Instrumentation for the ATF2 Facility

- Introduction
- Beam size monitor
- Beam position monitors
- Beam stabilization
- Others

N. Terunuma, KEK
the ATF International Collaboration
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Why ATF/ATF2?

An important technical challenge of ILC is the collision of extremely small beams of a few nanometers in vertical size.

This challenge involves following distinct issues:

- creating small emittance beams, ........................................ ATF
- preserving the emittance during acceleration and transport, and finally focusing the beams to nanometers before colliding them. ........................................ ATF2

Challenging goals for ATF2

1. achieving of the 37 nm vertical beam size at IP, ~2010~
2. demonstration of the stabilization of beam in a few nanometer level at the IP. ~2012~
Accelerator Test Facility (1.3 GeV)

ATF2 beam line (Jan.2009~)

Previous EXT line (~Jun.2008)

Photo-cathode RF gun
(electron source)

Damping Ring

S-band Linac
Δf ECS for multi-bunch beam
ATF2 Overview

Features

• uses low emittance beam extracted from ATF DR
• ATF2-FF optics is an energy scale down of the ILC final focus system.
• Demonstration of compact final focus optics for ILC
• Beam instrumentation has been developed with the ILC specifications.
• International participation in the commissioning and operation.
Oversea
25 Institutes, 
~70 people, 
~2000 people- 
days
+ 
KEK and 
Japanese Universities(6)
Instrumentation for ATF2

**Beam Size Monitors**
1. **Solid (W,C) wire Scanners** *(meas. for 2um or more)*
2. **Laser interference fringe monitor** *(meas. for 20nm~5um)*
3. **Pulsed Laser wire scanner**
4. **Optical Transition Radiation monitor**

**Beam Position Monitors**
1. **Strip-line BPM**
2. **Cavity BPMs** *(circular, C-,S-band, resolution 100nm)*
3. **IP BPM** *(rectangular, C-band, target resolution 2nm)*

**Beam Stabilization**
1. **Intra-train fast feedback (FONT)**
2. **Straightness monitor**
Single/Multi bunch beam for ATF2

Beam extracted from DR: (typically) $0.5 \times 10^{10}$ e/bunch, 1.56 Hz

(1) by a conventional kicker
   1~3 bunches, 154 ns spacing
   (routinely operated at present)

(2) by a fast kicker
   1~30 bunches, 308 ns spacing
   (routine operation in near future is expected)

Instrumentation for the ATF2 Facility
Beam Size Monitor for ATF2-IP
Principle of Laser Interference
Beam Size Monitor (Shintake Monitor)

Schematics of Shintake Monitor

Modulation depth

\[ M = \frac{N_+ - N_-}{N_+ + N_-} = \frac{\text{Amplitude}}{\text{Average}} \]

Beam Size

\[ \sigma_y = \frac{d}{2\pi} \sqrt{2 \log \left( \frac{|\cos \theta|}{M} \right)} \]

d: fringe pitch \hspace{1cm} \theta: crossing angle

Measured signal in FFTB at SLAC
T. Shintake et al., 1992
\(\sigma_y \approx 65\) nm beam size was measured
**Laser Interference Fringe Monitor for ATF2**

Univ. Tokyo/KEK

**FFT B ~70nm -> ATF2 37nm**

**Modifications for ATF2**

- Laser wavelength (1064 → 532 nm)
- add 2~8 deg. laser crossing
- new fringe phase control/stabilization
- Multi-layer γ-ray detector

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**Graph:**

- Modulation depth vs. beam size
- 1064nm laser (green), 532nm laser (red), FFTB result (70nm), ATF2 design (37nm)

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**Diagram:**

- Move stage
- Piezo stage
- Move fringe
- 50% Beam splitter

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**Graph:**

- Signal vs. Energy vs. FFT phase
- Frequency of signal varies with phase
**Laser Interference Fringe Monitor for ATF2**

fringe pitch: \( d = \frac{\lambda}{2 \sin \theta / 2} \)

\( \lambda \) = laser wavelength, \( \theta \) = crossing angle

<table>
<thead>
<tr>
<th></th>
<th>174°</th>
<th>30°</th>
<th>8°</th>
<th>2°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fringe pitch</td>
<td>266 nm</td>
<td>1.03 μm</td>
<td>3.81 μm</td>
<td>15.2 μm</td>
</tr>
<tr>
<td>Minimum</td>
<td>25 nm</td>
<td>100 nm</td>
<td>360 nm</td>
<td>-</td>
</tr>
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<td>360 nm</td>
<td>-</td>
<td>6 μm</td>
</tr>
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</table>

Expected Beam Size Resolution

[Graph showing expected beam size resolution]
Gamma-ray Detector

- Use multi-layered calorimeter
  - CsI(Tl), 4 thin layers + 1 bulk
- Calculate the amount of Compton signal and the background using the difference of energy deposit on each layer.

Energy deposit ratio on each layer

Measured resolution
Measurement of the vertical beam size at ATF2

Example:
Smallest beam size measured under the ATF2 commissioning (2010/May/20)
Modulation Depth = 0.87 @ 8.0 deg. mode
σ_y = 310 ± 30 (stat.) ±0-40 (syst.) nm
Beam Position Monitors

Cavity BPMs for ATF2 beamline
Cavity BPM for ATF2 IP
**ATF2 Cavity BPM system**

Cavity BPM: strong signal, possible to reach "nm" resolution
better mechanical rigidity and reliability of the electric center

- **IP BPM system**
  - BPM + Ref Cavity: 1 unit
  - Target: 2 nm
  - Aperture: 6 mm(V)
  - It will be installed in 2010.

- **S-band BPM system**
  - BPM cavity: 4 units
  - Ref. cavity: 1 unit
  - Target: 100 nm
  - Aperture: φ40 mm

- **C-band BPM system**
  - BPM cavity: 34 units
  - Reference cavity: 4 units
  - Target resolution: 100 nm
  - Aperture: φ20 mm
R&D of Cavity BPM prototypes

Several types of cavity BPMs were tested in ATF extraction line. **Cavity frequency: C-band ~6.5 GHz, most sensitive for the ATF beam**

"nano-BPM" experiments at ATF
2 sets of BPM triplet systems different idea of support and position control

Both of the systems have proved position resolutions smaller than 20 nm.

Active stabilization with optical interferometers

Achieved resolution 15.6 nm @dynamic range ±20µm
System performance of the ATF2 Cavity BPM

C-band BPM
- 20 dB attenuation of BPM signals, most of C-band BPMs to avoid saturation
- Downmix ~6426 MHz to 26 MHz
- 14-bit 100 MHz digitizers, digital down conversion
- CW calibration tone to monitor the gain and phase

Resolutions:
- with 20dB att. 200 nm ~ 1.2 μm
- w/o 20dB att. 27 nm

S-band BPM
- Large cross coupling on X, Y port

Improvements in near future
- Thermal effect on the mixer electronics
- LO power distribution
- S-band BPM: large cross coupling

DDC
- Raw signal for DDC
- Cal. tone
- DDC amplitude
- DDC phase

Resolution [μm]
- C-band BPMs w/ 20dB attenuator: resolution 200~1200 nm
- w/o attenuator, best resolution: 27 nm
Cavity BPM for the focal point

Goal resolution: 2 nm

Provide a direct demonstration of beam position stability

- tracks the beam trajectory during beam size measurements to correct the effects of position jitter
- produces a feedback signal to stabilize the beam orbits of the following bunches.

Rectangular shape: isolates two (x,y) dipole mode

Thin cavity: reduces the sensitivity to trajectory inclination.

Achieved resolution at ATF

$8.72 \pm 0.28\text{(stat)} \pm 0.35\text{(sys)}$ nm

@ $0.7 \times 10^{10}$ electrons/bunch,

@ $5 \, \mu m$ dynamic range

Low-Q Cavity BPM for multi-bunch beam at ATF2

low-Q BPM: to enable the bunch-by-bunch position measurement for the multi-bunch beam with bunch spacing of 154 ns

Sensitivity:
- Low-Q
- Prototype

Bunch-by-bunch signal separation for the 3 bunch beam, 154ns spacing

Low-Q IP-BPM tested at ATF2

Improvements on the readout electronics have been continued to achieve the 2 nm resolution.

Present:
- Electronics latency: ~17 ns
- Expected resolution: ~10 nm
Beam Stabilization at the IP

Fast Intra-Train Feedback (FONT)
Very Fast Beam Orbit Feedback

Challenging goals for ATF2
1. achieving of the 37 nm vertical beam size at IP
2. demonstration of the stabilization of beam in a few nanometer level at the IP.

Intra-train feedback system
• Correct the impact of fast jitter sources such as the vibration of the magnets in the final focus section.
• Essential system for the ATF2 second goal.

FONT
(Feedback On Nano-Second Timescales) has been developed
as a prototype of a beam-based feedback system for the interaction point of the ILC
**FONT: intra-train feedback R&D**

*Oxford, Daresbury, QMUL, SLAC, KEK, DESY, CERN*

The system was used to provide orbit correction to the train of bunches extracted from the ATF damping ring.

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**History**

1. prototypes: all-analogue feedback system (for very short bunch-train LCs)
   - **latency**
   - FONT1(NLCTA): 67 ns,
   - FONT2(NLCTA): 54 ns,
   - FONT3(ATF): 23 ns.

2. digital feedback system for long bunch-train ILC.
   - ILC bunch spacing, ~150/300 ns
   - allow the implementation of more sophisticated algorithms
**FONT4: first digital intra-train feedback**

3 bunches, 154ns spacing

**Extracted beam from DR**

Shift the beam positions by a beam-steering dipole to simulate the possible beam jitter etc.

**Drive amplifier**

**Analogue BPM processor**

**Digital feedback**

**Kicker**

3 bunches, 154ns spacing

Bunch 3 steered to an arbitrary vertical position.

**Feedback off**

Beam position vs. pulse number

**Feedback on**

Gain = 1700, feedback on

Gain = 1700, feedback off
**FONT5: intra-train feedback at ATF2**

**FONT5 P2 → K1 FB-loop**  
(February 2010)

- **Latency 133ns**

**FONT5 system**
- flexible configurations
  - two kickers and three BPMs
- coupled feedback system of two loops correcting both position and angle jitter in the vertical plane

**Incoming position scan**

![Graph showing incoming position scan with data for first, second, and third bunches.]
Beam jitter reduction by FONT5

Results of P2 $\rightarrow$ K1 loop (measured)
(April 16 2010)

Bunch 1  Bunch 2  Bunch 3

2.1 um $\rightarrow$ 0.4 um $\rightarrow$ 0.8 um

Assuming perfect lattice, no further imperfections (!)

FB OFF: jitter 14.7 nm
FB ON: jitter 2.6 nm

Jitter comparison at IP (simulation)
Key instruments toward the ATF2 goals

Goal 1:
achieving of the 37 nm vertical beam size at IP

*FONT:* stabilization of beam injection to Final Focus System
*IP-BPM:* position measurement at IP
*Interference fringe monitor:* beam size measurement

Goal 2:
demonstration of the stabilization of beam in a few nanometer level at the IP

*FONT+IP-BPM:* 
intra-train feedback in a few nanometer level at IP
[ Fast kicker: multi-bunch beam (up to 30, 308ns spacing) ]
Other Instruments at ATF2
Pulsed Laser Wire Beam size monitor

JAI(RHUL,Oxford)/KEK

Develop a system capable of reliably measuring an electron beam of order one micron in vertical size with a non-destructive method.

**ILC design requirement:**

< 1 um laser wire scanner

**Results at ATF extraction line**

smallest beam size (2008)

\[ \sigma_y = 3.65\pm0.09 \, \mu m \text{ (convoluted)} \]

\[ \sigma_{lw} = 2.2 \pm 0.2 \, \mu m \]

A laser beam is focused with a specially designed f/2 lens system.

![Diagram showing a laser beam focusing system with APD detector, Collimating lens, Power meter, BPM, FF lens, Scanner, Laser light, Dipole magnet, Compton x-rays, Electron beam, Detector, and Cerenkov signal vs. position graph.](image-url)
Upgrade of Laser wire monitor

The system has been re-commissioned in the ATF2 after the re-location.

Improvement for ATF2
inclusion of an OTR target in the system for collision optimisation and cross calibration

Beam size scanning by LW-OTR
OTR Monitors at ATF2

IFIC (CSIC-UV)/SLAC/KEK

OTR (Optical Transition Radiation) monitor developed at ATF demonstrated the ability to measure a 5.5 µm beam size in one pulse.
- damage of (Be)Cu target for smaller beam

Multiple OTR monitors for the ATF2
- realize the fast emittance measurement
- 4 OTR monitors near the Wire Scanners
- improved resolution of about 2 µm
- thin aluminized (1200 Å) Mylar target

The first test of multi-OTR system at ATF2 will be done in June 2010.
A laser interferometer system that will eventually correct the measurement of high-precision BPM used in the ATF2 Final Focus Steering Feedback for mechanical motion or vibrations.
Summary

A variety of beam instruments have been developed in ATF/ATF2.

The cavity BPMs with a nanometer level resolution, the beam size monitor based on the laser interference fringe and the fast intra-train feedback system are essential tools to realize two major goals of the ATF2 program;

1. achieving the 37 nm vertical beam size
2. establishing a few nm level beam-position stabilization.

- Thank you -