COHERENT DIFFRACTION RADIATION LONGITUDINAL BEAM PROFILE MONITOR FOR CTF3

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Abstract

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). In this report the status of the monitor development and results on the interferometric measurements of CDR spectra are presented. The CDR signal correlation with an RF pickup and a streak camera is reported. The future plans for the system improvements are also discussed.

INTRODUCTION

The longitudinal electron beam profile is one of many parameters that need to be monitored in particle accelerators. The optimisation and control of the longitudinal electron distribution in the bunch is crucial for the maximisation of the luminosity of future linear colliders. The longitudinal profile will not only be an important parameter for the Compact Linear Collier (CLIC) main beam, but also for the CLIC drive beam. For an optimal performance of the CLIC drive beam, the longitudinal beam profile must be controlled after it has been stretched for injection into the combiner rings and after it has been extracted and compressed. The power extraction in the so-called Power Extraction and Transfer Structures (PETS) also depends on the longitudinal beam profile, a good knowledge of which is highly desirable.

Coherent radiation, which is proportional to the squared number of electrons, is a widely used tool for monitoring the longitudinal bunch profile. The spectral distribution of the coherent radiation contains information about the electron distribution in the bunch [1, 2]. Coherent Diffraction Radiation (CDR) was suggested as a mechanism for coherent radiation generation due to its non-invasive nature [3, 4] and is utilised in this experiment.

SETUP AT CTF3

The location of the CRM line within CTF3 and a general layout of CTF3 is shown in Fig. 1. Specially designed vacuum hardware allows for an aluminised silicon wafer with dimensions of 60×40×0.3 mm to be translated and rotated with respect to the e^- beam. A 45° angle between the e^- beam and the DR radiator results in the emission of backward DR at a 90° angle with respect to the beam. Along this mirror reflection direction the optical equipment for the detection of CDR is installed. The optical equipment consists of an interferometer with broadband aluminised 4 inch mirrors and a 50 μm Kapton beam splitter for millimetre radiation. The mirror on the delay leg of the interferometer is moved by a linear stage with a 100 mm travel range and a resolution of 0.3 μm. The radiation is detected with Schottky barrier diode detectors of different frequency bands with a typical response time of 250 ps (FWHM). A more detailed description of the CDR setup at CTF3 can be found in [5].

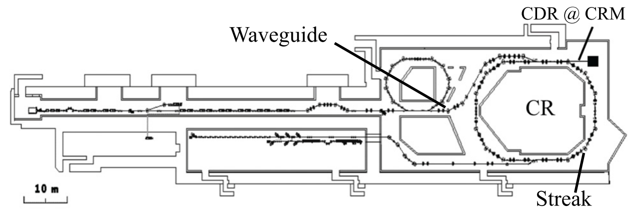

Figure 1: Schematic view of CTF3 with the combiner ring (CR) located at the right.

RESULTS

Interferometric Measurements of CDR

In order to record an interferogram, the DR signal along the electron train for every single pulse is recorded for a specific optical path difference. Once the desired number of readings for each optical path difference has been acquired, the delay line mirror is moved and data for the next path difference is taken. When analysing the data, only a small time slice along the train is used to obtain an interferogram since the bunch length varies quite significantly along the train, as discussed in the next section. An interferogram measured with a Schottky barrier diode with a spectral response of 60 - 90 GHz is shown in Fig. 2(a). The signal was integrated over a small time window of 20 ns in the region of interest. The resulting spectrum obtained from the Fourier transform of the interferogram can be seen in Fig. 2(b) and agrees well with the spectral response of the detector.

However, it has to be mentioned that the travel range of the linear stage and the increment of the optical path dif-

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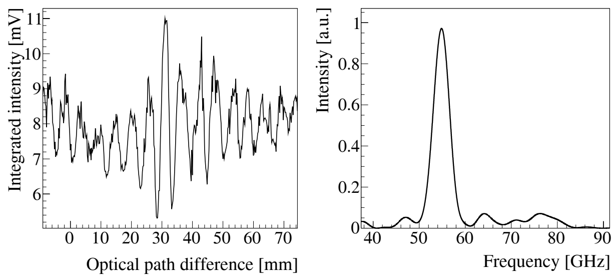


(a) CDR interferogram (b) Resulting spectrum

Figure 2: Example DR interferogram and corresponding spectrum

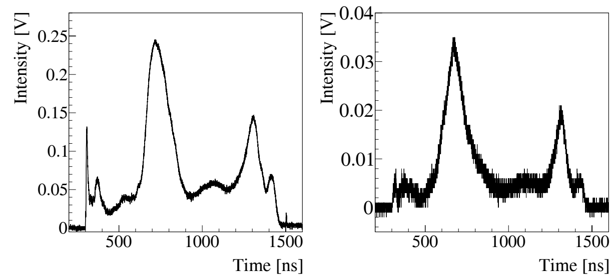
ference set constraints on the resolution and maximum frequency of the spectrum one can achieve. The theoretical resolution for the spectrum is $\Delta f = 1/T$. With the given optical path difference of the interferogram $d = 83.5$ mm, i.e. $T = 278$ ps, the best resolution would be $\Delta f = 3.6$ GHz. For the Schottky barrier diode used for this measurement one would only be able to obtain a maximum of 8 points within the given frequency band.

In order to achieve a better spectral resolution, the travel range would have to be extended. The maximum travel limit of the stage currently installed would allow for a best possible resolution of 1.5 GHz, yielding 20 points for the specified frequency band. However, for a 0.8 Hz beam repetition rate, a scan over the entire travel distance with a similar step size – to avoid statistical fluctuations – would be far too time consuming and one could potentially be subjected to a beam parameter drift of the machine.

Relative Bunch Length Measurements

Besides the CDR interferometric measurements, the setup also allows to measure the intra-train bunch length variation. For a fairly constant bunch charge along the train, as in CTF3, any variation of the signal throughout the train corresponds to a longitudinal beam profile variation. An additional linear stage is installed just in front of the primary detector which allows for an additional detector to be utilised by introducing an optional 90° bend with a mirror.

In this measurement two Schottky barrier diodes were used with a spectral response of 60 - 90 GHz (DXP-12) and 90 - 140 GHz (DXP-08), respectively. The acquisition was performed within a short period of time to take a measurement with the same beam conditions. The two CDR signals along the 1.3 µs long train are shown in Fig. 3. The overall shape of the signal for both the DXP-12 and the DXP-08 indicates a significant longitudinal beam profile variation along the electron train. Due to the spectral response of the DXP-12 and DXP-08 the detail of how this beam profile variation manifests itself in the signal is slightly different. The DXP-12 is able to monitor longer bunches since it is able to detect coherent radiation in the lower frequency band, whereas the DXP-08 is not capable of measuring

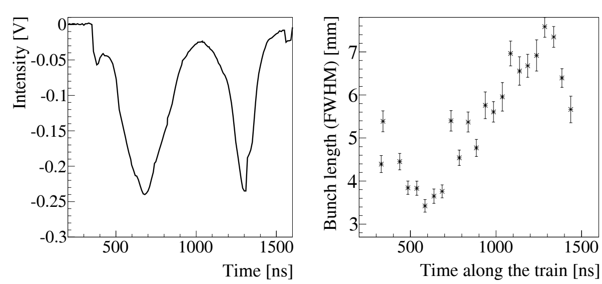


(a) 60 - 90 GHz (DXP-12) (b) 90 - 140 GHz (DXP-08)

Figure 3: CDR intensity along the 1.3 µs long train in the CRM line with two Schottky barrier diodes at two different frequencies

those low frequencies.

Additionally, in order to determine the consistency and proper functioning of the CDR setup, measurements on other systems throughout the machine close to the CDR setup were carried out at the same time. With the bending magnet at the beginning of the CRM line in the Combiner Ring turned on, a streak camera measurement can be performed in the second 90° arc of the ring. Moreover, in the Transfer Line towards the Combiner Ring a waveguide pickup is installed. This pickup is detecting radiation in the spectral range of 26.5 - 40 GHz. The longitudinal profile is expected to stay nearly unchanged throughout this region in the machine providing a good comparison between the different measurements. Therefore streak camera measurements at various times along the train and the waveguide



(a) Waveguide pickup at 26.5-40 GHz (b) Streak camera bunch length

Figure 4: Waveguide pickup upstream of the CDR setup and streak camera

pickup offer a possibility to check for consistency between the CDR setup and other measurement techniques at CTF3. A waveguide signal and the streak camera measurements are shown in Fig. 4 which were taken at the same time as the measurements displayed in Fig. 3.

The waveguide pickup in Fig. 4(a) is in very good agreement with the measurements in Fig. 3. As the waveguide pickup offers a spectral response in an even lower frequency band than the DXP-08 and DXP-12, more detail between the two predominant peaks can be seen.

For the streak camera measurements, as shown in

Fig. 4(b), the bunch length is obtained by fitting a suitable function to the streak camera CCD image. In this case an asymmetric Gaussian function was fitted to the trace and the FWHM is taken to be the bunch length. In the region where the streak camera measures short electron bunches, the waveguide pickup and Schottky diodes show a peak in intensity as one would expect. However, in the region of large beam size both the RF pickup and Schottky diodes show that the longitudinal profile is not uniform giving a sharp spike where the bunch length is longest.

UPGRADES

During the last shut-down of CTF3 minor upgrades of the detection system have been performed. As mentioned above, it is difficult to combine a fast narrow-band detector capable of measuring the longitudinal beam profile variation along the train and interferometric measurements with a good resolution. Therefore, an alternative broad-band pyroelectric detector was installed in the detection system to perform interferometric measurements.

Additionally, two more Schottky barrier diodes were installed in the detection system resulting in a total spectral response range of all detectors of 40 - 140 GHz.

SIMULATION STUDIES

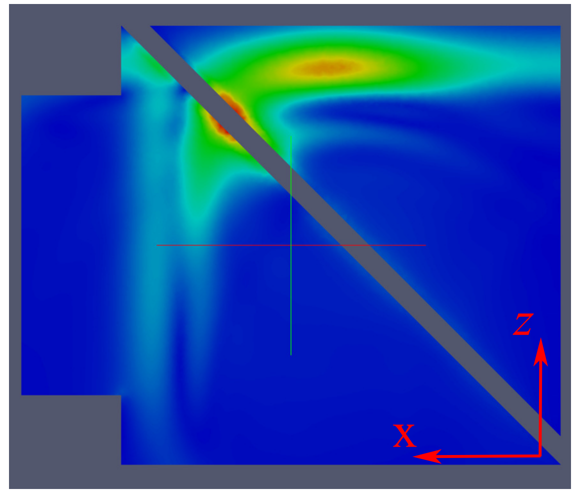
Besides the experimental efforts, electromagnetic time domain studies using the ACE3P code [6] have been carried out based on a simplified model of the current setup at CTF3. A snapshot of the electric field in the xz - plane of the 3D model for one discrete time step is shown in Fig. 5(a). One can clearly identify CDR from the target emitted in the positive x - direction, which has been induced by a 2 mm Gaussian beam propagating in the positive z - direction.

Moreover, the spectrum of the radiation exiting the model through the cylindrical viewport in the positive x - direction can be obtained and is shown in Fig. 5(b). The spectrum shows a clear suppression of low frequencies due to finite dimensions and an exponential suppression of higher frequencies due to the electron beam form factor.

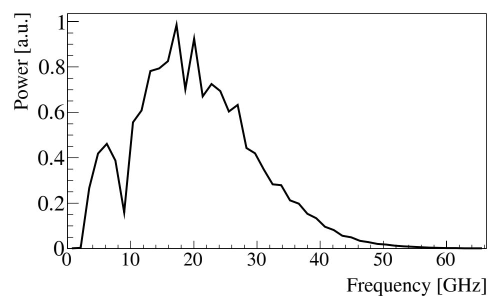
SUMMARY

Initial tests of the CDR longitudinal beam profile monitor at CTF3 have been successful and an in-depth understanding of the system has been achieved. Within CTF3, the CDR setup shows good agreement with the waveguide pickup. However, for longer electron bunches the bandwidth of the Schottky barrier diode detectors needs to be adjusted accordingly. Key issues for performing interferometric measurements with a better resolution have been identified and appropriate modifications of the system have been implemented during the winter shut-down.

The final version of the system has been installed and measurements with Schottky barrier diodes and a pyroelectric detector are expected to be taken in the near future.



(a) DR simulation snapshot of the electric field in the xz - plane of the 3D model. The beam propagating in the positive z - direction passes the target which is rotated by 45° and DR is emitted in the positive x - direction towards a cylindrical viewport



(b) DR spectrum from a 2 mm Gaussian bunch obtained from the electromagnetic time domain simulation

Figure 5: DR simulation studies

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