

BUNCH BY BUNCH BEAM MONITOR FOR ATF INJECTOR LINAC

T. Naito, T.Asaka\*, H.Hayano, H.Matsumoto and S.Takeda

KEK, National Laboratory for High Energy Physics  
 Oho 1-1, Tsukuba, Ibaraki, 305 Japan  
 \*Tohoku-Gakuin University

Abstract

An 80MeV injector of Accelerator Test Facility(ATF) accelerates multi-bunch beam. The beam has 20 bunches of  $2 \times 10^{10}$  electrons with 2.8 ns spacing and the repetition rate is 25Hz. In order to observe the beam characteristics, bunch by bunch beam profile monitor using optical transition radiation(OTR) has been developed. A fast gated camera which has ~3 ns gate width, is used for the OTR monitor. The profile of each bunch is distinguished by changing the delay of gate timing. This paper describes the monitor system, the measurement of profile, emittance, energy and energy spread.

Introduction

The Accelerator Test Facility(ATF) consists of a 1.5 GeV Linac and following a Damping ring which is under construction. The purpose of the ATF is development of accelerator components to realize future Japan Linear Collider(JLC)[1]. The 80 MeV injector linac of the ATF consists of a thermionic gun, two SHBs(357MHz), two pre-bunchers, seven cells of buncher following to a 3m long S-band(2856MHz) accelerating structure and beam diagnostics systems(fig.1)[2]. The ATF accelerates multi-bunch beam. The beam has 20 bunches of  $2 \times 10^{10}$  electrons with 2.8 ns spacing and its repetition rate is 25Hz. The diagnostics systems are an amorphous core current transformer(CT) and wall current monitors(WCMs) which measure the beam current, beam position monitors(BPMs) which measure the beam position, florescent screen profile monitors(PRM) which measure the beam size and the relative position, optical transition radiation monitors(OTRMs) which measure the bunch by bunch beam profile using a fast gate camera and measure the bunch length using a streak camera, a wire scanner(WS) which measure the bunch by bunch beam profile using a gated photo multiplier(GPMT).

The OTRM using a fast gate camera can measure bunch by bunch beam profiles as a visible image. The OTRMs were installed at after 90 degree bending section(OTRM4) for measuring the energy and the energy spread and at straight section(OTRM5) for measuring the emittance. The preliminary measurement and comparison with the measurement of the WS are discussed.

Measurement System of OTR

OTR is produced when the relativistic beam crosses the interface of two media which have different dielectric constant. The intensity distribution, in a unit frequency  $d\omega$  and a solid angle  $d\Omega$ , is given by [3]

$$\frac{d^2W}{d\omega d\Omega} = \frac{e^2\beta^2}{4\pi c} \frac{\sin^2\theta}{(1-\beta\cos\theta)^2}$$

The radiation exhibits a high directivity. The numbers of photons per electron, in an optical frequency interval  $\omega_1$ - $\omega_2$ , is expressed as[4]

$$N = \frac{2\alpha}{\pi} |\ln(2\gamma) - \frac{1}{2}| \ln \frac{\omega_2}{\omega_1}$$

where  $\alpha = e^2/hc = 1/137$  is the fine structure constant. The OTR have a good time resolution. If we can gate each of the OTR in the multi-bunch, we can measure the beam profile of each bunch.

Apparatus

The gate timing and the setup of apparatus are shown in fig.2a and fig2.b. A fast gate camera with image intensifier(Hamamatsu C2925) can gate the light with the minimum gate width of 3ns. The each profile is measured by shifting the gate timing with 2.8 ns spacing of delay.

A polished stainless steel screen is used as an emitter of the OTR. The thickness and the flatness are 1 mm and  $1/2 \lambda$ . The screen is inserted to the beam line by an air actuator. The OTR is observed by the fast gate camera using mirror,  $f=75\text{mm}(F1.8)$  lens and  $x4$

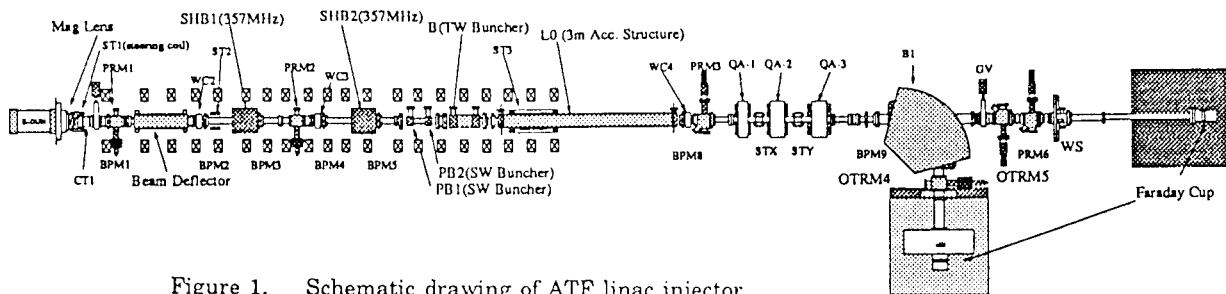


Figure 1. Schematic drawing of ATF linac injector.

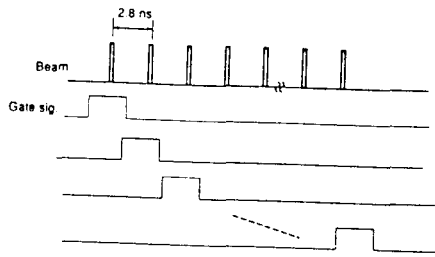


Figure 2.a Gate signal and beam timing for bunch by bunch profile measurement

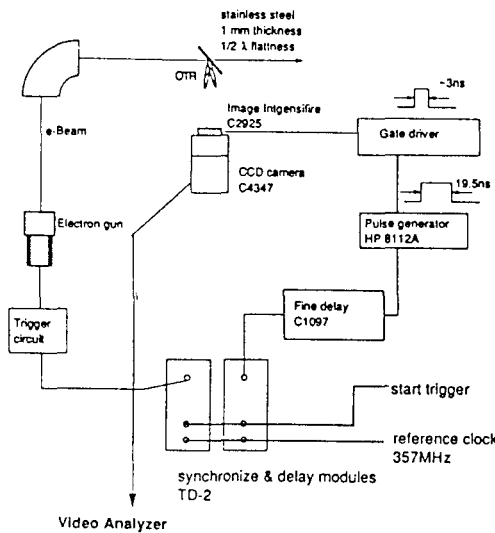


Figure 2.b bunch by bunch profile measurement setup

magnifier. The timing signal is generated by synchronizing and delay modules(TD-2s)[5]. The TD-2 counts a reference clock of 357MHz from start trigger and makes delay with 2.8 ns interval. This reference clock is also synchronized to the accelerating frequency of 2856MHz. One TD-2 hits electron gun and the others feeds to the camera through fine delay, pulse generator and gate driver. The fine delay adjusts gate timing to center of the beam timing. The pulse generator makes the gate width which includes offset of about 15 ns. It takes account of rise/fall time of pulse generator. The gate generator makes high voltage pulse for the gate switch. The video signal is transmitted to control room through CATV system and analyzed using a video analyzer. The video analyzer(made by Hamamatsu) consist of a HP workstation and a video frame memory. The analyzer calculates the projection, FWHM, peak position, peak value, etc. in real time. The calculation speed is 3 to 5Hz, it is adequate for human observation.

### Characteristics of fast gate camera

To test the sensible gate width of the fast gate camera, we measured the light of 30ps pulse laser and shift the timing of the light. The test setup and the result are shown in fig3.a and fig3.b. The sensible gate width is measured less than 2 ns however the intensity gain was reduced gradually. The light gain is not uniform on all view area at the gate width less than 3ns. This is called iris effect. From this measurement, we choose the input pulse width of 19.5ns to make 3ns gate time for this fast gate camera.

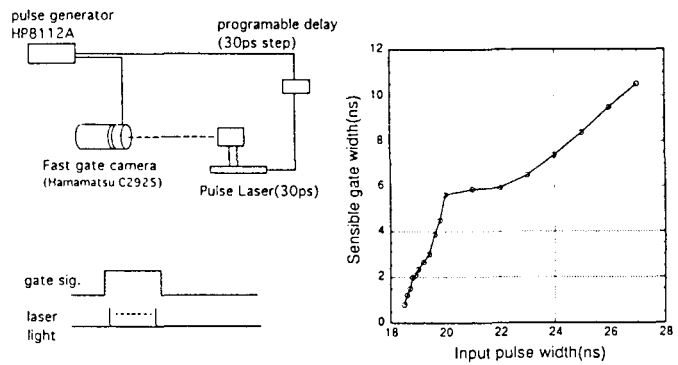


Figure 3.a measurement setup of gate characteristics of fast gate camera

Figure 3.b Sensible gate width of fast gate camera

### Measurement of ATF beam

The ATF is now under the multi-bunch beam acceleration test[2]. The wave form of multi-bunch beam measured at CT1(downstream of gun) and WC4(downstream of accelerating structure) are shown in fig.4. The bunch current except for head and tail several pulses was  $8 \times 10^9$  through these measurement.

### Bunch by bunch emittance measurement

At the OTRM5 in fig.1, the bunch by bunch profile is measured. The example of profile gated one bunch of bunch train is shown in fig 5. The emittance of each bunch was measured by changing the strength of the quadruple field at the upstream of the OTRM5. The square of the beam size versus the strength of the quadruple field is fitted to a parabola function. The variation of the beam sizes of each bunch are shown in fig. 6. From the fitting data, the normalize emittance of each bunch were calculated following:

$\epsilon_{nx}$ (1st bunch)	$2.5 \times 10^{-5}$ m rad,
$\epsilon_{nx}$ (5th bunch)	$2.8 \times 10^{-5}$ m rad,
$\epsilon_{nx}$ (10th bunch)	$2.5 \times 10^{-5}$ m rad,
$\epsilon_{nx}$ (15th bunch)	$2.7 \times 10^{-5}$ m rad.

The same measurement was carried by the WS using a GPMT. The GPMT(R5916U) has a minimum gate width of 2.5ns. The beam emittance were measured by the same way. The measurement values of emittance were 4 to 7 x

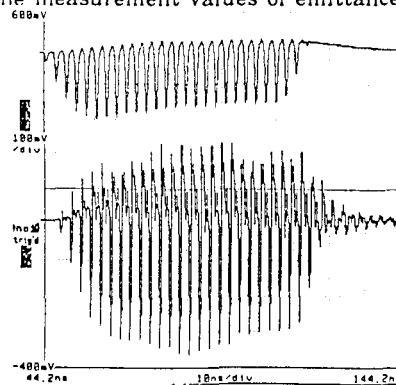


Figure 4. Multi-bunch beam: wave form of CT at downstream of electron gun(upper), wave form of WCM at downstream of 3m long accelerator structure

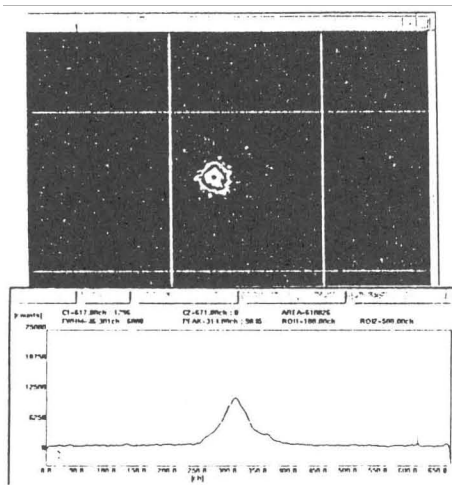


Figure 5. Example of gated beam profile

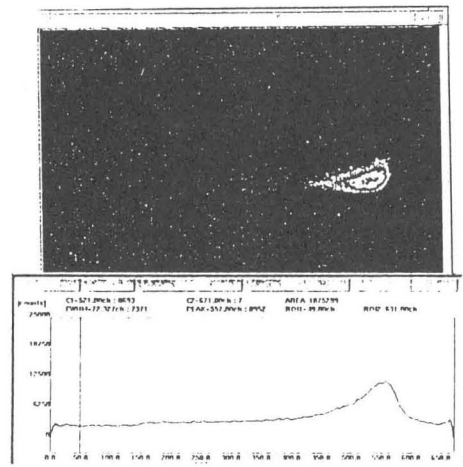


Figure 7. Example of profile after 90 degrees bending magnet

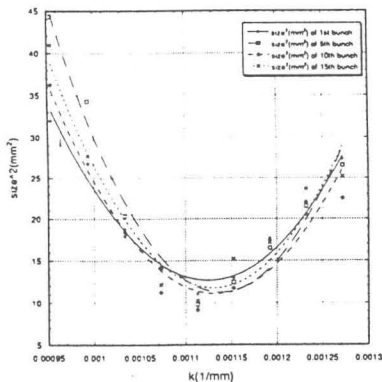


Figure 6. Square of beam size versus focal length of quadrupole for each bunch

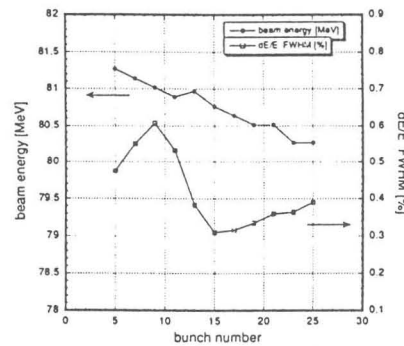


Figure 8. Energy and energy spread of each bunch

$10^{-5}$  m rad. The measurement of the WS includes shot by shot variation. The one reason of this difference on the emittance value is coming from this shot by shot measurement.

#### Bunch by bunch energy/energy spread measurement

At the OTRM4 in fig.1, the beam energy of the each bunch were measured from the strength of bending field and the each bunch of the beam energy spread were measured by the width(FWHM) of the profile. The example of the profile after 90 degrees bending magnet is shown in fig.7. In this figure, the left side correspond to a low energy part and vice versa. In this case, the beam has a high energy peak and low energy tails. The bunch by bunch energy plot and energy spread plot are shown in fig. 8. At the energy plot, about 2% of the energy decrease from front bunch to tail is observed. It is caused by the beam loading effect. In the energy spread plot, we adjusted the phase and amplitude of the bunchers to minimize the 15th bunch of beam. In this case, the other bunches had larger energy spread.

#### Summary

We could measure the bunch by bunch beam emittance, energy and energy spread of the ATF beam by the OTRMs. The result of the preliminary measurement were following. The emittance: clear difference were not

observed in front to tail bunchers. The energy: about 2% of energy decrease were observed in front to tail bunches. The energy spread: 0.3% to 0.6% of energy spread were measured.

#### Acknowledgment

We would like to express our thanks to Professors Y.Kimura and K.Takata for their encouragement. We also thank other members of JLC R&D group and Mrs. T.Matsui and S.Morita of ATC Corporation for their support.

#### References

- [1] JLC Group, "JLC-I", KEK Report 92-16,1992
- [2] H.Hayano et al, "An 80 MeV Injector for ATF Linac", in this conference.
- [3] L.Wriski et al., "Interference phenomenon in optical transition radiation and its application to particle diagnostics and multiple scattering measurements", J. of Appl. phy. 46 3644(1975)
- [4] J.Bosser et al., "Optical transition radiation proton beam profile monitor", NIM A238(1985) p45
- [5] K.Ishii, "Digital delay CAMAC module with 550MHz preset counter(TD-2)", KEK Report 83-14(1983)