Electron Bunch Length Monitors for the TESLA Test Facility Linac

K. Hanke*
Deutsches Elektronen-Synchrotron DESY, D-22603 Hamburg

Abstract. Coherent transition radiation from picosecond electron bunches can be used for bunch length measurement. This is done by spectroscopy at wavelengths of several millimeters. For the TESLA test facility linac, two types of spectrometers have been developed and built. They use a photo-acoustic detector for detection of the radiation. As an alternative, the use of a Josephson junction as a spectrometer for millimeter waves and its possible application for bunch length measurement is evaluated. It works at low radiation intensity and has the potential of a fast, non-destructive measurement.

Introduction

At the TESLA test facility linac, transition radiation is produced by moving thin aluminum targets into the beamline. By arranging the radiator at an angle of 45^o with respect to the electron beam direction, one can seperate the backward transition radiation from the electron beam and make use of it for beam diagnostics. While the visible part of the spectrum can be used for transverse imaging of the beam using otpical techniques, the long-wavelength part of the spectrum can be used to obtain the bunch length. This technique, reported for sub-picosecond bunches ([1],[2],[3] and references therein), has been adapted for picosecond bunch length [4].

1 Observation of Coherent Radiation

Since the bunch length at the TESLA test facility linac is supposed to be in the picosecond range, coherent transition radiation is expected at wavelengths of several millimeters. For the detection of millimeter waves, a photo-acoustic power meter from Thomas Keating Ltd. was chosen [5]. It has a flat response from 0.1 mm up to 10 mm wavelength (3 THz - 30 GHz).

Coherent transition radiation was observed using the photo-acoustic detector without any quasi-optical setup. The detector output is very sensitive to beam current and bunch length. In order to verify the non-linear behaviour of the radiation power, the beam current was varied and the detector output measured. Figure 1 shows the detector output as a funcion of the beam current. The non-linear increase of the radiation power can clearly be observed. This test of the theoretically predicted bahaviour can be used to verify that the detector signal is really due to coherent radiation.

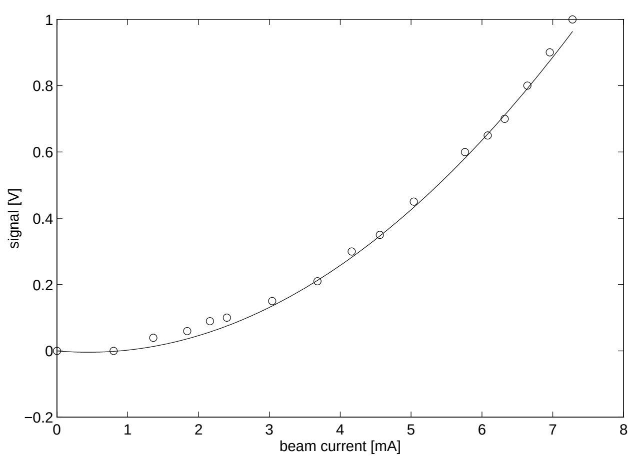

Figure 1: Output of photo-acoustic detector versus beam current. The expected non-linear dependence can clearly be seen.

2 Filter Spectrometer

A set of filters can serve, together with the broadband photo-acoustic detector, as a spectrometer [7]. The filter spectrometer allows a direct measurement of the coherent spectrum. Its resolution is limited by the number of filters available.

A periodic pattern of holes drilled into a brass plate acts as a high-pass filter for millimeter waves [8], [9]. The highpass filters are mounted on a rotatable wheel.

*for the TESLA Collaboration

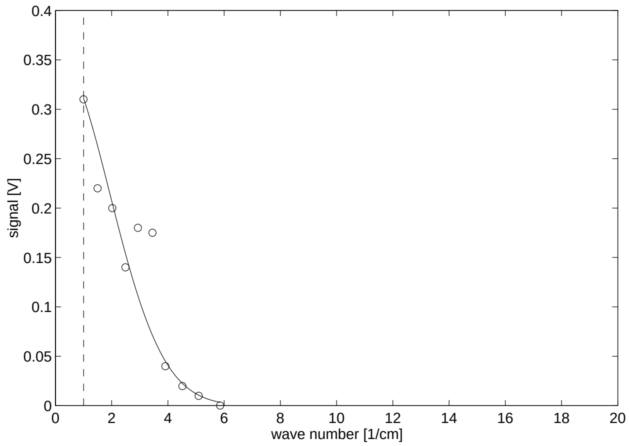

Figure 2: Spectrum of coherent tranistion radiation measured with the filter spectrometer. A Gaussian fit to the spectrum yields a bunch length of $\sigma = 2.76$ ps in the time domain.

The wheel is driven by a stepper motor such that the filters can be placed successively in front of the photo-acoustic detector which is mounted as close as possible to the filters. The filter spectrometer is placed directly at a transition radiation target such that the distance between the radiator and the detector is as small as possible.

The spectrum of the coherent transition radiation was measured using the filter spectrometer. The filters are moved successively between the photo-acoustic detector and the vacuum window of the transition radiation monitor. The detector output voltage is measured for each filter. Figure 2 shows the measured spectrum. Since the resolution of such a measurement is limited, an assumption on the bunch shape must be made. A Gaussian charge distribution which results in a Gaussian shape of the spectrum was chosen. From a Gaussian fit applied in the frequency domain, a Gaussian charge distribution in the time domain with $\sigma = 2.76$ ps is obtained.

3 Martin-Puplett Interferometer

Interferometers can serve as spectrometers for electromagnetic radiation. The principle of these measurements is called Fourier spectroscopy. The main advantage of interferometers is their very good resolution. Various kinds of intererometers can be used for spectroscopy in the far infrared. For the frequency range of interest here, a Martin-Puplett interferometer was used [10], [11]. It was designed and built with a flat efficiency over the whole millimeter wavelength range. From the measured interferogram, the spectrum can be obtained using the fact that the modulus squared of the Fourier transform of a pulse $f(t)$ equals the Fourier transform of its autocorrelation function $c_{ff}(t) = f(t) \odot f(t)$:

$$|F\{f(t)\}|^2 = F\{f(t) \odot f(t)\}. \qquad (1)$$

Equation (1) is known as the Wiener-Khintchine relation [12].

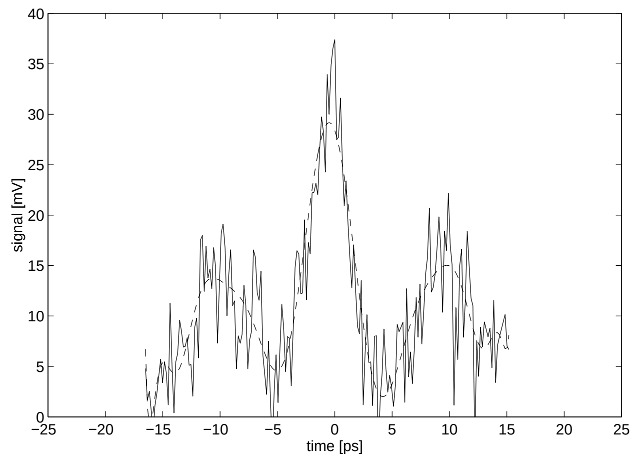

Figure 3: Autocorrelation of TTFL bunches. The detector output is plotted versus the optical path length difference of the interferometer arms. The solid line shows the measured data, the dashed line is a ploynomial fit which suppresses high frequent noise.

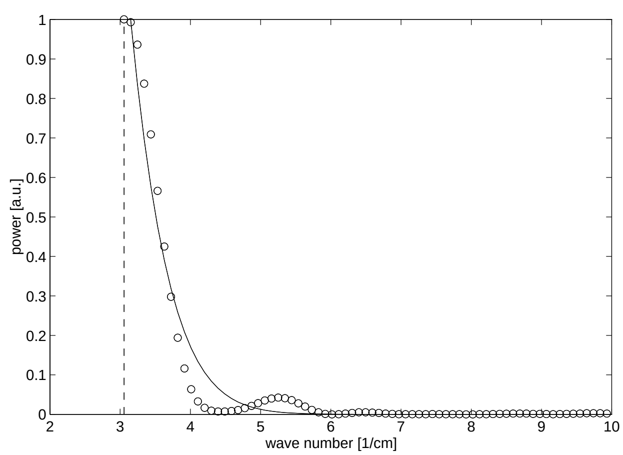

Figure 4: Spectrum calculated from the measured autocorrelation. The low frequency cutoff is found at $\bar{\nu} \approx 3$ cm^{-1} (vertical dashed line). The circles represent the data obtained from the Fourier transform, the solid line is a Gaussian fit. Assuming a Gaussian charge distribution, the fit yields $\sigma = 2$ ps.

The autocorrelation of the bunch shape was measured with the Martin-Puplett interferometer. The stepwidth was chosen to 25 μm and the total travel distance of the movable mirror to 5 mm. The mechanical path length difference can directly be transformed in an optical path length difference in terms of picoseconds. Figure 3 shows the interferometer scan. Each point was averaged over 30 single measurements. The central peak as well as two side minima are clearly seen. In order to suppress the high frequency noise which is superimposed to the autocorrelation, a polynomal fit is applied. The fit is shown as a dashed line in Fig. 3. From the measured autocorrelation function, the spectrum can be calculated. Figure 4 shows the power spectrum obtained by applying a Fourier transform to the fitted curve. The low frequency cutoff is found at about $\bar{\nu} = 3\ \mathrm{cm}^{-1}$. Since the cutoff due to the limited bandwith of the detector is expected at $1\ \mathrm{cm}^{-1}$, apparently the optical setup itself causes a further limitation due to diffraction or highpass action of components. Above cutoff, the decay of the first maximum can clearly be seen. A Gaussian fit applied to the first maximum yields a bunch length in the time domain of $\sigma = 2$ ps.

4 Hilbert-Transform Spectrometer

A new method to measure the coherent spectrum was for the first time used for bunch length measurements at the TESLA test facility linac. The spectrometer is based on a Josephson junction. The characteristic line of the junction is distorted under the influence of millimeter wavelength radiation. This effect can be used to determine the radiation spectrum applying a Hilbert transform [13]. First measurements indicated that the spectrometer is extremely sensitive and fast. Based on this technology, an ultrafast and non-destructive bunch length monitor will be developed [14].

Acknowledgements

I would like to thank all colleagues from DESY and the collaborating institutes who contributed to the setup and commissioning of the TESLA test facility linac. In particular, I would like to thank the colleagues from INFN Frascati who provided the transition radiation monitors.

References

[1] H. Lihn, D. Bocek, P. Kung, C, Settakorn, H. Wiedemann, *Measurement of Subpicosecond Electron Pulses*, Physical Review E, **Vol. 53**, No. 6 (1996).

[2] Y. Shibata, T. Takahashi, T. Kanai, K. Ishi, M. Ikezawa, J. Ohkuma, S. Okuda, T. Okada, *Diagnostics of an Electron Beam of a Linear Accelerator using Coherent Transition Radiation*, Physical Review E, **Vol. 50**, No. 2 (1994).

[3] R. Lai, U. Happek, A. J. Sievers, *Measurement of the Longitudinal Asymmetry of a Charged Particle Bunch from the Coherent Synchrotron or Transition Radiation Spectrum*, Physical Review E, **Vol. 50**, No. 6 (1994).

[4] K. Hanke, dissertation, Universität Hamburg, in preparation.

[5] Installation and Operating Instructions for the TK TeraHertz Absolute Power/Energy Meter Head , Thomas Keating Ltd.

[6] H. A. Zahl, M. J. E. Golay, *Pneumatic Heat Detector* , The Review of Scientific Instruments, **Vol. 17**, No. 11 (1946).

[7] K. Hanke, V. Schlott, K. Aulenbacher, H. H. Braun, F. Chautard, *Beam Diagnostics using Coherent Transition Radiation at the CLIC Test Facility*, CERN CLIC Note 298 (1996).

[8] F. Keilmann, *Infrared High-Pass Filter with High Contrast* , Intern. Journal of Infrared and Millimeter Waves, **Vol. 2**, No. 2, p. 259 (1981).

[9] A. Roberts, M.L. von Bibra, H.-P. Gemünd, E. Kreysa, *Thick Grids with Circular Apertures: a Comparison of Theoretical and Experimental Performance*, Intern. Journal of Infrared and Millimeter Waves, **Vol. 15**, No. 3, p. 505 (1994).

[10] J. Lesurf, *Millimetre-Wave Optics, Devices & Systems*, Adam Hilger, Bristol (1990).

[11] D. H. Martin, E. Puplett, *Polarised Interferometric Spectroscopy for the Millimetre and Submillimetre Spectrum*, Infrared Physics, **Vol. 10**, p. 105 (1969).

[12] E. Hecht, *Optics*, Addison-Wesley (1974/1987).

[13] Y. Y. Divin, H. Schulz, U. Poppe, N. Klein, K. Urban, V.V. Pawlowskii, *Millimeter-wave Hilbert-transform spectroscopy with high-T_c Josephson junctions* , Appl. Phys. Lett. 68 (11) (1996).

[14] Y. Y. Divin, M. Geitz, K. Hanke, U. Poppe, to be published.