OPTICAL TRANSITION RADIATION MEASUREMENTS OF A HIGH INTENSITY LOW ENERGY HOLLOW ELECTRON BEAM ON ELECTRON BEAM TEST FACILITY

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Abstract

Optical Transition Radiation (OTR) is commonly used in imaging systems of highly relativistic charged particle beams as the light yield and collection efficiency increase with beam energy. For low beam energies, scintillating screens are typically preferred but they saturate or even get damaged when using a high beam current. For such a beam, OTR screens can, therefore, still be an attractive diagnostic tool when using thermally resistant materials such as Glassy Carbon. This work presents the OTR-based beam imaging measurements of a high-intensity low energy (7 keV) hollow electron beam at the Electron Beam Test Facility (EBTF) at CERN. The mechanical design of the monitor, as well as the expected OTR angular distribution, are presented. Beam images obtained with an aluminium oxide scintillating screen are also shown and compared to the OTR results.

This contribution presents the design of the monitor and discusses the initial results obtained with a hollow electron beam at the EBTF.

INTRODUCTION

The ever-advancing accelerator technologies are continuously developing new tools to push the current limits of beam intensity, quality, stability and many more. One such tool is a new specialized electron source which generates a high intensity, low energy hollow electron beam which is part of a proposed LHC collimation stage called Hollow Electron Lens (HEL) [1]. HEL aims to magnetically guide a hollow electron beam concentrically around the main LHC beam to tenably increase the diffusion of the halo particles and therefore actively deplete the halo of the beam. The 10 keV hollow electron beam carrying a current of up to 5 A is currently being developed and tested at CERN's Electron Beam Test Facility (EBTF) [2].

Measuring such an electron beam can be a challenge. For very low energies, such as 10 keV, scintillating screens are typically utilised. At those low energies, the electrons will be fully absorbed inside the screen, such that saturating or even damaging the scintillator itself cannot be avoided when using high beam intensity. An Optical Transition Radiation (OTR) screen using thermally resistant material shall provide a good alternative. OTR is commonly used for highly relativistic charged particles due to its increasing light yield and collection efficiency with the beam energy. Nevertheless, OTR can be still an attractive measurement tool for low-energy high-current electron beams. In this proceeding, we showcase the viability of the OTR by measuring the transverse distribution of a hollow electron beam at EBTF.

OPTICAL TRANSITION RADIATION

Optical Transition Radiation [3] is emitted whenever a charged particle crosses the interface between two media with different relative permittivity. Typically first medium is vacuum or air and the second medium is an OTR screen.

The OTR spectral-angular distribution created by a particle with a charge Z propagating in a vacuum and entering a medium with a relative permittivity ϵ is given by the following formula:

$$\frac{dI}{d\Omega d\omega} = \frac{Z^2 e^2 \beta^2 \cot^2\theta |\epsilon - 1|}{4\pi^3 \epsilon_0 c [(1-\beta_x \cos\theta_x)^2 - \beta_z^2 \cos\theta]^2} ||A||^2 \quad (1)$$

where, I is light intensity, Ω a solid angle, ω a wavelength of the emitted light, e the electron charge, $\vec{\beta}$ is the beam's relativistic speed vector, and θ is the photon emission angle. Additionally, $||A||^2$ is a scaling parameter, the complete formula and more details on OTR from low energy particle and different materials is available in [3–7].

This distribution depends on the radiator tilt angle with respect to the particle trajectory, ψ, the material properties and the particle energy. The light emission is typically anisotropic. The theoretical angular distribution created by a single particle with $\beta = 0.195$ striking a smooth glassy carbon screen at $\psi = 0/30/60°$ is presented in Figure 1. It shows two lobes on each side of the particle's axis of motion. At very low energy they become wide and also asymmetrical with a nonzero tilt angle [6, 7].

EXPERIMENTAL SETUP

An OTR imaging system was installed at the EBTF at CERN [2] to measure a high-intensity, low-energy, hollow electron beam, magnetically confined. The measured beam reached up to a 1.6 A in current, and 7 keV in energy. The size of the beam could be varied by tuning the ratio of the

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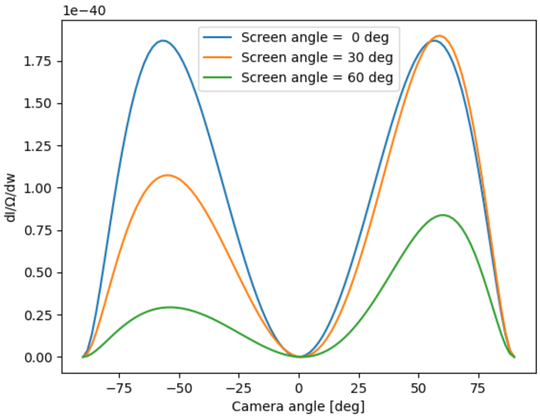

Figure 1: The spectral-angular distribution created by a charged particle with $\beta = 0.195$ enters from vacuum a glassy carbon screen $\psi = 0/30/60^\circ$

magnetic fields at the gun and the transport solenoids. The tested beam sizes were ranging in outer radius between 5 and 10 mm, while the inner radius was half the size. The ratio between the outer and inner radius is given by the cathode dimensions - $R_{out} = 8.05$ mm and $R_{in} = 4.025$ mm.

As depicted in Figure 2 the hollow beam was impinging the OTR screen, glassy carbon, which was installed in a vacuum chamber, at 30° with respect to the beam direction of motion. A double-stage intensified camera, used to increase the sensitivity to the photons and improve resolution, was placed at 90° to the beam, to measure the emitted optical transition radiation.

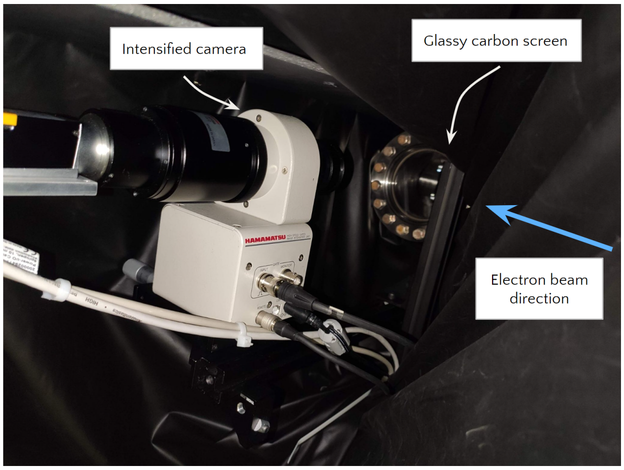

Figure 2: The experimental setup shows an intensified camera observing an OTR screen through a vacuum window.

The images were averaged over 100 beam pulses to increase resolution even further. Examples of raw, screen angle uncorrected, measurement of a single 25 μs beam pulse at 0.1 A and 1.2 A are shown in Figure 3. The 0.1 A was chosen as a lower dynamic range limit of the OTR setup. This was due to a plummeting resolution for lower currents shown in Figure 3 a).

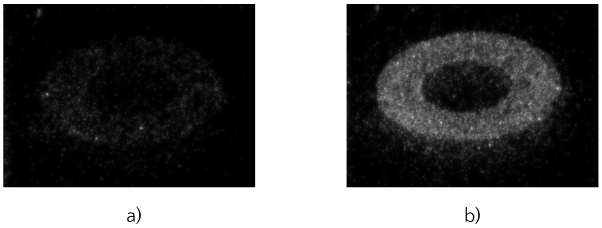
a) b)

Figure 3: A single shot OTR measurement of a 25 μs beam pulse. Beam current: a) 0.1 A, and b) 1.2 A

The OTR screen was installed on a pneumatic actuator which allowed the screen to be inserted and retracted from the beam path. The absolute values of the beam current were measured on the collector with the OTR screen retracted.

MEASUREMENTS AND DISCUSSION

The aim of the experimental campaign was to measure the beam distribution and observe its characteristics. Figure 4 shows a measurement of a 1.2 A beam which is 10.4 mm wide in the outer radius. Overall the position of the beam centre was very stable as it stayed constant within 0.1 mm while changing beam parameters such as the current and size. This can also be said about the repeatability of the beam.

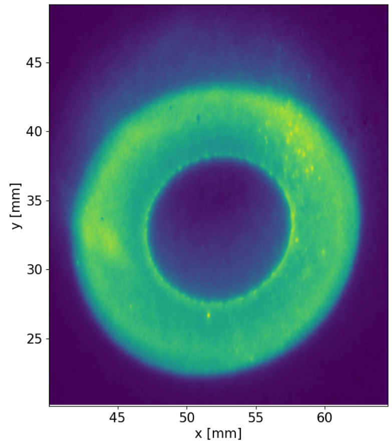

Figure 4: The 2D distribution measured by an intensified camera of an average of 100 7 keV beam pulses 25 μs long, 10.4 mm wide in the outer radius, and 1.2 A of current.

The 2D distribution in Figure 4 shows several characteristics, one being the bright spots in the right top corner of the beam. These are believed to be artefacts of unknown origin in the optical system, as their position did not move while changing the size and position of the beam. The second visible characteristic is the presence of larger, smoother trends of changing intensity (e.g. higher intensity on the left outer edge and lower on the inner edge). This effect is considered to be a property of the beam as it scales and changes with the beam size and current. The trends are developed during the beam transport as they are not measured closer to the electron gun as shown in [2].

All studied beam sizes and currents showed angular distribution homogeneity better than <10%. This is valid for both the whole beam distribution, and the distribution over the innermost 1 mm radius. The angular homogeneity of the inner 1 mm was also studied and found to be as well within the <10% margin.

The second set of measurements aimed at observing the evolution of the transverse profile of the beam during the pulse, as shown in Figure 5. This was possible thanks to precise triggering and the almost instantaneous nature of the transition radiation creation.

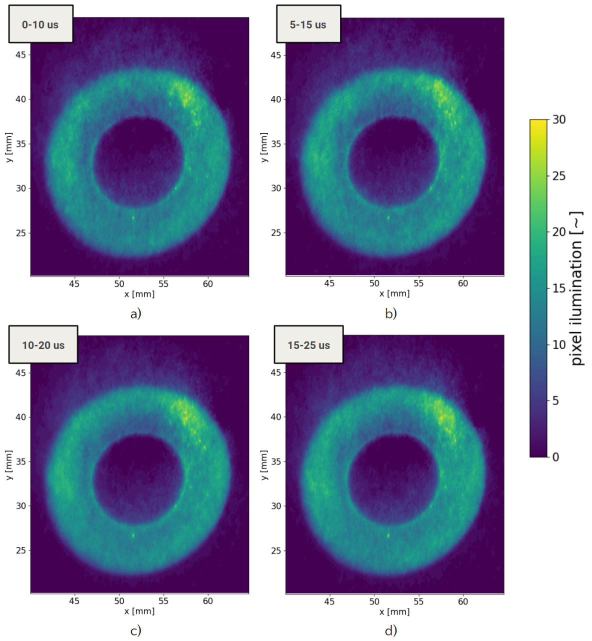

Figure 5: Transverse distribution of a 7 keV beam pulses 25 μs long, 10.4 mm wide in the outer diameter, and 1.2 A of current. Each distribution corresponds to: a) 0-10 μs i.e. head of the beam b) 5-15 μs i.e. first body of the beam c) 10-20 μs i.e. the second body of the beam and d) 15-25 μs i.e. tail of the beam

The transverse distribution was observed to be rather constant during the beam pulse. This makes the beam stable and longitudinally homogeneous. At the same time, there was an increase in the intensity throughout the beam. The head-to-tail increase was usually around 10%.

CHROMOX screen measurements

To complement the OTR dynamic range at low intensities, a chromox (Chromium-doped alumina) screen was also installed at the same position. This scintillation screen has a substantially higher light yield and should withstand the high-intensity low energy electron beam. An example of a 2 mA, 3 μs long beam pulse is shown in Figure 6 a). Unfortunately, only beam pulses of such low intensity and short duration had the expected "ring" shape. Higher beam currents or longer pulse lengths show the presence of a disruptive "tail" as shown in Figure 6 b-c). This effect is still under investigation and might be caused by charge build-up on the screen as chromox is an insulator. The addition of an aluminium coating could prevent this effect and will be tested in the future.

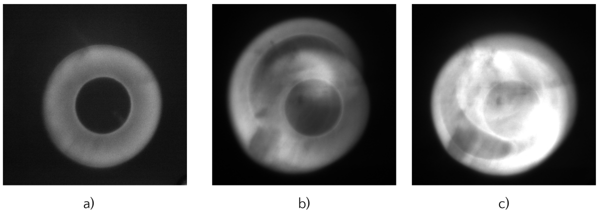

Figure 6: CHROMOX measurements of a 7 keV hollow electron beam: a) 2 mA b) 44 mA c) 87 mA

CONCLUSION

Optical transition radiation was found to be suitable for the purpose of measuring the profile of a 7 keV electron beam of a current up to 1.6 A. The hollow electron beam transverse and longitudinal characteristics were studied at the Electron Beam Test Facility at CERN using OTR.

It was found that the angular homogeneity of the beam is within 10%. Additionally, the evolution of the beam transverse profile during the beam pulse was studied, showing a constant transverse distribution, while the intensity increased by 10% from the head to the tail of the beam.

The measurements were found to be very useful for beam characterization. This was mainly thanks to the ease of setup, the spatial resolution of the images, and the μs-fast temporal resolution which allowed us to study the profile along the pulse. We, therefore, plan to keep such a measurement setup at the EBTF as a permanent installation for future tests and beams.

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