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Investigations of OTR Screen Surfaces and Shapes

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Abstract

Optical transition radiation (OTR) has proven to be a flexible and effective tool for measuring a wide range of beam parameters, in particular the beam divergence and the transverse beam profile. It is today an established and widely used diagnostic method providing linear real-time measurements. Measurements in the CLIC Test Facility (CTF3) showed that the performance of the present profile monitors is limited by the optical acceptance of the imaging system. In this paper, two methods to improve the systems' performance are presented and results from measurements are shown. First, the influence of the surface quality of the OTR screen itself is addressed. Several possible screen materials have been tested to which different surface treatment techniques were applied. Results from the measured optical characteristics are given. Second, a parabolic-shaped screen support was investigated with the aim of providing an initial focusing of the emitted radiation and thus to reduce the problem of aperture limitation.

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First, the influence of the surface quality of the OTR screen itself is addressed. Several possible screen materials have been tested to which different surface treatment techniques were applied. Results from the measured optical characteristics are given.

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INTRODUCTION

Optical transition radiation is produced when charged particles pass through media with different dielectric constants. Although its practical application for measuring a wide range of important beam parameters in accelerators was demonstrated a long time ago [1], it took about 10 years until it was finally chosen as one of the standard diagnostic techniques.

If a charge q hits a boundary surface with an oblique incidence, the emitted electric field has two components: One in the plane of observation and the other one perpendicular to it. The total emitted intensity W of a beam with a given relativistic γ therefore has to be calculated as the sum of these two components [1]

$$\frac{d^2W}{d\Omega\, d\omega} = \frac{d^2W_{\parallel}}{d\Omega\, d\omega} + \frac{d^2W_{\perp}}{d\Omega\, d\omega} \approx \frac{q^2}{\pi^2 c}\frac{\theta^2}{\left(\gamma^{-2}+\theta^2\right)^2} \qquad (1)$$

In CTF3, OTR screens are used e.g. for machine optimization, emittance measurements and studies of beam dispersion. With the aim to get a better understanding of the characteristics and in particular the present limitations of the optical systems used in CTF3 and to find possible improvements, systematic measurements and associated simulations were done, testing different OTR screen materials and shapes.

MEASUREMENTS IN CTF3

The light created by the electrons when passing an OTR screen is imaged at CTF3 via a set of achromatic lenses and mirrors on a CCD camera system. In the spectrometer lines, relatively large screens covering an area of 150 mm x 48 mm, mounted at an angle of 45° are typically used. Different screen materials were tested in the past and the problems that are described later in this article arose when going to higher beam energies.

In order to get a deeper understanding of the quality of the optical system and to possibly improve on present limitations, detailed studies with the program ZEMAX were done in the past [2, 3]. The main difference in the characteristics of OTR when using higher beam energies can be found by direct differentiation of equation (1). It turns out that the maxima of the resulting intensity distribution are a function of beam energy and can be found at angles $\theta_{max} = +/- 1/\gamma$.

Calculating the relative illumination on the CCD camera as a function of beam energy, i.e. by using the initial opening angle θ_{max} of the emitted light, yields to a rapid decrease in light intensity when moving across the OTR screen, Fig. 1. Main limiting factor is vignetting in the different lenses.

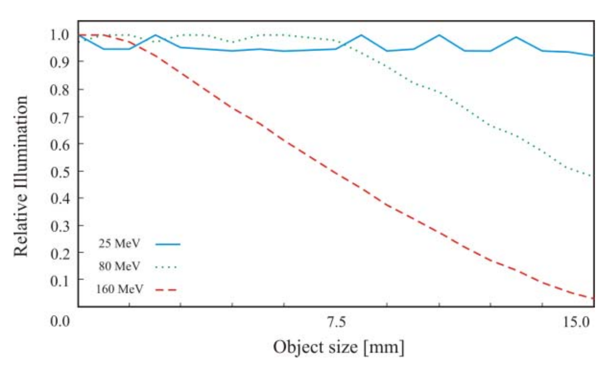

Figure 1: Calculated relative illumination from different OTR screens in CTF3 at beam energies of 25 MeV, 80 MeV and 160 MeV.

Measurements with beam confirmed this behaviour and showed that not only the intensity level is rapidly decreasing towards the screen edges, but – even more important for any later analysis – also the shape of the distribution changes completely, Fig.2.

These effects clearly lead to wrong results and need to be corrected.

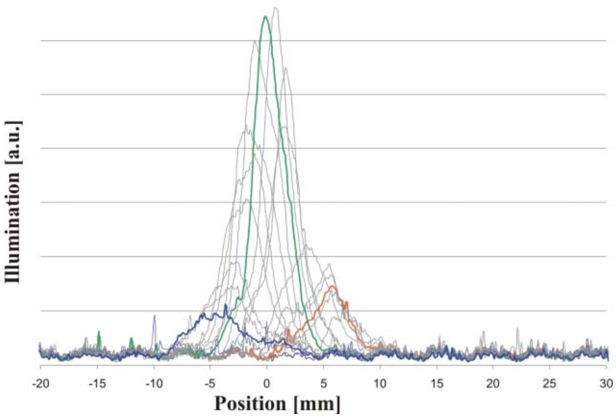

Figure 2: Measured intensity distribution at 100 MeV with a non-diffusive screen.

SCREEN TREATMENTS

To counteract the above mentioned effects, different methods are currently under investigation. Given the fact that the problems are directly related to the small emission angle of the OTR, one approach is to artificially increase the latter by a controlled manipulation of the screen surface.

A variety of different techniques, ranging from etching to rather aggressive sand blasting were applied to several possible screen materials and the resulting light characteristics were determined [3]. It turned out that the initial opening angle is quite sensitive to these treatments and can be changed in a controlled way between a few tenths of a degree up to completely diffusive behaviour. This could be a way to re-generate conditions as they are at lower energies and thus to avoid the above mentioned problems.

Measurements with beam were done at CTF in order to confirm this positive effect. For that purpose a diffusive Aluminium screen was installed at the spectrometer screen MTV0605, where electron beam energies between 95 and 115 MeV are available. This data could directly be compared to earlier measurements done at the same beam energy at spectrometer system MTV0455.

As can be seen in Fig. 3, the change in illumination with the diffusive screen towards the screen edges was smaller by at least a factor of two as compared to the earlier system with a reflective screen. The light level stayed practically constant over a large part of the central screen region and decreased to values below 50 % of the central light level only at the far edge of the screen.

Furthermore, the deviation of the beam width, determined at each of the different positions across the screen, could be practically eliminated, Fig. 4. While deviations up to more than 50 % in comparison to the central reference profile were observed in earlier measurements, this variation stayed below the 5 % level in all measurements with the diffusive screen.

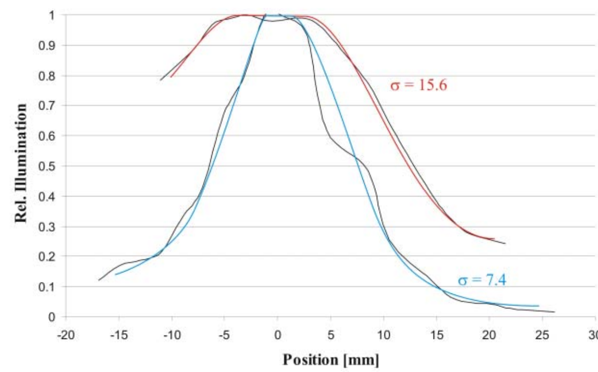

Figure 3: Relative Illumination as a function of the position on the screen for a diffusive (—) and a non-diffusive (—) OTR screen.

Changing the existing screens against diffusive ones thus provides a possible tool to reduce the negative effects observed at higher beam energies enormously. A clear advantage is that all screen supports can be kept unaltered and only the mounted foil needs to be changed, guaranteeing a smooth transition and a low-cost solution of this problem.

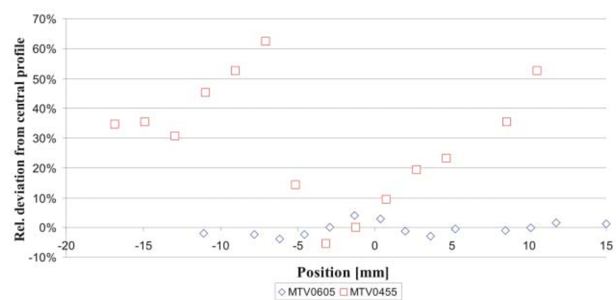

Figure 4: Relative deviation of beam width at different screen positions with respect to average width.

For some applications however, like e.g. the determination of the beam energy or the beam divergence, it is highly desirable to directly measure the opening angle of the OTR light. For these measurements, different techniques need to be applied.

PARABOLIC SCREEN

An alternative approach to limit the vignetting effect caused by the optical system is to use a curved screen instead of a flat one. A parabolic shape $y = x^2 / (4f)$ along the horizontal axis focuses the light in this plane at a distance f. It thus can be used to make sure that no emitted light is vignetted by the first lens of the optical system, typically placed at a distance of ~50 cm.

The resulting energy distribution by frequency ω and observation angle θ can then be calculated by [4]

$$W = \frac{\omega^2 q^2}{4\pi^4 c^3} \left| \int dx\, dy \frac{\omega}{\gamma v} \frac{x}{r} \cos\theta\, K_1\left(\frac{\omega r}{\gamma v}\right) e^{-i \bar{k} \bar{r}} \right|^2 \qquad (2)$$

where γ is the Lorenz factor and v the electron velocity. Any arbitrary surface given by $z(x,y)$ is expressed by the phase factor $k \cdot r = k\left(x \sin\theta + z(x,y)\cos\theta\right)$.

The relative illumination of the camera was greatly improved by the parabolic screen, Fig. 5. It stayed uniform over practically the entire usable surface. Due to the fact that the support was probably installed in the vacuum chamber at an unwanted tilt angle and problems related to the mounting of the foil, only a smaller screen area was used in measurements and local position-dependent changes in illumination were found. The focal length of the parabolic support was *f=500 mm*, what corresponds to the distance to the first lens.

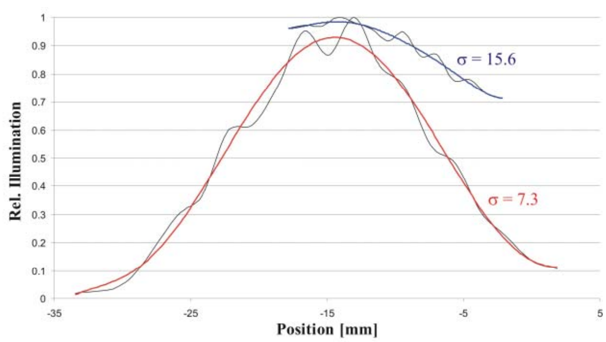

Figure 5: Relative Illumination as a function of the position on the screen for a flat (—) and a parabolic (—) OTR screen.

Already at this lower beam energy measured beam widths changed greatly in the past, Fig. 6. With the parabolic screen the measured beam width at different positions across the screen stayed basically identical to the one obtained in measurements at the screen centre.

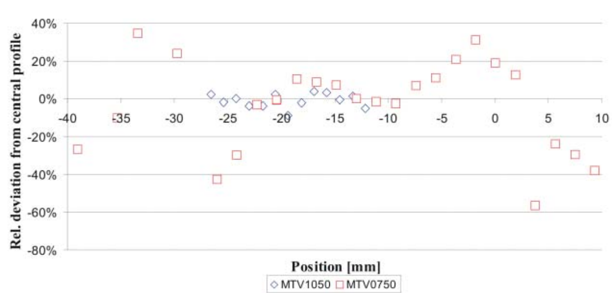

Figure 6: Relative deviation of beam width at different screen positions with respect to average width.

Due to the initial focusing effect of the parabolic surface, the overall light level is higher than in comparable measurements with a flat screen. In addition, the shape of the distribution is basically maintained throughout the scan and thus provides a reliable measurement even at positions far off-centre, Fig. 7. The scanned area corresponds to roughly 20 mm and thus can be directly compared to the data shown in Fig. 2. The improvement in both, the level of light away from the screen centre and the shape of the different distributions, can be clearly seen.

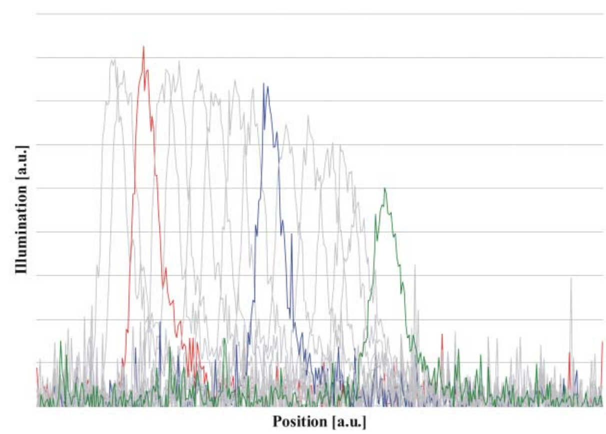

Figure 7: Measured intensity distribution at 100 MeV with a parabolic, non-diffusive screen.

CONCLUSION AND OUTLOOK

Different methods to reduce the vignetting effect observed at high beam energies at CTF3 were investigated. Measurements using a diffusive screen with the aim to increase the initial opening angle of the emitted OTR proved results found in the lab and improved the measurements substantially. The results obtained by using a parabolic support to provide an initial focusing of the emitted light were even better and will probably become the future standard in CTF3 after the encountered problems with screen and foil mounting are solved.

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