BUNCH LENGTH MEASUREMENTS IN CTF3

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Abstract

The CLIC Test Facility CTF3, being built at CERN by an international collaboration, should demonstrate the feasibility of the CLIC two-beam technology by 2010. One of the issues addressed is the control of the electron bunch length in the whole complex. A bunch length measurement system, with a good resolution, is therefore paramount. Two different systems are presently used in CTF3 based on microwave spectroscopy and on transverse rf deflectors, respectively. In the paper we describe the two systems, we discuss the different experimental methods used and present the results of the latest measurement campaigns.

INTRODUCTION

In the framework of the Compact Linear Collider (CLIC) project [1], a test facility named CTF3 [2] is constructed at CERN by an international collaboration. The CTF3 complex shall demonstrate by 2010 the key technological challenges for the construction of a high luminosity 3 TeV e^+-e^- collider. The overall machine starts with a linac delivering a 3.7 A, 1.5 μs long electron beam with an energy of 150 MeV. The bunches are then injected in two consecutives rings [3] where the beam average current and the bunch frequency are multiplied by a factor 8. With a current of 30 A and 2.5 cm distance between bunches, the resulting beam is finally sent to the CLIC experimental area (CLEX) where it will be used to test all key CLIC RF components.

The performances of the accelerator depend directly on the control of the electron bunch length. In the linac the bunches must remain short (about 2 ps r.m.s.) to keep the energy spread as low as possible, but need to be stretched (6 - 10 ps r.m.s.) before the rings to minimize emittance dilution due to coherent synchrotron radiation. Therefore, two magnetic chicanes have been implemented, the first downstream of the injector and the second upstream of the first ring. A sketch of the second magnetic chicane, composed of 4 bending magnets, is presented in Fig. 1. Normally, bunch shortening or lengthening is obtained by changing the phase of the rf in the last accelerating structure. Bunch length measurements can be performed using Optical Transition Radiation screens coupled to a streak camera [4], but the present system limits the time resolution to 2 ps. Shorter bunches are measured with the 1.5 GHz rf deflector [5], normally used to inject the particles in the Delay Loop, but for the purposes of the bunch length measurement, it is used in conjunction with an Optical Transition Radiation screen. Recently, a new detector has been commissioned based on microwave spectrometry, which we commonly refer to as the "rf-pickup" [6]. In this paper, the rf deflector and the rf-pickup bunch length measurement techniques will be presented.

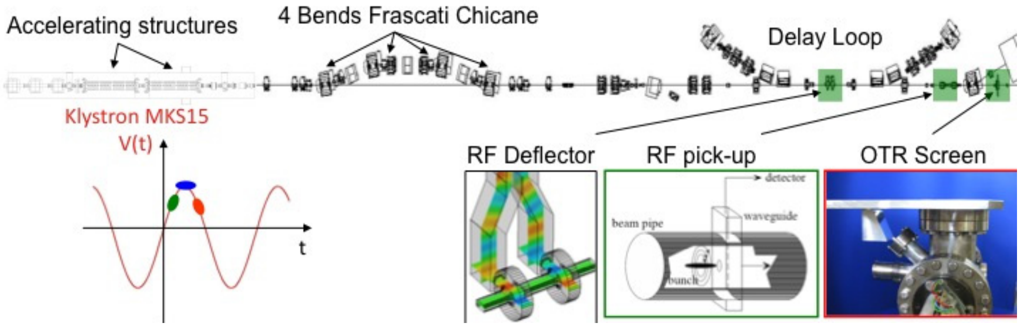

Figure 1: Layout of the Frascati chicane and locations of the bunch length monitors. By changing the Klystron MKS15 phase, the bunch length at the end of the chicane can get shorter (green), longer (red) or just be preserved (blue).

MICROWAVE SPECTROMETER EXPERIMENTAL SETUP

A non-destructive single shot bunch length monitor was commissioned in CTF3 in 2006 [6]. This device, the "rf pick-up", measures the frequency spectrum of the electromagnetic field emitted by the particles and collected by a rectangular K_a waveguide. The rf pickup was installed 50 cm upstream of the OTR screen, and hence cross calibrations can be performed between the rf deflector and the rf pickup monitor. This monitor has a sub-ps time resolution and the calibration is done in a self consistent manner. Moreover, this monitor has the advantage of being non destructive and relatively inexpensive compared to other techniques.

The rf pickup consists of a single WR-28 waveguide connected to the beam pipe as shown in Fig. 1. A 0.5 mm thick CVD diamond window [7] is used to isolate the vacuum in the beam pipe from the atmospheric pressure in the waveguide. Signal frequencies above the cut-off of the WR-28 waveguide (21.1 GHz) are transported in a

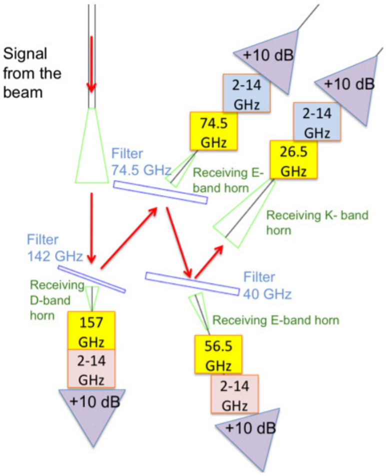

Figure 2: Schematic of the detection system.

continuous WR-28 waveguide for about 18 m to the detection station in a technical gallery.

At the detection station, the rf signal from the beam is emitted using a K_a band horn antenna, as shown in Fig. 3. The detection system is designed to measure the amplitude of the rf signals from the beam, simultaneously in four frequency bands, namely 26.5-40 GHz, 45-69 GHz, 75-90 GHz and 142-170 GHz.

As shown schematically in Fig. 2, two down-mixing stages in series are required in order to measure the high frequency rf signals. The first down mixing stage has a fixed local oscillator frequency for each band , namely 26.5 GHz, 56.5 GHz, 75 GHz and 157 GHz. The second down mixing stage is in common to each of two of the four detection bands, obtained by using two synthesizers with a variable frequency range from 2-14 GHz. From this setup, measurements of the beam harmonics of 30 GHz, 33 GHz, 36 GHz and 39 GHz are made using the K-band detection, the beam harmonics of 60 GHz, 63 GHz, 66 GHz and 69 GHz are made using the first E-band detection stage, and the beam harmonics of 78 GHz, 81 GHz, 84 GHz and 87 GHz are made with the second E-band detection stage. The D-band detection stage provides signals only for beam conditions with very short bunches, which was not the case for the measurements presented in this paper. The signals are amplified by +10 dB after the second down mixing stage, and then digitized using a fast Acqiris digitizing scope with 2Gs/s per channel. The data acquisition is controlled remotely by a LabView program, which stores, displays and analyses the signals in real time.

EXPERIMENTAL RESULTS

For each machine condition, which corresponds to a particular setting of the phase of the last Klystron (MKS15), 15 successive measurements are stored and their Fourier transforms performed. The mean height of the peak, corresponding to each beam harmonic is measured and used for the bunch length determination.

In order to extract the bunch length, the amplitude of each beam frequency measured as a function of the phase of MKS15 is used in the fitting procedure to extract the bunch length. The longitudinal distribution of the electrons is assumed to be single Gaussian distribution. A χ^2 minimization fit, to the Gaussian function, is then performed, with the fit parameters being the r.m.s. bunch length at each machine setting, and the response factor of each frequency band. The extracted r.m.s. bunch length is shown in Fig. 6, and the evolution of the bunch length with respect to the phase of the last Klystron can be seen. The χ^2/ν for the fit was $\chi^2/\nu=1.08$.

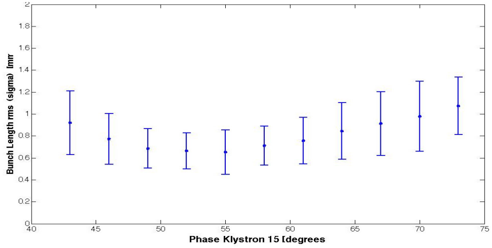

Figure 3: Evolution of the bunch length measured with the rf pickup as a function of the phase of Klystron 15.

BUNCHLENGTH MEASUREMENT USING RF DEFLECTOR

Bunch length measurements were also performed using the 1.5 GHz transverse rf deflector and an Optical Transition Radiation screen installed downstream from the RF deflector kick position, see Fig. 1. As the bunch passes through the cavity, the field in the rf cavity induces a strong correlation between the particle's longitudinal position in the bunch and the transverse position after the kick. Hence the measurement of the transverse beam profile of the beam downstream of the cavity gives direct information about the bunch longitudinal length before the kick.

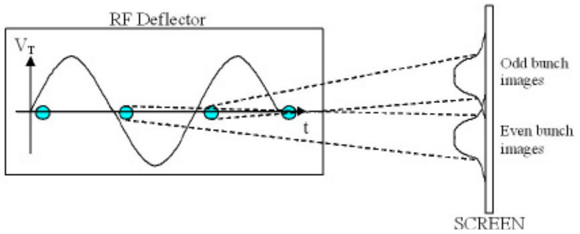

Figure 4: A schematic view of the rf deflector transverse kick on the bunches, a few degrees off the zero crossing[†].

During the bunch length measurement, the beam bypassed the delay loop, and the rf deflector was powered and phased such that the beam arrived close to the rf zero crossing. In this configuration, the head and the tail of each bunch were then kicked in opposite directions. Because the 3 GHz bunching of the beam during this measurement campaign, and the rf deflector operating at 1.5 GHz, the phase of the rf deflector was adjusted

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[†] Plot courtesy of Frascati note, CTF3-010

slightly off zero crossing, to image the two beam spots separately on the one screen, see Fig. 4.

Once the two beam spots were separated using the appropriate phase of the rf deflector, a horizontal corrector magnet was used in order to move one beam spot to the center of the screen, in order to maximize the light collection from the optical line. The second beam spot was therefore out of the acceptance of the screen. The increase in the observed transverse beam size, when the rf deflector was switched on was used to determine the bunch length, see Fig. 5.

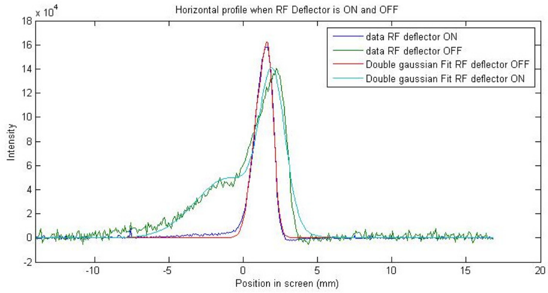

Figure 5. The transverse projection of the beam size with the rf deflector ON and OFF as imaged by the OTR screen.

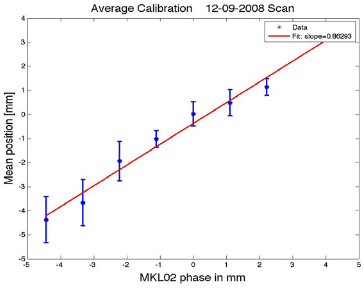

Figure 6: Typical calibration curve, showing the relationship between the phase of the MKL02 in units of longitudinal mm and the transverse position of the peak of the distribution on the screen.

In order to get a calibration of the system, which was independent of the transverse beam parameters, a calibration scan was done by measuring the position of the peak of the bunch distribution as a function of the rf phase of the deflector. A phase change of 1 degree of the 1.5 GHz rf deflector corresponds to a longitudinal distance of 200/360 mm. The calibration curve for a typical measurement is shown in Fig. 7, and the calibration constant is measured to be CAL=0.86±0.02 mm(screen)/mm(longitudinal).

To calculate the bunch length, quadratically the two rms transverse dimensions, measured when the rf deflector is on (and a few degrees off zero crossing) and when the rf deflector is OFF, are subtracted [8].

$$\sigma_{zrms} = \frac{1}{CAL} * \sqrt{\sigma^2_{x_{rms}(RFon)} - \sigma^2_{x_{rms}(RFoff)}}$$

In this approximation we extract the bunch length, as a function of the phase of MKS15, see Fig. 7. For this data taking the setting of the upstream compressor chicane, R56 = 0.45, and the measured minimum of σ_{zrms} = 1.5 mm seems to be in good agreement with expectations [9].

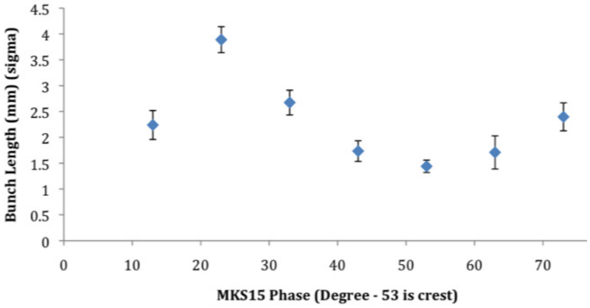

Figure 7: Evolution of the bunch length measured with the RF deflector as a function of the phase of the klystron MKS15.

CONCLUSIONS AND PERSPECTIVES

The rf-pickup monitor and the rf deflector were both used in the latest measurement campaign at CTF3 to measure bunch length. Both detectors measure the same shape response to the change in bunch length as a function of the phase of the last accelerating structure, however there seems to be a systematic difference between the results of the two techniques for these machine conditions, with the rf pickup measuring shorter bunches than the rf-deflector. More detailed studies in the future will be dedicated to understand the reason for this difference, in particular the effect due to the double Gaussian bunch shape and the enhanced sensitivity to high frequency components which seem to be biasing the rf-pickup detector to lower bunch length values.

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