BEAM HALO MEASUREMENT UTILIZING YAG:CE SCREEN

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Abstract

We are aiming to produce an extremely small beam having a vertical beam size of 37nm at KEK-ATF2. The beam halo surrounding the beam core will make the background for the beam size measurement using a Laser interferometer beam size monitor. An understanding of beam halo distribution is important for the measurement of the beam size at the final focus point of the KEK-ATF2. In order to measure the beam halo distribution, we developed a beam halo monitor based on fluorescence screen. A YAG:Ce screen, which has 1mm slit in the center is set in the beam line. The image on fluorescence screen is observed by imaging lens system and CCD camera. In this configuration, the beam in the core will pass through the slit. The beam in surrounding halo will hit the fluorescence screen, and we can observe the distribution of beam halo. The intensity contrast of beam halo to the beam core is measured by scanning the beam position for the fixed fluorescence screen position. The results of observation of beam halo are presented.

INTRODUCTION

ATF2 is a test beam line for developing the final focus system for the International Linear Collider (ILC). The very low emittance beam is supplied from the damping ring(DR). The energy is 1.3GeV and the design emittances for the horizontal and vertical are 1.3nm and 10pm, respectively. The final focus optics in the ATF2 beam line generates an extremely small beam. The design vertical beam size is 37nm at the virtual focal point [1]. A laser interferometer beam size monitor is used for the beam size measurement [2]. The collision of the electron beam and the fringe of two laser beams makes the Compton scattered photons. The beam size is estimated from the modulation depth of the Compton signal when scaning the fringe position of the laser beams. A Gussian distribution is assumed for the electron beam in this estimation. The beam halo causes the background of the Compton signal and the measurement error. The beam halo distribution is important for the measurement of the beam size.

The beam-gas scattering, beam-gas bremsstrahlung and intra-beam scattering cause the beam halos in the storage ring. The beam halo distribution in the case of the ATF damping ring was estimated in reference [3]. The vertical beam distribution with different vacuum pressure due to the beam-gas scattering is shown in Fig. 1. The calculation shows some deviation at 10^{-3} of the intensity in the case of 10^{-7}Pa of the vacuum level.

We developed a screen monitor utilizing a YAG:Ce screen, which has both high resolution and high sensitivity[4]. This monitor is also used at the KEK LUCX (Laser Undulator Compton X-ray) facility [5]. The beam halo monitor is an application system of the screen monitor, which can visualize the beam halo distribution.

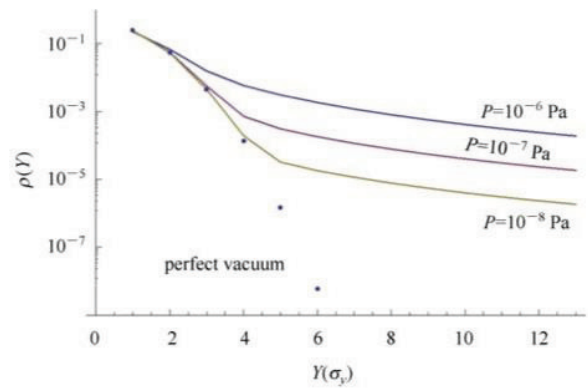

Figure 1: Vertical beam distribution with different vacuum pressure (vertical axis:provability, Horizontal axis : normalized RMS beam size), from Chinese Physics C, Vol. 38, No. 12 (2014) 127003

HARDWARE

The beam halo monitor consists of a YAG:Ce screen held on the air actuator and an imaging system. The YAG:Ce screen has 1mm slit in the center. The size is 10mmϕ and the thickness is 100μm. The picture of the YAG:Ce screen on the actuator holder is shown in Fig. 2.

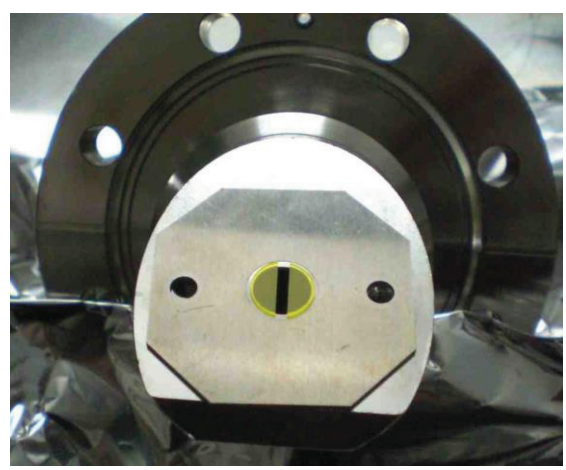

Figure 2: YAG:Ce screen on the actuator holder: The beam core goes through a slit at the center of the screen without any interaction for the scintillator.

In this configuration, the beam in the core passes through the slit and the beam halo hit the screen. The

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fluorescent light is observed by the imaging lens and the CCD camera. An example of the measured image of the beam halo monitor is shown in Fig. 3. The beam core passes through the right side and the beam image suddenly disappear at the slit location. We can observe only the beam halo. The amount of the beam halo is measured by scanning the beam position.

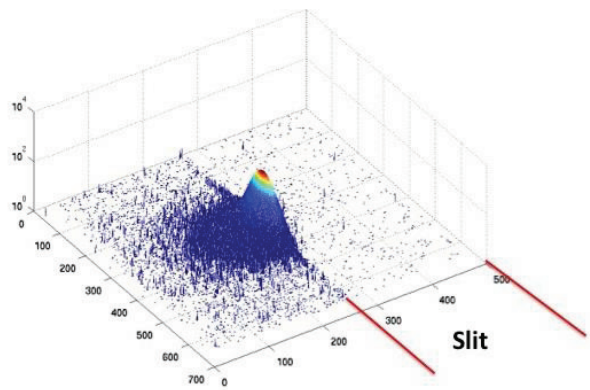

Figure 3: Example of the beam halo image

Figure 4 shows the layout of the YAG:Ce screen and the imaging lens. The screen is inserted into the beam orbit with a 45-degree angle for horizontal direction by the air actuator. The CCD observes the scintillation light of the screen from a perpendicular direction. The optical system can fully focus on the screen when the beam position moved. This layout can be avoided the reflection of the synchrotron radiation (SR) and coherent optical radiation (COTR), which are reflected to a 90-degree angle.

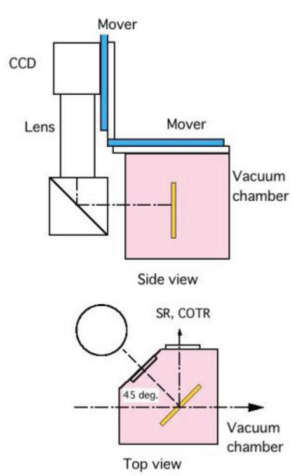

Figure 4: Layout of the YAG:Ce screen and the imaging lens

The scintillation light is delivered onto 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 lens has three times of the magnification ratio, 0.3mm of the focal depth and 4.3μm of the resolution. The point spread function (PSF) is estimated from the Fourier transform of the modulation transfer function of the lens. The PSF is shown in Fig. 5. The resolution is estimated from the Gaussian fitting of the PSF. The lens has enough resolution to measure less than 10μm of the beam image.

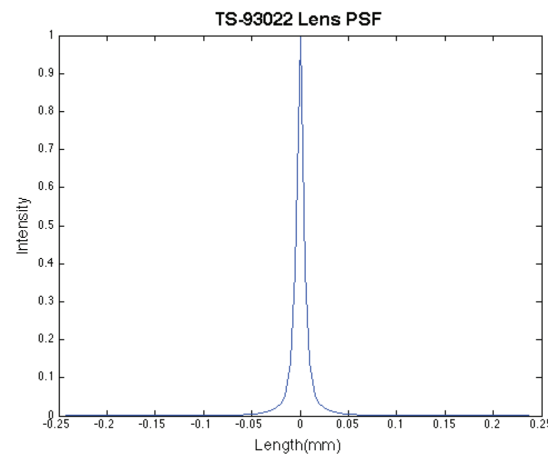

Figure 5: Point spread function (PSF) of the TS-93022 lens

CCD IGV-B0610M (IMPREX Co.) is used for the imaging. The CCD has 648 x 488 resolution with 7.4μm^2 pixel size and the external trigger function with 2μs of minimum exposure time. The scintillation time of the YAG:Ce is 100ns.

BEAM MEASUREMENT

Saturation of the YAG:Ce Screen

The beam halo monitor is located at the diagnostic section of the ATF beam line. The assumed beam sizes for horizontal and vertical are 50μm x 25μm, respectively, at the location. The electron density is very high at the location. YAG:Ce has the saturation of the scintillation light for high beam density. The measured saturation level is 0.25pC/μm^2. [4] It is difficult to measure the peak intensity of the beam image for the saturation in this measurement. We measured the saturation effect as a function of the beam intensity when set the beam center on the screen. The peak intensity is estimated from the liner fitting of the non-saturated area. The measured light intensity of the YAG:Ce as a function of the beam charge is shown in Fig. 6. The saturation starts from less than $0.05x10^9$ electrons.

Vacuum Dependence

The beam halo measurement was done with following procedure. 1) The screen is inserted into the beam line. 2) The beam position for the screen slit is scanned using a

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steering magnet located at the upstream. It is better to change the slit position for the beam, however we don't have the mover of the screen. The dispersion effect is negligible when the beam position is changed. 3) The halo image is acquired and the peak intensity of the halo is estimated from the acquired image.

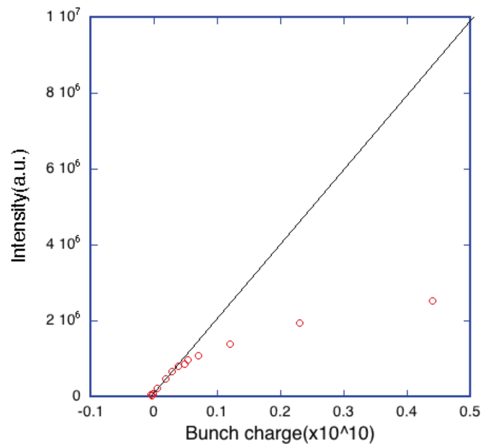

Figure 6: Light intensity of the YAG:Ce as a function of the beam charge

The distribution of the beam halo for the different vacuum condition is plotted in Fig. 7 in the case of the beam intensity 0.23 x 10^{10} electrons. Three different vacuum conditions are plotted, 4.3x 10^{-7}Pa, 7.6 x 10^{-7}Pa and 12.0 x 10^{-7}Pa, respectively. The Ion pumps in the damping ring were turned off to change the vacuum level. The core part of the beam is not plotted for the saturation of the screen. The red line in Fig. 7 shows sigma=25µm of Gaussian distribution. The peak of the Gaussian distribution was estimated from the saturation characteristics in Fig. 6, which is shown as a red cross. There is a clear difference of the beam halo for the different vacuum level. The core part is same for the different vacuum level.

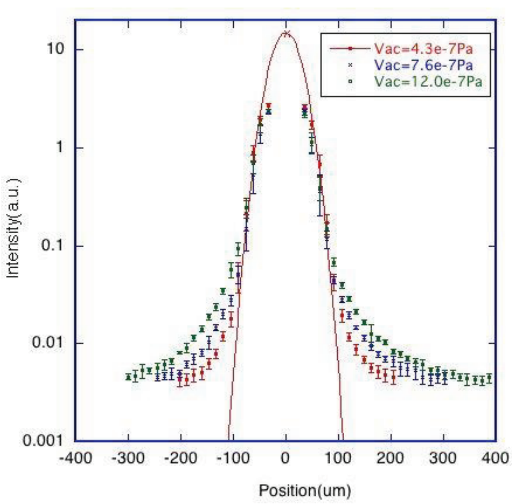

Figure 7: Distribution of the beam halo for the different vacuum condition in the case of the beam intensity 0.23 x 10^{10} electrons

The intensity of the halo for the position is plotted in Fig. 8 in the case of the beam intensity 0.45 x 10^{10} electrons. Three different vacuum conditions are plotted, 4.3x 10^{-7}Pa, 8.7 x 10^{-7}Pa and 13.1 x 10^{-7}Pa, respectively. The red line in the Fig. 8 shows sigma=27µm of Gaussian distribution. The peak of the Gaussian distribution was estimated from the saturation characteristics in Fig. 6, which is shown as a red cross.

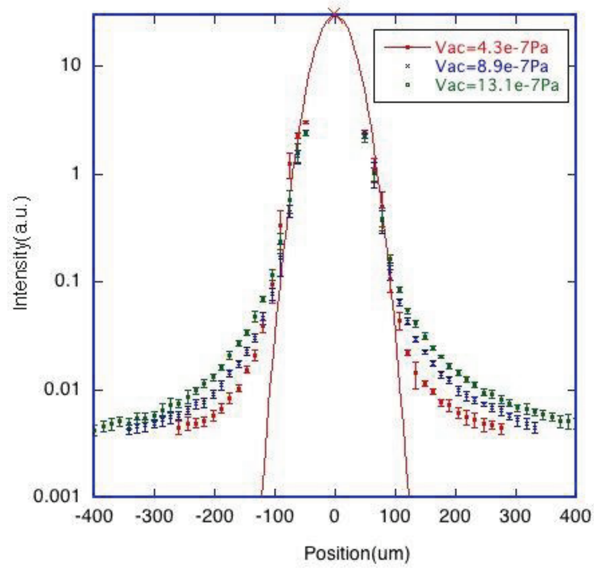

Figure 8: Distribution of the beam halo for the different vacuum condition in the case of the beam intensity 0.45 x 10^{10} electrons

RF Voltage Dependence

The distribution of the beam halo for the different rf voltage of the damping ring is plotted in Fig. 9 in the case of the beam intensity 0.23 x 10^{10} electrons. Two different rf voltages are plotted, Vrf=283kV and Vrf=110kV, respectively. The bunch length of the beam is a function of the rf voltage and the difference is about 10% for the two cases. The bunch length affects the core beam size by the intra-beam scattering. The measurement shows almost same beam halo and a little bit increased the beam core. The red line in the Fig. 9 shows 25µm of Gaussian distribution. The peak of the Gaussian distribution was estimated from the saturation characteristics in Fig. 6, which is shown as a red cross.

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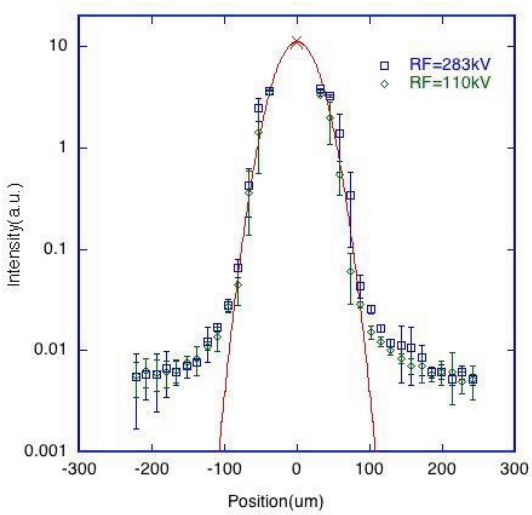

Figure 9: Distribution of the beam halo for the different rf voltage of the damping in the case of the beam intensity 0.23 x 10^{10} electrons

SUMMARY AND FUTURE PLAN

We developed a beam halo monitor to measure the electron beam distribution utilizing a YAG:Ce screen. The beam halo measurement at the KEK-ATF2 beam line showed the clear deviation from the Gaussian distribution. The amount of the deviation was from 10^{-2} to 10^{-3} of the peak intensity, which was a function of the vacuum level of the damping ring. The measurement agrees with the simulation result. The beam halo was no change for the rf voltage of the damping ring. In these measurements, the peak intensity of the beam core was estimated from the saturation characteristics. The beam density of the core was too high for the YAG:Ce screen measurement. We have a plan to install an OTR screen monitor at same location to measure the peak of the beam core. By super impose the data of the OTR screen monitor and the data of the beam halo monitor, we will get the wide range of the beam profile from the peak to the halo.

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