INSTRUMENTATION FOR LONGITUDINAL BEAM GYMNASTICS IN FEL'S AND AT THE CLIC TEST FACILITY 3

T. Lefèvre, H.H. Braun, E. Bravin, S. Burger, R. Corsini, S. Döbert,
L. Søby, F. Tecker, P. Urschütz, C.P. Welsch, CERN, Geneva, Switzerland
D. Alesini, C. Biscari, B. Buonomo, O. Coiro, A. Ghigo,
F. Marcellini, B. Preger, INFN Frascati, Roma, Italy
A. Dabrowski, M. Velasco, Northwestern University, Illinois, USA
P. Craievich, M. Ferianis, M. Veronese, Sincrotrone, Trieste, Italy
A. Ferrari, Uppsala University, Sweden

Abstract

Built at CERN by an international collaboration, the CLIC Test Facility 3 (CTF3) aims at demonstrating the feasibility of a high luminosity 3 TeV e^+-e^- collider by the year 2010. One of the main issues to be demonstrated is the generation of a high average current (30 A) high frequency (12 GHz) bunched beam by means of RF manipulation. At the same time, Free Electron Lasers (FEL) are developed in several places all over the world with the aim of providing high brilliance photon sources. These machines rely on the production of high peak current electron bunches. The required performances put high demands on the diagnostic equipment and innovative longitudinal monitors have been developed during the past years. This paper gives an overview of the longitudinal instrumentation developed at ELETTRA and CTF3, where a special effort was made in order to implement at the same time non-intercepting devices for online monitoring, and destructive diagnostics which have the advantage of providing more detailed information.

INTRODUCTION

The single-pass seeded FEL project FERMI at ELETTRA [1] will be a user facility providing high-quality photons in the EUV to soft X-ray range. With a peak brightness more than ten orders of magnitude greater than 3rd generation sources, full transverse coherence, a choice of pulse lengths of the order of 1 ps or less, variable polarization and energy tunability, the FERMI source will provide a powerful tool for scientific investigation.

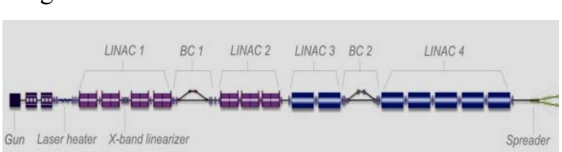

Figure 1: Overview of FERMI at ELETTRA

Figure 1 shows the layout of the facility. The accelerator starts with a photo-injector followed by two short linac sections providing acceleration up to 100 MeV. The main linear accelerator will alternatively time compress or accelerate the electron bunches. Two magnetic chicanes will be installed along the linac at beam energies of 220 and 600 MeV and will provide a total longitudinal compression factor of 10. The resulting bunch length will be as short as 200 fs RMS with a peak current of 800 A. After the second bunch chicane, the beam will be further accelerated up to 1.2 GeV before being sent to the undulators.

In parallel, in the framework of the Compact Linear Collider (CLIC) project [2], a test facility named CTF3 [3] is constructed at CERN by an international collaboration. It shall demonstrate by 2010 the key technological challenges for the construction of a high luminosity 3 TeV e^+-e^- collider. The generation of the CLIC RF power source is one of them, which relies on the production of a high average current (30 A) high frequency (12 GHz) bunched beam as depicted in Figure 2.

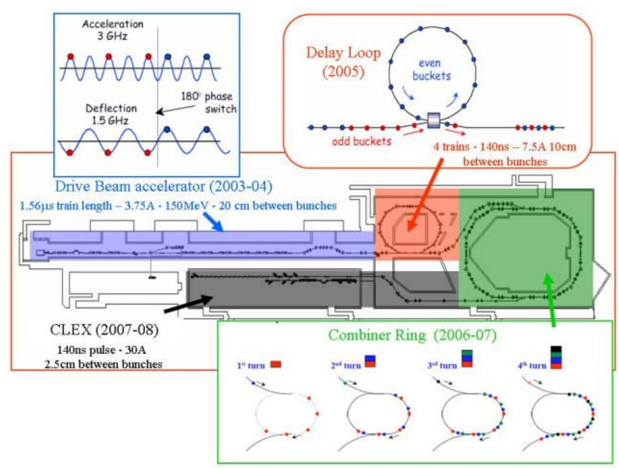

Figure 2: Overview of the CTF3 complex

In the present scheme, a long train of bunches with a bunch spacing of 20 cm is converted into an eight times shorter train with a 2.5 cm bunch spacing. The complex starts with a 3 GHz linac (twice the bunch frequency) that produces a pulsed electron beam with a present maximum energy of 150 MeV. Moreover, the macro pulse consists of alternated sequences of even and odd buckets with a duration of 140 ns each. The difference in phase between the trains is one RF wavelength, i.e. the phase of the RF is changed by 180º every 140 ns. The linac is connected to the Delay Loop (DL) [4] where a 1.5 GHz RF deflector deviates the odd bunch sequences to the left inside the Delay Loop and the even ones to the right. The DL length corresponds to a time of flight of 140 ns so that after one turn the odd sequence will be recombined with the incoming even sequence to fill the interleaved empty buckets. At the exit of the DL, the beam is composed of four consecutive bunch trains, each of them having a 7.5 A average current and 10 cm bunch spacing. The electrons are then injected into the Combiner Ring (CR) by a 3 GHz RF deflector [5]. After the 4^{th} turn, the bunch trains are combined into a single one with a current of 30 A and a 2.5 cm distance between the bunches. The beam is finally extracted and sent to the CLIC experimental area (CLEX) where it produces high peak power at 12 GHz passing through the CLIC decelerating structures.

BUNCH LENGTH MONITORS

High peak current electron beams are crucial for the performance of single pass FELs. This demands high quality bunch compressors and high resolution longitudinal beam diagnostics. In a similar way, the bunch length needs to be controlled precisely in the CTF3 complex. In the linac the bunches must remain short to keep the energy spread as low as possible, but need to be stretched before the rings to minimize emittance dilution due to coherent synchrotron radiation.

Streak cameras combined with Optical Transition Radiation (OTR) or Synchrotron Radiation (SR) have been used for decades for bunch length measurements [6]. State of the art streak tubes allow measurements with time resolutions down to 200 fs [7]. These measurements are complemented by other techniques that have proven their ability to measure sub-ps bunch lengths.

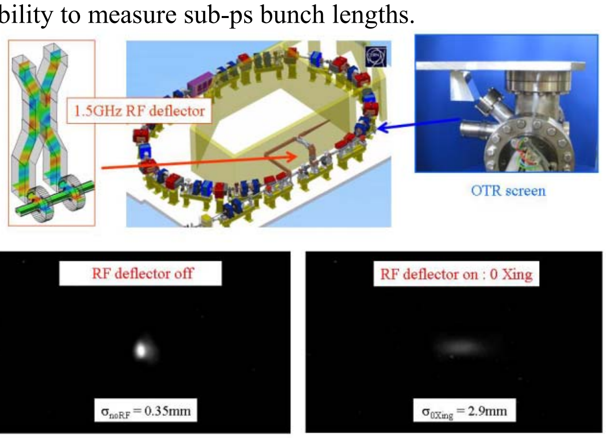

Figure 3: RF deflector measurement at CTF3

One of the most promising alternative techniques is based on the use of RF deflecting cavities. As the bunch is passing through the cavity, it experiences a time dependent deflection which converts time into spatial information. By measuring the beam size at a downstream location, the longitudinal profile can be extracted. The time resolution depends on the deflecting power available, the beam optics at the location of both the deflector and the beam profile monitor, and finally on the spatial resolution of this monitor [8]. With this method time resolutions of 10 fs have already been obtained [9].

An example of a bunch length measurement made at CTF3 is presented in Figure 3. The deflection is done using the 1.5 GHz standing wave cavity installed in the DL [10]. The beam is then imaged by an OTR screen and the bunch length is measured by switching on and off the RF power in the deflector. A bunch length of 6.7 ps was measured in this case.

Two RF deflectors will also be implemented at FERMI, one located after the first magnetic chicane and the second at the end of the linac. For the latter, a sophisticated set-up is foreseen to fully characterize the beam before the FEL. With two cavities providing deflection in X and Y planes, the system will measure not only the bunch length but also the slice emittance monitored by five different OTR screens. Moreover, downstream of the deflectors, a dipole followed by an additional OTR screen will be installed to measure the slice energy spread. A complete design of the system, including particle tracking simulations with the ELEGANT code is presented in [11].

NON-INTERCEPTIVE MONITORS

In FEL's, the need for peak current stabilization implies the development of non-destructive bunch length monitors. The aim is to provide reliable input signals for RF phase and amplitude feedback systems. The technique considered for this application is based on the fact that electron bunches start to radiate coherently for wavelengths which are longer than the bunch length. Therefore, by analyzing the corresponding frequency spectrum, the bunch length can be determined. Pyroelectric detectors are being developed and will be implemented in the magnetic chicane to detect coherent synchrotron radiation (CSR) and coherent diffraction radiation (CDR) as depicted in Figure 4. CSR is emitted from the last dipole of the chicane and CDR is emitted from a slit located just downstream of the chicane. For electron bunches with ps and sub-ps duration the coherent emission is in the mm/sub-mm wavelength range. The design of the system developed for FERMI is presented in [12].

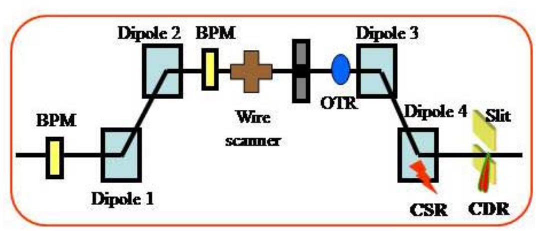

Figure 4: Magnetic chicane monitors at FERMI

The development of non-intercepting bunch length monitors is pursued also at CTF3, in particular through the use of an RF pick-up. Using a series of down-converting mixing stages and filters, the detector analyzes the power spectrum of the electromagnetic field picked-up by a single waveguide. In the present set-up, the signal amplitude and phase are measured simultaneously in four different frequency bands: 26.5-40 GHz, 45-69 GHz, 75-90 GHz and 157-170 GHz. Each signal is then digitized using ADCs with a bandwidth of 2 GHz. The system is capable of performing single shot bunch length measurements with a 300 fs time resolution. The pick-up is installed close to the RF deflector and used for cross-calibrations. Detailed results of the recent commissioning of the detector are presented in [13].

BUNCH TRAIN COMBINATION

The bunch frequency multiplication performed at CTF3 is an innovative and flexible way of producing high frequency bunched beams. It relies on the performance of the phase coding inserted in the 1.5 GHz Sub-Harmonic Bunching System (SHBS) and on the accuracy of the bunch combination in the rings using RF deflector injection.

Successfully operated since 2006, the details and the results on the SHBS can be found in [14]. In order to control the bunch interleaving, the beam time-of-flight in the ring must be precisely equal to an integer number of RF deflector periods. This is performed with a wiggler, installed in the DL, which tunes the path length of the electrons accordingly.

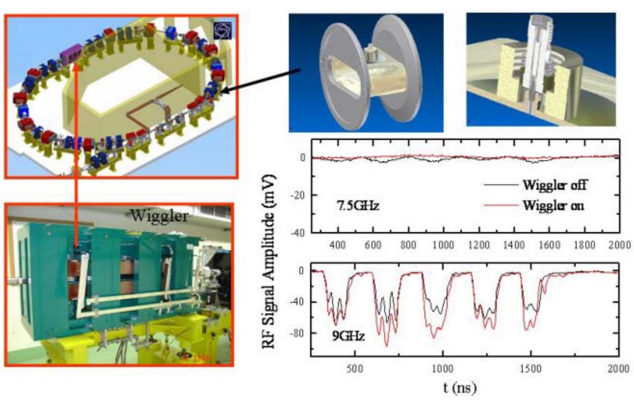

Figure 5: Bunch train combination in the Delay Loop

The bunch train combination is observed using an OTR screen located downstream the DL that is coupled to a streak camera [6] via a long optical line. For the same purpose, a non-intercepting monitor, called phase monitor, was installed close to the OTR screen for comparison and calibration. The detector is an RF antenna as shown in Figure 5, which was already tested several years ago at a previous test facility [15]. It measures the amplitude of the electromagnetic field at harmonic frequencies of 1.5 and 3 GHz. In the present design, the signal from the antenna is split into two, bandpass filtered at 7.5 and 9 GHz and finally measured by Schottky diodes. As a consequence of the bunch frequency multiplication, the signal at 7.5 GHz should disappear and the one at 9 GHz should double. As shown in Figure 5, the signal of the pick-up can be used to accurately tune the combination using different settings of the wiggler field.

CONCLUSIONS AND PERSPECTIVES

The longitudinal gymnastics performed for FELs and for the linear collider study at CTF3 present a number of similarities and rely on the development of high-quality beam diagnostic elements.

Measuring short bunches has been investigated in much detail during the past years and very sophisticated methods are now available, providing time resolutions in the sub-ps regime. To ensure the stable operation of these accelerators, a special effort has been carried out to develop simple and reliable non-intercepting devices capable of providing input signals for feedback stabilization systems.

REFERENCES

[1] E. Allaria *et al*, “FERMI@ELETTRA: A Seeded FEL Facility for EUV and Soft X-rays”, Proceeding of FEL 2006, Berlin, Gemany, pp.166

[2] H.H. Braun *et al*, “Updated CLIC parameters 2005”, CLIC note 627, (2005)

[3] G. Geschonke, “Status of the CLIC Test Facility 3 (CTF3)”, Proceeding of LINAC 2006, Knoxville, Tennessee, USA, pp.11

[4] R. Corsini *et al*, “Commissioning Status of the CTF3 Delay Loop”, Proceeding of EPAC 2006, Edinburgh, UK, pp.771

[5] C. Biscari *et al*, “CTF3: Design of Driving Beam Combiner Ring”, Proceeding of EPAC 2000, Vienna, Austria, pp.450

[6] C. Welsch *et al*, “Longitudinal Beam Profile Measurements at CTF3 Using a Streak Camera”, Journal of Instrumentation, 1, (2006), P09002

[7] Model FESCA 200 from Hamamatsu

[8] C. Welsch, E. Bravin and T. Lefevre, “Investigations of OTR Screen Surfaces and Shapes”, Proceeding of EPAC 2006, Edinburgh, UK, pp.1220

[9] P. Emma *et al*, ”A Transverse RF Deflecting Structure for Bunch Length and Phase Space Diagnostics”, LCLS-TN-00-12, (2000)

[10] A. Ghigo *et al*, “Commissioning and First Measurements on the CTF3 Chicane”, Proceeding of PAC 2005, Knoxville, Tennessee, USA, pp.785

[11] P. Craievich *et al*, “A Transverse RF Deflecting Cavity for the FERMI@ELETTRA Project”, These proceeding

[12] M. Veronese *et al*, “The Diagnostics of the FERMI@ELETTRA Bunch Compressors”, Proceeding of FEL 2006, Berlin, Germany, pp.629

[13] A. Dabrowski *et al*, “Non Destructive Single Shot Bunch Length Measurements at CTF3”, To be published at PAC 2007, Albuquerque, New Mexico, USA

[14] P. Urschütz *et al*, “Beam dynamics and First Operation of the Sub-Harmonic Bunching System in the CTF3 Injector”, Proceeding of EPAC 2006, Edinburgh, UK, pp. 795

[15] R. Corsini et al, “Experimental Results on Electron Beam Combination and Bunch Frequency Multiplication”, Phys. Rev. STAB 7, 04101, (2004)