1. Introduction (Historical process on the establishment of 1st order optics and the stabilization)

2. Alignment

3. Beam Tuning/Diagnostics

4. Summary (plans for JLC)
KEK-ATF (Accelerator Test Facility for JLC)

KEK-ATF Extraction line

1.28 GeV Damping ring

1.28 GeV S-band LINAC

KEK-ATF parameter
energy 1.28 GeV (γ~2500)
emittance vertical $(1.5\pm0.25) \times 10^{11} \text{m rad}$
horizontal $(1.4\pm0.3) \times 10^{9} \text{m rad}$
bunch length 20 ps $\rightarrow 30$ ps
max intensity $1.2 \times 10^{10}$ electrons/bunch
The Optics model improved after the correction. (data June 6, 1998)

Original model

Corrected model (based on data on March 19, 1998) magnetic field error between model and mean is ≤ 0.01% on March 1999
Horizontal dispersion.
Measured (plots) and model calculation (line).

Measured vertical dispersion.
Before and After dispersion Correction

before correction

after correction

reset all v-stems zero
co2 y correction
by y correction
Horizontal Emittance Evaluation

Two different methods are used for horizontal emittance evaluation. One is a waist scan method, and the other is a four wire method. The waist scan method is the method to evaluate a beam emittance by measuring a beam size with single wire scanner while changing strength of a quadrupole magnet located upstream of the wire scanner. The four wire method is the method to evaluate a beam emittance by measuring beam sizes with four wire scanners.

![Graphs showing horizontal emittance evaluation](image)

<table>
<thead>
<tr>
<th>Method</th>
<th>Monitor</th>
<th>Emittance [nm]</th>
<th>$B_{\text{mag}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waist Scan</td>
<td>MW1X</td>
<td>1.47 ± 0.06</td>
<td>1.03 ± 0.07</td>
</tr>
<tr>
<td>Waist Scan</td>
<td>MW2X</td>
<td>1.27 ± 0.06</td>
<td>1.00 ± 0.03</td>
</tr>
<tr>
<td>Waist Scan</td>
<td>MW3X</td>
<td>1.38 ± 0.05</td>
<td>1.02 ± 0.05</td>
</tr>
<tr>
<td>Four Wire</td>
<td>All Monitors</td>
<td>1.29 ± 0.11</td>
<td>1.06 ± 0.34</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>1.37 ± 0.03</td>
<td>$\alpha_x$:3.83 $\beta_x$:6.77</td>
</tr>
</tbody>
</table>
Assembly result of magnets on mover tables

\[ \text{RMS}(\Delta X) = 26 \, \mu m \]
\[ \text{RMS}(\Delta Y) = 21 \, \mu m \]

Tolerance \( \delta_Y < 90 \, \mu m \)

Assembly result of magnets on mover tables

\[ \text{RMS}(\Delta Z) = 52 \, \mu m \]
Stored Beam Intensity

1999 July

Bunch Population

Time [hours]

Linac and Damping Ring Tuning

Beam was stopped by machine troubles

\[ \times 10^{10} \]
Stored Beam Intensity
(We did not change to all of the accelerator parameters)
2000 April

2.8 % r.m.s. Intensity Jitter

Access to Tunnel in order to adjust for the SR monitor
Beam Energy for Stored Beam

1999 July

We observed the clear energy drift within a few hours.

Beam was stopped by machine troubles.
Beam Energy for Stored Beam
(We did not change to all of the accelerator parameters)
2000 April

We did not observe the clear energy drift.

Access to Tunnel in order to adjust for the SR monitor
Single bunch
low emittance beam generation

DR beam tuning
Magnets alignment
Vacuum level
  keep ave. pressure less than 1 E-6 Pa
COD correction
  correct within +/- 0.5 mm both x and y
Dispersion correction
  correct Y dispersion within +/- 5mm
  without disturbing Y COD
Coupling correction
  by skew-Q component from SX trim coil
  minimizing Y orbit response from X steer kick
  minimizing tune separation at coupling resonance
  reduce betatron coupling less than 0.2%

Extracted beam tuning
Orbit correction within +/- 1 mm
Dispersion correction at wire scanner
  correct X, Y dispersion less than 10mm
  \[ \leq 5\text{mm (necessary)} \]
2.0 mm peak to peak Horizontal COD
1.0 mm peak to peak Vertical COD

**Horizontal Emittance**

- 30 μm Alignment Error
- 40 μm Alignment Error
- 50 μm Alignment Error

Horizontal Emittance Enhancement
from 1.07 nm to 1.20 nm

**Vertical Emittance**

- 30 μm Alignment Error
- 40 μm Alignment Error
- 50 μm Alignment Error

Expected Vertical Emittance
0.005 nm - 0.03 nm
Recent progress in Accelerator Test Facility at KEK

K. Kubo, KEK, Tsukuba, Japan, for ATF Collaboration

Abstract

The mission of the ATF at KEK is to test the feasibility of the production of multibunch beams with extremely low transverse emittance for future linear colliders. Until this summer the main goal had been to produce low emittance beams with single bunch operation. Recently, we established a tuning method of the damping ring for the small vertical dispersion and small x-y orbit coupling. Simulation studies indicate that low vertical emittance should be attainable with this tuning. Substantial progress has been made in the past year in reducing the measured vertical beam emittance at ATF. We observed that the beam emittance and beam momentum spread vary, depending on the bunch population and RF voltage. This suggests the existence of strong intra-beam scattering effects in the beam with very low vertical emittance in the ring. Some technical issues associated with the beam size measurements are also noted. Multibunch operation is another main program of ATF. A bunch train consisting of 18 bunches was produced, accelerated in the linac, injected in the damping ring and extracted to the extraction line. Development of bunch-by-bunch instrumentation is also reported.

1 INTRODUCTION

ATF consists of an S-band linac, a damping ring and an extraction line[1]. The ring has been designed to produce extremely low emittance beam. The designed natural horizontal emittance is \(1.1 \times 10^{-9}\) rad-m and the target value of vertical emittance is 1% of that. History and summary of the past beam operation are reviewed in references [1][2].

The initial stage operation of ATF has been focusing on confirmation of low emittance beam production at a low repetition rate (1.56 Hz). As detailed in Section 2 of this paper, substantial commissioning experiences have been accumulated, and the target vertical emittance has been achieved at the bunch intensity of about \(2 \times 10^9\). Thus, studies are currently also being started on multibunch beam which is essential for future linear colliders. Beam loading compensation of the multibunch beam in the injector linac has been successfully tested. However, issues with uniformity of the bunch intensity and bunching still remain. They are discussed in Section 3. Section 4 describes the hardware improvement programs at ATF.

2 SINGLE BUNCH OPERATION

2.1 Low emittance tuning in DR

Our tuning method of the damping ring for low vertical emittance is a series of corrections as follows:
- COD correction.
- Vertical COD + dispersion correction.
- Coupling correction.

The strengths of a set of steering magnets is calculated to minimize

\[ \sum \eta_{x_{\text{meas}}}^2 \quad \text{and} \quad \sum \eta_{y_{\text{meas}}}^2 \]

in the COD correction and to minimize

\[ \sum \eta_{x_{\text{meas}}}^2 + r^2 \sum \eta_{y_{\text{meas}}}^2 \]

in the vertical COD + dispersion correction. Here, \(x_{\text{meas}}, y_{\text{meas}}, \eta_{x_{\text{meas}}, \eta_{y_{\text{meas}}}}\) are beam horizontal position, vertical position and vertical dispersion measured at each BPM. In this COD + dispersion correction, both the vertical COD and vertical dispersion are considered simultaneously. The factor \(r\) is the relative weight of the dispersion and COD, and it was chosen to be 0.05 based on a simulation study. For the coupling correction, trim coils of all 68 sextupole magnets are wired so as to produce skew quadrupole fields. The strengths of these skew fields is calculated to minimize

\[ \sum_{\text{steer}} \left[ \frac{\sum_{\text{BPM}} (\Delta y_{\text{steer}})^2}{\sum_{\text{BPM}} (\Delta x_{\text{steer}})^2} \right] \]

Here, \(\Delta x_{\text{steer}}\) and \(\Delta y_{\text{steer}}\) are measured horizontal and vertical position responses to each horizontal steering magnet. Usually, two horizontal steering magnets, which are apart by approximately \(3/2\pi\) in horizontal and \(1/2\pi\) in vertical phase advance, are chosen for this correction.

Fig. 1. Distribution of simulated vertical emittance after damping ring tuning.

Simulations were performed to study this tuning method where realistic magnet misalignment and random errors of BPM are considered [3]. Fig. 1 shows the distribution of the vertical emittance from 500 random seeds for magnet alignment errors and BPM errors in the...
Coupling correction using skew-Q of SX trim

minimizing Y orbit response by X steer kick

ZH1R steer kick

X

Y response

Y response after correction

ZH3R steer kick

X

Y response

Y response after correction
Coupling correction

minimizing tune separation at coupling resonance

skew off
k=1.4%

skew corr.
by using Y orbit response
k=0.9%

additional manual skew corr.
k=0.2%
Tungsten Wire Scanner in EXT-line

5 monitors installed in Ext line

10 and 50μm gold plated tungsten wire
7 μm Carbon wire
down to 5μm beam size measureable

Air cherenkov+PMT γ-detector for single bunch
Air cherenkov+APD γ-detector for multi-bunch
Wire Scanner  Wire mount

+/-10 degree wire, 7μm Carbon wire

moving direction 45deg

50μm Tungsten wire

10μm Tungsten wire

7μm Carbon wire

0.5μm-step stepping motor stage
0.5μm resolution digital scale
Laser wire monitor (principle)

- use thin laser light (laserwire) as a target
- detect compton scattered gamma ray
- scan laserwire position measuring gamma ray yield
SR interference monitor (X)

Double Slit

2nd Mirror

Mirror

5375

2nd SR port

crystal

SR interference monitor (Y)

f=600mm Lens

Polarization filter

CCD Camera

x5 magnifier Lens

Band Pass Filter 500nm

2nd Lens

1st Lens

Mirror

Mirror

Fresnel zone plate Lens

X-ray CCD Camera

Bending Magnet

Source Point

Source Point

Electron Beam

Bending Radius 5.73m

X-ray SR

SR

SR monitor optics set-up

X-ray SR port in Jan. 2002
Experimental layout

γ-detector to beam dump
bending magnet
screen monitor
rotatable mirror
collimator
reflecting mirror
PMT
alignment laser
mirror chamber
screen monitor
target chamber
CCD
CCD
beam line

\[ z = 2.6m \]
\[ \Delta \theta_x = \Delta \theta_y = 0.192 \text{mrad}(0.48/\gamma) \]

PMT energy range \( \sim 0.3 - 0.65 \mu m \)
ODR and OTR measured by IIT at one shot
Measurements WITHOUT optical filters

ODR (OTR) angular distributions

Dependence on Impact Parameter

Preliminary
Cavity BPM installation in EXT line

relative position measurement
for precise dispersion control

max. resolution 0.2μm for 100μm range
mover stage resolution 0.3μm

dispersion can be reduced less than 2mm
2mm dispersion -> 1.6μm beam size effect

2mm dispersion -> 5.2μm position shift by 4kHz freq. change
Dispersion measurement

The dispersion in the extraction line is measured by detecting the orbit change induced by changing of rf frequency in the ring. At injection into the ring, rf frequency has to be synchronized with the linac rf. A few 100 $\mu$s after the injection, the rf frequency is ramped over a time period of 50 ms. The beam is extracted from the damping ring about 450 ms after the end of the frequency ramp. The orbit change is proportional to $\eta \Delta f_r / \alpha_c$, where $\alpha_c$ is momentum compaction factor. The $\eta$ and $\eta'$ at the extracted point from the ring and $\alpha_c$ are fit by the measured coefficients. The energy spread was measured using screen monitor at the place of large dispersion.

Frequency ramp

Measured horizontal and vertical dispersion in the extraction line (plot) and fitted result (line).
Vertical Emittance Evaluation from Momentum Spread Enhancement

Vc Dependence of Momentum Spread

Momentum Spread [%]

Vertical Emittance Evaluation

Vertical Emittance at Zero Current [nm]

Cavity Voltage [kV]

Bunch Population

Vc = 306.0 kV
Vc = 275.5 kV
Vc = 248.0 kV
Vc = 217.8 kV
Vc = 187.9 kV
Vc = 158.2 kV

× 10^{10}
SR interferomenterによって計測した垂直エミッタンスの電流依存性 - 測定系は実際の値に対し最大値を計測するが、< 1.8x10^{-11}m(@4mA)を計測した。

measured by SR interferometer.
SR interferometer vs Laser wire

Vertical emittance measurement

The vertical emittance measurement by both SR and LW (SR error is only statistic)

Laser wire reach to $0.5 \times 10^{-11}$ m rad on the other hand SR was saturated on lower emittance region.

LC2002 Hiroshi Sakai
Vertical Emittance Evaluated by the Touschek Beam Lifetime

Example of the Current Decay
\( V_c = 280 \text{ kV} \)

At the Zero-Current, The Vertical Emittance was Roughly 0.005 nm.
Single Bunch Y emittance

- SR monior 2001/3/9
- Laser wire 2000/12/5
- Laser wire 2000/12/14
- Wire scanner 2001/2/8
- Wire scanner 2001/6/12
- calc. emittance ratio=0.004
- calc. emittance ratio=0.006
- calc. emittance ratio=0.008

Vertical emittance (m-rad)

Bunch population
Wire scanner multibunch detection

Waveform from APD detector with wire on beam

Peak detection by software through GPIB

APD: Avalanche Photo-Diode
BW: 1GHz

scope: TDS694C
10Gs/s, 3GHz BW
RFgun概念図

Nd:YAGレーザー
1064nm / 4 = 266mm
1μs / bunch

4μC / bunch

フォトカソード面
Cs2Te
Q.E. ≈ 1%

光電子
>100MeV

電子ビーム
≤10psec

c>5MeV
Photocathode RF-gun & 80MeV pre-injector for positron production Linac

~3x10^6 rad.m
~200 bunches/train
~10^10 electrons/bunch
Nanometer Beam Size Measurement

Spot size Monitor based on Laser Interferometry

Interferometer

YAG - Laser

Compton Scattered γ-ray flux

γ-ray Detector

Magnet

e-

Electron Beam

Steering Magnet
Experimental Test at FFTB
RF-BPM tested at FFTB
Nanometer Beam Position Monitor

Beam Trajectories measured by the RF-BPM Triplet Set
1 mm Resolution at 10° particles/bunch by single beam pass.

1 GHz > 714 MHz Signal Process.

Cross section of BPM camber

Button electrode assembly

EBW

Reference plane

Reference plane

Reference plane

Top block (Ti)

HIP transition

Brazing (Al)

Flange (A3003)

Button (SUS304)

SMA connector

Brazing (Ag-Cu)

Ceramics

Pin (Kovar)

ø24 mm

ø8 mm

19.5 mm

70 mm
moving direction 45 degree

beam

+10 degree

-10 degree

y wire

150

u wire

x wire

$\phi 7\mu m$
Carbon wire

0.5\mu m-step stepping motor stage
0.5\mu m resolution digital scale
1 μm Resolution by single pass.

SMA feed-through

ICF70

stripline electrode l=40mm

Q-magnet pole

A

A'

56

345
~100mm Resolution by single pass.
(<50mm)

260

temperature control

79

sMA feed-through

reference cavity 6.5GHz

wave guide

X1

Y1

X2

Y2

ref.

senser cavity 6.5GHz

Q magnet

455

φ75

φ100

φ20 bore

φ16 beam aperture
Summary

Luminosity
Low emittance tuning has been established. dE/E, X emittance were consistent with IBS theory prediction. 3pm Y emittance at zero current is expected.
(EXT Y emittance is larger than expected.)

Instrumentation
Laser wire in DR, EXT wire scanner, EXT cavity BPM are worked well. EXT OTR, ODR, X-ray SR monitor are commissioned. BBA is under the study.

Multibunch operation
Ring scrubbing by Multibunch beam makes vertical emittance reduced. Multibunch wire scanner is commissioned and Multibunch BPM is under the study.

Misc. studies
Pol.-positron study: pol. High brilliance Gamma-ray was generated. Photo-cathode RF-gun was tested. Multibunch RF-gun study is in progress. DR BPM upgrade is in progress.