ISBN: 978-3-95450-201-1 doi:10.18429/JACoW-IBIC2018-WEPB04

COMPARISON OF YAG SCREENS AND LYSO SCREENS AT PITZ

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Abstract

The Photo Injector Test facility at DESY in Zeuthen (PITZ) is dedicated to the development of high-brightness electron sources for free-electron lasers. At PITZ, to measure the emittance of space-charge-dominated beams, the slit scan technique is used. For slice emittance measurements a transverse deflecting structure (TDS) is employed. The electron beam distribution is measured by means of scintillator screens. Both the TDS and the slit mask reduce the signal strength, giving stringent requirements on the sensitivity of the screens. At PITZ, high-sensitivity Ce:LYSO screens have been installed at the same screen stations as the standard Ce:YAG screens to solve low-intensity issues. A comparison of both screens is presented.

INTRODUCTION

Scintillator screens are used to measure the beam distribution and position in particle accelerators. At the Photo-Injector Test Facility at DESY in Zeuthen (PITZ) cerium-doped ytterbium aluminium garnet (Ce:YAG) powder is used as standard screen material [1]. However, advanced electron beam diagnostics require precise measurements of the electron distribution with rather low charge density and, therefore, with low signal intensity from the detector.

Measurement of properties like the slice emittance, the longitudinal phase space [2] or the projected emittance of low-charged beams need a significant increase of the signal strength, especially during time-resolved measurements with the transverse deflecting structure (TDS). The TDS, developed by the Institute for Nuclear Research (INR RAS, Moscow, Russia) in collaboration with DESY, only allows to streak up to three consecutive electron bunches [3].

For a correct reconstruction of the beam distribution the screen and imaging system have to have a high homogeneity, a good signal linearity, a high spatial resolution and a high signal-to-noise ratio. In order to perform a cross-check with the existing system, several high-sensitivity cerium-doped lutetium yttrium orthosilicate (Ce:LYSO) screens were installed at the same screen station as Ce:YAG screens. The same TV read-out system was used for the image analysis.

In this paper, both the screen homogeneity and linearity in terms of light production are measured for both Ce:LYSO and Ce:YAG screens. Additionally, the beam size measurement uncertainty caused by screen non-uniformity is simulated.

At PITZ, the electron beam comes in bunch trains with a repetition rate of 10 Hz [4]. The number of electron pulses per train can be increased to up to 600 pulses at 1 µs bunch spacing [5]. For each measurement, ten beam images, i.e. images from ten consecutive bunch trains, and ten background images were taken. The images from the bunch trains were averaged in the postprocessing, after the averaged background was subtracted.

LARGE-SCALE SCREEN HOMOGENEITY

To estimate the screen homogeneity, the electron beam has been steered to nine different positions on the screen. At each beam position, the Ce:YAG and Ce:LYSO screen image was taken. At the screen station the two different screen types were inserted into the beam path and the screen image was taken by one single camera for both screens, i.e. camera gain and imaging from screen to camera was the same. Camera gain and exposure time were kept the same for both screen images. The sum of pixels[1] inside a squared frame with an edge length of 123 pixels around the beam centroid is calculated as measure for the beam intensity. The observation camera has 1024 × 1360 pixels [6]. It was used

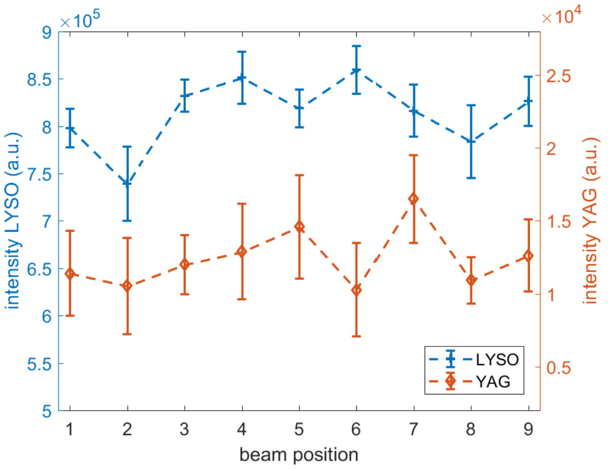

Figure 1: Intensity and rms intensity jitter for Ce:LYSO (blue) and Ce:YAG (orange) screens. The area of interest is square, with an edge length of 123 pixel (of the 512 × 680-wide images) for both screen materials. The AOI is centred around the beam centroid position, i.e. the AOI has a different position at each beam position.

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[1] Sum of pixel fillings inside the area of interest

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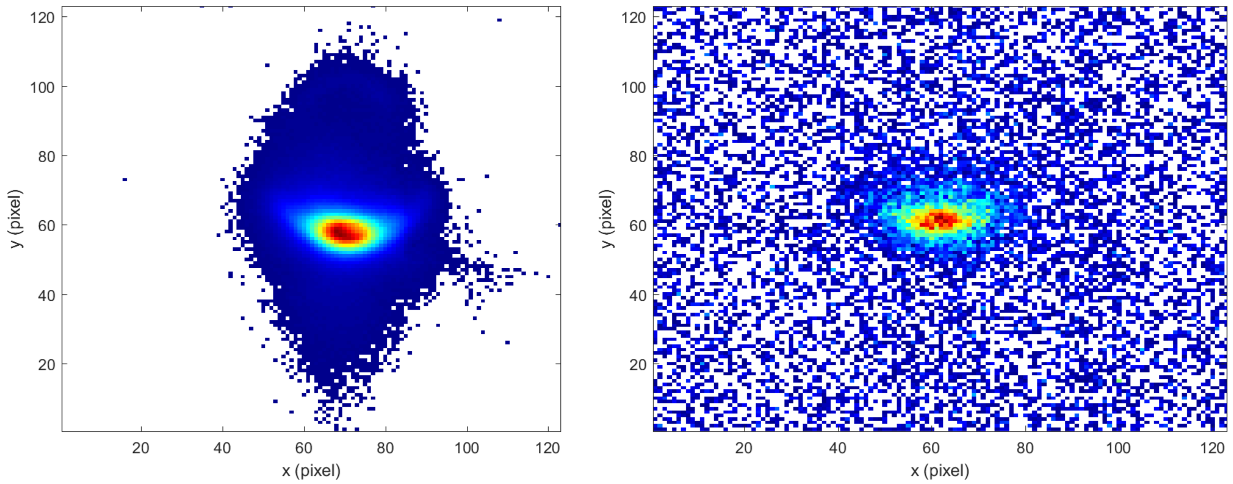

Figure 2: Background-subtracted and averaged beam image at the beam position 3 on the Ce:LYSO screen (left) and the Ce:YAG screen (right). It clearly shows, that the signal-to-noise ratio is higher on the Ce:LYSO screen. The colourmap was set to range from 0 to the maximum value on each screen individually, i.e. negative pixel values are shown white as well.

in a 2×2-binned setting, i.e. the obtained images have a size of 512×680 pixels.

During the measurement the electron momentum was 23 MeV/c and the bunch charge was set to $Q = 30$ pC. Figure 1 shows the measured intensities at nine different beam positions on both screen materials. The beam positions were chosen in a way, that the centroid position differs by ~60 pixels to the previous one, either horizontally or vertically. The averaged intensity from the Ce:LYSO screen is almost 70 times higher than the averaged intensity from the Ce:YAG screen. The error bars show the rms intensity jitter of the ten single images taken at each beam position. Inside the area of interest (AOI) the rms intensity change among the nine locations is 4.3 % for Ce:LYSO screen and 19.8 % for the Ce:YAG screen, indicating a better global uniformity of the Ce:LYSO screen. A direct comparison of beam images on the two screen materials at the same beam position is given in Fig. 2. The image shows the ten-times-averaged screen image, after the averaged background has been subtracted.

LINEARITY WITH BUNCH CHARGE

Additionally to the screen homogeneity, the linearity of the light yield versus the charge was verified. The charge was set by changing the transmission of a variable, optical attenuator of the photocathode laser which generates the electrons. The laser transmission was set to 100 % and was stepwise reduced, yielding bunch charges between 129 pC and 1 pC, measured with a faraday cup. During the measurement, the beam focussing and steering remained unchanged. The electron momentum during the measurement was 19 MeV/c. Figure 3 shows the light intensity on both screen materials. The intensity of both screens shows good linearity with bunch charge density increase, even though the charge is very small compared to the typical bunch charge of $Q = 500$ pC. The linearity was only tested for small charges to avoid signal saturation of the Ce:LYSO screen. Figure 4 shows the charge density for the applied charges. The beams size $\sigma_x \sigma_y$ was calculated for each applied charge at each screen material individually. The error bars shown arise from the uncertainty in the charge measurement.

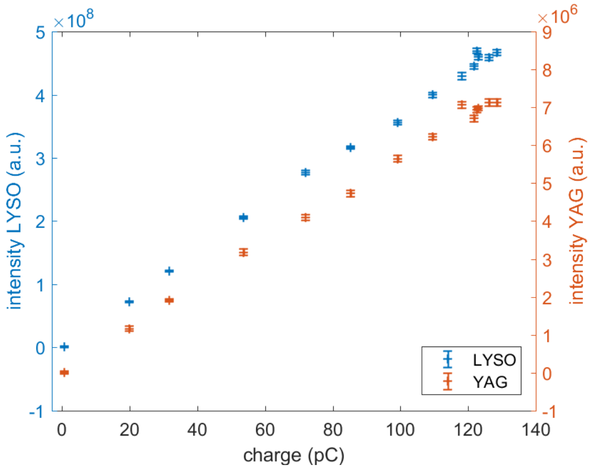

Figure 3: Beam intensity against bunch charge for Ce:LYSO and Ce:YAG screens. Both show a high linearity.

SYSTEMATIC ERRORS FROM SCREEN INHOMOGENEITY

Due to screen inhomogeneity, the rms beam size calculation might be spoiled, depending on the original beam size. To estimate the systematic error arising from screen inhomogeneity, the following simulation was done. A 2D Gaussian beam with an rms width in the range of 3 pixels to 15.5 pixels was used. Pixelwise, a uniformly distributed screen efficiency modulation was added to the uniform screen. The screen efficiency modulation amplitude ranged between 0

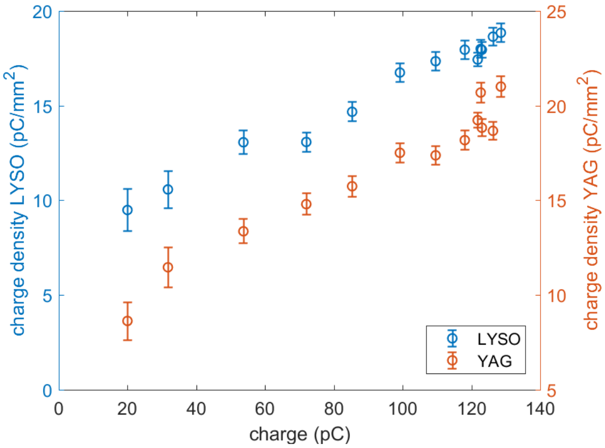

Figure 4: Charge density versus bunch charge. The beam size was calculated from the signal on the Ce:LYSO screen (blue, left axis) and the Ce:YAG screen (orange, right axis).

and 100 %. The obtained image was projected on one axis and the rms size was calculated. This was done 10 000 times for every beam size and each screen modulation amplitude. The standard deviation of the calculated beam sizes, divided by the original beam size, is shown in Fig. 5 for all original beam sizes and noise amplitudes. It shows, that even for the inhomogeneous screens, i.e. the one with more than 80 % modulation of the screen signal from the beam distribution, the beam size uncertainty stays below 2.5 % for the smallest beam sizes, which are only a few pixel wide. In a real experiment beam sizes which are ˜10 pixel or bigger are favourable, to ensure a good resolution of the beam, see Fig. 2. For these conditions the beam size uncertainty drops below 1 %.

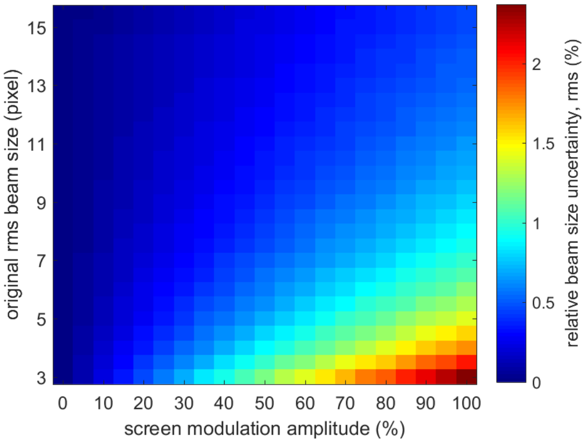

Figure 5: Systematic error in the calculation of the beam size in dependence of the original beam size (vertical axis) and the modulation amplitude of the uniformly distributed noise (horizontal axis). Even for the strongest noise and the smallest considered beam sizes, the uncertainty stays below 2.5 %.

CONCLUSION

The comparison states that the light sensitivity of the newly installed Ce:LYSO screens is significantly higher than the one of the Ce:YAG screens, which are in use at PITZ, by a factor of 70, see Figs. 1 and 3. The Ce:LYSO screens will help solving intensity problems which will arise in measurements of the slice emittance with a slit mask or other low-intensity measurements, in which the beam is distributed on a wide screen area or the bunch charge is small, e.g. during electron diffraction experiments [7]. However, possible degradation of the signal processing due to imaging errors or camera readout errors might worsen the beam distribution reconstruction. Rough estimations of the screen noise shows, that the growth of systematic error due to uncertainty in the beam size calculation is on the order of 2.5 % or below, depending on the original beam sizes, see Fig. 5.

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