STATUS OF THE CTF3 SYNCHROTRON LIGHT-MONITORING-SYSTEM

C.P. Welsch[1-4], E. Bravin[1], A. Dabrowski[1], T. Lefèvre[1]
[1]*CERN, Geneva, Switzerland*
[2]*University of Heidelberg,* [3]*GSI, Darmstadt, and* [4]*MPI-K, Heidelberg, Germany*

Abstract

Synchrotron radiation has proven to be a flexible and effective tool for measuring a wide range of beam parameters in storage rings, in particular information about the longitudinal beam profile.

It is today an established and widely used diagnostic method providing online measurements and thus allowing for continuous optimization of the machine performance. At the CLIC Test Facility (CTF3), synchrotron radiation is routinely used at a number of diagnostic stations, in particular in the Delay Loop and the Combiner Ring. Measurements with both standard CCDs and a streak camera showed the wide range of possible applications of this method, including determination of inter-bunch spacing, charge per pulse and monitoring of the manipulation of the effective path length by an undulator.

This contribution first addresses the critical points during the design phase of long optical lines with lengths of more than 30 meters as they had to be realized at CTF3. Second, a summary of the present installations is given and results from measurements are shown.

INTRODUCTION

CTF3 is being installed at CERN in the existing buildings of the LEP pre-injector accelerators LIL and EPA with the aim to demonstrate the technical feasibility of CLIC [1,2,3,4]. The complex starts with a 3 GHz linac that produces a pulsed electron beam with a present maximum energy of 150 MeV. The separation between individual bunches at the end of the linac is 20 cm - twice the linac RF wavelength. Moreover, the macro bunch is composed by alternated sequences 140 ns long of even and odd buckets, with the difference in phase between them being one RF wavelength.

The linac is connected by a transfer line to the Delay Loop [5] where a 1.5 GHz RF deflector deviates the odd bunch sequences to the left inside the DL and the even ones to the right, Figure 1. The DL length is 140 ns times the velocity of light c so that after this ring the odd sequence will be recombined with the incoming even sequence to fill the interleaved empty buckets. Precise adjustment of the longitudinal structure can be done with the integrated wiggler. The resulting macro bunch structure at the DL output presents 140 ns long trains of buckets separated now by 10 cm, followed by 140 ns long voids.

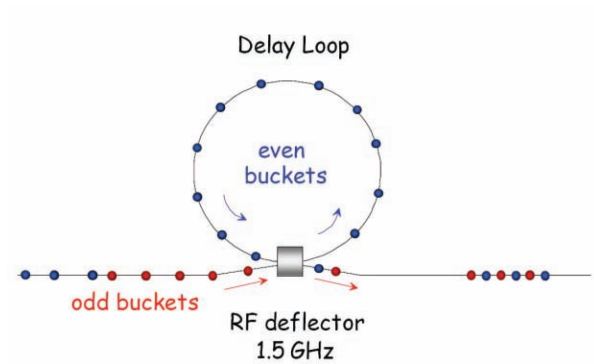

Figure 1: Schematic drawing of the injection scheme into the CTF3 Delay Loop [2].

The timing of the bunches of subsequent batches is adjusted such that they have a phase difference of 180 ° with respect to the 1.5 GHz RF of the deflector, Figure 2.

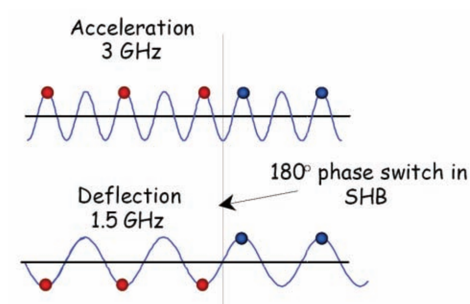

Figure 2: Illustration of required 180° phase switch between two batches of bunch trains [2].

An overview of the overall bunch combination process is shown in Figure 3. The necessary timing is controlled by the sub-harmonic bunchers working at 1.5 GHz in the injector region [6]. Every 140 ns the phase of the RF is changed by 180 degrees. This requires wide band sub-harmonic buncher structures as well as an RF power source capable of switching phase over a few bunches.

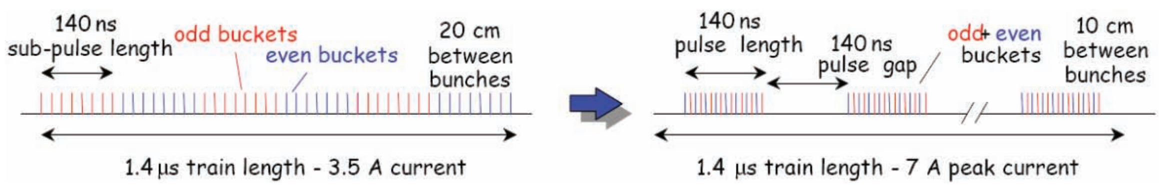

Figure 3: (x2) bunch frequency multiplication in the CTF3 Delay Loop [2].

High bandwidth travelling wave tubes (TWT) were chosen as an RF power source [7], which are pulsed giving the sub harmonic bunchers a 4 µs 40 kW RF pulse with a repetition rate of 5 Hz [8]. The voltage stability of the power supply is critical in order to achieve a phase variation on the output of the TWT that is less than 2° for a duration of 1.6 µs within the pulse. Since the beam loading is different in each of the three sub harmonic bunchers, the structures are individually detuned.

One possibility to analyze in detail the longitudinal behavior of the electron bunches in the DL as well as after the recombination process is to use a high speed streak camera with time resolutions down to a few picoseconds [9], Figure 4. In order to achieve a good time resolution, first the photons from the radiation to be analyzed are converted to electrons, which are then accelerated and deflected using a time-synchronized, ramped HV electric field. Thus the deflecting filed converts the time information into a spatial information much easier to analyze. The signal from the electrons is subsequently amplified with a micro channel plate (MCP), converted to photons via a phosphor screen and finally detected using an imager like a CCD array, which converts the light into a voltage signal.

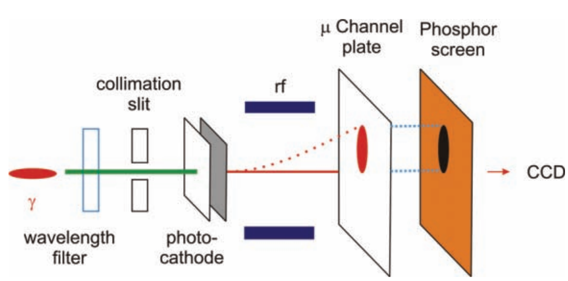

Figure 4: Principle of the streak camera.

PRESENT INSTALLATIONS

It is highly desirable to have the possibility to do time resolved measurements with a good time resolution with light originating from different places in the machine. Due to the high radiation level in CTF3 and the sensitivity of the streak camera, adequate measures have to be taken in order to protect the camera. A measurement close to the accelerator clearly is not feasible.

Thus optical lines had to be designed in order to guide the light to be observed to the streak camera. It needs to be ensured that a maximum of the created light is collected and projected onto the entrance slit of the streak camera. The distances that needed to be covered by these optical lines reached up to 40 meters and thus required a careful layout. The design steps can be summarized as follows:

- Transmission of light over large distances using telescopic arrangements, i.e. two identical lenses placed apart two times their focal length;
- Optimization of the overall system between collecting, transmitting and demagnifying optics;
- Minimization of the number of optical elements in order to maximize light transmission and reduce aberrations. Each lens will absorb about ~10% of the incident light.
- Optimization of the optical resolution. Even though (transverse) aberrations are not the most critical point in streak camera measurements, one would still like to have a final image where these are minimized.

In addition, constraints from the available space in the machine, type of lenses on hand and installations of other diagnostic equipment, using part of the optical lines in parallel, influenced the final layout of the optics to a high degree.

Further details on the design considerations, results from numerical simulations with the ZEMAX code [10], and on the optical elements used in the long optical lines can be found in [11,12].

As it is depicted in the following figure 5, synchrotron light is presently being extracted via three different viewports in the DL and via two viewports in the CR. While in the DL only one viewport is equipped with an optical line towards a streak camera laboratory (the other two being used for observation with a local CCD camera only), synchrotron light from both viewports in the CR is used for monitoring with a streak camera system and a CCD.

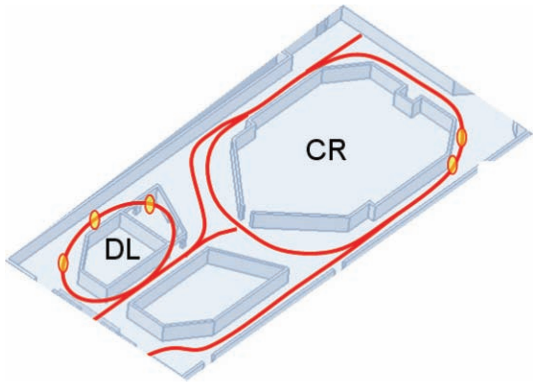

Figure 5: Synchrotron light viewports in the DL and CR.

Earlier measurements in the DL [10,11] clearly showed that the aberrations caused by the large distances between the light source and the point of observation reached a level where the quality of the measurements suffered. It was thus decided to build up a new dedicated laboratory for optical measurements in building 2012, adjacent to the CR.

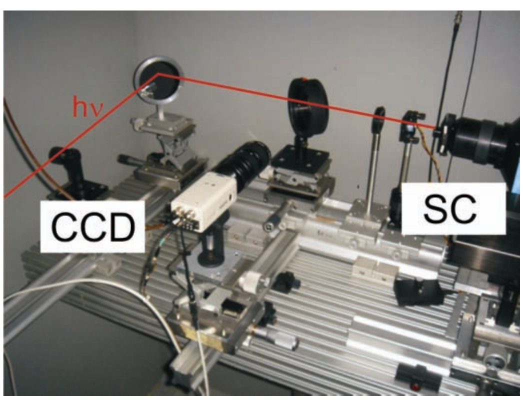

Figure 6: Setup for data acquisition in building 2012.

The two optical lines were aligned and tested early in 2008 with first results from measurements with both the Streak Camera and the CCDs being expected until end of May 2008.

MEASUREMENTS

The light from one of the synchrotron viewports in the DL as well as from an OTR screen in the transfer line between DL and CR were routinely used for beam observation in 2006 and 2007. Measurements with the streak camera allowed for determination of inter bunch separation, monitoring of the optimization of the DL track length with a wiggler, and for bunch length measurements. Some examples from measurements are shown in the following sections with more details being shown in [10].

Monitoring of RF Bunch Combination

As outlined in the beginning, the CTF3 DL is used for combining two 140 ns bunch trans with an inter bunch distance of 20 cm into a single 140 ns long bunch train where the individual bunches are 10 cm apart from each other. With one optical line monitoring the light from inside the DL and the other one from behind it, i.e. after bunch combination, the streak camera is the ideal tool for monitoring the longitudinal bunch profiles in both cases.

Measurements of bunch combination were done with a sweep speed of 250 ps/mm and an image of the measured bunch separation inside the DL is shown in the following Figure 12. The intrinsic resolution of the streak camera used for all the here-presented measurements is 0.25 ps.

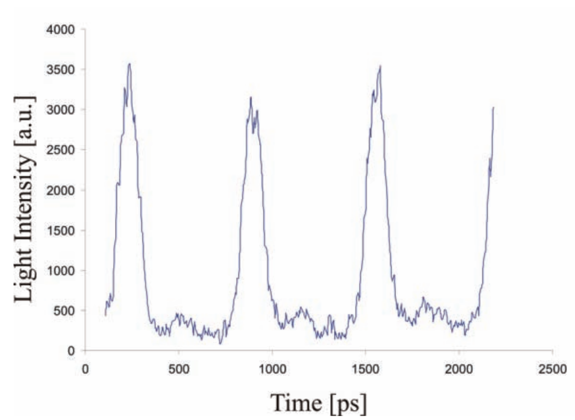

Figure 7: Measured bunch separation in the Delay Loop.

It can be seen that the train consists not only of the main bunches, but also of weaker satellite bunches of 8.5% of the main bunches' intensity. The spacing between individual bunches is 666 ps as can be extracted from the beam profile shown on the right of Figure 7.

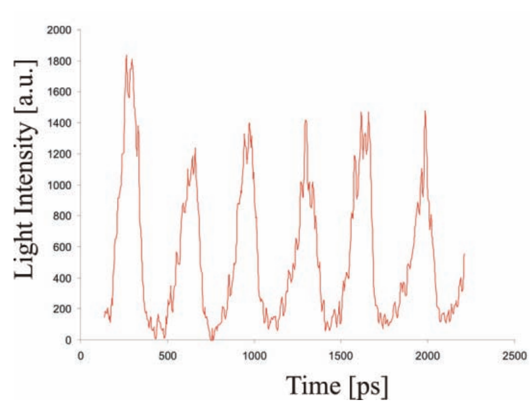

Figure 8: Measured bunch separation after RF recombination.

In a second step, the light emerging from the OTR screen at MTV0550 was used to monitor the combined bunch trains after RF deflection, Figure 8. Due to the lower transmission of the line the signal amplitude is not as high as in the previous case.

With the 1.5 GHz deflector the two bunch trains were successfully combined, resulting in a final bunch spacing of only 10 cm and double the current of the individual trains. In a future step, these trains will be further combined in the Combiner Ring [12,13] - another important step towards the demonstration of CLIC feasibility.

Track Length Modification

For the fine tuning of the machine, a compact wiggler magnet is integrated in the DL. It allows the modification of the ring circumference and thus the optimization of the timing between the two bunch trains to be combined.

In the following figure 9 the bunch from the DL is slightly off-centre the two bunches from the linac that are at a distance of 666 ps. This profile was measured with the wiggler off.

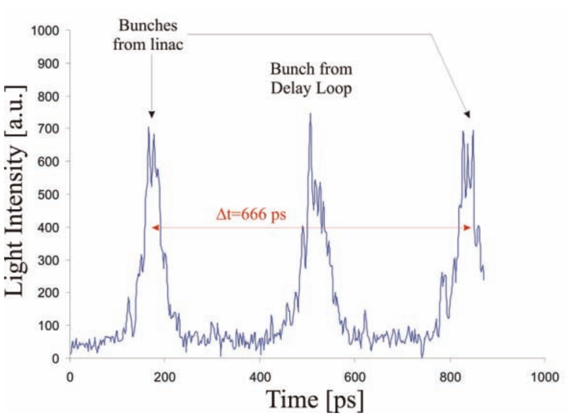

Figure 9: Measured longitudinal beam profile from MTV0550.

The wiggler was then used for optimization of the bunch spacing and an optimum value was found for a current of 62.5 A. Using the streak camera a change by 12 ps - or 3.6 mm - between the bunches was found, corresponding to about half of the total tuning range in the wiggler, Figure 10. Sweep speed in this measurement was 100 ps/mm.

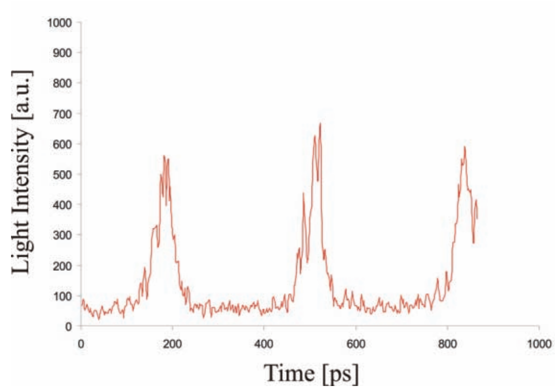

Figure 10: Measured longitudinal beam profile from MTV0550 with an initial offset time of 12 ps.

Bunch Length Measurements

When moving to the highest sweep speed of the streak camera of 10 ps/mm even bunch length measurements become feasible. Figure 11 shows measured profiles and corresponding τ-values for bunches in the DL and after the CTF3 linac for two different beam conditions.

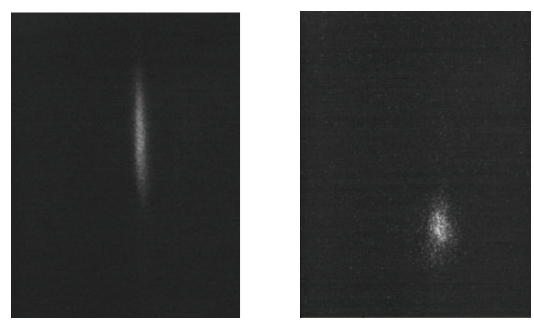

Figure 11: Measurement of single-bunch longitudinal beam profiles using the highest sweep speed (10 ps/mm) of the streak camera. Time is shown on the vertical axis. Left: Synchrotron radiation from MTV0361.
Measured σ = 8.9 ps. Right: Optical transition radiation from MTV0550. Measured σ = 4.5 ps.

This data was compared to calculations based on the optical functions of the machine and an assumed initial bunch distribution and good agreement with the measurements was found.

CONCLUSION AND OUTLOOK

The two streak camera lines installed in 2005/2006 allow in-detail monitoring of the longitudinal beam structure at CTF3. This gives access to e.g. bunch length monitoring, monitoring and optimization of the RF recombination as well as tuning of the machine with the integrated wiggler. The streak camera thus provides an ideal tool for measurements on shortest time scales.

With the new optical lines in the CR, detailed information about the longitudinal pulse structure in this ring will become available. These installations were just completed and first results from measurements are expected soon.

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