td>
<td>60</td>
</tr>
<tr>
<td>Beam Emittance</td>
<td>(\varepsilon_n)</td>
<td>2</td>
</tr>
<tr>
<td>Bunch Length</td>
<td>(\Delta_z) FWMH</td>
<td>100 0.3</td>
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<tr>
<td>Transverse Beam Size</td>
<td>(\sigma_{x,y})</td>
<td>100</td>
</tr>
<tr>
<td>Peak Current</td>
<td>(I_p)</td>
<td>1</td>
</tr>
<tr>
<td>Charge per bunch</td>
<td>(q)</td>
<td>0.3</td>
</tr>
<tr>
<td>Undulator Parameter</td>
<td>(\lambda_u) (K) (L)</td>
<td>15 1.3 10</td>
</tr>
<tr>
<td>FEL Saturation Length</td>
<td>(L_{sat})</td>
<td>20</td>
</tr>
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</table>
Tunnel Construction started June 2007

- Accelerator tunnel, on surface.
- Site length 700 m
Construction site (looking down east)

Stake hole machine's head. 1.6 m diameter

Piling started in June 2007

Vertical drilling machine.
Lifting soil through drilling shaft.

Inserting reinforcing structure.

Filling concrete
Basement Construction

(Strengthening foundation)

8 GeV Linear Accelerator (400 m)

- Total Number of stakes: 139
- Size: 1.5 m ~ 1.6 m
- Length: average ~30 m (max 52 m)
- Piling: June ~ October

Legend:
- Yellow: Soil
- Light blue: Soft hardness rock
- Dark blue: Mid hardness rock
RF Acceleration System in 8 GeV SPring-8 XFEL

- Gun: 238 MHz, 476 MHz
- Injector
- 50 MeV
- BC-0
- S-band
- BC-1
- S-band
- BC-2
- C-band Sector-1
- C1-1, C1-12, C1-16, C1-16
- C-band Sector-2
- C2-1, C2-16
- 12 GeV
- 1.5 GeV
- 4 GeV
- 6 GeV
- 8 GeV
- Klystron 64
- Acc. Str. 128
- To Undulator
- T. Shintake 2007 March
Acc. Mass Production, July 20

Cells for C-band Choke Mode Cavity No. 0

Coupler Matching Test
### Undulator for XFEL/SPring-8

Takashi Tanaka

<table>
<thead>
<tr>
<th>Feature</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Magnetic Circuit</strong></td>
<td>Hybrid</td>
</tr>
<tr>
<td><strong>Length</strong></td>
<td>5 m</td>
</tr>
<tr>
<td><strong>Period</strong></td>
<td>18 mm</td>
</tr>
<tr>
<td><strong>Number of Periods</strong></td>
<td>276</td>
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<tr>
<td><strong>Gap</strong></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>2 mm</td>
</tr>
<tr>
<td>At 1 ope</td>
<td>4 mm</td>
</tr>
<tr>
<td>Max</td>
<td>40 mm</td>
</tr>
<tr>
<td><strong>K-value</strong></td>
<td></td>
</tr>
<tr>
<td>Max</td>
<td>2.1</td>
</tr>
<tr>
<td>At 1 ope</td>
<td>1.9</td>
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</tbody>
</table>
\[ I = 3.5 \text{kA} \]
\[ \varepsilon = 1\pi \text{mm.mrad} \]
\[ \Delta E/E = 0.01\% \]
DFB Solid State Laser looked to Acetylene Absorption Spectrum (1538 nm)

Principle of Optical Comb
Driven by Master Oscillator (5712 MHz)

Y. Otake

Wave Form of Optical Comb

Spectrum of Comb Light (Envelope)

Noise Spectra of Optical comb Generator & Master Oscillator

 OSC

 Comb

Frequency (Hz))

Amplitude (dBc/Hz))

175 ps
The optical fiber length was controlled within 3 \( \mu m \) for 2km long.

**fs time stability**

Error Spectra of Fiber Length Feedback Control

Experimental set up

This experiment was carried out by using a 1 km phase stabilized optical fiber laid in the Spring-8 ring accelerator.
First Lasing at SCSS Prototype Accelerator.

June 15, 2006
User Experimental Room has been build

New Exp. Hall

X-ray beam pipe

User run will start in October 2007
What learned from SCSS Test Accelerator

- **CeB6 thermionic cathode is very stable and long life.** One and half year after installation, it’s still OK.

- After stabilizing RF power supply and cavity temperature, **SASE lasing became very stable.**

- Measurement on **arriving time jitter showed only 50 fs jitter.** Bunching process (x100~x400) is fairly stable.

- **Collimator is important** to stabilize lasing.
  - Collision less bunching.
CeB$_6$ Cathode & Heater Assembly

- CeB$_6$ Cathode 3 mm Diameter
- Emittance 0.4 $\pi$.mm.mrad (thermal emittance, theoretical)
- Beam Current 3 Amp.
  at 1450 deg.C
  (using graphite heater)
- Current Density > 40 A/cm$^2$
CeB$_6$ Thermionic Gun provides stable beam.
Test Accelerator Layout

**Injector**

- $E = 500 \text{ kV}$
- $q = 1 \text{ nC}$
- $I_{pk} = 1 \text{ A}$
- $\Delta t = 1 \text{ nsec}$

**C-band Main Acc.**

- 50 MeV
- 0.25 nC
- 250 A
- 1 psec

**Undulator**

- $E = 250 \text{ MeV}$
- $q = 0.25 \text{ nC}$
- $I_{pk} = 200 \text{ A}$
- $\Delta t = 1 \text{ psec FWHM}$
- $\epsilon_n = 2 \pi \text{ mm.mrad}$

**Parameters**

- $\lambda_u = 15 \text{ mm}$
- $K_{max} = 1.3$
- $\text{gap.min} = 3.5 \text{ mm}$
- $<\beta_{x,y}> = 10 \text{ m}$
- $L = 4.5 \times 2 = 9 \text{ m}$

**Diagram Details**

- 500 kV Pulse Gun
- 238 MHz Sub-harmonic Buncher ~200 kV
- 476 MHz Booster ~700 kV
- Chopper 1 nsec
- S-band Linacs 1 m 50 MV/m
- $32 \text{ MV/m}$
- $1.8 \text{ m} \times 4/\text{unit}$
- C-band Linac $x1/4$
- X-ray FEL

**VUV Beam**

**e-Beam Dump**
Temperature Control on Sub-Harmonic Buncher Cavity

- Upstream **238 MHz Sub-harmonic buncher** cavity provide **time base** in this accelerator.
- It has same function as “**Mode-locker**” in the laser system → **time base**.
- Stability of this cavity dominate system performance.
  → Cavity body is made by “**Massive Copper**”, which **eliminates jitter**.
- Using **electric heater**, the inlet water temperature is controlled at **constant**.
Phase Jitter = 0.086 deg. at 238 MHz (10 minute)

→ Cavity Temperature Fluctuation < 0.1 mK
Stability of Beam Energy without RF Feedback on SHB and booster cavity.

\[ \frac{\delta E}{E} \sim 6 \times 10^{-4} \text{ (20 minute)} \]

without RF Feedback on SHB and booster cavity.
Stability of Lasing

**Repetition 10Hz Before Improvement**

- **Photo-diode Signal**
- **Δ E/E**

4000 sec from 2007/07/12 16:40:09

**Repetition 10Hz After Improvement**

- **Photo-diode Signal**
- **Δ E/E**

4000 sec from 2007/07/20 15:36:13
The Block Diagram of the Beam Jitter Detection System

Synchronized with acceleration RF

Cavity BPM 476MHz

IQ mixer

Position detection cavity

Reference cavity

Reference Cavity Amplitude (I Signal): 390 mV
Reference Cavity Amplitude (Q Signal): 0.54 mV

0.54mV (1 mrad) ≈ 0.54/390 = 1.38 mrad

Arriving Time Jitter:
1.38 mrad / 4760 MHz / 2 = 46 fs 😄
Schedule & Summary

- User run will start in October 2007 at SCSS Prototype Accelerator
- Mass production for 8 GeV main linac has started.
- Mass production of undulator will start in 2008
- Civil construction will end April 2009.
- Installation : 2009-2010
- First X-ray beam : End of FY 2010
Thank you very much!