Recent status of laserwire monitor development at KEK-ATF

Y.Honda[a], N.Sasao[a], S.Araki[b], Y.Higashi[b], K.Hirano[b], M.Nomura[b], T.Okugi[b], T.Taniguchi[b], J.Urakawa[b], Y.Yamazaki[b], H.Sakai[c], M.Takano[d]
[a]*Department of Physics, Kyoto University, Kyoto 606-8502, Japan*
[b]*High Energy Accelerator Research Organization (KEK), Ibaraki 305-0801, Japan*
[c]*The Institute for Solid State Physics, The university of Tokyo, Chiba 277-8581,Japan*
[d]*National Institute of Radiological Sciences, , Chiba 263-8555, Japan*

Abstract

We have been developing a laserwire beam profile monitor at KEK-ATF. This monitor is based upon the Compton scattering of electron beam with a laser target, which is produced by injecting a cw laser beam into a Fabry-Perot optical cavity. Various improvements have been made since [1] and [8]. As a result, data taking is speeded up. It takes 10 minutes to obtain one beam profile. Recent configurations (Jun/2002) of our system is summarized. To measure the beamsizes of each bunch in a multibunch beam at the same time, a series of signal processing system is newly developed. It is also reported in this paper.

1 INTRODUCTION

Electron storage ring operating with low emittance multibunch beam is becoming a standard design for third-generation synchrotron light sources. Future linear colliders also require such low emittance multibunch electron/positron beams.

The Accelerator Test Facility (ATF [2]) at KEK was built to demonstrate the feasibility of production and manipulation of such a beam required at linear colliders. It consists of an electron linac, a damping ring, and an extraction line. The electron beam energy is 1.28 GeV, the ring revolution frequency is 2.16 MHz. About 20 electron bunches with 2.8nsec period are contained in a single bunch train. Typical horizontal and vertical beamsize in the damping ring is $100\mu m$ and $10\mu m$ respectively.

In order to measure transverse beam size in the damping ring, laserwire monitor has been developing ([1],[8]). This monitor is based upon the Compton scattering process of electrons with laser light. A thin “wire” of light is placed on the beam orbit in the damping ring, and scanned across the electron beam. The yield of Compton scattered photon is measured as a function of laserwire position, and a transverse beam profile is obtained. The salient features of this kind of laser based beam diagnostics are its directness, non-invasiveness and durability in an intense beam. In order to achieve good spacial resolution and signal intensity, target light must be thin and intense. To realize such a laser light stably, we have employed a optical cavity which is externally excited by a cw laser. The advantage of this cw laserwire system, compared with pulsed ones ([3],[4]), are its easiness to make a collision, power stability , and reliability on the laser waist size. It is also possible to measure beamsizes of each bunch in a multibunch beam simultaneously.

Our present setup and data taking system are described in the following sections.

2 EXPERIMENTAL SETUP

The experimental setup consists of two main components: a laser system and a photon detector system. The systems are installed one of the straight section of the ring (Figure 1). Before describing detail, we summarize the Compton scattering kinematics. Electrons of energy 1.28 GeV elastically scatter off the laser light of wave length λ = 532 nm with the crossing angle of 90 degrees. The scattered photon takes its maximum energy of 28.6MeV when scattering angle is zero. Collimeter systems are placed in front of the detector to reduce background. The detector aperture is limited by the collimeter and it corresponds to the scattering angle of less than 0.2mrad. This determines the minimum energy of scattered photon on the detector to be 23 MeV.

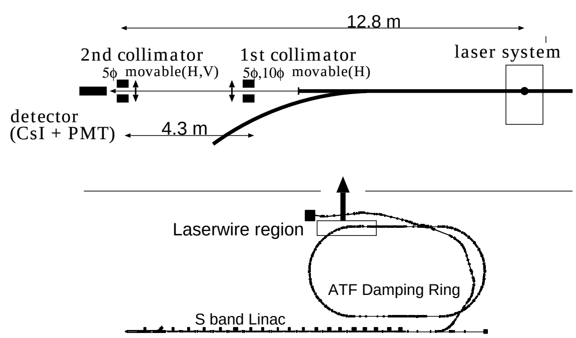

Figure 1: Geometrical layout of laserwire setup.

2.1 *Laser and optical system*

The linewidth of the laser must be much narrower than the resonant width of the optical cavity, which is about 10MHz in the present configuration. We have selected the LightWave Series 142 [5] Nd:YAG laser. It is a diode-pumped solid state NPRO laser. The wave length is $532nm$,the output power is $300mW$,and the linewidth is less than 10kHz.

Optical layout is described in Figure 2. Laser light is aligned with respect to the cavity axis and focused by a lens system to match fundamental mode of the cavity. Photo Diodes are placed to monitor original laser intensity (PD1), the reflection intensity from cavity (PD2), and the transmission intensity through cavity (PD3). The whole system is mounted on a movable table whose position is monitored with $1\mu m$ resolution.

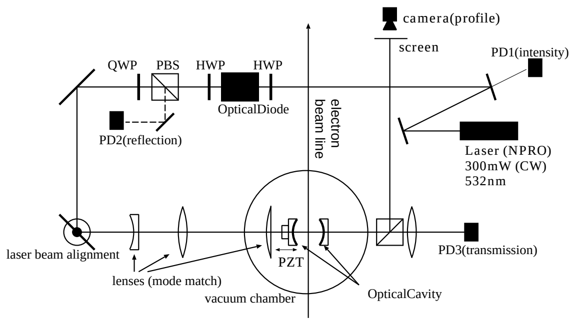

Figure 2: Optical system. Whole optical system is mounted on a movable table.

2.2 Optical cavity

Laserwire is created in a Fabry-Perot optical cavity, which consists of a pair of spherical mirrors facing each other in a nearly concentric configuration. The optical cavity has two main roles, amplification of laser intensity and control of laser-beam-waist-size.

High reflectivity and low loss are required for the cavity mirrors. Both cavity mirror substrates are fabricated from fused silica, and have concave surface of radius of curvature 20mm. They are coated with multi-layer dielectric film to have high reflectivity at wave length of 532 nm light. Reflectivity of the front and rear mirror is 98.8% and 99.85% respectively. The finesse of the optical cavity is measured to be 480 ± 20, and power gain on resonance is estimated to be 470 ± 30. The intra-cavity laser power is calculated to be more than 100W.

Laser-beam-waist is focused at the center of the cavity, where laser-beam collision occur. Geometries of mirror surfaces define the spacial property of laser beam which can be resonated in the optical cavity. Hence, we can control the laser-beam-waist-size with the distance of the mirrors. We developed a harmetical mirror housing system, which defines cavity length mechanically. Once mirrors are installed, their distance is kept stable within a few μm. As a result, thin laserwire is stably realized in the cavity. The laser beam waist size was measured with our conventional methods ([6],[7]). And it was found to be $w_0 = 12.0 \pm 0.2\mu m$. It corresponds to a photon target of gaussian profile with $6.0 \pm 0.1\mu m$ in RMS size. The Rayleigh range is calculated to be $850\mu m$.

The maximum power gain is obtained when the cavity length is set to the resonance peak. The resonant width is equivalent to 0.5nm in cavity length. The front mirror is supported by a piezoelectric transducer(PZT), and its position is controlled in less than 0.05 nm precision. The cavity resonance condition is controlled by this servo system. Since laser transmission intensity through cavity is proportional to the laser power stored in the cavity, we use the signal from PD3 to control the cavity in a feedback system.

2.3 Detector

Detector system is placed $12.8m$ downstream of the collision point. Detector should have a good energy resolution to separate Compton scatter signal from background events, and also good time resolution to identify the bunch number where scattering takes place. We selected CsI(pure) crystal as active material because of the fast response and high light yield. The dimensions of the crystal are $70mm \times 70mm$ in cross section and $300mm$ in length. Most of the shower energy from the Compton scattered gamma ray is deposited in the crystal. A 2” photomultiplier(PMT) is attached to the scintillator. Energy scale was calibrated using passing through cosmic rays.

To reduce background events, lead blocks with 5ϕ bore are placed in front of the detector. We are able to control the transverse positions of these collimeters remotely.

3 DATA TAKING

3.1 Cavity control and operation

We control the laser power stored in the cavity with a feedback system (described in Figure 3). This system works to keep the output from PD3 to be equal with the reference voltage externally given. Since intra-cavity laser power is proportional to the transmission intensity through cavity (monitored by PD3), we can control it through controlling the reference voltage.

There exists unnegligible yield of background gamma rays. To statistically single out the Compton scattered event rate from the background one, we employed the laser power modulation. The reference voltage is varied using a function generator so that laser power is changed from zero to almost maximum value. We can measure laser-on and laser-off data simultaneously in this intensity modulation operation.

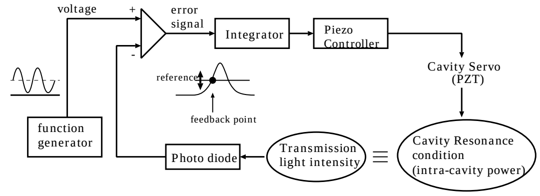

Figure 3: Block diagram of feedback system: The voltage signal from the PD3 is compared with a reference voltage externally given. The difference of these two signals (error signal) is integrated and then transfered to the cavity servo system.

3.2 Signal processing

Since the signal yield at the detector is much smaller than the beam revolution frequency in the ring, pile-up of events can be neglected. Energy and timing of each event are measured by a set of electronic circuit.

On the first stage, signal from PMT is amplified and inputted to a set of discriminators. We defined signal energy region as between 15MeV and 25MeV, considering detector response for Compton scattered gamma rays. Timing signal for each event is also generated at the same time, output timing of a discriminator is compensated to be constant for different pulse height signals by using leading edge extraporation technique. Time resolution for gamma ray in signal energy region is measured to be 0.56 nsec in RMS, it is enough for identifying 2.8ns spacing bunches. This timing signal gated by energy window is used in the following circuit.

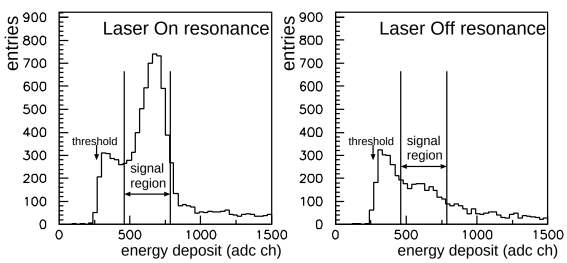

Figure 4: Energy spectrum when cavity is laser-on state (left) and laser-off state (right).(laserwire is positioned at beam center.)

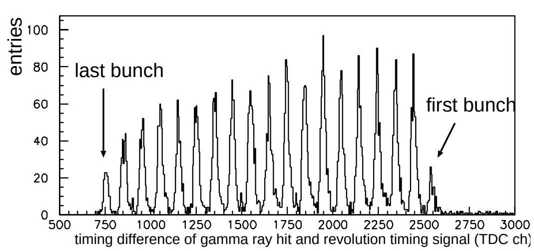

Figure 5: Time spectrum of detector hit at multibunch beam operation.

Bunch identification is done in the second stage. We developed a new circuit module to identify bunch number for each event. This module has 24 output terminals corresponding to each bunch number. It detects the time difference between the detector hit timing signal and the beam revolution timing signal provided from accelerator, and outputs from one of its 24 terminals. Its threshold separation is carefully adjusted to match bunch spacing. The signals from Nth output channel mean gamma ray events from Nth bunch.

Output signals from each terminal of this module are counted by two sets of scalers. One set of them is activated only when laser power inside the cavity is high (laser-on), the other set is activated only when it is low (laser-off). Since the intensity modulation is applied on the laser power, these two states are realized by turns. The judjement of laser-on/off is made by a voltage comparator with PD3 signal, and it directly controls the scaler status. The laser-on state occupies 30% of the total time and average power is 85% of the maximum, the laser-off state also occupies 30% of the total time and average power is 7.5% of the maximum. The modulation frequency is set to be 113Hz, By subtracting the count rate at the Nth channel of the laser-off scaler from the laser-on one, we can obtain the Compton scatter event rate of Nth bunch.

3.3 Data taking procedures

Prior to the scanning of the beam, the collimeter s should be aligned with respect to the gamma ray beam axis. This alignment is performed in a beam based way, monitoring energy spectrum of Compton scattering event on the detector. This procedure is repeated every week.

The beam size measurement is done by scanning whole laser system. After electron beam is stored in the ring, data taking process is started. The scalers are read out every one second. Beam current, table position(laserwire position), and photo diode outputs are also logged. We can get statistically enough data in 15sec for one position. Then, laserwire is positioned to next step. It takes about 10 minutes to obtain one beam profile. The beamsizes of each bunch are obtained at the same time.

4 SUMMARY AND DISCUSSION

As a result of improvement on signal-to-noise ratio and data taking efficiency, data taking is speeded up. Beam size of about $10\mu m$ can be measured with error about $\pm 0.5\mu m$. The dominant error comes from the reproducibility of the data for same laserwire position after some time intervals. We are considering this is caused by the orbit drift of the beam. It is estimated about $2\mu m$ for time scale of 1 scanning. Beam position monitoring in μm resolution should be essentially important for further improvement.

Bunch identification technique by gamma ray timing detection is well studied, and beamsize measurement of each bunch in a multibunch beam is started.

5 ACKNOWLEDGMENT

The present work has been carried out under a partial support of the project of “Development of Advanced Compact Accelerators” in Japan ,and Grant-in-Aid Scientific Research (No.10440074) from the Ministry of Education,Science,Sports, and Culture of Japan.

6 REFERENCES

[1] H. Sakai et al., Phys. Rev. ST Accel Beams 4, 022801 (2001).

[2] F.Hinode et al., KEK Internal Report No. 95-4,1995

[3] M.Ross et al., LINAC96 proceedings p.308 (1996)

[4] G.A.Blair et al., SLAC-PUB-9091,PAC-2001-TPAH051,Dec 2001. 3pp.

[5] LightWave Model 142 Users Manual

[6] H. Sakai et al., Nucl.Instrum.Methods. A 455 (2000), 113

[7] H. Sakai et al., submitted to JJAP.

[8] H. Sakai et al., submitted to Phys.Rev.