Measurement of the Bunch Length at the TESLA Test Facility Linac

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Abstract. An autocorrelation method is proposed to measure the bunch length at the TESLA Test Facility linac. The coherent part of the spectrum of transition radiation is to be examined using a quasi-optical setup and a Golay Cell (1). The experimental setup is presented and the proposed measurements are discussed.

INTRODUCTION

The TESLA Test Facility (TTF) linac is presently under construction at DESY by an international collaboration (2). It will be operated at 1.3 GHz using 9-cell superconducting cavities. Four modules are planned, each of them consisting of eight cavities. This yields an energy of 500 MeV at an accelerating gradient of 15 MV/m or an energy of 800 MeV at a gradient of 25 MV/m respectively.

The beam parameters of the TTF linac are summarized in Fig.1. Sophisticated diagnostic devices are required. In particular, the bunch length of 3.3 ps is just at the critical limit for the operation of streak cameras. Very fast streak cameras have been designed for time resolution down to 600-300 fs. However, these devices are extremely expensive and it is not entirely sure whether they can provide the desired resolution. Since the TTF linac will later be used as a driver for a free electron laser (3) with an even shorter bunch length, other measurement techniques have been examined.

It is planned to use the coherent part of the spectrum of transition radiation for an autocorrelation technique. This method is comparatively cheap and provides excellent resolution. An experimental setup was designed and is under construction at DESY.

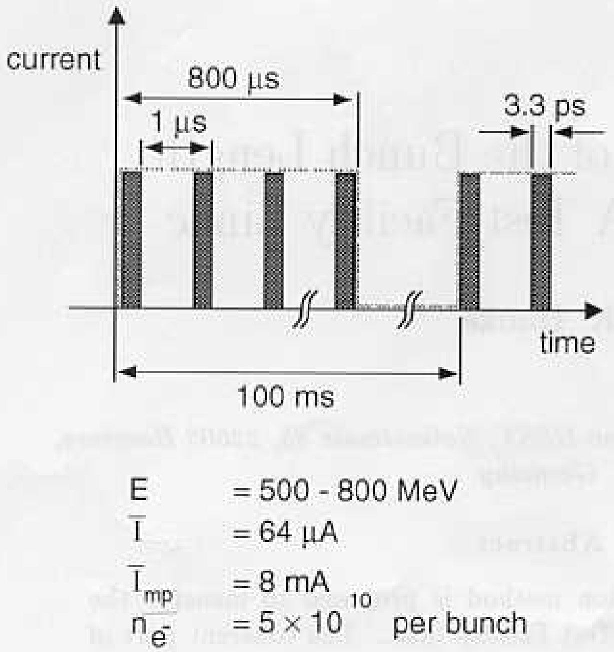

Figure 1: TTF linac beam parameters.

COHERENT TRANSITION RADIATION

Transition radiation is produced by charged particles as they pass through the interface of two materials with different dielectric constants. The visible part of the spectrum is known as optical transition radiation and can be used for transverse beam imaging, energy measurement, emittance measurement etc. There is a significant increase in the power of transition radiation at wavelengths of the order of the bunch length and longer. This is due to the fact that the bunch can then be considered as one charged macro-particle. The power of the emitted radiation is then no longer proportional to the number N of particles per bunch but to N^2. In this wavelength range, the bunch radiates coherently. This allows the application of autocorrelation methods for determining the bunch length.

EXPERIMENTAL SETUP

At the TTF linac, transition radiation will be produced by moving aluminum coated kapton foils into the beam. Several diagnostic stations will be distributed along the beamline (4). One of them will be adapted for the observation of millimeter radiation. The foil is moved into the beam at an angle of 45°. The radiation is directed through a polyethylene window out of the vacuum chamber. The autocorrelation function is obtained by using a Michelson Interferometer as shown in Fig.2. Commercial optical mirrors and lenses have been gold coated so that they can be used in the millimeter wavelength range.

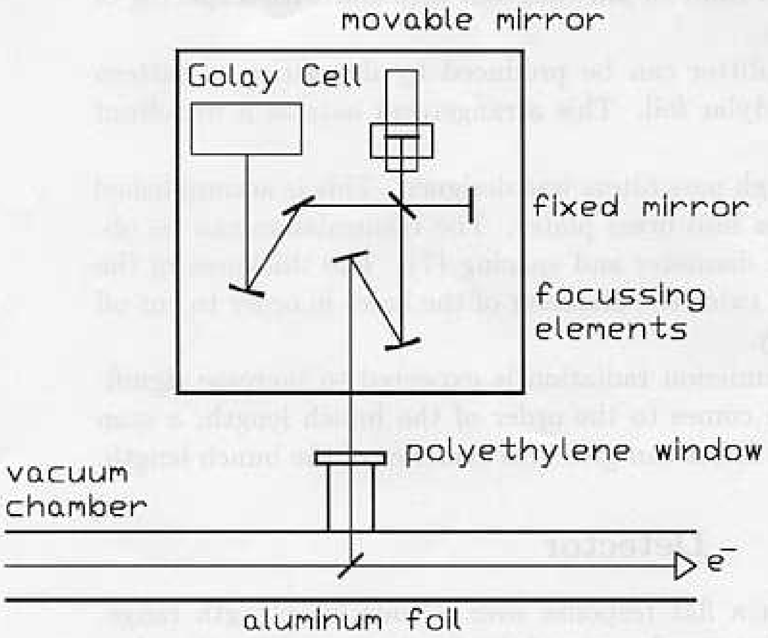

Figure 2: Experimental setup; transition radiation is directed out of the vacuum chamber and focussed on the detector by a system of gold coated flat mirrors and concave lenses. A Michelson Interferometer is used to measure the autocorrelation of the longitudinal charge distribution.

Beamsplitters and Filters

Special care must be taken with the beamsplitter. The use of Mylar foil is not possible since it becomes entirely transparent in the millimeter wavelength range. Several types of beamsplitters are being manufactured and tested.

Wire grids can be used as polarizers or beamsplitters respectively. The transmission T, reflexion R and absorption A of a grid are given by

$$T = [\frac{2g}{\lambda} ln \frac{g}{\pi b}]^2 \quad (1)$$

$$R = 1 - [\frac{2g}{\lambda} ln \frac{g}{\pi b}]^2 \quad (2)$$

$$A = \frac{2g}{\pi b} \sqrt{\frac{2}{\epsilon''}} R \quad (3)$$

where b is the wire diameter, g is the wire spacing, λ is the wavelength and ϵ'' is the imaginary part of the dielectric function of the material (5). These formulas are valid for circular wire cross sections and for $\lambda > 2g$. A series of grids has been manufactured from 20 μm tungsten wire and with a spacing of 100,150,200,250 and 300 μm.

Another type of beamsplitter can be produced by depositing a pattern of metal dots (copper) on Mylar foil. This arrangement acts as a wavefront splitter (6).

In addition, a series of high pass filters was designed. This is accomplished by drilling a pattern of holes into brass plates. The transmission can be obtained as a function of hole diameter and spacing (7). The thickness of the metal plate should be about twice the diameter of the holes in order to cut off large wavelengths sufficiently.

Since the power of transmission radiation is expected to increase significantly when the wavelength comes to the order of the bunch length, a scan with a series of narrow band filters can give first evidence of the bunch length.

Detector

A detector was chosen with a flat response over a wide wavelength range. Pyroelectric detectors cut off at wavelengths of about 0.1 mm and can therefore not be used at the TTF linac, where the bunch length will be about one millimeter. A Golay Cell, however, is able to detect radiation from 0.1 mm to 10 mm. It consists of a thin metal film within a gas volume. Heating of the film causes a change of pressure of the gas that can be read out. First tests of the detector were undertaken using a heated iron plate as a radiation source. Figure 3 shows the detected signal of the chopped radiation source.

MEASUREMENTS

The Golay Cell will be used to detect transition radiation in the millimeter wavelength range. An increase of the detected power can be interpreted as a shortening of the bunch. This information will be important when commissioning the linac. In a second step, a scan with bandpass filters will be carried out. This will provide a first estimate of the bunch length. Finally, the autocorrelation function will be measured using the Michelson Interferometer. From the measured autocorrelation function, the spectrum can be determined. The frequency spectrum can be obtained as the fourier transform of the measured autocorrelation function. It can be expressed as

$$I_{tot}(\omega) = I(\omega)[N + N(N-1)F(\omega)] \qquad (4)$$

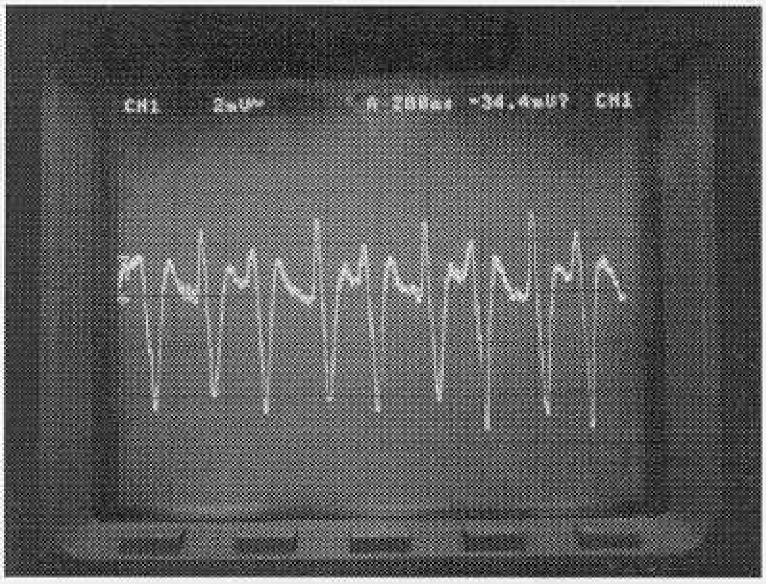

Figure 3: Signal of a chopped radiation source detected with a Golay Cell. Radiation from a heated metal plate was chopped at approximately 5 Hz and directed on the detector head.

where

$$F(\omega) = |\int_0^\infty dz S(z) e^{i\frac{\omega}{c}z}|^2 \qquad (5)$$

is called the bunch form factor and $S(z)$ is the charge distribution. Comparing the measured spectrum with the expected spectra of various charge distributions will yield information about the bunch form factor.

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