IMPROVEMENT OF SCREEN MONITOR WITH SUPPRESSION OF COHERENT-OTR EFFECT FOR SACLA

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Abstract

The construction of SACLA (SPring-8 Angstrom Compact free electron LAser) was already completed and it is under operation. A screen monitor (SCM) system has been developed and was installed in order to obtain a direct image of a transverse beam profile with a spatial resolution of about 10 μm, which is required to investigate electron-beam properties, such as a beam emittance. The SCM originally has a stainless steel target as an OTR radiator or a Ce:YAG crystal as a scintillation target. At the beginning of SACLA operation, strong coherent OTR (COTR), which provides incorrect beam profile image, was observed after full bunch compression to make a peak-current of over 1 kA. In order to suppress the COTR effect on the SCM, the stainless steel target was replaced to the Ce:YAG scintillation target. Since the COTR was still generated from the Ce:YAG target, a spatial-mask was employed. The mask was mounted on the optical axis around the center of the SCM image, because the COTR light is emitted forward within ~$1/\gamma$ radian, while the scintillation light almost has no angular dependence. Clear beam profiles with a diameter of a few tens of micrometre are observed by means of the SCM with this simple improvement.

INTRODUCTION

In the SPring-8 site, construction of SACLA, which is an XFEL facility, was already completed and it is under operation [1,2]. For SACLA to stably generate a high-intense X-ray laser pulse of shorter than 0.1 nm wavelength, the electron-beam injected into the undulator section is demanded to have a high peak-current of more than 3 kA and a low-emittance of less than 1 π mm mrad. The 1 ns width electron-beam, which is generated from a thermionic gun with a low emittance of 0.6 π mm mrad and is formed from a 3 μs width (FWHM) at the gun by a beam chopper, is compressed to nearly 10 fs by the velocity bunching process of an injector part and three bunch compressors without emittance growth. The electron-beam for generating high-intense X-ray laser pulses is made by fine tuning of the accelerator, investigating the beam properties. In SACLA, a monitor system for a beam profile and a beam bunch length is indispensable for the SASE operation of the XFEL.

A large number of screen monitors (SCM) have been installed along the accelerator and the undulator line for measuring beam profiles [3,4]. Especially after the third bunch compressor (BC3), the values of the emittance and bunch length of the beam should be obtained. The emittance is measured by the Q-scan method [5] with the SCM. For the bunch length measurement, a temporal beam profile is monitored by converting the temporal structure to a spatial profile using the RF-deflector in order to achieve a temporal resolution of 10 fs [6]. In these measurements, the transverse beam size of a few 10 μm (rms) should be observed with the SCM. Therefore, the SCM is demanded to have a spatial resolution of 10 μm for SACLA.

At the beginning of SACLA operation, however, some of the spatial profiles were not correctly able to be monitored by the SCM on account of strong coherent OTR (COTR), which made an incorrect beam profile image, after the BC3. The COTR is also observed at LCLS, FLASH, and other facilities [7,8,9], when an electron-beam is compressed over a certain pulse width. Our SCMs, nevertheless, did not have a countermeasure against the COTRt, because the COTR has not been observed in the SCSS test accelerator [10], which is a small-scaled machine of SACLA.

Therefore, the SCM has been improved for mitigation of the COTR effect to increase availability of the SCMs placed downstream of the accelerator.

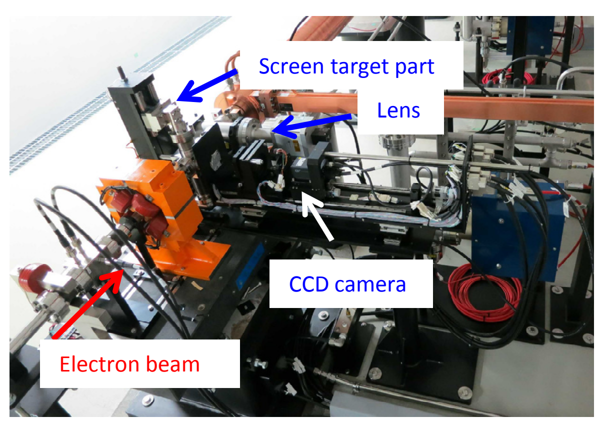

Figure 1: Setup of the SCM system.

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SETUP OF THE SCM SYSTEM AND OBSERVATION OF COTR

The SCM is a standard method for profile measurement of an electron-beam, which directly images the beam profiles using light emitted from a view screen by the electron-beam. In SACLA, 46 SCMs were installed in order to obtain transvers beam images with a spatial precision of below 10 µm.

The configuration of the SCM is shown in Fig. 1 and Fig. 2. The SCM is composed of a screen target part with a vacuum chamber and an optical system part with an optical lens and a CCD camera. In order to obtain a high-resolution image, the optical system has a customized complex lens with minor optical aberrations and a large diameter of 2 inch. The CCD camera has a pixel size of 6.5 µm and horizontal and vertical pixel numbers are 1492 x 1040, respectively. Two kinds of radiators, which are a stainless steel foil to emit OTR and a Ce:YAG crystal for fluorescence, are employed for a screen target.

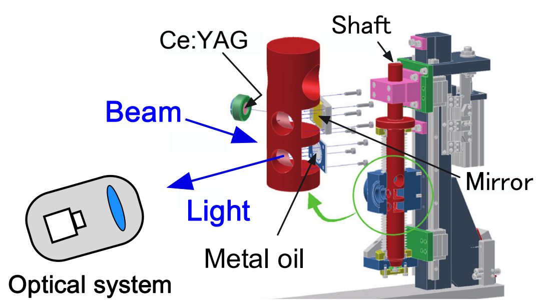

Figure 2: Configuration of the screen target part in the SCM. The shaft equips apertures to pass through an electron-beam and to install two kinds of the screen targets, which are a stainless steel foil and a Ce:YAG scintillator.

The Ce:YAG screen was designed to be 100 µm thick that was optimized the image resolution and the mechanical strength. Since the Ce:YAG screen has a emission depth along an electron beam path, the target should be as thin as possible to obtain the sufficient resolution. On the other hand, the target should have a certain thickness for the mechanical strength. A thickness of 100 um satisfies both demands. The Ce:YAG screen is perpendicularly attached with respect to the beam path in order to minimize the path length. The scintillation is reflected by a mirror with the angle of 45 deg. toward the optical system. The OTR screen is made of stainless steel that has 100 µm thicknesses. This screen is attached to the screen holder at a 45 deg. angle with respect to the beam axis in order to produce the OTR toward the optical system.

In the original plan, the Ce:YAG scintillator was used for a lower energy beam below 30 MeV, and the OTR screen was used for a high energy beam over 30 MeV. However, after the BC3 the COTR was emitted from the OTR screen. The COTR light makes an incorrect beam profile image due to abnormally intense coherent-light. The intensity of the light is several orders of magnitude higher than that of normal OTR. Furthermore, the intensity has large fluctuation shot-by-shot. As a result, the profile image taken by the CCD camera is saturated by a very-large intensity shot, as shown in Fig. 3. For the purpose to mitigate the COTR effect of the SCM to observe a proper beam profile image, the stainless steel target was replaced with a Ce:YAG scintillation target even for the high energy region.

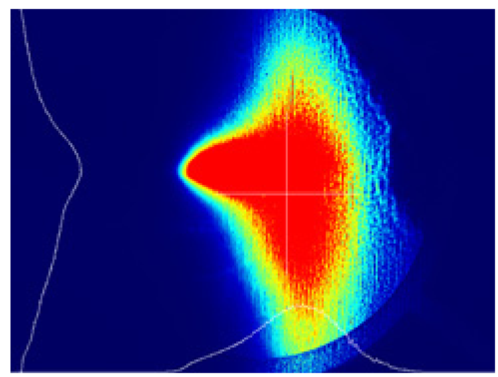

Figure 3: Profile image with COTR disturbance.

MITIGATION OF COTR EFFECT IN THE SCM

Separation Method Using Scintillator

In order to mitigate the COTR problem, scintillator screens are generally employed in SCM systems. The scintillator emits fluorescence from excited atoms by an electron-beam. Although the scintillator screen emits COTR, the fluorescence light has some differences from COTR in the emission angle distribution and the time response. The COTR light coming into the SCM can be considerably reduced by using the difference of the emission mechanism in temporal or spatial characteristics.

One of the methods to reduce the COTR light is the temporal separation between the fluorescence and the COTR, which uses the difference of the emission time structures between them. The emission time is over ten nanosecond in the Ce:YAG scintillator case and a few tens of femtosecond, which correspond to the electron bunch length, in the OTR case. Accordingly, it is possible to separate the COTR light by using a high-speed gated camera, such as an intensifier CCD camera [6]. However, these cameras are very expensive. Therefore, it is difficult to use these high-speed cameras for the 30 SCMs in SACLA.

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The other COTR reduction method is a spatial separation. In this method, a spatial-mask is inserted before the lens to block the COTR light. The configuration of an improved SCM is shown in Fig. 4. The COTR light is emitted forward within ~1/γ rad, where γ is the Lorentz factor. The divergence angle of the COTR is less than 0.5 mrad for over a 1 GeV energy region. On the other hand, the scintillation light has no angular dependence. The profile image was obtained without the COTR disturbance by using the SCM with the spatial-mask at the center line of the optical system. Since this method is much more cost-effective than the temporal separation method, we employed the spatial separation method to solve the COTR problem.

Experience in Spatial Separation

When the electron-beam was focused into a few 10 μm region so as to measure a beam emittance by a Q-scan method, the COTR was again observed in the SCM. The reason was that the divergence angle of the COTR became larger than the masked area due to diffraction effect at a small light source. Although the emission angle of the COTR is basically within ~1/γ rad, A diffraction angle can be much larger than 1/ γ rad for a small-size beam. The diffraction angle is approximately expressed as a ~λ/*d* rad, where λ is the wavelength and *d* is the beam diameter. For a focused beam, the divergence of the COTR light was larger than the initial size of the central spatial-mask. The angular divergence was estimated to be about 100 mrad at an electron-beam size of 10 μm on the screen. Therefore, the mask size was necessary to cover this area.

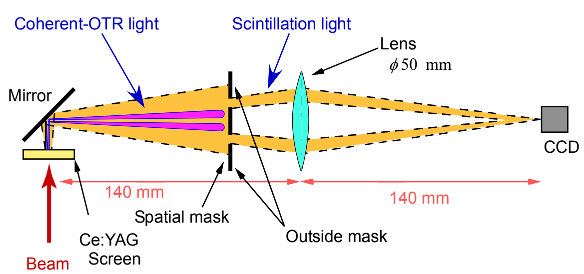

Figure 4: Configuration of the spatial separation of the COTR light using a mask in the SCM.

Moreover, we observed some stray light in the image of the SCM with the central spatial-mask. The stray light was caused by the high-intense COTR light, which was reflected in the vacuum chamber and it was scattered out through a viewing port. Accordingly, an outside mask was installed along with the central spatial-mask in order to reduce the stray light. The shape of the final spatial-mask is like a double-pinhole, which is shown in Fig. 4. Clear beam profiles were observed by means of the SCM with this spatial-mask.

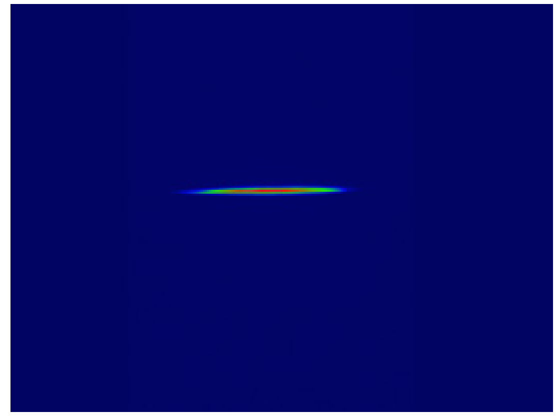

Figure 5: Profile image observed by the SCM with the spatial-mask. The electron-beam was focused in the vertical axis by Q-magnets.

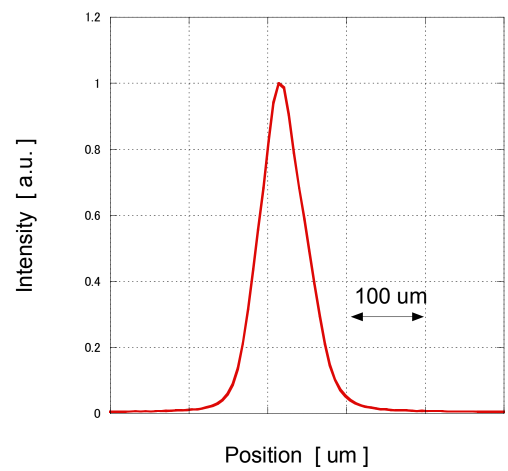

Figure 6: Vertical beam charge distribution of Fig. 5.

A profile image and the vertical beam charge distribution of this image are shown in Fig. 5 and Fig. 6, respectively. The beam profile image focused by Q-magnets was observed on the Ce:YAG screen in the vertical axis. The beam size was measured to be 30 μm (rms) from the beam profile of Fig. 6. Moreover, a small beam size of 17 μm (rms) was observed by using another focused beam.

Consequently, an appropriate beam profile was observed without the COTR disturbance by using the spatial separation method between the COTR and the scintillation. Since this method is much simpler than the temporal separation, the spatial separation method is possible to be easily used for the already installed SCMs. The improved SCMs have a spatial resolution of lea than about 10 μm, which is demanded from tuning of the SACLA.

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Further Improvement for Mitigation of COTR Effect

In order to further improve the spatial separation of COTR light, we have employed a perforated mirror for a SCM. A schematic drawing in the case of using the perforated mirror is shown in Fig. 7. The COTR light, which is generated on the surface of the Ce:YAG, passes through the hole of the perforated mirror. In this case, most of the COTR light and scattered light in the chamber do not come out though the viewing port. An example of an appropriately observed beam image is shown in Fig. 8. The image still shows stray light which is scattered at the hole edge and the mirror face. However, the intensity of the scattered light is negligibly small to the beam profile intensity in the image. The separation between the COTR and the fluorescence by using the perforated mirror seems to be sufficient for our SCM. This separation method is still under study in SACLA for further improvements.

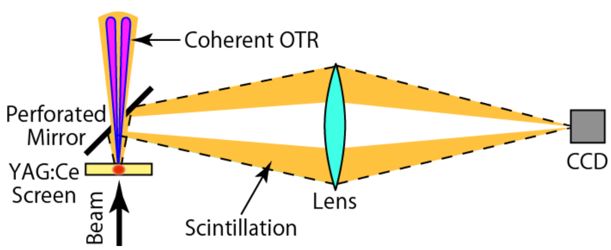

Figure 7: Configuration of the SCM to mitigate the COTR light with a perforated mirror.

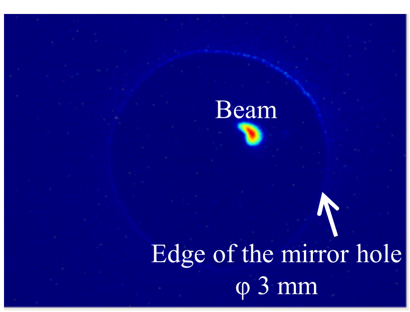

Figure 8: Profile image by the SCM with a perforated mirror. Size of the hole in the perforated mirror is 3 mm.

CONCLUSION

We improved the SCM of SACLA so as to mitigate the COTR disturbance by means of the spatial separation between COTR light and fluorescence light using the difference of their emission angles. A Ce:YAG scintillation screen and a spatial-mask were employed in the SCM. The spatial-mask obstructs the COTR light to the CCD camera. As a result, the profile image was appropriately observed by focusing the scintillation light through the mask. Clear beam profiles with a diameter of a few tens of micrometre in rms were observed by means of the method using the improved SCM with the spatial-mask. This fact indicates that the SCM has a spatial resolution of about 10 μm.

Since the implementation of this method, a projected emittance value of around 1 π mm mrad has been precisely measured by the Q-scan method with the SCM after the bunch compressors. Furthermore, a beam bunch length of about 30 fs was measured by using an RF-deflector. The improved SCMs are effectively utilized in the XFEL tuning of SACLA.

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