BUNCH LENGTH MEASUREMENTS AT TTF USING COHERENT DIFFRACTION RADIATION

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Abstract

The coherent diffraction radiation technique has been for the first time intentionally employed in the bunch length measurements at the TTF linac. Diffraction radiation (DR) is emitted as a beam passes through an aperture in a highly reflecting screen and, therefore, in contrast to transition radiation (TR), is a really non-intercepting tool - a very attractive feature to diagnose high-power beams of small transverse and longitudinal dimensions. In our measurements, the radiation produced by a 225 MeV electron beam centred in an adjustable rectangular slit was analysed by means of the autocorrelation method using a Martin Puplett interferometer in the millimetre range. Effects of the slit width and the beam displacement with respect to the centre of the slit on the radiation intensity and spectrum were studied in the context of the bunch length retrieval. In particular, we did not observed any perceptible influence of these factors on bunch length measurements. The presented results reveal that coherent diffraction radiation can be successfully used in beam diagnostics.

1 INTRODUCTION

The development of the next generation of high luminosity e^{-}-e^{+} Linear Collider and short-wavelength Free Electron Lasers requires electron pulses of ever higher peak current. This can be obtained by the use of a series of magnetic compressors working at intermediate energies to avoid emittance blow-up. An accurate measurement of sub-millimeter bunch lengths is thus necessary at every stage for a good setting of the compressor parameters.

Since standard time domain measurements become difficult and expensive in this bunch length range, in the last years a technique based on coherent radiation emitted by the beam in different conditions has been developed [1].

Coherent diffraction radiation (CDR) was suggested [1, 2] as a non-intercepting instrument for bunch length measurements - an attractive feature for the next generation of low-emittance and high-power beam facilities. Diffraction radiation arises when a charged beam passes through an aperture in a metallic screen, and , therefore, the beam interaction with the screen material is minimal. Furthermore, a smaller perturbation to the beam is generated in this case compared with most of other diagnostics.

Up to date there was only a single experimental evidence of CDR [3] that, however, due to the experimental layout, was observed in superposition with TR produced by the beam on a mirror used to extract the radiation from the vacuum chamber. In this paper we present the first ”clean” bunch length measurement using CDR generated by a short-bunch beam crossing a horizontal slit of a variable width, and compare it with that based on coherent transition radiation (CTR), taken with the same apparatus and under the same experimental conditions.

2 EXPERIMENTAL SET-UP

The experiment was performed at the TESLA Test Facility superconducting linac that is being constructed at DESY. In the current configuration the linac comprises the laser driven rf gun, the capture cavity and two accelerating modules. The bunch compressor II, a magnetic chicane, located between the two modules, is used to shorten the bunches longitudinally down to sub-millimetre range. The experimental station for bunch length measurements is placed just after the second accelerating module. The radiation produced by 225 MeV electrons on the diffraction screen (radiator) tilted by 45° with respect to the beam direction and extracted from the vacuum pipe at 90° through a quartz window was analysed by means of a Martin - Puplett interferometer. During measurements the linac was operated in a single-bunch mode to avoid saturation of the detector. The bunch charge was 1 nC.

For a number of practical reasons, we made the radiator in the form of a variable width slit, i.e. a rectangular screen divided in two parts movable one with respect to the other [7]. When the two parts are closed together it operates as an TR radiator, otherwise, in the DR mode, the slit aperture can be adjusted to the beam size and positioned with respect to the beam. For these purposes two independent movements are available by means of coaxial UHV linear actuators driven by stepping motors. A resolution of 5 μm/step was achieved for the insertion motion and 2.5

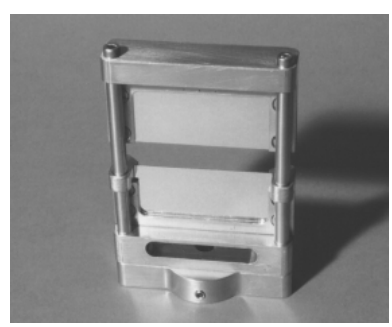

Figure 1: Diffraction radiator.

μm/step for the slit width variation within a range 0-10 mm. The screen was prepared using a monocrystalline silicon wafer of 380 μm thickness as a substrate and aluminized for higher reflectivity. The two constituent parts of the radiator were cut by means of a micrometric saw with the cut sharpness of the order of 20 μm, each in the form of a rectangle with dimensions of 44 x 20 mm^2. The two screens were then mounted on the holder, a picture of which in the open position is shown in Fig. 1. The screen planarity was measured by scanning the surface with a laser beam. Both half screens presented a concave curvature in the horizontal plane of ± 0.45 mrad. A co-planarity between the two halves of the radiator was ± 3 mrad, an acceptable value for the experiment.

The Martin - Puplett interferometer has been developed and constructed by the University of Aachen, and was reported elsewhere [8]. At the entrance of the interferometer a metallic parabolic mirror, with a focal length of 200 mm and the DR radiator in the front focal plane, converts the diverging radiation fan into a nearly parallel beam. A wire grid admits transmission of the vertically polarized radiation component into the interferometer. The grid is transparent to visible light, so inserting a flat mirror in the optical path, we were able to observe an image of the beam spot using a CCD camera. This was used for beam positioning and for setting the beam-line magnetic optics.

3 EXPERIMENTAL RESULTS AND DISCUSSION

Raw data in our measurements were interferograms registered by the two detectors for several slit widths in the range from 0 to 10 mm. When varying its width, the slit

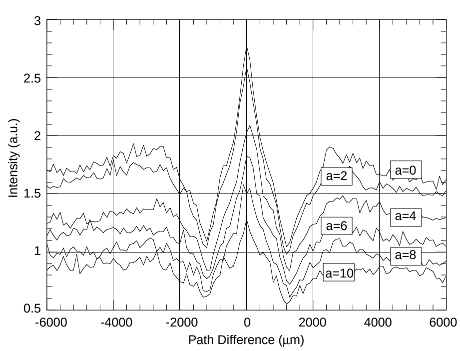

Figure 2: The detector signal as a function of the optical path difference for different slit widths.

as a whole was kept centred with respect to the beam. The full set of interferograms for one of the detectors is presented in Fig. 2. Each interferogram shows the detector signal as a function of the optical path difference in the two interferometer arms and consists of the variable autocorrelation component superimposed to a constant base-line proportional to the integrated power of the radiation pulse. To eliminate possible signal fluctuations, the pure autocorrelation signal is normally taken as their ratio.

Beam CDR spectra for various slit widths derived from the autocorrelation curves by Fourier transform are given in Fig. 3. Weak deviations in the spectra for different slit

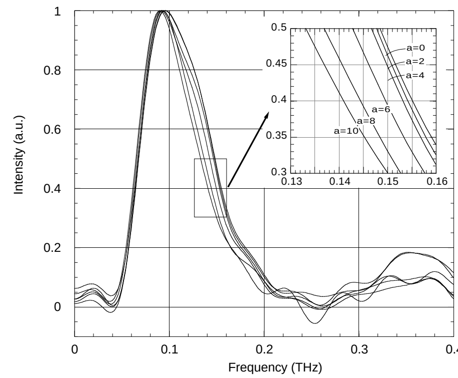

Figure 3: Normalized coherent radiation spectra for different slit widths.

widths can be attributed to the incoherent diffraction radiation properties. The low-frequency cut-off below 0.1 THz is almost independent of the slit dimensions and, therefore, controlled by other experimental factors (detector spectral response, diffraction phenomena etc.).

The measured radiation power is shown in Fig. 4 and compared with theoretical predictions. The conventional

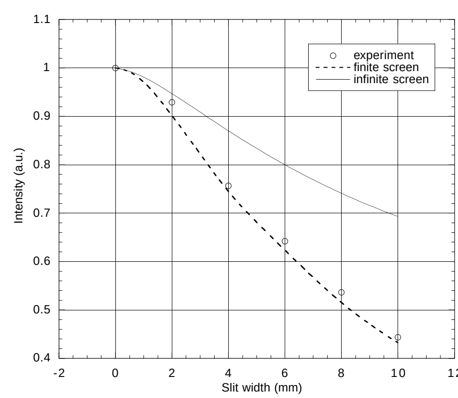

Figure 4: Radiation power versus slit aperture.

far-field theory [4], formulated for a slit in an infinite screen, is not adequate to account for experimental data. For that, effects of the screen size and corrections to the far-field approximation should be taken into account [5]. The very good agreement between experimental points and the theory can be regarded as an evidence of small contribution from the background mechanisms. It should be noted that the experimental observation of the screen size effect is reported here for the first time.

Another important feature of DR is the dependence of radiation intensity on the position of the electron beam with respect to the centre of the slit. Figure 5 shows the detector signal while scanning a slit of 10 mm width across the beam, together with the theoretical curve. This property of

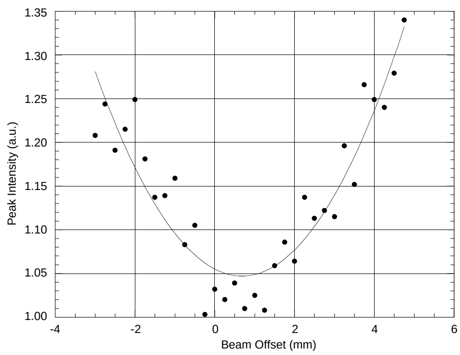

Figure 5: Radiation intensity versus the beam position.

DR can be used to centre a slit on the beam even without any imaging device.

The main goal of this paper was not in obtaining a very precise bunch length value, but to compare the result of TR case to that of DR from a slit of different apertures. For this reason, to extract information on the bunch length we followed the simple technique of Ref. [6]. The essence of the method consists in making certain assumptions about the bunch shape and the form of the spectrum and testing them with respect to measurements.

In previous bunch length measurements at TTF [8], a rectangular-like bunch shape was obtained. Bearing in mind this information, we took a rectangular shape smoothed by the convolution with a single Gaussian as a model bunch density distribution

$$\rho(z) = \frac{1}{\sqrt{2\pi}\delta}\int_{-\infty}^{\infty} u(z-z_0)e^{-z_0^2/2\delta^2}dz_0 \ ,$$
$$u(z) = \begin{cases} 1/\sigma & ,|z| \le \sigma/2 \\ 0 & ,|z| > \sigma/2 \end{cases} \ . \quad (1)$$

Depending on values of the parameters σ and δ, the assumed bunch shape can change between rectangular and gaussian ones. The incoherent radiation spectrum was assumed to be flat. The low frequency cut-off effect is introduced by a filter function suggested in Ref. [6]

$$g(\omega) = 1 - e^{-(\xi\omega/c)^2} \ . \quad (2)$$

This allowed us to get easily an analytical expression for the autocorrelation curve. By fitting the model dependence to experimental data we obtained best estimations for the parameters characterising the bunch itself and the cut-off effect. An example of the fit (fit #1) is shown in Fig. 6. We observed that agreement between experimental data and a model curve may be improved by an adequate choice of the filter function. The filter function of Eq. (2) diminishes gradually as ω goes to zero. Meantime, how it follows from Fig. 3, the radiation spectra are truncated at a certain frequency ω_t, below which the intensity is almost negligible. Fit #2 is a fit using the filter function being a product of Eq. (2) and the step function. It should be noted, however, that the bunch length estimated from the fit remains almost invariant to the choice of the filter function. The values of the

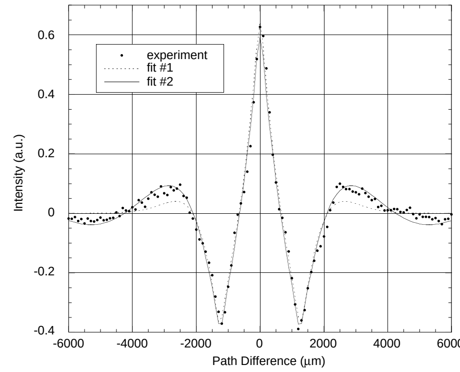

Figure 6: Fits of model autocorrelation curves to the experiment.

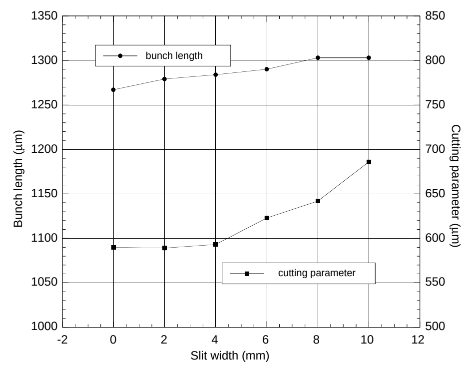

Figure 7: The bunch length and the cutting parameter versus the slit width.

parameters δ and ξ obtained from fits over all the set of data are given in Fig. 7 . As follows, the bunch length variation in all the range of the slit widths is less then 3%. This value is much less than an expected errors of measurements. The cutting parameter varies about 15 % and its dependence on the slit width is in a qualitative agreement with the theoretical prediction.

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