LONGITUDINAL BEAM PROFILE MEASUREMENTS AT CTF3 USING COHERENT DIFFRACTION RADIATION

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Abstract

The diagnostics of a 6D phase space distribution is a crucial and challenging task, which is required for modern and future installations such as next generation light sources or linear colliders (CLIC). The longitudinal profile is one of the parameters which needs to be monitored. A setup for the investigation of coherent diffraction radiation (CDR) from a conducting screen as a tool for non-invasive longitudinal electron beam profile diagnostics has been designed and installed in the combiner ring measurement (CRM) line of the CLIC Test Facility (CTF3, CERN). This setup also allows the measurements of coherent synchrotron radiation (CSR) from the last bending magnet. In this report we present the status of the experiment and show some preliminary results on coherent synchrotron radiation and coherent diffraction radiation studies. The plans for interferometric measurements of coherent radiation are also presented.

INTRODUCTION

Diffraction radiation (DR) has been theoretically studied for over 40 years [1] with the first measurements performed around 15 years ago [2]. With the development of XFEL and e^+e^--colliders, DR as a tool for non-invasive beam profile measurements has become very popular over the last few years [3, 4]. DR appears when a charged particle moves in the vicinity of a target with impact parameter (the shortest distance between the target and the beam) $h \leq \frac{\gamma\lambda}{2\pi}$, where γ is the particle Lorentz factor and λ the observation wavelength. It can be used for both transverse and longitudinal parameter monitoring of an electron/positron beam.

The optimal performance of the CLIC RF power source is based on the performances of a high current electron beam, the drive beam, which generates RF power by being decelerated in Power extraction and transfer structures (PETS) [5]. Its longitudinal beam profile must be controlled precisely and adequately all along the machine. The bunches must be stretched before injection into the combiner rings in order to minimize emittance dilution due to CSR and have to be compressed afterwards in order to maximise the efficiency of the RF power production.

EXPERIMENTAL SETUP

The CDR setup is installed in CTF3 [6]. CTF3, as seen in Fig. 1, consists of a linac producing a 125 MeV electron beam. During CDR running the electron beam had a train

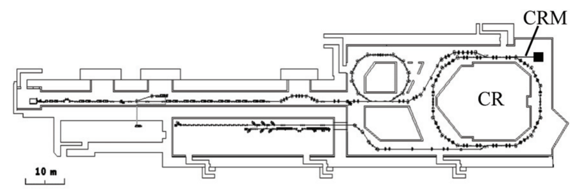

Figure 1: Schematic view of CTF3 with the combiner ring (CR) located at the right.

length of 100 ns to 200 ns, a bunch sequence frequency of 3 GHz, and a nominal current of 3.5 A. For the CDR setup, the delay loop (DL) after the linac is bypassed and the beam is injected into the combiner ring (CR). After the first bending magnet in the combiner ring, an extended straight section can be found, which is the CRM line. A schematic layout of the CRM line with a section of the CR can be seen in Fig. 2. Two ultra-high vacuum (UHV) six-way crosses are

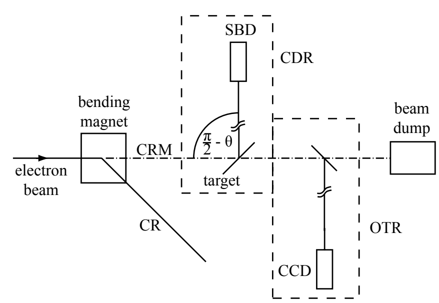

Figure 2: Initial CDR setup in the CRM line

installed along the CRM line. The downstream cross contains the aluminum coated silicon target, which is attached to an UHV 4D manipulator. The target with dimensions of 60 mm × 40 mm is placed to one side of the beam with impact parameter h. The manipulator is mounted on top of the cross and provides precise remote control over the vertical target translation and horizontal rotation.

The opening facing the ground is sealed with a blank flange, while the horizontal openings of the cross perpendicular to the beam line are equipped with UHV windows. The vacuum window through which the radiation is de-

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tected is a quartz fused silica vacuum window, while the adjacent viewport is a standard Kodial window and only used for alignment purposes. The upstream cross is equipped with a vacuum ion pump at the moment. As it only plays an important role in a future upgrade, it is not explained here in detail.

The radiation originating from the target is translated vertically with a periscope to avoid backgrounds from the horizontal particle beam plane. It is then detected with an ultra fast Schottky barrier diode (SBD) detector (response time around 250 ps) mounted on an optical table. The detector used at the moment is sensitive in a wavelength region from 2.14 mm to 3.33 mm (90 - 140 GHz). An example signal of DR is shown in Fig. 3. It can be seen that for a fairly constant beam current the DR intensity varies significantly. It suggests that the longitudinal electron distribution throughout the train is non-uniform.

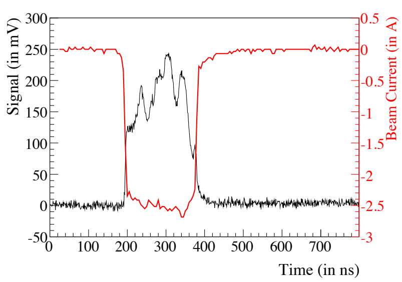

Figure 3: Example CDR signal with corresponding beam current reading from a nearby BPM

With the CDR setup in the CRM line, diffraction and synchrotron radiation (SR) can be measured. With the bending magnet turned on and the electron beam circulating in the combiner ring, SR can be observed. The target is therefore lowered and used as a mirror to direct SR into the detector. For DR measurements the magnet is simply turned off. After the CDR setup and the OTR screen, the beam is terminated in the CRM beam dump.

PRELIMINARY RESULTS

DR is emitted in a backward and forward direction. The backward component is emitted in a specular reflection from the target with respect to the electron beam, while the forward component is emitted along the particle beam axis [1]. The backward direction is the most interesting component as the background signal is kept to a minimum.

In order to perform the measurement the target is kept at an angle of around $45°$ with respect to the incident particle beam, i.e. $\theta = 0°$ in Fig. 2, which hence provides an observation perpendicular to the electron beam.

The spatial distribution of DR from a rectangular conducting screen is a lobe with azimuthal symmetry. The vertical polarisation component is a simple lobe as well, while the horizontal component has two horizontally spaced lobes with a minimum in the center and horizontal symmetry.

Using the polarisation sensitive SBD detector and selecting the horizontal polarisation component a 2-dimensional scan over the vertical target translation and target rotation was performed. For each point of the scan, the raw signal of 10 shots was averaged over the train length and the arithmetic mean over the 10 shots was found. The arithmetic mean was then plotted in a contour plot. Such a 2D

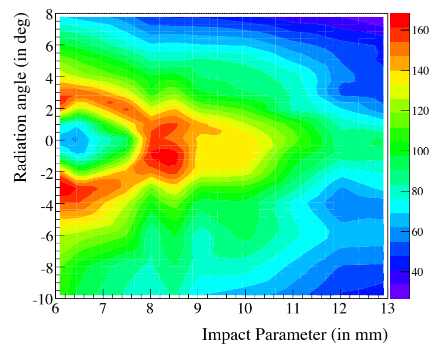

Figure 4: 2D scan of the horizontal polarisation component intensity (in mV) of the CDR spatial distribution

scan of DR can be seen in Fig. 4. Where the zero impact parameter corresponds to the target edge being at the center of the electron beam.

For the target as close to the beam as possible the plot shows a rotational symmetry around the specular reflection direction ($\theta = 0°$). However, there is still some asymmetry in the distribution and some ambiguities as to why there is an intensity maximum in the center of the distribution. There are some indications that this might be due to some background caused further upstream (CSR, wake fields etc.). Investigations about these obscurities are still ongoing and will be presented at a later stage.

Similar to DR, SR manifests itself in two polarisation components. These two components are opposite to those of DR, i.e. the horizontal polarisation component is a simple lobe, while the vertical component has two vertically spaced lobes [7]. Performing a 2D scan with the bending magnet in the CR turned on and again measuring the horizontal polarisation component, a SR distribution was obtained. This distribution is shown in Fig. 5.

As one would expect for SR, a central maximum in the distribution was measured which monotonically decreases for increasing vertical position. The distribution is not centered around the specular reflection direction but has a slight offset. This can be explained by a horizontal offset of the electron beam in the bending magnet and the distance to the CDR setup from there. However, there are some ambiguities when the target is fully inserted in the beam line and some distortion of the distribution occurs.

INTERFEROMETRIC MEASUREMENTS

This section outlines the plan for interferometric measurements and the upgrade of the system at CTF3.

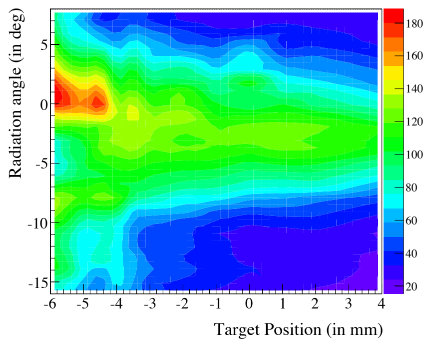

Figure 5: 2D scan of the horizontal polarisation component intensity (in mV) of CSR spatial distribution.

In order to reconstruct the longitudinal electron beam profile at CTF3, the coherent diffraction radiation spectrum has to be measured. This spectrum contains information about the longitudinal electron distribution. The relationship is as follows:

$$S(\omega) = [N_e + N_e (N_e - 1) F(\omega)] S_e(\omega) \quad (1)$$

where $S(\omega)$ is the signal at the detector, N_e is the number of electrons in the bunch, $S_e(\omega)$ is the single electron radiation spectrum, and $F(\omega)$ is the longitudinal form factor, which is a Fourier transform of the longitudinal particle distribution in a bunch. The first summand in the square brackets is the incoherent part while the second summand is the coherent part.

From Eq. 1, the longitudinal form factor of the bunch can be found. Subsequently, the longitudinal beam profile can be reconstructed using Kramers-Kronig relation [8] when a good knowledge of the detector signal $S(\omega)$ over a broad spectrum is obtained, and the bunch charge N_e and the single electron radiation spectrum $S_e(\omega)$ are known.

The single electron radiation spectrum $S_e(\omega)$ for the case of the CDR setup at CFT3 can be determined quite accurately by simulation studies [9]. In order to measure the convoluted diffraction radiation spectrum from the particle beam, i.e. $S(\omega)$, and the bunch charge N_e, the system as outlined in Fig. 2 is updated accordingly.

This upgraded version is shown in Fig. 6. In addition to the initial system it now comprises a Michelson interferometer and a more advanced charge reading in the OTR optical line. With the Michelson interferometer the convoluted diffraction radiation spectrum $S(\omega)$ can easily be determined by performing simple Fourier analysis.

For the charge reading, a beam splitter was introduced in the OTR optical line just in front of the CCD camera. The transmitted light will be observed by the CCD camera as before. The reflected light will be focused by a lens and detected by a fast photo diode, to collect the integrated OTR light emitted by the bunches along the train. Since the bunches are emitting incoherent OTR, this provides a reading which is linearly proportional to the bunch charge N_e throughout the train.

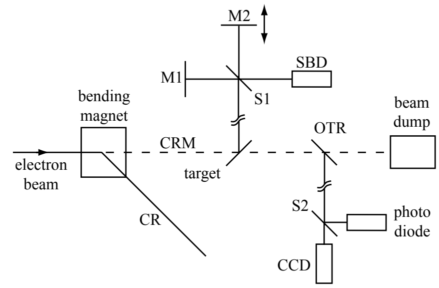

Figure 6: Upgraded CDR setup in the CRM line. A Michelson interferometer, consisting of a beam splitter S1, a fixed and movable mirror, M1 and M2, and a Schottky barrier diode (SBD) detector is installed. Along the OTR optical line a beam splitter S2 is installed, providing a simultaneous beam position and charge reading with the CCD camera and photo diode, respectively.

CONCLUSION AND OUTLOOK

A functioning system for the detection of diffraction radiation, and synchrotron radiation as a byproduct, has been installed in the CRM line at CTF3. The working order of the system is confirmed by initial measurements as shown in Fig. 4 and Fig. 5. The initial measurements with an ultrafast SBD detector suggest that the bunch length is nonuniform throughout the train.

For future interferometric measurement of diffraction radiation the system is now equipped with a Michelson interferometer and a fast charge reading capability. The first interferometric measurements of the CDR spectrum are planned to be conducted in the near future.

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