SR Monitor System for the ATF Damping Ring

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Abstract

Preliminary results of the synchrotron radiation (SR) monitor system developed for the Damping Ring of the accelerator test facility in Tsukuba-KEK (KEK-ATF-DR) are described; The system consists of a two dimensional CCD camera and a double-sweep streak camera for observing the vertical and longitudinal shapes of bunched beams, respectively.

1. Introduction

The ATF-DR has been developed as a prototype and low-energy part accelerator complex of the JLC project, which aims to produce multi-bunched electron beams with an extremely small emittance [1]. The design parameters are given in Table 1. The beam commissioning of the ATF-DR began from January of 1997, and 0.96 GeV beams of 3~6 x 10^9 e / bunch were obtained in a single-bunch operation (repetition rate of 1.5 or 0.8 Hz). At the present time the beam energy is increased up to 1.3 GeV.

While the SR monitor has succeeded in observing the first circulating beam image at the end cell of the west arc of the ATF-DR, major developments of both the hard- and soft-ware were performed using the INS (KEK-Tanashi) 1.3 GeV electron synchrotron beams [2].

Beam Energy	1.54	GeV
Repetition Rate	25	Hz
No. of Bunch Trains	5	
No. of Bunch /Train	20	
No. of particles / Bunch	$(1\text{-}3)\times10^{10}$	
Damping Time		
horizontal	6.9	ms
vertical	9.2	ms
longitudinal	5.5	ms
RF Frequency	714	MHz
Normalized Emittance		
horizontal	4.49×10^{-6}	m-rad
vertical	3.00×10^{-8}	m-rad
Bunch Length	4.33	mm

Table 1 Design Parameters of the ATF-DR.

2. System Features

2-1 Optical System

The calculated photon flux emission from the DR and our optical system are shown in Fig. 1 and 2, respectively.

The source point is located at 270 mm downstream of the entrance edge of a bending magnet (bending radius equals to 5.73 m). The first mirror which is made of aluminum-coated copper and cooled by water reflects the SR light by 90 upward for all the visible lights. After the reflection, the SR light is fed to the optical stage by the second mirror. Passing through the first lens (f = 1000 mm, achromatic doublet), the path is divided into two. One is fed to a fast

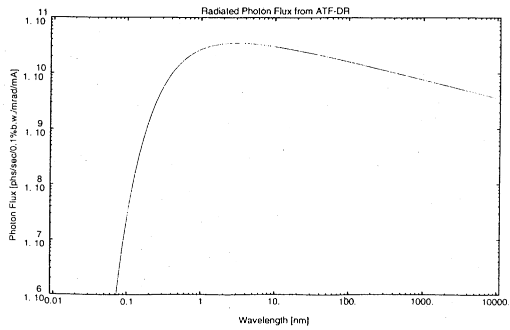

Fig. 1 Calculated photon flux from the ATF-DR.

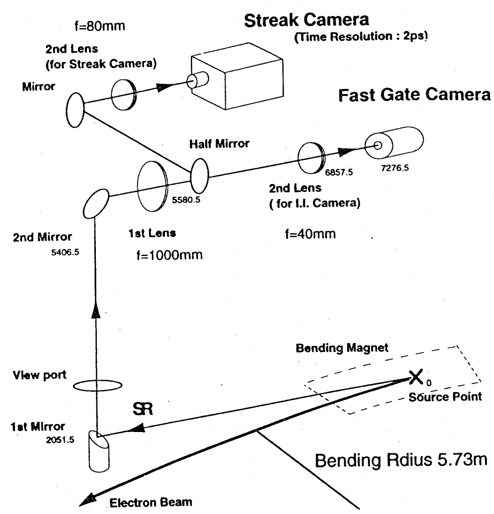

Fig. 2 Layout of the SR monitor optics.

gated camera placed after the second lens (f = 40, achromatic triplet), and the another to a double-sweep streak camera via a mirror and a second lens (f = 80 mm, achromatic doublet). For the wave length between 420 nm to 950 nm, the color aberration of such achromatic lenses is less than 0.5 %.

The optical magnification at the fast gated camera is 1.17. On the other hand, at the entrance of the streak camera, the SR light is collimated with a movable slit. For the setting of 30 μm width, an offset for our measurement corresponds to the time resolution of 1.4 ps (FWHM).

For the calibration of the optical magnification and focusing, the reference target is inserted at the source point with an air-actuator system and several illuminated patterns (1 mm square and 0.4 mm rectangles) are observed in a good reproducibility.

2-2 Fast gated camera

The camera (Hamamatsu-V5548) with a sub-nano second gate is used to observe an image with a very short gate width with a good light amplification. Its main parameters are given in Table 2. Since the minimum bunch-separation expected in the ATF-DR is 2.8 ns, the SR signals can be well discriminated with the camera.

Gate Width	0.3-100	ns
Repetition Frequency	1	kHz
Luminous Gain	14000	
Sensitive Wave Length	160-850	nm

Table 2 Main features of the sub-nano sec. gated camera.

2-3 Streak Camera

The double-sweep streak camera (Hamamatsu-C5680) is employed to measure the variation of a bunch length during the damping process. In the vertical sweep the information of the bunch length, while in the horizontal sweep the bunch-image information at the specified time interval is obtained, respectively. Several tens of streak images are, thus, acquired in a same frame. The main characteristics of the streak camera are given in Table 3.

Vertical Sweep Unit	
Streak Time	0.2-50 ns
Resolution	better than 1.5 ps
Repetition Rate	10 kHz max.
Horizontal Sweep Unit	
Sweep Range	100 ns - 100 ms
Sensitive Wave Length	400-900 nm
MCP Gain	3000 max.

Table 3 Main characteristics of the streak camera .

2-4 Host CPU

The obtained data has been analyzed in a host CPU (hp725/75; UNIX) placed in the optical room. The streak camera is controlled with the host CPU via a GPIB interface. The other client machine is also able to control the streak camera and handle the measured data with the network.

3. Measurement errors

Since the beam size of the ATF-DR is so small, two influential errors have been considered. One is the diffraction error, i.e., the beam image fades as near as the diffraction limit. The other is the field-depth error, which is predestinate since the practical optical system has finite aperture. The measured data has been written in consideration of them as follows:

$$\sigma_{meas} = \left(\sigma_{true}{}^2 + \sigma_{diff}{}^2 + \sigma_{fd}{}^2\right)^{1/2}, \qquad (1)$$

where σ_{mess} is the measured beam size, σ_{true} is the true beam size, σ_{diff} is the diffraction error and σ_{fd} is the field depth error.

3-1 Diffraction Error

In the vertical direction, the diffraction error expressed by the following equations [3,4].

$$\Delta\sigma_{diffy} \bullet \Delta\sigma_{diffy}' = \lambda/4\pi \qquad (2)$$

$$\Delta\sigma_{diffy}' = \frac{0.723}{\gamma}\left(\frac{\lambda}{\lambda_c}\right)^{1/3} \qquad (3)$$

$$\lambda_c = 0.559\frac{\rho[m]}{E^3[GeV]} \qquad (4)$$

In these equations λ is the selected wave length, γ is the Lorentz factor, ρ is the bending radius at the source point and E is the beam energy. In the beam energy of 1.3 GeV, λ is about 450 nm (which is the most resolutive wavelength in our optical system) and $\Delta\sigma_{diffy}$ is obtained as 27.5 μm with above eqns.

In the horizontal direction, the diffraction error is obtained with the following Frounhofer diffraction equation:

$$\Delta\sigma_{diffx} = 0.38\lambda d/D\ , \qquad (5)$$

where d is the distance between the source point and the position of the first lens, and D is the opening aperture of the total system. In 1.3 GeV the $\Delta\sigma_{diffx}$ is evaluated as 38 μm.

3-2 Field Depth Error

The Field Depth is a quantity concerning to the geometry of the optical-device arrangement. It strongly depends on the aperture of the optical system and bending radius at the source point. In our case the field depth errors are 33.8 μm in vertical direction and 38.3 μm in horizontal one.

4. Diagnostics

4-1 Transverse Beam Profile

The transverse beam profile at the selected turn can be easily measured with the gated camera because of the flexibility of its gate timing [5]. This measurement is repeated at a different gate timing to diagnose the transverse beam damping. The beam size σ is expressed as a function of time by

$$\sigma^2(t) \propto \varepsilon(t) = \varepsilon_i e^{-2t/\tau} + \varepsilon_e\left(1 - e^{-2t/\tau}\right), \qquad (6)$$

where ε_i is the initial emittance at injection, ε_e is the equilibrium emittance and τ is the damping time. Fig. 3 shows the measured σ^2 as a function of the storage time. The measured damping time is compared with the calculated one where an emittance coupling of 1 % is assumed. These are listed in Table 4.

The dispersion at the SR emission point is included in the horizontal beam size measured, namely,

$$\sigma_x{}^2 = \varepsilon_x\beta_x + (\eta_x \Delta p/p)^2, \qquad (7)$$

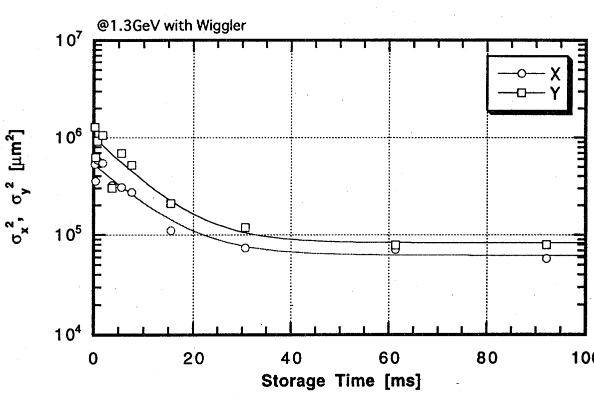

Fig. 3 Results of the measured traverse damping times.

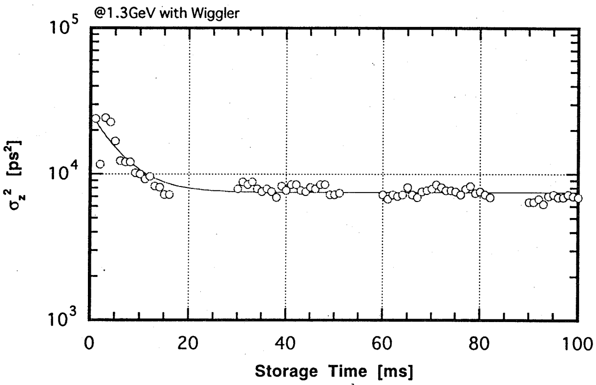

Fig. 4 Results of the measured longitudinal damping times.

with design parameters of η = 48 mm and $\Delta p/p$ = 9.2 x 10^{-4}, the correction amounts 44 μm.

4-2 Bunch Length

Trigger signals for the streak camera are generated with the rf and the revolution frequencies. Moreover since our streak camera is a double sweep type, many longitudinal profiles of the certain bunch are obtained, e.g., about 20 profiles / image within the same pulse. The damping of the bunch length is shown in Fig. 5. The measured and expected damping times are summarized in Table 4.

	Measurement (corrected)	Calculation
Equilibrium beam size (Wiggler ON)		
σ_x	102.3 (88.5) μm	36 μm
σ_y	107.9 (98.7) μm	6.4 μm
σ_z	35 ps	22 ps
Damping time (Wiggler OFF)		
τ_x	17.9 +/- 2.6	17.5 ms
τ_y	41.0 +/- 2.7	27.6 ms
τ_z	18.0 +/- 0.8	19.4 ms
Damping time (Wiggler ON)		
τ_x	17.7 +/- 4.6 ms	11.9 ms
τ_y	17.2 +/- 6.5 ms	16.5 ms
τ_z	18.5 +/- 1.9 ms	10.2 ms

Table 4 Comparison of the measured and calculated beam size and damping times.

5. Near future R&D

5-1 Optical Chopper

It is the serious problem for the optical system that the deformation of the first mirror due to the thermal stress caused by the SR light. Since the beam size is very small, the SR light power on the mirror surface is estimated to be about 10 W/mm^2 for a stored beam current of 600 mA. From such a consideration copper with a good thermal conductance has been chosen as the base material of the first mirror.

While some efforts against the deformation of the mirror has been made or planned at other facilities [6,7], an SR beam chopper system has been employed in our system[8]. When the driving frequency of the chopper is 0.1 Hz, the SR light power can be decrease to 0.1 W/mm^2. According to the transient analysis with ANSYS, the deformation is reduced to 1/50, i.e., from about 1 μm to 20 nm. Such a performance has not been verified yet, since up to now the operation beam current is small (about 0.5 mA).

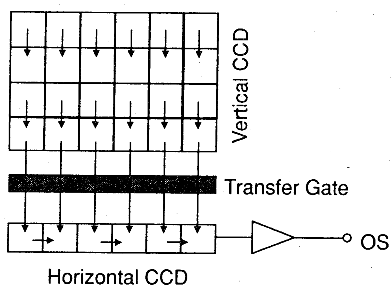

Fig. 5 Layout of TDI camera scheme

5-2 Real Time Damping Monitor

While our system obtained with the fast-gated camera makes it possible to make projection and analyze, the maximum acquisition rate is 1 Hz. Thus the transverse damping profile cannot be obtained in the same pulse.

For improving this, a Time Delayed Integration (TDI) camera will be employed as shown in Fig. 5. There are 96 line-CCD sensor stages at the detection part (stage number is selectable and optionable). The each line-CCD has 512 elements (13mm x 13mm x 512). The deposited charge on the CCD element in some stage moves downward in one stage step at 45 kHz (22 μsec). The exposure for the CCD is always ON. Finally the charge achieves to the horizontal line-CCD positioned at the most downside. It takes a time of a stage number multiplied by 22 μsec. The data on horizontal line-CCD has been transferred to the external CPU every 22 μsec via a PCI bus. In other words the projection of the integrated beam image has been obtained within every 22 μsec, i.e., the integration time is obtained as 22 μsec period multiplied by the number of selected stages.

6. Summery

As an SR monitor system has been designed and build for the ATF-DR. Some discrepancies have been found between the measured and calculated image size parameters. Studies are now in progress while investigating the cause of errors both in our system and the ATF-DR.

Acknowledgments

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