YAG:Ce SCREEN MONITOR USING A GATED CCD CAMERA

Takashi Naito#, Toshiyuki Mitsuhashi
KEK, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

Abstract

Due to its good spatial resolution, the YAG:Ce screen monitor is often used for small beam profile measurement in the Linac and beam transport line. We constructed a high-resolution YAG:Ce screen monitor at KEK-ATF2 for the observation of small size beam. We tested two types of screen, one is ceramic (sintered alumina powder) YAG:Ce and the other is single crystal YAG:Ce. Both screens have 50μm thickness. To escape from the Synchrotron radiation(SR) from the upstream and the Coherent Optical radiation(COTR), we applied delayed timing of the gate for the CCD camera. A microscope having a spatial resolution of 4.3μm is set outside of vacuum chamber to observe the scintillation light from the YAG:Ce screen. The results of the difference between the two screens, the camera performance with delayed gate and the optical performance of microscope will be presented in this paper.

INTRODUCTION

The low emittance beams using the state-of-the-art technology are generated and accelerated in recent electron accelerators for the FELs and the collider machines. The beam monitors are required to have a high resolution to measure the small beam size. Screen monitor is often used to measure the transvers profile at the linac and the beam transport. Usually, a chromium doped Alumina (AF995R, Desmaruquest Co.) fluorescent plate is used for the screen material. Recently, the other materials are tested and used to improve the resolution. We developed a high resolution screen monitor using YAG:Ce for the momentum spread measurement at KEK-ATF2 beam line.

ATF2 is a test beam line to develop the final focus system for the International Linear Collider. The beam test is carried out to realize 37nm of the vertical beam size [1]. The ultra-low emittance beam is supplied from the damping ring(DR). The energy is 1.3GeV and the design emittances for horizontal and vertical are 1.3nm and 10pm, respectively. The momentum spread is one of the key parameters of the beam. In the DR, the intra-scattering effect increases the momentum spread, which is a function of the beam emittance and the bunch charge. The momentum spread is calculated from the horizontal beam size at the large dispersion location,

$$X = \sqrt{\left(\sqrt{\varepsilon_x \bullet \beta}\right)^2 + \left(\eta \frac{\Delta p}{p}\right)^2} \ .$$

where, X is the horizontal beam size, ε_x is the horizontal emittance, β is the beta function, η is the dispersion function and Δp/p is the momentum spread. The first parentheses can be ignored in the case of the large dispersion. The dispersion function can be measured by the horizontal beam position change when the RF is changed. At the ATF2, the dispersion function at the screen monitor location is about 0.5m. When the momentum spread is assumed at 6 x 10^{-4}, the horizontal beam size is estimated to be 300μm. However, the fluorescent screen does not have enough resolution to measure the beam size. OTR monitors are used at the downstream of the ATF2, however, OTR does not have enough light yield at the low bunch charge. We decided to employee YAG:Ce screen. YAG:Ce has a good scintillation property at 550nm wavelength. We tested two types of screen, one is ceramic (sintered alumina powder) YAG:Ce [2] and the other is single crystal YAG:Ce [3]. Both screens have 50μm thickness.

The hardware design and the beam test results are described in the following sections.

HARDWARE

Fig. 1 shows the schematic layout of the YAG:Ce screen monitor(YSC). The screen is inserted into the beam orbit at a 45-degree horizontal direction by the air actuator. The CCD observes the scintillation light of the screen from a perpendicular direction. The screen has an oblique angle (45 degrees) for the beam and the horizontal beam image is magnified by $\sqrt{2}$. The benefit of using the oblique angle is that, 1) the optical system can fully focus on the screen when the beam position moved, 2) the reflection of the synchrotron radiation (SR) and coherent optical radiation (COTR) can mostly be avoided, which are reflected to a 90-degree direction. Avoiding the COTR is a significant problem for the FEL application [4]. In the case of the ATF2, the CTOR is negligible small.

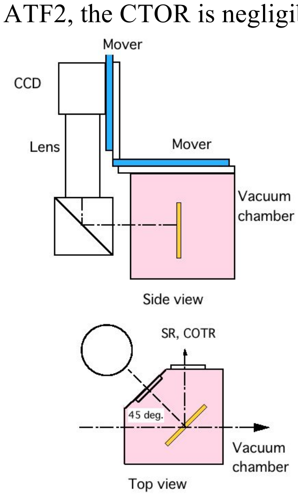

Figure 1: Schematic layout of YSM.

takashi.naito@kek.jp

There is a limitation for the minimum observable image size in the horizontal direction. The beam comes across the screen at the oblique angle of 45 degrees. The CCD observes the scintillation light from the surface to the deep side, because YAG:Ce is almost transparent. Even if the beam has zero-μm in horizontal, the observed image size is limited to the screen thickness. Consequently, the observed image size becomes a convolution of the thickness of the screen and the incident beam size. Fig.2 shows the calculation of the incident beam size and the observed image size in the case of 50μm thickness screen. The beam size is limited to 50μm.

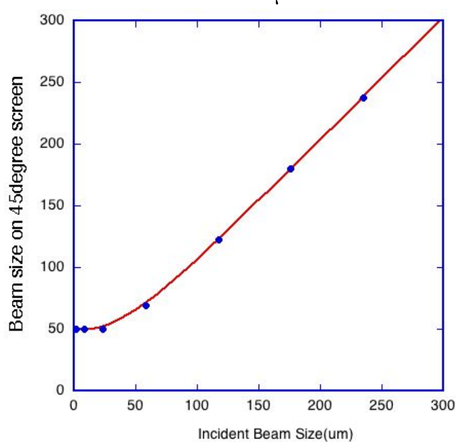

Figure 2: Calculation of the horizontal beam size at oblique angle of 45 degrees screen in the case of 50μm thickness.

Lens System

The scintillation light is delivered to the CCD using a 90-degree reflective mirror and a zoom lens. The reflective mirror is used for changing the optical axis and avoiding the X-ray on the CCD. A zoom lens (TS-93022: Sugito Co.) is used for the lens. The parameter of the lens is summarized in Table 1.

Table 1: Parameters of the *Lens(SUGITOH TS-93022)*

Magnification ratio	0.38~3
Diameter of lens	38mm
Focus length	165 mm
Focal depth	0.3mm
Resolution	4.3μm

The CCD sits on three directional movers to adjust the horizontal/vertical positions, and the focus. The observation area is 1.6mm x 1.2mm at the maximum magnification ratio. The focal depth of the lens is longer than the thickness of the screen. The lens can focus from the surface to the deepest area of the screen. The resolution is estimated from the Fourier transform of the modulation transfer function of the lens. The distribution of the point spread function (PSF) differs a little bit from the Gaussian distribution. The Gaussian fit of the PSF peak area is defined to the resolution.

Characteristics of the Gated CCD Camera

The SR and the COTR exist only during the duration of the bunch length. The YAG:Ce has 100ns of the scintillation time [5][6]. To distinguish the SR, COTR and the scintillation light, a gate function of the image intensifier was used [4]. Image intensifier is an expensive device, so we tried to use the commercially available CCD with an electric shutter. To check the gate function of the electric shutter, we measured the very short laser light by scanning the gate timing.

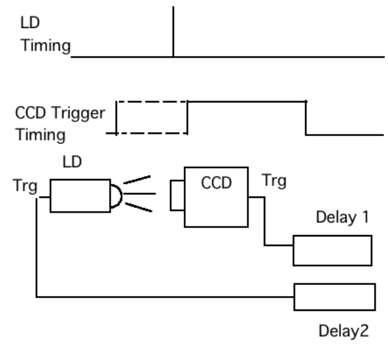

Figure 3: Measurement setup of the gate characteristics of the CCD.

Figure 3 shows the setup of the measurement. The light of the laser diode (Hamamatsu C4725, the duration of the pulse light: 30ps) was observed with the CCD in the electric shutter mode. The light intensity of the image was plotted when the trigger timing was scanned. CCD IGV-B0610M(IMPREX Co.) is used for the test. The exposure time in this measurement was 2μs. The measurement result is shown in Fig.4.

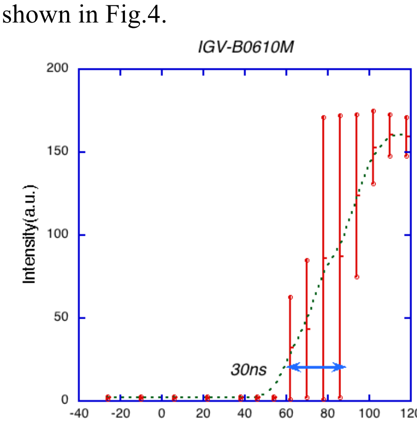

Figure 4: Gate characteristics of IGV-B0610M.

The exposure timing of the CCD has an asynchronous jitter for the external trigger. The start timing of the exposure is synchronized with the internal clock. The external trigger is not synchronized with the internal clock. The width of the jitter corresponds to a period of the internal clock. IGV-B0610M uses a 40MHz clock. The jitter exists at least 25ns. The measurement result shows that: 1) the exposure timing starts with a 50ns delay from the trigger, 2) the exposure includes about 30ns of jitter and 3) the rise time of the exposure is at

ISBN 978-3-95450-141-0

60ns. If the beam timing is set to just before the exposure, the SR and the COTR can be avoided and the scintillation light of YAG:Ce can be measured using this CCD.

BEAM MEASUREMENT

Horizontal Beam Size Measurement

The example of the measured beam profile is shown in Fig. 5 and the current dependence of the horizontal beam size is shown in Fig. 6.

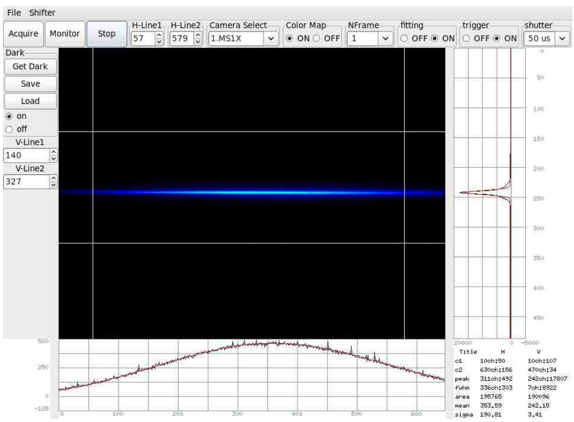

Figure 5: Example of the measured profile with the YSM.

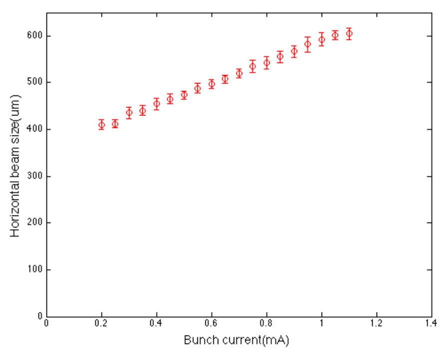

Figure 6: Current dependence of the horizontal beam size.

The horizontal beam size was changed from 600 to 400µm when the current changed from 1.2 to 0.2mA. The measurement error did not increase even at low current, which means the measurement kept a good signal-to-noise ratio.

Vertical Beam Size Measurement

To confirm the resolution of the YSM, the vertical beam size was measured when the focus strength of the upstream quadruple magnet was changed. The estimated vertical beam size at this measurement is several-µm.

We tested three of the YAG:Ce screens, 1) ceramic YAG:Ce with a 100µm thickness, 2) ceramic YAG:Ce with a 50µm thickness, 3) crystal YAG:Ce with a 50µm thickness [3][4]. The projections of the vertical profile at the minimum beam size condition are shown in Fig. 7. The measured beam sizes were 1) 13.9µm, 2) 8.6µm, 3) 7.0µm, respectively. There are some enlargement effects,

a) Blurring effect of the screen
b) Resolution of the lens c)
Saturation effect of the screen

There was a clear difference between 1) and 2) beam sizes. The difference of the thickness contributes to the blurring effect. The scintillation light emits in all directions. The scintillation light from the deep side of the screen spreads to the transverse direction. The effect is stronger than in a thick screen. Especially, the profile of 1) has a larger tail.

There was not a clear difference between 2) and 3) beam sizes. Lumpkin et. al. reported that crystal has better resolution than ceramic [7]. We used a small grain size ceramic, 2µm [3]. It is assumed that the scattered reflection inside of the screen is small in our case.

In the case of 3), the measured beam size was affected by the resolution of the lens. The beam size takes into account the resolution of the lens that was estimated at 5.5µm, which almost agreed with the estimation.

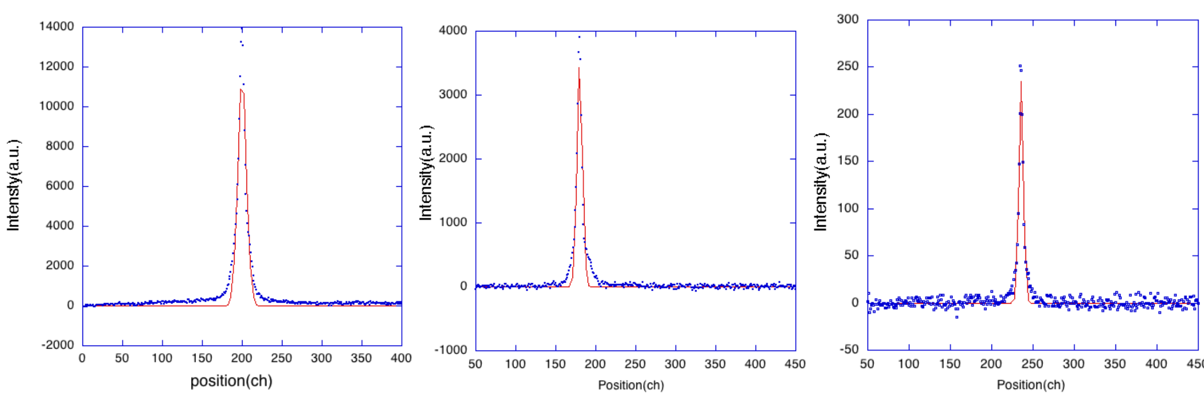

Figure 7: 1) Ceramic YAG:Ce 100µm thickness(left) σ_y=13.9µm, 2) Ceramic YAG:Ce 50µm thickness(center) σ_y=8.6µm, 3) Crystal YAG:Ce 50µm thickness(right) σ_y =7.0µm(right).

It is difficult to check the saturation effect by this measurement. As described in the previous section, this location has a large dispersion function. The beam size is very large for the horizontal direction. The density of the beam is not so high compared to the other location. We moved the YSM to a no-dispersion location and measured the profile. Fig. 8 shows the example of the image. The horizontal profile of the center is clearly saturated. The saturation of the beam density was estimated at $0.25\mathrm{pC}/\mu\mathrm{m}^2$.

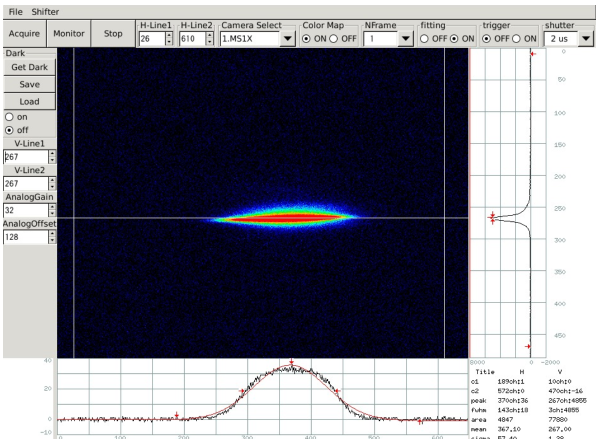

Figure 8: Example of the saturated beam profile.

Gate Timing of the CCD

The beam profile was measured as a function of the gate timing. Fig 9 shows the scintillation light intensity and the vertical beam size as a function of the gate timing. The gate timing of the electric shutter opened at 0μs and the gate width of the electric shutter was at 2μs. The timing scan corresponds to observe the tail part of the scintillation with a 2μs window. The scintillation light intensity almost agreed with YAG:Ce scintillation characteristics. The measured vertical beam size was not dependent on the gate timing, which means that the tail of the scintillation light has the same information of the beam profile except for the light intensity. The beam size could be measured over 500ns after the beam timing. The light intensity of the CCD can be controlled adjusting the gate timing.

SUMMARY

We developed a screen monitor using YAG:Ce screen(YSM) for the momentum spread measurement of the KEK-ATF2 beam line. The YSM could measure the horizontal beam size with a good signal-to-noise ratio, which means the YSM has enough performance for the momentum spread measurement. The minimum beam sizes for the vertical direction were: 1) ceramic YAG:Ce 100μm thickness: σ_y=13.9μm, 2) ceramic YAG:Ce 50μm thickness: σ_y=8.6μm, 3) crystal YAG:Ce 50μm thickness: σ_y=7.0μm, respectively. The saturation of the YSM was $0.25\mathrm{pC}/\mu\mathrm{m}^2$.

The gate function of the CCD was tested with the test bench and the beam test. The gate function can be applicable for avoiding the SR and COTR.

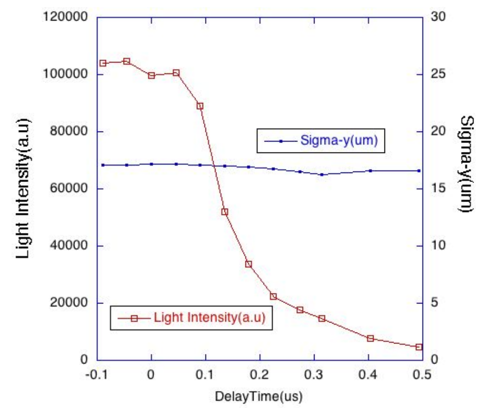

Figure 9: The scintillation light intensity and the measured vertical beam size as a function of the gate timing of the CCD.

ACKNOWLEDGMENT

We acknowledge to Professors S.Yamaguchi, A.Yamamoto and K. Oide for their encouragement. We also thank to the members of the ATF group for giving machine time for testing of the monitor.

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