EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN – A&B DEPARTMENT

CERN-AB-2006-067

CLIC-Note-683

CTF3-Note-075

Beam Dynamics and First Operation of the Sub-Harmonic Bunching System in the CTF3 Injector

P. Urschütz, H. H. Braun, G. Carron, R. Corsini, S. Döbert, T. Lefèvre,
G. McMonagle, J. Mourier, J. Sladen, F. Tecker, L.Thorndahl, C. Welsch

CERN, Geneva, Switzerland

The CLIC Test Facility 3 (CTF3), built at CERN by an international collaboration, aims at demonstrating the feasibility of the CLIC scheme by 2010. The CTF3 drive beam generation scheme relies on the use of a fast phase switch of a sub-harmonic bunching system in order to phase-code the bunches. The amount of charge in unwanted satellite bunches is an important quantity, which must be minimized. Beam dynamic simulations have been used to study the problem, showing the limitation of the present CTF3 design and the gain of potential upgrades. In this paper the results are discussed and compared with beam measurements taken during the first operation of the system.

Presented at
EPAC'06, Edinburgh, UK,
June 26-30, 2006

Geneva, Switzerland
June 2006

BEAM DYNAMICS AND FIRST OPERATION OF THE SUB-HARMONIC BUNCHING SYSTEM IN THE CTF3 INJECTOR

P. Urschütz, H. H. Braun, G. Carron, R. Corsini, S. Döbert, T. Lefèvre, G. McMonagle, J. Mourier,
J. Sladen, F. Tecker, L.Thorndahl, C. Welsch, CERN, Geneva, Switzerland

Abstract

The CLIC Test Facility 3 (CTF3), built at CERN by an international collaboration, aims at demonstrating the feasibility of the CLIC scheme by 2010. The CTF3 drive beam generation scheme relies on the use of a fast phase switch of a sub-harmonic bunching system in order to phase-code the bunches. The amount of charge in unwanted satellite bunches is an important quantity, which must be minimized. Beam dynamic simulations have been used to study the problem, showing the limitation of the present CTF3 design and the gain of potential upgrades. In this paper the results are discussed and compared with beam measurements taken during the first operation of the system.

INTRODUCTION

One of the main goals of CTF3 [1] is the demonstration of the CLIC drive-beam bunch combination and acceleration scheme on a smaller scale. In CTF3 a long train of bunches with a bunch distance of 20 cm is converted into a series of short bunch trains, with individual bunches spaced by 2 cm. This is done in two stages, first by a factor 2 in the Delay Loop, then by a factor 5 in a Combiner Ring. In order to multiply the bunch frequency and the beam current, the bunches must be phase coded, meaning that bunches of subsequent batches have a phase difference of 180° with respect to the 1.5 GHz RF.

THE CTF3 INJECTOR

The injector [2], shown in Figure 1, consists of a thermionic gun, three 1.5 GHz sub-harmonic bunchers (SHB), an S-band pre-buncher, a tapered phase velocity travelling-wave buncher and two S-band, 1.2 m long accelerating structures. The transverse beam size control is accomplished with solenoids and the orbit is controlled with steering coils. Various diagnostic tools are used throughout the injector to aid in tuning and characterizing the electron beam from the injector.

Each of the three sub-harmonic bunchers is powered by a travelling wave tube (TWT) producing a peak RF power of 40 kW. The phase coding, necessary for the bunch frequency multiplication, is done by means of a fast phase switch of the 1.5 GHz RF of the SHB system. Every 140 ns the phase of the RF is changed by 180°. This requires wide band sub-harmonic buncher structures as well as an RF power source capable of switching over a few bunches. For this, high bandwidth TWT's were chosen as a RF power source for these cavities [3]. The TWT's are pulsed giving a 4 μs 40 kW RF pulse with a repetition rate of 5 Hz [4]. 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. According to Fig. 2 a phase stability of about 1.6° over 3 μs was reached.

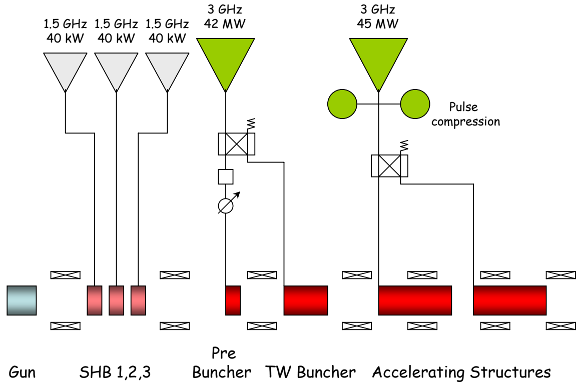

Figure 1: The CTF3 Injector.

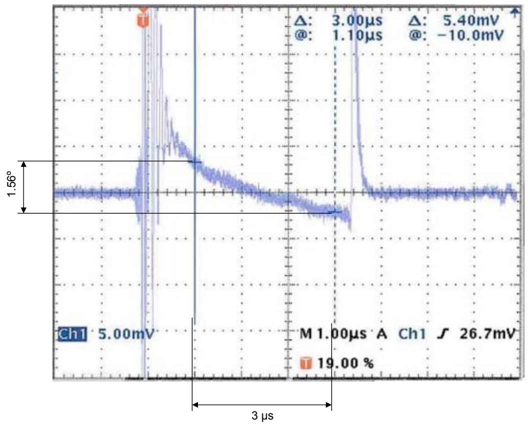

Figure 2: RF phase stability over the 4 μs pulse.

Since the beam loading is different in each of the three SHBs, the structures are individually detuned [5]. The common parameters for the SHBs are listed in Table 1.

Another important aspect is to keep the charge in the satellite S-band buckets as small as possible. For the present injector layout, PARMELA [6] simulations yielded 6 - 7% unwanted bunch charge in the satellites with respect to the main bunch. Further simulations were performed

Table 1: Common parameters of the sub-harmonic bunchers.

Quantity	Value
Frequency	1.49928 GHz
Number of cells	6
Iris diameter	66 mm
Cell length	26 mm
Input power	40 kW

with the goal to decrease this unwanted charge. One identified injector upgrade scenario would be, to swap the third SHB and the 3 GHz pre-buncher and to optimize the drift spaces between the buncher elements. According to simulations, the satellites are thus reduced to 3 - 4% of the main bunch charge.

Table 2 summarizes the main requirements for the present CTF3 drive-beam injector.

Table 2: CTF3 drive-beam injector target parameters.

Parameter	Target Value
Beam Energy	$\geq$ 20 MeV
Beam Current	3.5 A
Charge per Bunch	2.33 nC
Charge in Satellite	$\leq$ 7%
Switch Time	$\leq$ 10 ns

OPERATION OF THE SUB-HARMONIC BUNCHING SYSTEM

The first run in 2006 was dedicated to the commissioning of the CTF3 Delay Loop, hence demonstrating the bunch re-combination. For this, the sub-harmonic bunching system had to be fully operational. Before switching on the SHB system, a well defined 3 GHz beam (3.5 A beam current, 1.4 μs pulse length) was already sent to the Delay Loop.

Switching on the SHB system

The SHBs were then switched on one after each other and were operated with full power. The 1.5 GHz RF phases were adjusted with respect to the RF of the 3 GHz bunching system, by maximizing the 30 GHz signal of a RF Pick-Up located at the end of the injector. For the optimization of the second SHB, the beam loading signal at the output of the third SHB was maximized too. Optimum performance of the system was found, as expected, for an unloaded operation of the second SHB, while some beam loading in the third one further improved the transmission in the Linac and the RF Pick-Up signal.

Verification of the beam quality

The transverse beam parameters of the 1.5 GHz beam were determined at different locations in the Linac by means of quadrupole scans [7]. With the knowledge of the Twiss parameters the Linac was successfully re-matched to the Delay Loop.

Information on the longitudinal properties of the beam, like an estimate for the rise time of the phase switch and the amount of charges in the satellites, was obtained from streak camera images and Beam Position Monitor (BPM) signals. At present, two optical lines to the streak camera exist: One in the Delay Loop, where synchrotron radiation light is analysed; one after the Delay Loop, where OTR light is used.

Switch time To determine the rise time of the phase switch of the SHB system, the beam was sent straight (without going into the Delay Loop) to the final dump. Fig. 3 shows on top the image from the streak camera and below the charge profile over eight bunches. In between the first two main bunches, spaced by 666 ps, the satellite is visible. The RF phase of the SHB system then starts the 180° flip. With advancing time, the new main bunches develop at the position of the former satellites. After about eight 1.5 GHz periods the switch is completed and only the satellites remain at the position of the former main bunches. The rise time of the phase switch was therefore calculated to 5.7 ns, which satisfies the target value.

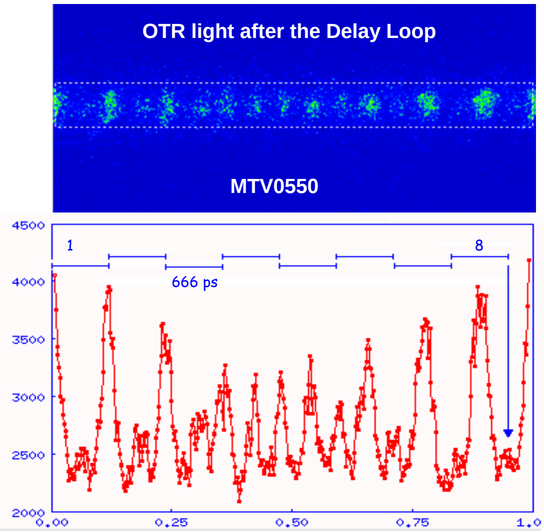

Figure 3: Streak camera image proving the fast phase switch.

Satellites The amount of unwanted charges in satellite bunches was estimated from streak camera images and the current readings from BPMs.

Fig. 4 shows the synchrotron light intensity over time acquired with the streak camera. The light intensity was integrated over the main bunch and compared to the satellites.

In this (not very precise) way, the charge in the satellites was calculated to 8.5% with respect to the main bunch.

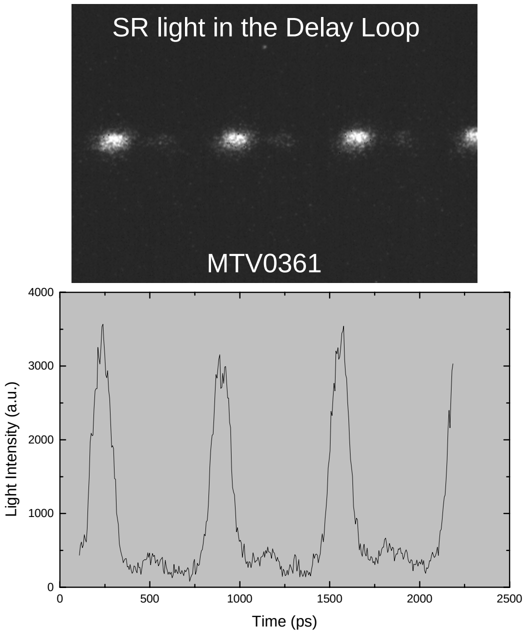

Figure 4: Streak camera image showing unwanted satellites in between the main bunches.

Fig. 5 demonstrates the successful bunch re-combination with the Delay Loop [8]. The 1.5 μs long incoming pulse is converted into a series of five 140 ns short pulses containing twice the bunch charge. Between these pulses with an average current of 5.8 A, the doubled satellite current (0.5 A) is present. The charge in the satellites was measured to 8.5%, confirming the results from the streak camera analysis. Furthermore, the satellite level is not too far from the target and simulation value.

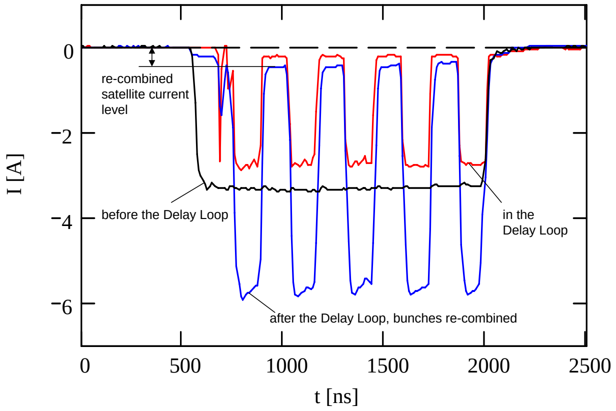

Figure 5: BPM current readings demonstrating the successful bunch re-combination with the Delay Loop.

CONCLUSIONS

The first run in 2006 of CTF3 was dedicated to the commissioning of the sub-harmonic bunching system and the Delay Loop. A fast RF phase switch of 180° is an indispensable tool in order to multiply bunch frequency and beam current. By means of a streak camera and BPM signals, the switch time was estimated to 5.7 ns and the amount of unwanted charges in satellite bunches was calculated to 8.5% with respect to the main bunch. Both results are in good agreement with the specification of the system and predictions from simulations. Furthermore, a possible injector upgrade was identified with simulations, with a potential decrease of the amount of charges in satellite bunches by about a factor 2.

REFERENCES

[1] G. Geschonke, A. Ghigo, “CTF3 Design Report”, CERN/PS 2002-008 (RF), CTF3 Note 2002-047, CERN, Geneva.

[2] A. Yeremian, R.Miller, R.Ruth, H. H. Braun, G. Geschonke, L. Groening, L. Rinolfi, L. Thorndahl, I. Wilson, F. Zhou, “CTF3 Drive-Beam Injector Design”, EPAC’02, June 2002, Paris.

[3] G. McMonagle, L. Thorndahl, “ Technical Specification for the Supply of 4 Traveling Wave Tubes (TWT’s) as a Power Source for the Sub Harmonic Buncher of the Compact Linear Collider Test facility (CTF3)”, CTF3 Note in preparation.

[4] G. McMonagle, “Technical specification for manufacture of three power supply systems to power TWT’s in CTF3”, CERN Invitation to tender IT-3287-AB/CLIC.

[5] P. Urschütz, “Parameter list of the CTF3 Linac and CT line”, CTF3 Note 071, January 2006, CERN, Geneva.

[6] James H. Billen, “Documentation of PARMELA”, LA-UR-96-1835, May, 2005, Los Alamos National Laboratory.

[7] P. Urschütz, H. H. Braun, R. Corsini, S. Döbert, A. Ferrari, F. Tecker, “Beam Dynamics Studies and Emittance Optimization at the CTF3 Linac at CERN”, MOPLS102, EPAC 2006, Edinburgh, Scotland.

[8] R. Corsini, S. Döbert, F. Tecker,P. Urschütz, C. Biscari, A. Ghigo, F. Marcellini, B. Preger, A. Stella, “Commissioning Status of the CTF3 Delay Loop”, MOPLS093, EPAC 2006, Edinburgh, Scotland.