COMPARISON OF DIFFERENT RADIATORS USED TO MEASURE THE TRANSVERSE CHARACTERISTICS OF LOW ENERGY ELECTRON BEAMS AT PITZ

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Abstract

The Photo Injector Test facility at DESY, Zeuthen site (PITZ), has been established for developing and optimizing electron sources for linac based Free Electron Lasers (FELs). Characterizations of the beams with maximum energies of about 25 MeV are carried out at PITZ. In order to study properties of the electron beams, several diagnostic systems are applied. An important investigation is the study of transverse beam profiles at different beam conditions. Two screen types - Ce-doped Yttrium Aluminum Garnet (YAG) powder coated and optical transition radiation (OTR) - are used as beam profile monitors and are installed in screen stations at different locations along the beam line. Two wire scanner systems are available for the same purpose. In addition, a chemical vapour deposition (CVD) diamond screen is installed in the screen station prior to a beam dump for testing. In this contribution a comparison of experimental results from all three screen types and the wire scanner will be presented and discussed.

INTRODUCTION

Characterization and optimization of photo injector electron sources to produce electron beams with required parameters for the European X-ray Free Electron Laser (European XFEL) are underway at PITZ. The setup consists of an L-band 1.6 cell normal conducting RF gun with a Cs_2Te photo cathode. The Yb:YAG cathode laser system used at PITZ can generate UV laser pulse trains of up to 800 micro pulses spaced at 1 μs. The beam is post-accelerated by a normal conducting booster cavity located ~3 m downstream of the cathode. Several diagnostic systems are installed in the beam line to study electron beam properties. Details of the PITZ components in the current setup are described in [1, 2] and references therein. To investigate transverse size and profile of the beam, several screen stations equipped with CCD cameras are used. In this study, a YAG powder coated, an OTR, and a CVD-diamond screen are experimentally investigated. For comparison, measurements using a wire scanner were also performed.

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METHODICS AND INSTRUMENTS

In this study, we investigated the properties of radiators using different beam intensities and momenta. The influence of the beam intensity to the performance of the radiators was studied by varying either the number of the laser pulses or the electron bunch charge. Camera gain was varied to cope with saturation of the YAG screen.

YAG Screen

YAG powder coated screens are commonly used at PITZ since they have high sensitivity at low energy electron beams. They are made of a silicon wafer with 5-20 μm of Ce:YAG powder coated on the back side [3]. The screen can be mounted at a 45^o or 90^o angle with respect to the beam axis (Fig. 1). The 90^o geometry was chosen for standard transverse beam profile measurements at PITZ to avoid a depth-of-focus problem. For this geometry, an aluminum coated silicon wafer, placed 45^o at distance "d" downstream, deflects the light to the optical system and the CCD camera.

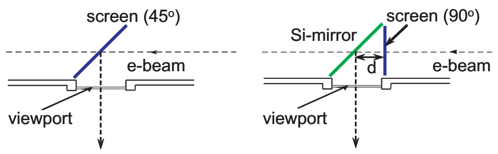

Figure 1: Schematic diagram of 45^o (left) and 90^o (right) mounting geometry of the screen in screen stations at PITZ.

OTR Screen

OTR light is emitted when electrons pass an interface between two media with different dielectric constants. An aluminum coated silicon wafer is used as OTR radiator at PITZ. The screen is tilted by 45^o with respect to the beam direction and backward radiation is emitted perpendicularly to the beam axis (Fig. 1 left). The depth-of-focus effect due to the 45^o orientation has to be considered. Although the OTR screen provides good spatial resolution, it has the limit of light intensity at low beam energies [4]. Calculated angular distribution and relative intensity in Fig. 2 show that the light intensity of the electron energies $\leq$7 MeV is very small. Therefore, the OTR screen is not suitable to be used as a beam profile monitor for electron beams in the low energy section at PITZ.

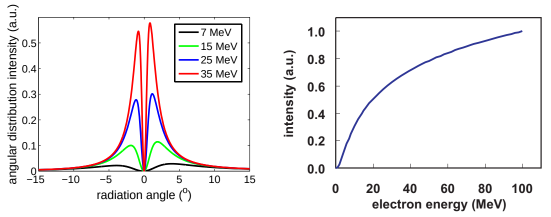

Figure 2: Calculated angular distribution (left) and relative intensity (right) of OTR for different electron energies.

CVD-diamond Screen

A CVD-diamond screen is made by a deposition process using microwave plasma reactors to deposit polycrystalline diamond out of the gas phase. It is radiation hard and has high thermal conductivity. A screen was provided by H. Schulte-Schrepping (HASYLAB) for test purposes and it is installed at the last screen station in the PITZ beam line to investigate the operation with high intensity beams and long pulse trains. A 100-μm CVD-diamond screen is mounted 45^o with respect to the beam direction and the backward radiation is emitted perpendicularly to the beam axis when the electron beam is hitting the screen (Fig. 1 left).

Wire Scanner

Wire scanners are used to measure beam profiles by measuring the bremsstrahlung and secondary electrons produced by the primary beam in the wire material. Two wire scanners utilizing tungsten wire with 20 μm diameter are installed in the current PITZ setup. They can be used to measure the beam projection by moving the wires horizontally or vertically. The step size of the movement can be adjusted [5]; an average step size of 100 μm per second was used in this study.

RESULTS AND DISCUSSIONS

Comparison of YAG and OTR Screen

We compared characteristics of the YAG and the OTR screens at the same screen station, where the mounting geometry of the YAG and the OTR screens are 90^o and 45^o, respectively. In the measurements we observed that the YAG screen has better sensitivity than the OTR for low energy beams. We could measure the OTR light with reasonable intensity when the electron momentum was higher than about 15 MeV/c. Contrary, the YAG screen can be used to measure the beam image with good intensity for electron beam momentum down to a few MeV/c. An example of a beamlet image for 14.7 MeV/c beam measured with the YAG screen is shown in Fig. 3 (a). This beam was created by a vertical slit of 10 μm located 1.76 m upstream of the YAG screen during emittance measurements using a single slit scan technique [1]. An RMS vertical image size of 68 μm and a detail structure as small as 50 μm could be observed. For the same condition, we could not measure this small beamlet with the OTR screen. For increased electron momentum, higher light signal was observed for the OTR screen and the intensity increased by more than a factor of two when the momentum was increased from 15 to 25 MeV/c as shown in Fig. 3 (b).

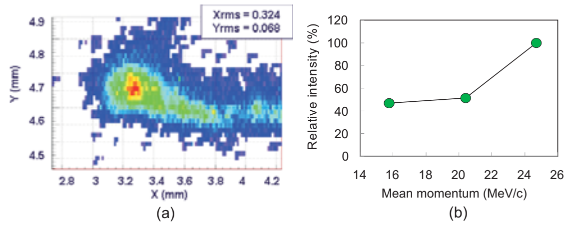

Figure 3: (a) Beam image measured with Ce:YAG coated powder screen at 1.76 m downstream a vertical 10 μm slit position for electron momemtum of 14.7 MeV/c. (b) Measured relative intensity of the OTR light as a function of beam momentum.

Comparison of the beam size measured with the YAG and the OTR screens are shown in Fig. 4. The geometric RMS beam size (σ_{xy}) is defined as $\sigma_{xy} = \sqrt{\sigma_x \sigma_y}$, where σ_x and σ_y are the horizontal and the vertical RMS beam size, respectively. The difference of the distance "d" between the YAG and the OTR screens is corrected by adjusting the path length in the optical system. Investigations of the influence of multiple scattering on the measured beam size due to the thickness of the silicon substrate of the YAG screen using Monte Carlo simulations were performed in [3]. The beam size measured with the YAG screen was reduced by 3% to account for this effect. The difference between the beam sizes measured with the YAG and the OTR screens in Fig. 4 (b) was calculated as 100%$\cdot(\sigma_{YAG} - \sigma_{OTR})/\sigma_{OTR})$. The difference could be due to e.g. the finite gain size and thickness of the YAG powder film or the possible background from the OTR light created by the silicon mirror during the YAG measurements.

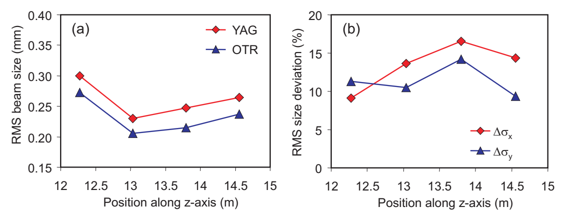

Figure 4: (a) Geometric RMS beam size measured with YAG and OTR screens at different locations. (b) Horizontal and vertical RMS size deviation ($\Delta\sigma_x, \Delta\sigma_y$) between the measurements with YAG and OTR screen. The beam momentum was 24.8 MeV/c and quadrupole fields were applied.

In Fig. 5 (a), the light intensity measured with the YAG and the OTR screens was varied by changing the electron bunch charge with fixed camera gain. This sensitivity test shows that the OTR screen has light output about a factor of 25 less than the YAG screen. The light intensity emitted from both screens increases linearly when the charge increases. Comparison results using the YAG and the OTR screens shows good agreement to the earlier studies in [3, 6].

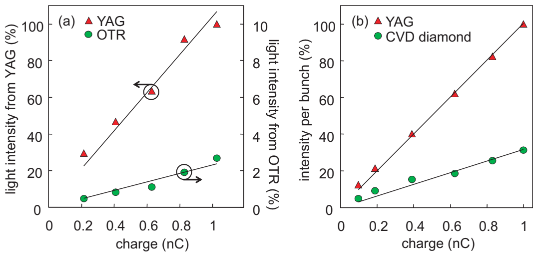

Figure 5: Light output intensity per bunch measured with (a) YAG and OTR screens at 8.4 m downstream of the cathode and (b) YAG and CVD-diamond screens at 19.8 m downstream of the cathode. The beam momentum in these measurements was 24.8 MeV/c.

Comparison of YAG and CVD-diamond Screen

Comparing measurements for the YAG and the CVD-diamond screens were performed at the same screen station with the same mounting geometry of 45^o (Fig. 1 left). The sensitivity test in Fig. 5 (b) shows that the YAG screen provides a light intensity of about 5 times higher than the CVD-diamond screen for each bunch charge. In this measurement, the light intensity per bunch was measured as a function of the bunch charge while the camera gain was held constant. The results show linear dependence of the light intensity on charge for both screen types. Rough estimation shows that the image sizes measured by the CVD-diamond screen is about 36% larger than that measured by the YAG screen. To test the capability of the CVD-diamond screen with high intensity beams, a 24.8 MeV/c beam of 1 nC bunch charge and 100 electron bunches was focused on the screen for a couple of hours. There was no damage observed after the test. However, more tests are required for the operation with longer pulse trains.

Comparison of YAG Screen and Wire Scanner

Beam profiles measured with the YAG screen and beam projections measured with the wire scanner for the bunch charge of 1 nC and momentum of 24.8 MeV/c are shown in Fig. 6. For this measurements, the YAG screen and the wire scanner are at 8.92 and 9.47 m downstream of the cathode, respectively. We observed detailed structures of the beam image in the measured profiles and projections for both detectors. The beam size was then measured at different locations and with different bunch charges using the YAG screens and the wire scanner (Fig. 7). For this study, the beam of 24.8 MeV/c was focused at about 8.4 m downstream of the cathode using the solenoid field. Since there was no any magnetic field applied between these detectors, the beam size should increase linearly. The results show good agreement to the expectation for all bunch charges. We assume that the different slopes from different bunch charges are due to the space-charge effect.

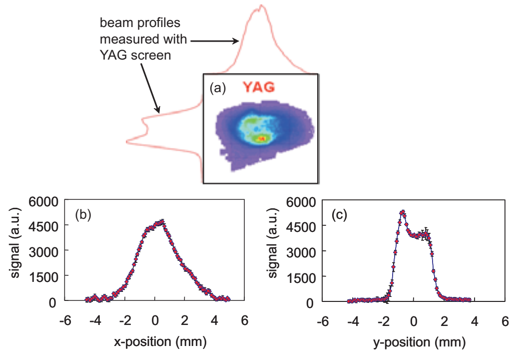

Figure 6: Beam profiles measured with YAG screen (a) and beam projections measured with wire scanner (b and c).

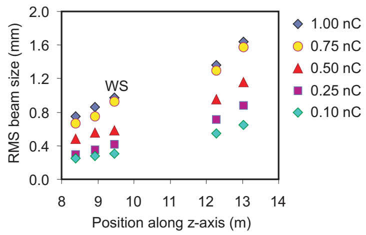

Figure 7: RMS beam size measured with wire scanner (WS) and YAG screens at different positions.

CONCLUSION AND OUTLOOKS

Characteristics of the YAG powder coated, the OTR and the CVD-diamond screens were investigated. The study results show that the output light intensity obtained from all three screen types is linearly proportional to bunch charges and the YAG screen has higher sensitivity than other radiators, especially for low energy beams as we have at PITZ. Although the OTR screen has a better spatial resolution than the YAG, the signal to noise ratio is much lower. Therefore, it is not suitable to be used as an observation screen of the beamlet in the standard emittance measurement at PITZ. The beam size of different bunch charges was measured at different locations using the YAG screens and the wire scanner. The results shows excellent agreement for the beam size evolution along the beam line.

In brief, the YAG screen is useful for beams with low energy and low charge while the OTR screen is more practical for high energy beams and high charge. The CVD-diamond screen can be considered as the radiator for high intensity beam and long pulse trains.

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