

PERFORMANCE OF PARABOLIC AND DIFFUSIVE OTR SCREENS AT THE CLIC TEST FACILITY 3

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Abstract

At the CLIC Test Facility 3, OTR screens are commonly used in beam imaging systems for energy and energy spread characterization in dedicated spectrometer lines. In these lines the horizontal beam size is typically of the order of one centimeter. Already in 2005 a limitation was observed resulting from a strong dependence of the intensity of the light captured by the camera, on the position on the screen (vignetting). The severity of this effect increases with the electron energy, as the aperture of the optical system is finite and the OTR photons are emitted in a small cone of $1/\gamma$ angle. To mitigate this effect, different shapes and surface polishing of the screens were investigated. Parabolic and diffusive OTR radiators were tested in several spectrometer lines all along the CTF3 complex. The results are presented in this paper.

INTRODUCTION

Optical transition radiation (OTR) has become a popular method of beam imaging, ever since it was first introduced in beam diagnostics applications in the late 70s by Wartski [1]. OTR is emitted when a charged particle meets a boundary between two materials of different dielectric properties. If a conducting foil intercepts a particle's path, a cone of light is emitted, around the specular direction, as the particle enters the foil (backward OTR) and another when it exits the foil (forward OTR), see Figure 1.

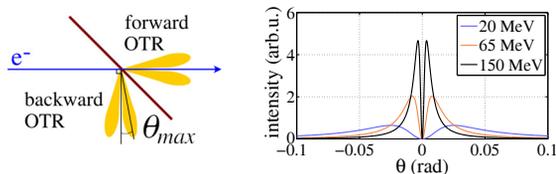


Figure 1: OTR emission at the entrance and exit of a screen, and the corresponding angular distribution around the specular direction

Though, the light yield is generally low, in comparison to e.g. scintillating light, it has other strong advantages for beam imaging, such as perfect linearity to the number of charge crossings (i.e. no risk of saturation) and the possibility of a femtosecond time resolution.

The angular distribution of the OTR intensity, for ultra-relativistic particles, is given by the expression in Equa-

tion 1 [1]. The peak intensity occurs at $\theta_{max} = 1/\gamma$, a peak which is more pronounced for higher particle energies.

$$\frac{d^2I}{d\omega d\Omega} = \frac{q^2}{\pi^2 c} \frac{\theta^2}{(\gamma^{-2} + \theta^2)^2} \quad (1)$$

Figure 1 shows the OTR intensity distribution for an electron at 20 MeV, 65 MeV and 150 MeV, which are typical beam energies at the different spectrometer lines at CTF3.

SPECTROMETER SCREENS AT CTF3

A standard OTR imaging system in the CTF3 [2] spectrometer lines consists of an aluminum screen 150 mm × 50 mm large, 50–200 μm thick, intercepting the beam path at a 45° angle. The backward OTR light is guided to a CCD camera, through an optical line of mirrors, achromatic lenses, and filters for light attenuation. The typical spatial resolution of such system is a few hundred microns, normally determined by the optical magnification of the system and of the image digitizer [3].

Vignetting

The optical aperture of the first lens is generally the limiting factor for the overall acceptance of the system. Unlike e.g. scintillating light, which can be seen as an isotropic light source, OTR is highly directional, as was illustrated by the distribution in Figure 1. This has an undesired consequence that becomes worse with increasing beam energy, illustrated in Figure 2. For low energy particles the light is so divergent that, irrespective of the emission point, some of the light will fall within the optical aperture. For high energy particles, however, the angle of maximum emission becomes smaller, and most of the OTR will be emitted within a small cone, given by Equation 1. Therefore, light generated at the screen center may be completely detected, while light generated further away from the center may escape the image system partially or entirely.

In optics, the term *vignetting* is used to describe the situation where less light is collected from the edges of an optical system. Similarly in this case the amount of light reaching the imaging system (CCD) will depend on where it was generated, which means that large beams at higher energy, as in the case of most of the CTF3 spectrometer screens, will not be imaged properly.

The relative illumination of the CCD camera as a function of emission point at the screen, has been simulated in Zemax [4] for typical CTF3 beam energies. The result lead to a study of how to best reduced this effect [5].

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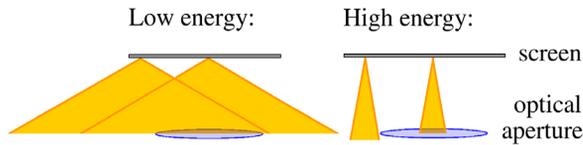


Figure 2: The higher the beam energy, the more pronounced light loss from the edges of the system.

MITIGATION METHODS

To some extent, OTR emission can be seen as a two-step process: *i*) generation and *ii*) reflection from the surface, where *i*) is determined by the dielectric properties of the radiator, and *ii*) is given by the surface reflectivity. Two different methods to mitigate the vignetting effect were tried at CTF3, attacking *ii*) from opposite directions: concentrating the light onto the optical aperture, or an intentional diffusion of the light at the point of emission.

Parabolic Screens

The idea of using a parabolic screen support is to not let any light escape the first lens in the optical line between the radiator and the detector. By choosing a curvature given by $y = x^2/(4f)$, with f being the approximate distance between radiator and the first lens, the emitted light is focused onto the lens. No matter where on the screen the light emanates from, it will have a great chance of reaching the camera. Note that the curvature is modest enough to avoid any significant distortion of the image.

Parabolic screen supports, covered by a 50 – 100 μm thin aluminum foil were installed at three locations at CTF3: one in the CTF3 Linac and two in the CLIC Experimental area (CLEX), see Table 1.

Diffusive Screen

By increasing the diffusivity of the radiator surface the average angular distribution of the total reflected light is increased. This means that the emission becomes almost isotropic and the vignetting effect is reduced. However, this implies an overall light loss, which is why it requires good margins in terms of initial light yield. The high charge beam at CTF3 offers ideal conditions for such measures.

An extensive test of how to best produce screens with a controlled diffusivity was performed in 2007 and is described in [5]. Polished, reflecting surfaces were then intentionally de-polished by various methods, until the reflectivity of the material was significantly reduced. The result of these tests, led to the installation of diffusive aluminum screens at two locations at CTF3: one after the Delay Loop (DL) and one in CLEX, see Table 1.

MEASUREMENT METHOD

In order to quantify the improvement of the new screens, systematic measurements on four screen systems at CTF3

Table 1: OTR Systems for Spectrometry at CTF3

Name	Location	Energy	Type
CLS 0440	Linac	(20 MeV)	flat
CLS 1050	Linac	72 MeV	parabolic
CTS 0840	DL	112 MeV	diffusive
CCS 0980	CLEX	112 MeV	parabolic
CBS 0300	CLEX	120 MeV	diffusive
CMS 0630	CLEX	(150 MeV)	parabolic
CTS 0455	(removed)	105 MeV	flat

have been made. The performance of each screen has been investigated using a dipole scan technique: The beam is moved across the screen by changing the dipole magnet current in small steps and, for each current setting, an image is acquired. Assuming that the beam properties otherwise stay constant, these images can reveal how well the screen reflects the beam profile depending on position.

An example of how the quality of the measurement can vary from one system to the next can be seen in Figure 3. It shows a few horizontal projections from dipole scans on (a) a standard flat screen, formerly in use at CTF3, and b) a diffusive screen. Both the amplitude and the shape of the profile may vary. In order to minimize sensitivity to noise, a Gaussian fit to each individual projection has been made, and by extracting the position, amplitude, and width of the Gaussian, the variation can be quantified.

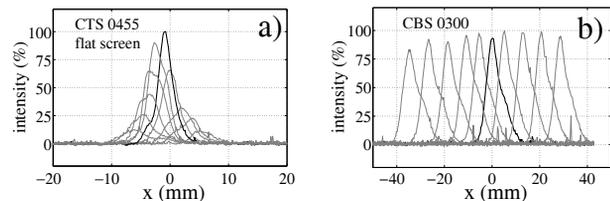


Figure 3: The horizontal projection of screen images for different dipole current settings with a standard flat screen (left) and a diffusive screen (right)

RESULTS

Results from the measurements are displayed in Figure 4. Plots a) and b) show the relative, total, light intensity, detected by the CCD, for different peak positions x . The final effect that this has on the measured beam momentum spread is demonstrated in plot c) and d). Here, the relative deviation from a reference momentum spread is plotted, with a well centered measurement, or, for CCS 0980, the position that gives the maximum intensity, used as a reference. The momentum and momentum spread have been calculated from the magnetic field strength and the dispersion at the position of the screen. For comparison, the plots at the top also contain the corresponding data from a flat, polished screen (CTS 0455 in Table 1).

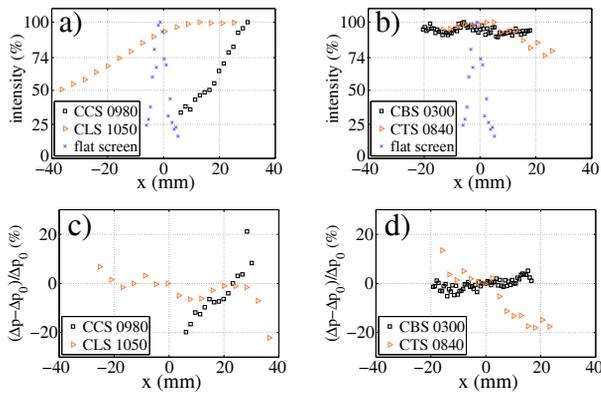


Figure 4: Results from a dipole scan measurement on four screens: two parabolic, plots a) and c); and two diffusive, plots b) and d), with a flat, polished screen. for comparison.

Parabolic Screens

The parabolic screens demonstrate a clear position dependence on the relative integrated intensity seen by the camera, plotted in Figure 4 a). Not only is the relative intensity as low as 30 % at a certain position, but there also seems to be a misalignment of both the parabolic screens. One of the screens, CCS 0980, has its maximum response 30 mm away from the center, and, with the beam centered, an intensity level which is hardly distinguishable. Note, though, that the light loss on the edges is less abrupt than for the standard flat screen.

Also, the energy spread obtained with the parabolic screen CCS 0980 is position dependent, which, once again, indicates that the alignment of the system needs to be looked into. CLS 1050 exhibit a momentum spread measurement good within 10 %, in Figure 4 c). Part of this deviation, but not all, comes from difficulties in making a good fit due to high noise levels.

Diffusive Screens

Both of the diffusive screens in Figure 4 b) give much more promising results: an intensity variation of < 10 % at the very center of the screens, and < 20 % over a horizontal range of ± 20 mm. The improvement from the standard flat screen is remarkable.

The best result is offered by CBS 0300, for which the deviation in energy spread is less than ± 6 % from the reference, in Figure 4 d). The spread measured with the second diffusive screen, CTS 0840, varies with up to 20 %. The origin of the discrepancy in performance may be due to a difference in the optical line or, possibly, a misalignment. Further investigations, including Zemax simulations of the optical lines, will be needed for a full understanding of the differences between the systems.

If a vignetting problem is present, a beam well centered on the screen should appear smaller than it actually is. Another method of characterizing the system performance is therefore a comparison between a single-shot measurement

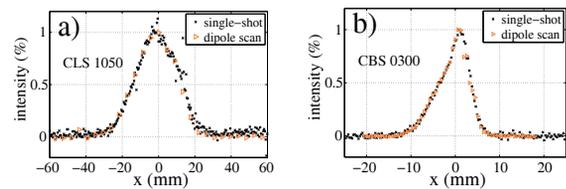


Figure 5: A good agreement between dipole scan and single-shot measurement, both for a parabolic (left) and a diffusive (right) screen.

and a measurement where only a slice of the screen is used for scanning the beam. The intensity on the slice is plotted as a function of equivalent screen position, corresponding to a given dipole current, which is extracted from how the Gaussian peak changes with the dipole current.

Figure 5 b) shows an example of such a comparison done for CBS 0300. The profile obtained from a dipole scan is accurately reproduced with a single-shot measurement. A similar comparison with CTS 0840 and the parabolic CLS 1050, Figure 5 a), give also a good agreement, while the comparison could not be made for the parabolic CCS 0980, due to problems already noted above.

CONCLUSION

OTR screens are indispensable tools in the daily operation of CTF3, in particular for energy spread measurements through spectrometry. Studies of how screen shapes and surface conditions can improve the overall performance of the OTR based diagnostics systems have been performed in connection to CTF3. It has been found that non-linear response of spectrometer screens due to a vignetting effect in lenses can be reduced either by mounting screen foils on parabolic support (for initial focusing of the emitted light) or by making the radiator surface diffusive (intentional increase of light divergence). Measurements show that parabolic screens, although less subject to the vignetting effect previously observed with polished flat screens, are sensitive to misalignment. Diffusive screens, on the other hand, offer excellent mitigation of the vignetting effect. Considering the improvement in performance that diffusive radiators constitute, and how easily they can be manufactured and installed, these should be the primary choice for spectrometer screens, where the beam intensity allows it.

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