

RESPONSE OF SCINTILLATING SCREENS TO HIGH CHARGE DENSITY ELECTRON BEAM

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Abstract

Scintillating screen such as YAG is widely used for beam size/profile diagnostics. However, the inorganic scintillator shows light output saturation. That causes a degradation of the diagnostics. However, response of scintillating screens to high current density electron beam is not clear yet. We have evaluated the saturation effect on the beamsize measurement by using a simple model. Beam tests of screens, YAG:Ce, LYSO:Ce, BGO and $\text{Al}_2\text{O}_3:\text{Cr}_2\text{O}_3$, were performed at KEK e+/e- injector linac. Scintillating crystals, YAG, LYSO and BGO, showed similar resolution, but the saturation of the light output was confirmed for those crystals in the charge density of 0.5-9 nC/mm².

INTRODUCTION

Inorganic scintillating screens are very useful tool to measure transverse profile of charged particle beams. The cerium-doped yttrium:aluminum: garnet (YAG:Ce) crystal scintillator is used in many accelerating facilities. The scintillating screen shows good resolution comparable to that of OTR screen [1]. However, response to high charge density electron beam has not been clarified. Saturation of the fluorescence of scintillating screens causes broadening of measured beam size. In case of YAG screen, Murokh *et al.* reported the saturation on YAG:Ce screen for the high brightness ultra-relativistic electron beam [2]. They found that the saturation becomes real at the beam intensities of the order ~ 0.04 pC/mm² for 100 MeV beam. In another report, the saturation was observed when the electron beam charge density exceeds 1.5 nC/mm² [3]. In KEK e+/e- linac [4], the charge density (σ) of the electron beam for SuperKEKB high energy Ring will exceed 25 nC/mm². Thus, beam tests were performed on cerium doped YAG ($\text{Y}_3\text{Al}_5\text{O}_{12}$), LYSO ($\text{Lu}_{1.8}\text{Y}_{0.2}\text{SiO}_5$), and BGO ($\text{Bi}_4\text{Ge}_3\text{O}_{12}$) crystals for 1.5 GeV, 1 nC/bunch electron beam at the linac.

OVERESTIMATION OF THE BEAM SIZE DUE TO SATURATION

The degradation of the beamsize measurement caused by the saturation has been estimated by using a simple model. The saturated distribution $g(x)$ is given by

$$g(x) = r(s)f(x) \quad (1)$$

$$r(s) = \frac{1}{s} \left(\frac{2}{1 + e^{-2s}} - 1 \right) \quad (2)$$

$$s = \frac{f(x)}{f(x=0)} s_0 \quad (3)$$

where $f(x)$ is an original distribution, $r(s)$ is reduction factor due to the saturation which is known as a logistic function, s_0 stands for the strength of the saturation. The Eq. (3) represents decrement of the saturation in the outside of the distribution. The plots in the Fig. 1 (a) show saturated distributions of the Gaussian distribution with $\sigma=1$ for some s_0 . Beam sizes for those distributions are estimated by fitting the Gaussian to the data. In the case of $s_0=1.0$, 25% decrease of the signal at the center is shown. The beamsize is over estimated by 10% although a discrepancy between the distribution and fitted function (green line) is small. Figure 1 (b) shows the degree of the overestimation as a function of the decrement factor at the center for the Gaussian distribution. In actual beam size measurement, it is difficult to estimate the amount of the saturation which leads to more than 10% overestimation of the beamsize.

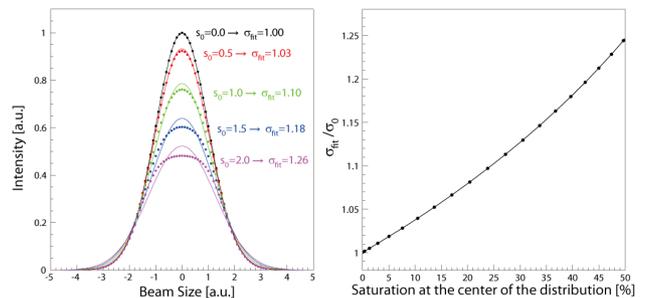


Figure 1: Saturation of the Gaussian distribution (a) and degree of over estimation of the beamsize as a function of the strength of the saturation at the center of the distribution. Solid lines in (a) show the Gaussian distributions fitted to the saturated data.

EXPERIMENT

Scintillating Screens

We have tested three different scintillating crystals and an alumina-ceramic that are listed in Table 1 together with their properties. Those crystals were chosen because they have visible light output enough for the beam profile diagnostics, good radiation hardness and processing char-

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acteristics to make thin flat surface screen (no cleavability). Thickness of those screens is 100 μm . While YAG:Ce and LYSO:Ce show extrinsic luminescence based on Ce, pure BGO has intrinsic one. The saturation is caused by some quenching processes. Those processes depend on luminescence mechanism and properties of material (e.g. Concentration quenching depends on concentration of doped ion). Thus, different response to high current density electron beam is expected.

Table 1: Properties of Scintillators

	τ_{decay} [ns]	λ_{max} [nm]	Relative output (NaI:Tl =100)	Radiation hardness [rad]
YAG:Ce	70	550	35	$>10^6$
LYSO:Ce	41	420	75	$>10^6$
BGO	300	480	21	$>10^{5-6}$
$\text{Al}_2\text{O}_3:\text{Cr}_2\text{O}_3$	$> \text{ms}$	690	Large	High

Experimental Setup

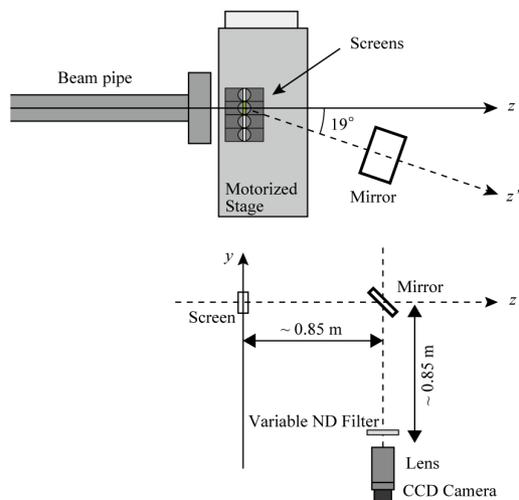


Figure 2: Experimental setup.

The beam profile measurements were performed at the beam dump line of the first straight section of the linac. The experimental setup is shown in Fig. 2. The electron beam was generated by the thermionic gun and accelerated up to 1.5 GeV. Horizontal and vertical normalized emittances of the incident beam were about 50 and 100 mm mrad, respectively. The beam passed through a 30 μm thick stainless steel window. The distance between the window and the screen was 11 mm. The screen at the exit of the window could be moved by using the motorized stage. The beam size spread at the screen due to multiple scattering was estimated to be 3 μm (sigma) by using EGS5 code [5]. This effect is negligible for the experiment. The variable ND filter was used to avoid

saturation of the 12-bit CCD camera. The beam repetition rate was 1 Hz to avoid the effect of the afterglow.

A magnetic quadrupole triplet which was set 9.7 m long upstream was used to focus the beam. After the optimization of the optics to get minimum beamsize at the screen position, the quadrupole scan using the last quadrupole was performed for each screen. The electron beam was stable during the measurement; the beam current variation and position jitter at the screen were less than 0.3% (sigma) and 0.1 mm (RMS), respectively.

RESULT

Figure 3 shows beam profiles taken by 4 different screens. Because the ceramic is formed by sintering that causes diffuse reflection in the screen, the beam profile on the $\text{Al}_2\text{O}_3:\text{Cr}_2\text{O}_3$ is larger than that of scintillating crystal screen. In case of alumina-ceramic, due to a long exposure time (20 ms) for the CCD camera, many white spots exist on the image. The exposure time for other screen was set 10 μs .

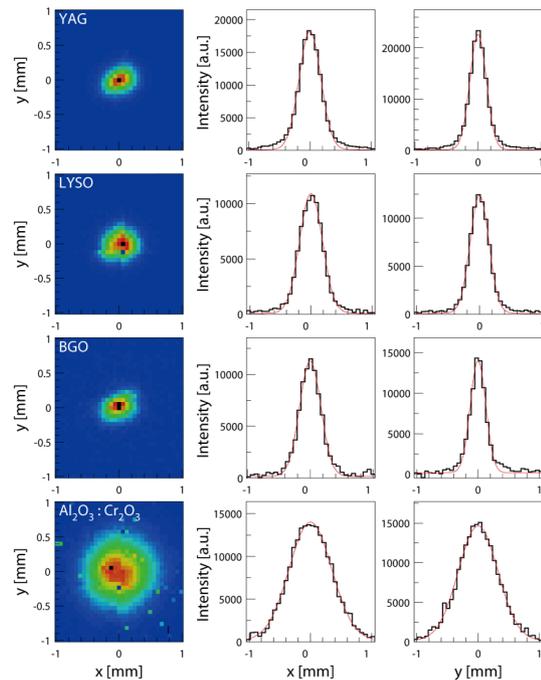


Figure 3: Background corrected beam images and projected beam profiles at 1 nC/bunch beam (single shot) on four different screens. The red line represents a Gaussian fit.

The beam size which is 10 shots average as a function of the quadrupole magnet is shown in Fig. 4. The strength was changed from -14.03 to -13.07 T/m. The alumina-ceramic shows bad resolution as seen in Fig.3 and the shape of the scan curve is different from the others that can arise from the afterglow. Three crystal scintillating screens exhibit same beamsizes except for defocusing step after the bottom of the curve in the left figure. We assume

that the difference is attributed to a difference of the degree of the saturation. The saturation effect seems to remain for a time because beamsize discrepancies were observed in large beamsize area in defocusing step.

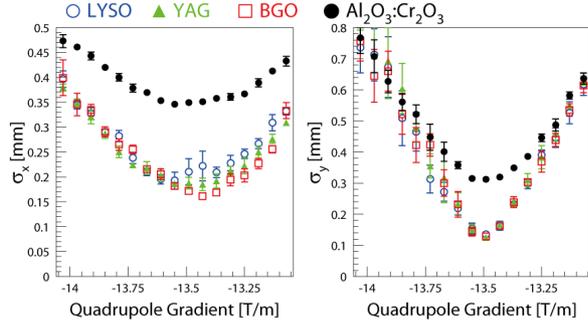


Figure 4: Horizontal and vertical beamsize (10 shots average) as a function of quadrupole strength.

Figure 5 shows relative total light output as a function of the charge density. Because of the beamsize is different on the each screen for the same condition, the size measured by BGO for corresponding quadrupole strength is used to estimate charge density. The charge density is given by $Q_{\text{total}} / (\pi \sigma_x \sigma_y)$ [mm^2]. The relative output should be 1, because the bunch charge was fixed to 1 nC. However, decrements of the light output along with the charge density are shown for all scintillating screens. It suggests that the saturation of luminescence is occurred above 1 nC/mm^2 for those scintillating screens. The saturation on the YAG consists with Ref. [3]. The decrement of the light on the LYSO is much larger than the BGO and the YAG. It could be related to larger beamsize than that of the BGO at the bottom of curve in Fig.4. In this experiment, we used only scintillating screen. Thus, simultaneous measurement using OTR or wire scanner is required to estimate more accurate charge density and amount of overestimation of the beamsize.

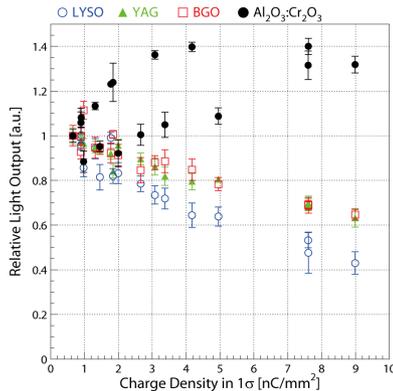


Figure 5: Variation of total light output and charge density at the screen position. The relative light output is normalized by total light output at the quadrupole strength of -14.03 T/m which corresponds to the start point of the quadrupole scan.

SUMMARY AND PROSPECT

We have studied the saturation of the scintillating screens and its influence on the beamsize measurement for the high charge density electron beam. In case of the simple saturation model, more than 10% overestimation of the beamsize can be occurred if above 25% decrease of the signal at the center of the distribution. The beam test of scintillating screens, YAG:Ce, LYSO:Ce and BGO, were performed at KEK e+/e- Linac. Those screens showed same resolution in charge density within a range of 0.5 to 9 nC/mm^2 . However, the saturation was observed on those screens above charge density of 1 nC/mm^2 for 1.5 GeV beam. In order to estimate the quantity of the saturation and its effects accurately, we plan to experiment with OTR.

REFERENCES

- [1] R. Ischebeck, et al, "Transverse profile imager for ultrabright electron beams", *Phys. Rev. ST Accel. Beams*, vol. 18, p. 082802, Aug. 2015.
- [2] A. Murokh, et al, "Limitation on the resolution of YAG:Ce beam profile monitor for high brightness electron beam", in *Proc. 2nd ICFA Advanced Accelerator Workshop*, California, USA, Nov. 1999, pp564-580.
- [3] U. Iriso, G. Benedetti, and F. Perez, "Experience with YAG and OTR screens at ALBA", in *Proc. 9th European Workshop on Beam Diagnostics and Instrumentation for Particle Accelerators (DIPAC09)*, Basel, Switzerland, May, 2009, paper TUPB15, pp. 200-202.
- [4] M. Satoh, et al., "Commissioning status of SuperKEKB injector linac", in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May, 2016, paper THPOY027, pp. 4152-4154.
- [5] EGS5, <http://rcwww.kek.jp/research/egs/egs5.html>