SR MONITOR FOR THE ATF DAMPING RING

T. Naito, H. Hayano, N. Terunuma, J. Urakawa, Y. Hashimoto, M. Muto
High Energy Accelerator Research Organization (KEK)
Oho, Tsukuba-shi, Ibaraki-ken, 305 Japan
T. Okugi, Tokyo Metropolitan University, Japan

Abstract

The ATF Damping Ring (ATF DR) aims to demonstrate the technical feasibility of a low-energy part of next-generation electron-positron linear colliders by producing an electron bunch train with extremely small emittance. To diagnose the beam profile and radiation damping there, a synchrotron radiation (SR) monitor which uses visible light has been designed and built. This paper presents the system configuration of this SR monitor and the preliminary results from the initial beam commissioning.

1 INTRODUCTION

The ATF aims to serve as a prototype accelerator complex of a low energy part of a next-generation linear collider, which is responsible for producing a multi-bunch electron beam with extremely small emittance. The design parameters of the ATF DR include: beam energy $= 1.5$ GeV, beam current $= 600$ mA max, bunch population $= (1 \sim 3) \times 10^{10}$/bunch, repetition rate $= 25$ Hz. The target equilibrium beam emittance is: $\epsilon_{nx} = 5.1$ μm, $\epsilon_{ny} = 30$ nm, ϵ_{nz} =12 mm [1]. The beam commissioning of the ATF DR began in January of 1997 in a single-bunch operation ($3 \sim 6 \times 10^9$ e / bunch) with a beam energy of 0.96 GeV, and a reptition rate of 1.5 (or 0.8) Hz.

An SR monitor which uses visible light was prepared as one of the tools for measuring the transverse beam size and the bunch length. The system features: (1) a fast gate camera to distinguish the SR images turn-by-turn and bunch-by-bunch, (2) a retractable reference target for calibrating the image focus point, (3) a mechanical shutter in the SR beam line to prevent deformation of the first mirror due to the thermal stress caused by the SR power deposit, (4) a double-sweep streak camera for observing variations of the bunch length during the damping process.

Major portions of the hardware and software were prechecked at the INS 1.3 GeV electron synchrotron [1], before installing them in the ATF DR. At the ATF DR the system functioned flawlessly from the beginning, and successfully observed the first beam circulating in the DR.

2 APPARATUS

2.1 Optical System

Figure 1 shows the layout of the optical system. The source point is located 270 mm downstream of the entrance edge of a bending magnet (bending radius $= 5.73$ m) at the end of the west arc. The first mirror, made of aluminum-coated copper, reflects the SR light by 90° upward. After reflected by the second mirror and passing through the first lens ($f = 1000$ mm), the SR light is divided into two paths: one is fed to a fast gate camera after a second lens ($f = 40$ mm), the other to a streak-camera through a mirror and a second lens ($f = 80$ mm). The maginification ratio of the optical system for the fast gate camera is 1.17. At the entrance of the streak camera, the SR light is collimated with a slit (30 μm wide), corresponding to a 14 ps (FWHM) offset for our measurement.

When the beam is absent,by inserting the reference target at the source point with an air-actuator mechanism, several illuminated patterns (1 mm square and 0.4 mm rectangles) can be observed with the optical system.This is used for calibration of the magnification ratio and focusing.

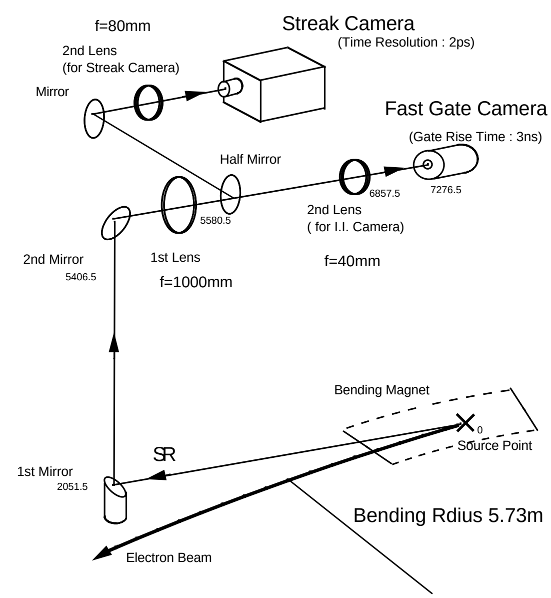

Figure 1: Layout of the optical system.

2.2 Fast Gated Camera

A fast gate camera (Hamamatsu, C2925) is used to observe an image with very short gate width with good light amplification. Its main parameters are given in Table 1. Since the minimum bunch separation expected in the ATF DR is 2.8 ns, the camera can discriminate SR signals on a turn-by-turn and bunch-by-bunch basis by appropriately selecting the gate timing and width.

2.3 Streak Camera

A double-sweep streak camera (Hamamatsu, C5680) is used to measure the variation of a bunch length during the

0-7803-4376-X/98/$10.00 © 1998 IEEE

Table 1: Main parameters of the fast gate camera.

Gate width	3 ns $\sim$ 100 μs
Gate jitter	less than 200 ps
Repetition frequency	10 kHz
Luminous gain	7000 ft-L/ft-C
Sensitive wavelength	160 $\sim$ 840 nm
Extinction ratio	1.6×10^{10}

damping process. The vertical sweep in the streak image gives the bunch length information, while the horizontal sweep gives the bunch images at specified time intervals. Several tens of streak images are, thus, acquired in a same frame. The main parameters of the streak camera are given in Table 2.

Table 2: Main parameters of the streak camera.

Vertical sweep unit	
streak time	0.2 ns $\sim$ 50 ns
resolution	better than 1.5 ps
repetition rate	10 kHz max.
Horizontal sweep unit	
sweep range	100 ns $\sim$ 100 ms
Sensitive wavelength	400 $\sim$ 900 nm
MCP gain	3000 max.

3 DIAGNOSTICS

3.1 *Transverse Beam Profile*

The transverse beam profile at a selected turn is measured by appropriately setting the gate timing of the fast gate camera [2]. An example of the observed image profile is shown in Figure 2. This measurement is repeated at different gate times to diagnose the transverse beam damping. The beam size as function of time ($\sigma(t)$) is expressed by

$$\sigma^2(t) \propto \epsilon(t) = \epsilon_i e^{-2t/\tau} + \epsilon_e(1 - e^{-2t/\tau}), \qquad (1)$$

where ϵ_i is the initial emittance at injection, ϵ_e the equilibrium emittance, and τ the damping time. Figure 3 shows the measured σ^2 as function of the store time. Table 3 compares the measured damping time with expectations assuming an emittance coupling of 1%. The measured horizontal beam size has contributions from the dispersion at the SR emission point, namely,

$$\sigma_x^2 = \epsilon_x \beta_x + (\eta_x \Delta p/p)^2. \qquad (2)$$

With design values of $\eta = 48$ mm and $\Delta p/p = 9.2 \times 10^{-4}$, the correction amounts 44 μm. The measured image size in the equilibrium condition is known to be enlarged by a diffraction effect ($\sim 21\mu$m) and a focusing depth effect [3, 4]. Their contributions require careful analyses.

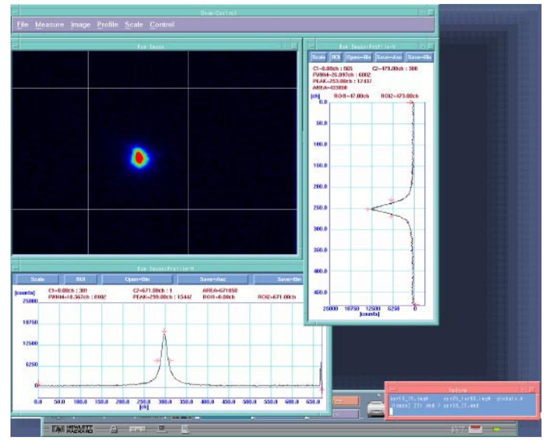

Figure 2: An example of the observed beam profile.

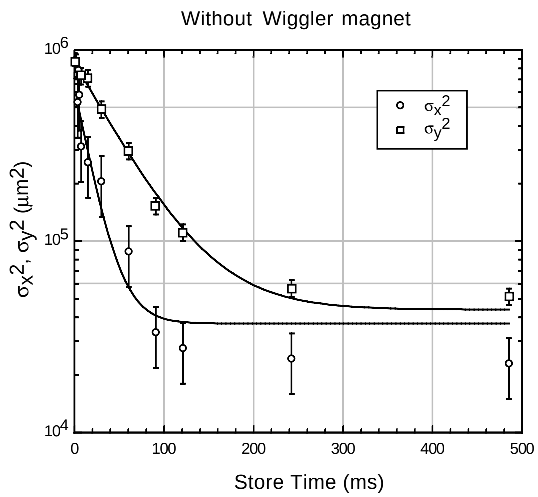

Figure 3: Result from a damping time measurement.

3.2 *Bunch Length*

The trigger signals for the streak camera are generated based on the revolution frequency. Measurement of the bunch length immediately after injection requires a pretrigger with a large lead-time (80 ms), which, is difficult to create without jitters with the present circuit. A new trigger circuit the jitter-free high-precision pretrigger, based on a digital delay circuit, is under development.

An example of the streak image is shown in Figure 4. The damping of the bunch length is illustrated in Figure 5. The measured and expected bunch length damping times are summarized in Table 3.

4 SR BEAM CHOPPER

Deformation of the first mirror due to the thermal stress cause by the SR light is a concern. The SR power on the mirror surface is estimated to be 10 W/mm^2 for a stored beam current of 600 mA. Copper has been chosen as the material of the mirror for advantages of thermal conductance. Some efforts against the deformation have been

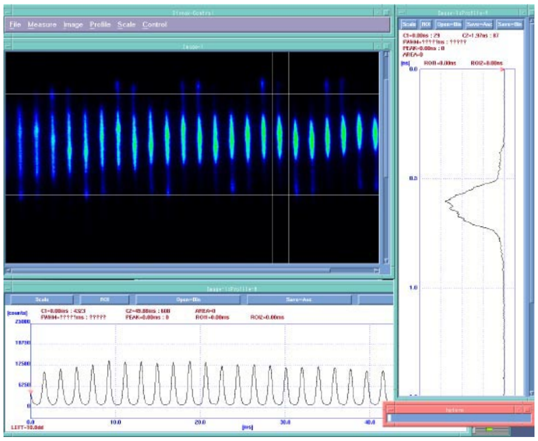

Figure 4: An example of the observed streak image.

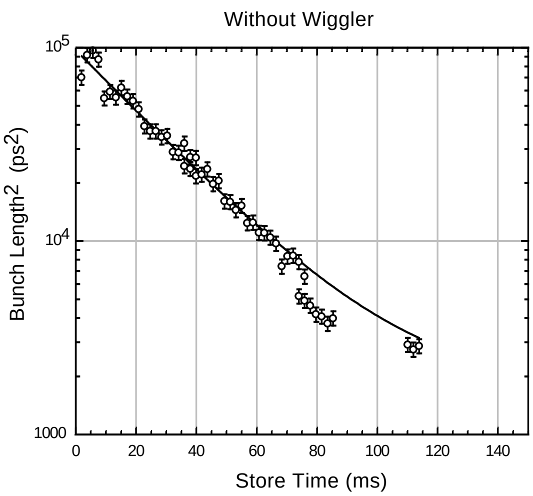

Figure 5: Measurement of the damping of the bunch length.

Table 3: Comparison of the measured and calculated values of the image/beam sizes and damping times.

	Measurement	Calculation
σ_x	76.4 μm	45.2 μm
σ_y	113 μm	7.9 μm
σ_z	41.6 ps	25.5 ps
Damping time (wigglers off)		
τ_x	36 ± 12 ms	46.8 ms
τ_y	100 ± 10 ms	68.5 ms
τ_z	54 ± 2 ms	44.6 ms
Damping time (wigglers on)		
τ_x	29 ± 2.4 ms	30.0 ms
τ_y	58 ± 10 ms	39.7 ms
τ_z	no meas.	56.3 ms

made or planned at other facility [5, 6]. To further reduce the SR power on the first mirror, an SR beam chopper system has been built, whose layout is shown in Figure 6. By driving the shutter at 0.1 Hz, the SR power on the mirror surface can be reduced to 0.1 W/mm^2. In this case, according to calculations with ANSYS, the expected deformation is reduced from $\sim 1\mu$m to ~ 20 nm. The performance of the system has not been verified, since up to now the ATF DR has been operated at a small store current ($\sim$0.5 mA).

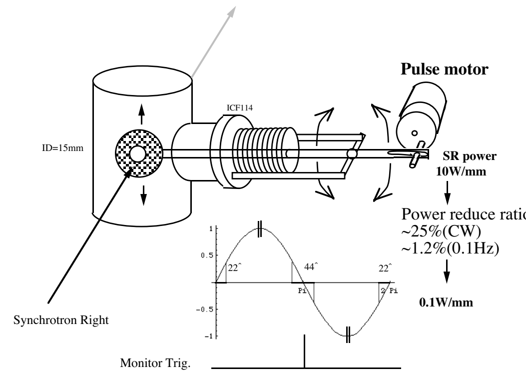

Figure 6: Layout of the SR beam chopper.

5 SUMMARY

An SR monitor system has been designed and built for the ATF DR. The first data set was successfully collected during the initial beam commisioning of the ATF DR. Some discrepancies have been found between the measured image size parameters and calculations. Studies are in progress on diagnosing possible errors in the SR monitor optics system as well as possible set-up errors in the ATF DR.

6 ACKNOWLEDGMENTS

We would like to express our gratitude to Professors M. Kihara and K. Takata for their continous encouragement. We wish to thank Dr. S.Kamada for conducting detailed calculations on the photon distributions and for useful dicussions. We also wish to thank the ATF operation group for their support.

7 REFERENCES

[1] Ed. by F. Hinode, et al., “ATF Design Study Report,” KEK Internal 95-4, June 1995.

[2] M. Minty, et al., “Using a Fast-Gated Camera for Measurements of Transverse Beam Distributions and Damping Times,” SLAC-PUB-5993, Nov., 1993.

[3] A. Ogata, “On Optical Resolution of Beam Size Measurements by Means of Synchrotron Radiation,” Nucl. Instr. and Meth., vol. A391 (1991) 596.

[4] A. Hofman, et al., “Optical Resolution of Beam Cross-section Measurements by Means of Synchrotron Radiation,” Nucl. Instr. and Meth., vol. A203 (1982) 483.

[5] T. Mitsuhashi, et al., “A Construction of Optical Beam Profile Monitor for High Brilliance Configuration of the Photon Factory,” Proc. of EPAC (1996).

[6] “Optical Beam Diagnostics,” ESRF / MAC-19/13a.