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BEAM PROFILE MONITORING USING INCOHERENT CHERENKOV DIFFRACTION RADIATION AND SCINTILLATING SCREENS AT ILSF

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Abstract

The Iranian Light Source Facility (ILSF) plays a crucial role in advancing accelerator science and applications. In this study, we explore innovative techniques for precise beam profile monitoring, focusing on two complementary methods: Incoherent Cherenkov Diffraction Radiation (ChDR) and scintillating screens. Incoherent ChDR occurs when a charged particle passes through a dielectric medium with a velocity exceeding the phase velocity of light in that medium. This phenomenon leads to the emission of electromagnetic radiation in the form of a cone. Our investigation focuses on incoherent ChDR as a powerful tool for beam position diagnostics. By analysing the angular distribution of ChDR photons, we extract valuable information about the transverse position of the electron bunch. Our simulations demonstrate the feasibility of ChDR-based diagnostics at ILSF. We discuss optimal radiator materials, and geometries.

In addition, we examine the use of YAG scintillating screens as beam profile monitors. We present detailed considerations on screen material, thickness, and the optimal orientation of the detection system to ensure high-resolution measurements.

By utilizing both ChDR and radiation from scintillating screens for comparison, we can ensure reliable and accurate beam profile measurements at ILSF.

We believe that our research significantly contributes to the development of robust and efficient beam diagnostics at the storage ring of ILSF.

INTRODUCTION

Beam diagnostics is of prime importance for the effective operation of particle accelerators. Among the various diagnostic techniques available, non-invasive ones are more advantageous as they allow continuous monitoring without disrupting the beam. Since the first observation of incoherent Cherenkov diffraction radiation (ChDR) with 5.3 GeV positrons in a 2 cm long fused silica radiator at Cornell electron-positron storage ring [1], the possibilities of ChDR as a non-destructive beam diagnostics have been extensively investigated [2, 3]. In recent years, coherent and incoherent ChDR have been employed as non-invasive beam length and position monitors in accelerator facilities worldwide [2, 4].

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Table 1: Beam Parameters of ILSF Storage Ring in the Middle of its Straight Sections [5]

Parameter	Value
Beam Energy	3 GeV
Beam Current	100 mA
Horizontal Beam Size (rms)	68.9 μm
Vertical Beam Size (rms)	2.96 μm

SIMULATION RESULTS

Cherenkov Diffraction Radiation [5]

The experimental chamber for this diagnostic will be located in the middle of straight sections of the ILSF storage ring, where the background synchrotron radiation from the bending magnets is reduced. The parameters of the electron beam in the storage ring are listed in Table 1.

In this chamber, the ChDR spectrum emitted from a prismatic dielectric radiator, when the electron beam moves parallel to one of its sides at a distance b, has two polarization components: vertical, which is perpendicular to beam motion, and horizontal, which is parallel to it. The spectral-angular distributions of these two polarization components are discussed in detail in Ref. [6].

The impact parameter, which is the perpendicular distance between the beam's trajectory and a reference point, influences the detected wavelengths of ChDR, as shown in Fig. 1. This wavelength dependence indicates that for a ChDR-based beam position monitor at ILSF, the optical system must account for the impact parameter. Specifically, for a working range in the millimetre region, the optical system should be optimized for optical wavelengths. Furthermore, a ChDR beam halo monitor would benefit from an optical detection system sensitive to shorter wavelengths to suppress signals from the beam's core.

In Fig. 2, the angular distribution of an electron for different wavelengths is plotted. In this figure, the impact parameter is $1mm$, and the index of refraction of the fused silica is 1.46. As it is clear in this figure, the radiation intensity decreases for shorter wavelengths. Additionally, the azimuthal distribution of horizontally polarized radiation for arbitrary θ and $\phi = 0°$ is zero, as evident in Fig. 2(b), due to symmetry of radiation.

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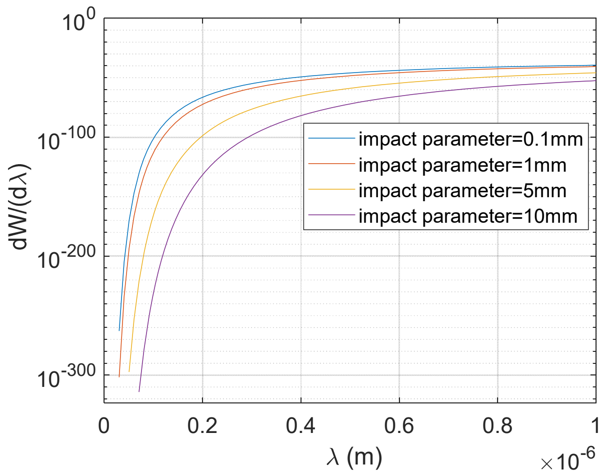

Figure 1: The effect of impact parameter on the ChDR spectral emission of an $3GeV$ electron.

Scintillating Screen

Scintillating screens, are widely used in many particle accelerators. While Optical Transition Radiation (OTR) methods are effective for high-energy beam diagnostics, recent studies have shown that at high energies, coherence effects caused by microbunching instabilities can distort the beam image, rendering OTR-based techniques ineffective [7]. Therefore, at ILSF, scintillating screens will be employed as beam profile monitors to ensure reliable measurements of beam parameters.

YAG scintillating screens can be used to design a beam profile detector at the Iranian Light Source Facility (ILSF). These screens are polished on both sides. Additionally, to prevent charge build up on the surface, a conductive coating of indium tin oxide can be applied. The crystal thickness is selected as $100 - 200\ \mu m$. To achieve better resolution considering the thickness of the scintillating screen, the following two angles (according to Snell-Descartes and Scheimpflug) are carefully determined:

To minimize the effect of the scintillating screen thickness on image resolution (achieving the smallest RMS image radius), the detector is placed at the Snell-Descartes angle:

$$\Theta = -arcsin(n\, sin(\chi))\,, \qquad (1)$$

in which, Θ is the observation angle, χ is the angle between the screen's normal and the electron beam, and n is the index of refraction of the crystal.

The angle χ, according to this relation can range from 0 to $arcsin(1/n)$. As χ increases, the field of view expands, leading to a decrease in resolution. Since high-resolution imaging is required, χ is chosen to be small, around $|\chi| = 8°$, so the detector should be at observation angle of $|\Theta| = 15°$.

In addition to accurately determining the detector angle for each beam angle, the detector angle must be set at a specific value to form the best image. According to the Scheimpflug principle, i.e., $arctan(tan(\Theta/M))$, the angle between the photons emitted towards the detector and the normal to the detector depends on the lens magnification (M). According to this criterion, the detector should be tilted about 14° relative to the optical axis.

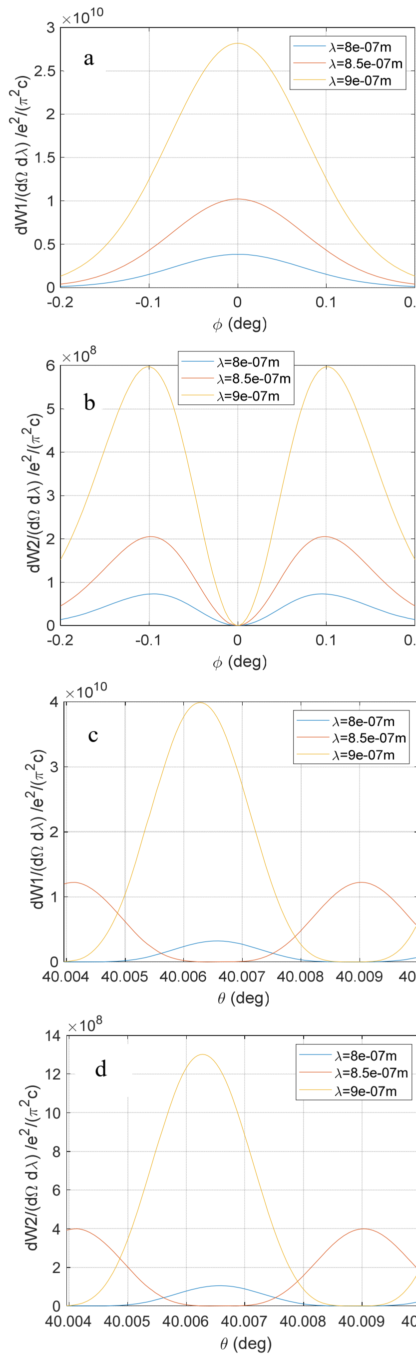

Figure 2: Angular distribution produced by 3GeV electrons in deferent λs. Azimuthal distributions of vertically(a) and horizontally (b) polarized radiation, and, polar distributions of vertically (c) and horizontally (d) polarized radiation.

For imaging, a macro lens with a focal length of f = 200 mm and a CCD or CMOS detector can be used.

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CONCLUSION

In this study, we have explored two complementary techniques – ChDR and scintillating screens – for beam profile monitoring at ILSF. Our investigation into ChDR highlights its potential as a non-invasive diagnostic tool for beam position monitoring. By analysing the spectral-angular distribution of emitted ChDR, we have demonstrated its sensitivity to the impact parameter, providing valuable insights into optimizing the optical detection system for precise beam position measurements.

In addition, the implementation of YAG scintillating screens at ILSF ensures reliable and accurate beam profile measurements, especially in high-energy environments where OTR techniques may fail due to coherence effects. Although the resolution of this approach is smaller than ChDR, the precise determination of detector angles using the Snell-Descartes and Scheimpflug principles, combined with an optimized imaging system, enhances spatial resolution and image quality.

Future work will focus on experimental validation and further optimization of these techniques to meet the evolving demands of beam diagnostics in ILSF synchrotron facility.

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