STATUS OF THE CTF3 COMMISSIONING

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Abstract

The Preliminary Phase of the new CLIC Test Facility CTF3 consists of a low-charge demonstration of the electron bunch train combination process on which the CLIC drive beam generation scheme is based. The principle of the combination relies on the injection of short electron bunches into an isochronous ring using RF deflecting cavities. The commissioning of this facility started in September 2001, with alternating periods of installation work and beam studies. In this paper, we present the status of the facility, the first beam measurements and the next steps towards the completion of the experiment.

1 INTRODUCTION

The Compact Linear Collider (CLIC) [1] RF power source scheme is based on the production of a 30 GHz RF pulse which requires electron pulse compression and bunch frequency multiplication [2]. The goal of the new CLIC Test Facility CTF3 is to demonstrate the technical feasibility of this scheme [3]. The so-called Preliminary Phase aims at testing the bunch combination process at low charge. The principle relies on the injection of short electron bunches into an isochronous ring using RF deflecting cavities in order to achieve frequency multiplication. For that purpose, the former LEP Pre-Injector (LPI) complex at CERN has undergone major modifications to host the facility shown in Fig. 1. The first phase of the commissioning started in September 2001 and ended in December 2001, with alternating periods of installation work and beam studies.

In this paper, we describe the present status of the facility as well as the results of the first beam measurements performed during the commissioning [4, 5]. These results are compared to beam dynamics predictions [6]. Finally, the next steps towards the completion of the experiment are described.

2 COMMISSIONING WITH BEAM

2.1 The Front-End and the Linac

The new thermionic gun built by LAL ("Laboratoire de l'Accélérateur Linéaire d'Orsay") was successfully installed and commissioned [7]. This triode gun produces a train of up to seven pulses at a repetition rate of 50 Hz. The pulse length can be varied between 2 ns and 10 ns FWHM and the pulses are spaced by 420 ns, corresponding to the revolution period of the ring, as required for the bunch frequency multiplication process. Although most of the commissioning activities were performed with one single pulse, the multi-pulse operation was also successfully tested. The peak current was varied within the range of 50 mA to 1.8 A (the nominal value is 1 A).

At the exit of the gun, the bunching system produces a 3 GHz bunched beam in which each pulse is made of approximately 20 bunches for the nominal pulse length of 6.6 ns FWHM. The beam energy at the exit of the bunching system was measured using a steering magnet and a beam position monitor (BPM) located downstream and was about 5 MeV [5], as expected.
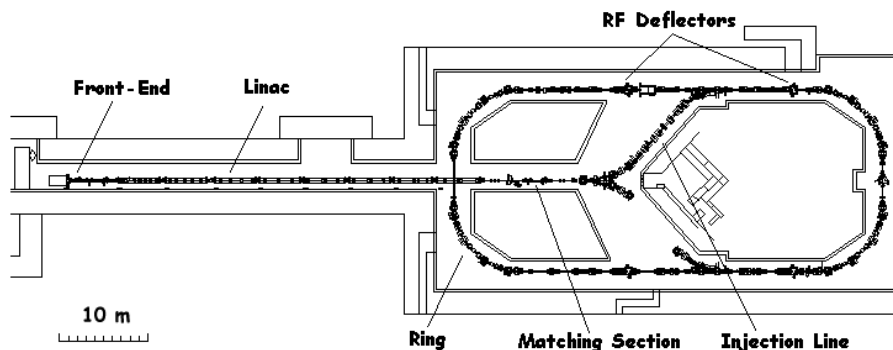

Figure 1: General layout of the CTF3 Preliminary Phase.

The linac is made of eight travelling wave accelerating structures which are powered in groups of four by two 45 MW klystrons. The design energy at the end of the linac is 350 MeV, but the machine was usually operated around 330 MeV, ensuring more stable klystron operation. Quadrupole scans were performed along the linac [5] in order to determine the Twiss parameters and the emittances ($\epsilon_{x,y} \simeq 15$ mm mrad normalised rms). The stability and the reproducibility of the machine were checked by comparing different series of measurements performed on different days, which gave similar results. These results were compared to MAD simulations [8] with a fairly good agreement (Fig. 2), which confirms the reliability of the linac model.
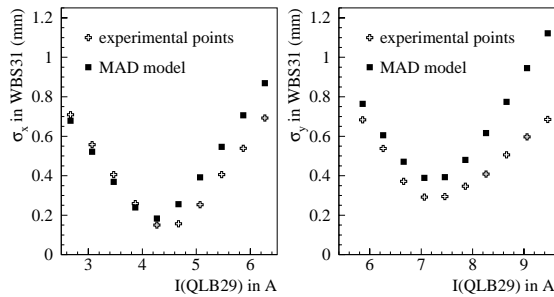
Figure 2: Transverse quadrupole scans in the linac: horizontal and vertical beam sizes versus quadrupole current.

In order to achieve the combination process with RF deflectors, electron bunches shorter than 6.5 ps rms are required. Two methods were used to measure the bunch length at the end of the linac. The first one makes use of a streak camera to analyse the light emitted from a Cherenkov screen located in the matching section (Fig. 3). For the nominal charge of 10^{10} electrons per pulse, the smallest measured value was 4.2 ps rms [5].
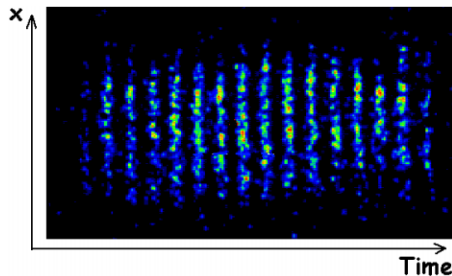
Figure 3: Streak camera image of one pulse at the end of the linac (nominal length of 7 ns FWHM).

The second method is based on the measurement of the energy spread as a function of the accelerating phase in the linac [9]. The data match the simulated energy spread for a Gaussian bunch length of 3 ± 0.3 ps rms [5] (Fig. 4). The two values are consistent when assuming a resolution of about 3 ps for the streak camera.
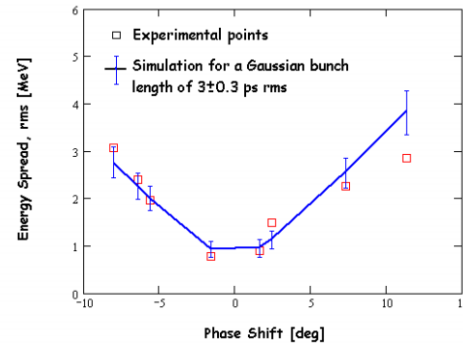
Figure 4: Bunch length measurement at the end of the linac: energy spread versus RF phase.

2.2   The Injection Line

The design optics of the injection line is isochronous at first order to avoid direct bunch lengthening between the linac and the ring. The dispersion matching also requires that the line be achromatic. Precise dispersion measurements were performed in the injection line, in order to check the consistency of the experimental dispersion pattern with the nominal optics [5]. Fig. 5 shows the measurement points in the horizontal plane (three cameras, one BPM and one secondary emission monitor), and the curve given by the MAD model for the experimental settings. The agreement between the model and the measurement is very good, although these settings were not optimal for the longitudinal matching (non-zero dispersion at the end of the line).
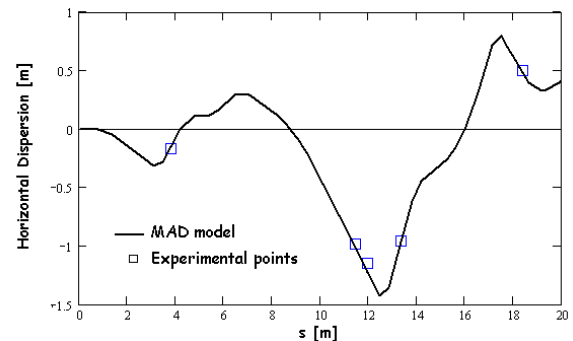
Figure 5: Horizontal dispersion measurement in the injection line.

2.3   The Ring

Two different optics were tested in the ring: the isochronous optics (the momentum compaction α is zero) which is the nominal optics for the combination process, and a non-zero alpha optics used to accumulate higher intensity beams in the ring to perform beam optics studies.

The isochronous optics was easily set-up. Fig. 6 shows the signal of a BPM in the ring during the tests of the isochronous optics. Significant losses occur at the first turns: they are probably due to a bad matching between the injection line and the ring.

With the isochronous optics, the synchrotron radiation light was transported to a streak camera where a constant bunch length was measured over the first 20 turns, thus confirming that the optics was close to isochronicity. However, the bunches were longer than expected even at the first turn (close to 12 ps rms). This is probably due either to a non-isochronous injection line or to a residual second order momentum compaction, resulting from the wrong polarity of the horizontal sextupole family (found afterwards), as suggested by simulations.
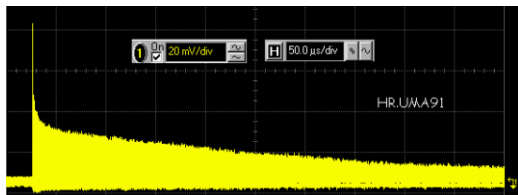

Figure 6: Beam intensity signal in the isochronous ring as a function of time (more than 1000 turns). Initial losses are visible. Further losses are due to the synchrotron radiation energy loss (the RF cavity is off).

The accumulation mode required some optimisation work to improve the injection efficiency and minimise the losses during the first turns. Eventually, a total of 4×10^{11} particles were accumulated with one bucket filled out of eight, thus allowing beam measurements.

The closed orbit of the ring was measured at various frequencies. Fig. 7 shows the measured closed orbit difference as a function of position s for a change in frequency from 19.084525 to 19.086814 MHz (black points). This difference is proportional to the dispersion in the ring. The agreement with the curve calculated with MAD using the experimental quadrupole currents (dashed curve) is not very good. However, the measurement could be well reproduced by the model when increasing the current of one quadrupole family by 13% (solid curve). This inconsistency has to be further investigated.
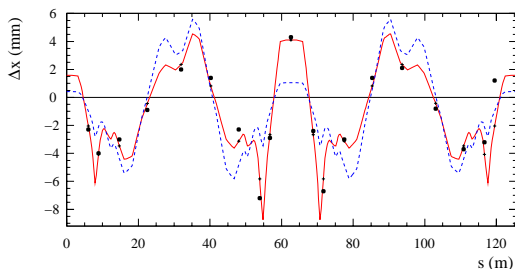

Figure 7: Dispersion measurements in the ring. See text for details.

Preliminary tune measurements were performed in the ring. Unfortunately, the model fails to reproduce the experimental values of the tune and more data are needed to understand this discrepancy.

The former LPI positron injection line was transformed into an electron extraction line. The extraction process using the former positron septum and injection kicker with a new timing was successfully tested, with an efficiency close to 100%.

3 NEXT STEPS TOWARDS THE BUNCH FREQUENCY MULTIPLICATION

The next major step towards the completion of the bunch combination experiment is the use of the RF deflectors to inject the beam. During the first phase of commissioning described above, the RF deflectors were not yet in place. Their installation and the connection to the RF network took place during the 2001-2002 shut-down period. Before using the deflectors, some important beam studies must be performed: dispersion measurements in the injection line and in the ring to check isochronicity, transverse measurements in the ring for transverse matching at injection, streak camera measurements in the ring to study the bunch length. For that purpose, the kickers were kept in place, thus allowing conventional injection into the ring.

4 CONCLUSION

The new CLIC Test Facility CTF3 is now in operation at CERN. During the first phase of the commissioning, the beam measurements showed a good agreement with the analytical estimates and the numerical simulations, although the ring optics has to be better characterised with further measurements. With the recent installation of the RF deflectors, all conditions are fulfilled to perform the RF injection and the bunch frequency multiplication.

5 ACKNOWLEDGEMENTS

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