ISBN: 978-3-95450-204-2 ISSN: 2673-5350 doi:10.18429/JACoW-IBIC2019-TUPP019

EXPERIMENTAL TESTS OF SCREEN MATERIALS FOR HIGH-PRECISION TRANSVERSE BEAM-SIZE MEASUREMENTS AT THE SuperKEKB INJECTOR LINAC

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Abstract

The SuperKEKB injector linac is required to deliver low-emittance electron and positron beams. Wire scanners are employed to measure Twiss parameters and to adjust beam optics conditions. Screen monitors also play important roles for single-shot measurements. However, the beam size became more than 10-times smaller compared with that of the KEKB injection. Beam tests have been performed in order to evaluate materials for high-precision transverse beam-size measurements at the injector. The main purpose of the beam tests is to quantitatively investigate the saturation effect of each screen material for generating the scintillation light, which is strongly depending on the beam fluence. Several scintillating screen materials including YAG:Ce, LYSO:Ce, BGO and aluminum ceramic doped chromium oxide (Al_2O_3:Cr) have been tested with high energy and high fluence. The results are compared with that obtained by the OTR measurement. The saturation of the luminescence was confirmed for all crystals and evaluated in fluence of the ~1 nC/mm^2.

INTRODUCTION

A very thin inorganic scintillator, YAG:Ce crystal is used in many facilities, is used to measure the charged particle beam profile or the temporal structure with the rf deflector. Beam profile measurement using a scintillating screen is easier to align the optical system than the optical transition radiation (OTR). In case of ultrashort bunch length, coherent OTR gives incorrect beam profile. By employing optimized imaging system, the resolution of the profile is comparable to the OTR screen monitor [1]. The response of YAG:Ce crystal to the high brightness electron beam was studied and the limitation of the resolution is discussed in Ref[2]. In case of YAG:Ce screen, the saturation becomes real at the electron beam fluence of the order ~0.04 pC/mm2 for 100 MeV and this limit scales with energy. In the KEK linac, the electron beam with the bunch charge of 4 nC, the energy of 7 GeV and the normalized emittance of 40(Horizontal) / 20(Vertical) µm is required for SuperKEKB HER injection [3]. Because the beam size in the linac is ~100-200 µm, the fluence exceeds the limitation scaled by the beam energy. Thus, we have performed beam tests of scintillating screens, YAG:Ce, LYSO:Ce, BGO and Al2O3:Cr, to confirm the saturation of the light output to the high fluence electron beam [4]. Properties of those scintillators are summarized in Table 1. The saturation of the luminescence of those scintillators, except for Al2O3:Cr, was observed at fluence of 1 nC/mm2 for 1.5 GeV beam, but there was no reference measurement using the OTR screen. Thus, we have measured a beam profile measurement using those scintillating screens and an OTR screen.

Table 1: Properties of Scintillators

	τ_{decay} [ns]	λ_{max} [nm]	Light yield [10^3 ph/MeV]	Density [g/cm^3]
YAG:Ce	70	550	17	4.6
LYSO:Ce	41	420	33	7.1
BGO	300	480	9	7.1
Al_2O_3:Cr_2O_3	> ms	690	Large	4.0

EXPERIMENT

The KEK linac consists of 2 straight sections and 180 degrees arc section between them. The beam profile measurements were performed at a test beam line with a beam dump located downstream of the first straight section. The linac has an RF-gun for the generation of the low emittance electron beam and a thermionic gun for low current beam for PF/PF-AR storage rings or high bunch charge beam to produce a positron beam for SuperKEKB LER. In this experiment, a bunch charge of 1.15 nC beam generated by the rf-gun was used, and the beam accelerated up to 1.5 GeV. The experimental setup is shown in Fig. 1. The beam pass through a 30 µm thick stainless steel window and a blackout fabric to block the OTR generated at surface of the window. Scintillating screens and OTR screen are set on a motorized stage. The thickness of these scintillating screens is 0.1 mm. Two imaging system are located in the direction of 90 (OTR screen) and 19 (scintillating screens) degrees to the beam line respectively. The layout of the imaging system is also shown in the figure. To avoid saturation of the CCD and adjust quantity of light on the CCD for each scintillating screen, the variable neutral density (ND) filters is used. Because Al2O3:Cr has a long decay time, signal level of pixel outputs were adjusted by exposure time (500 µs for the Al2O3:Cr, 50 µs for other screens). The CCD camera has a sensor resolution of 659x493 pixels (cell size 7.4 µm) and 12bit ADC. The bandpass filter is used for limiting wavelength region for the OTR and Al2O3:Cr. The

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resolution of the imaging system around beam spot is better than 20 μm that is 4 times smaller than the previous study.

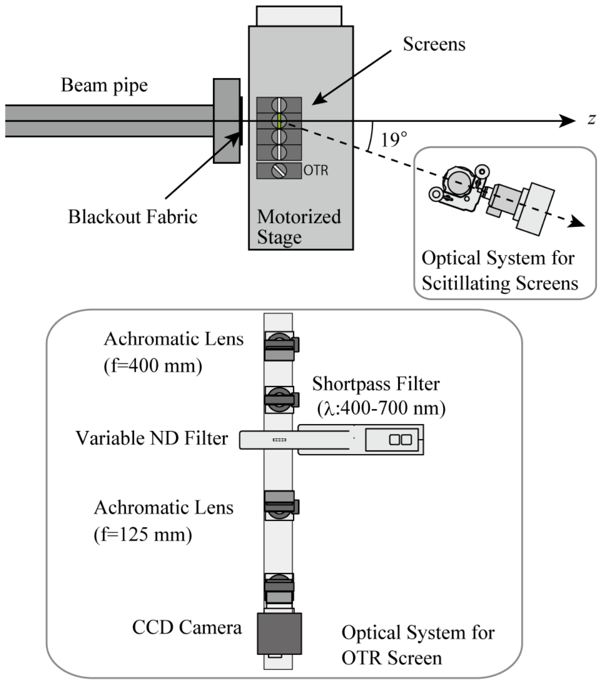

Figure 1: Experimental Setup.

The electron beam was focused on the screen by using a quadrupole triplet which was set 9.7 m long upstream. In order to investigate the change in the amount of light with respect to the beamsize, the last quadrupole magnet in the triplet used to change the beamsize. To suppress an effect of the afterglow to the measurement, the repetition rate was set to 2 Hz. The data acquisition of the profile measurements were synchronized with measurements of BPMs which gives accurate bunch charge of the beam. Variations of the bunch charge and beam position at the screen were less than 1.5% and 50 μm respectively.

RESULT

Sample of beam 2D beam profiles and hor./vert. beam size measured by 5 different screens are shown in Fig. 2 and Fig. 3 respectively. Since the beam is not Gaussian, the beam sizes were evaluated by the RMS of the distribution with background subtraction. In previouse work, the Al_2O_3 :Cr shows a poor resolution compared with other scintillating screens. In this study, beamsizes measured with the Al_2O_3 :Cr are consistent with the beam size measured with the others. The degradation of the resolution in previouse work is considered to be caused by chromatic aberration due to wavelengths longer than 700 nm. However, since the Al_2O_3:Cr is formed by sintering, 2D profile with the Al_2O_3:Cr appears to be blurred.

Variations in the quantity of light output which normalized by measurement value with maximum beam size with respect to the strength of the quadrupole magnet are shown in Fig. 3. Saturation of the luminescence can be confirmed for those scintillating screens except for the Al_2O_3:Cr. Figure 4 shows correlation between the fluence of a region exceeding half maximum estimated by OTR measurement and relative light output of those scintillating screens. The YAG:Ce and the BGO show the same rate (~7%/mm^2/nC) of light reduction with increasing fluence, but reduction rate of the LYSO is about twice as large as them. It is assumed that the main cause of saturation is ionization quenching. An index related to ionization quenching is the α/β ratio which is given by the ratio of the light yield to alpha and beta rays with a kinetic energy of ~5.5 MeV (the α/β ratio of many crystal is 0.2-0.3), and a large ionization quenching means a small α/β ratio. The α/β ratio of LSO:Ce, which is very similar to LYSO:Ce, is 0.14, that is smaller than the ratio of 0.2 (BGO) and 0.3 (YAG:Ce) [5]. This is considered to be one reason why LYSO:Ce is highly saturated. In the LYSO:Ce, the saturation clearly worsens the resolution. At the most convergent point (OTR: 0.18 mm x 0.26 mm), the beamsize is about 1.2 times that of other scintillating screens and OTR screen. The reason why the light output of the Al_2O_3:Cr increases with fluence is not clear. In this paper, we could not determine the threshold at which saturation began for those scintillators. In YAG:Ce case, by scaling the intensities reported in Ref. 2 to 1.5 GeV, the saturation may appear from ~0.3 nC/mm^2.

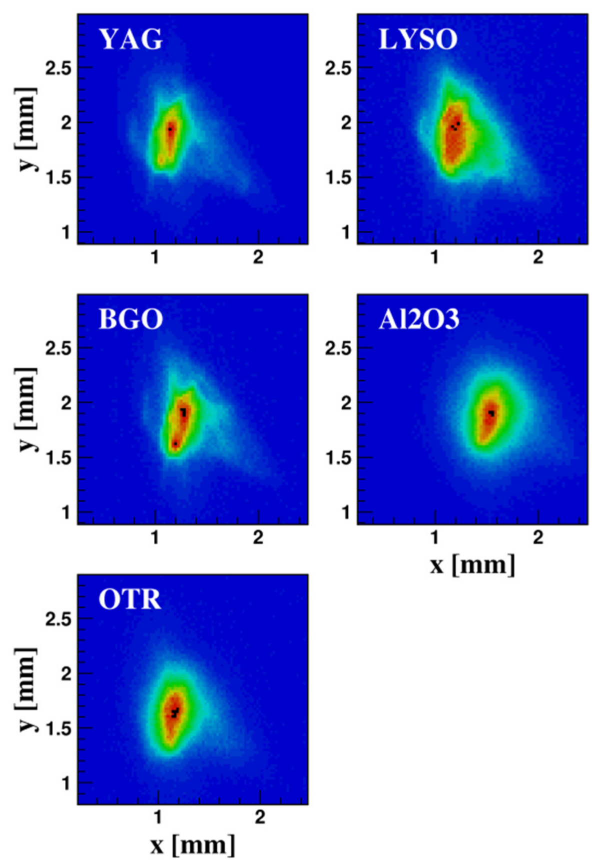

Figure 2: Beam profiles measured by scintillating screens and OTR screen.

8th Int. Beam Instrum. Conf. IBIC2019, Malmö, Sweden JACoW Publishing
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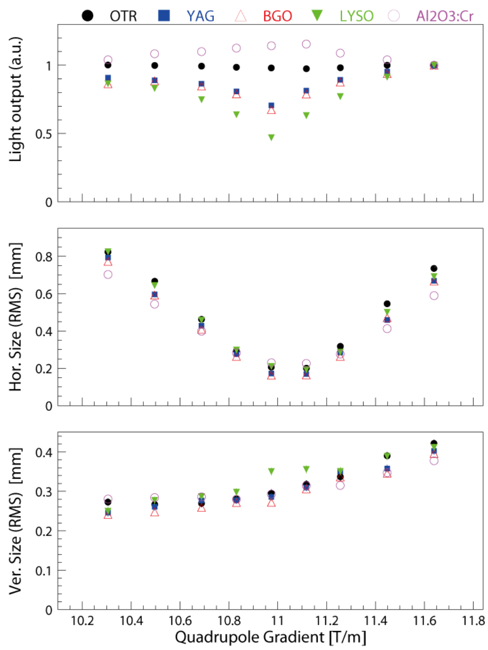

Figure 3: Relative light output and beamsize as a function of the quadrupole gradient. Plotted data is an average of 10 measurements with the bunch charge of 1.150±0.005 nC. The light output is normalized by the data at 11.64 T/m.

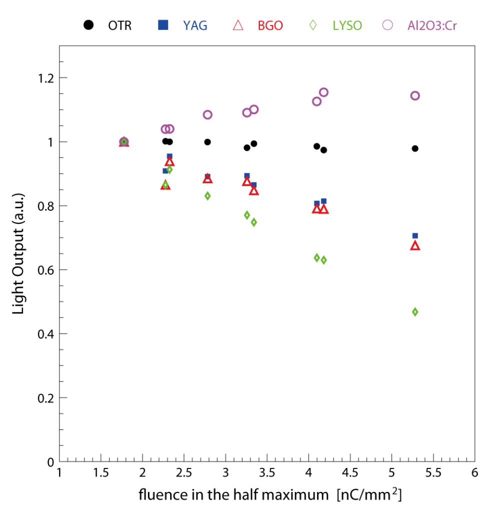

Figure 4: Relative right output, normalized by the most convergent point, and fluence of the beam.

CONCLUSION

In order to investigate the response of the scintillating screen to a high fluence and high energy electron beam, beam tests for scintillating screens, YAG:Ce, BGO, LYSO:Ce and Al_2O_3:Cr, were performed, and quantity of luminescence and beam size were compared with measurement using OTR screen. Those scintillating screens, except for Al_2O_3:Cr, show the saturation of luminescence for the fluence above ~1 nC/mm^2. YAG:Ce and BGO have the same rate of decrease of luminescence with respect to the fluence, and LYSO:Ce has the rate more than twice that of those scintillators. In the case of A_2O_3:Cr, it was found that the quantity of the light output increased with the fluence. The maximum fluence estimated in a region exceeding half maximum in the OTR measurement was ~5.3 nC/mm^2, and beam size was larger than 0.18×0.26 mm^2 (RMS). In this case, YAG, BGO and Al_2O_3:Cr did not show no increase in beam size compared with the OTR, but the measured beamsize with LYSO:Ce was increased by about 20%. We could not clarify the fluence at which saturation began for those scintillators. Thus, more detailed analysis and experiments are required.

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