CTF3 COMBINER RING COMMISSIONING

F. Tecker*, R. Corsini, S. Döbert, P. Skowronski, P. Urschütz, CERN, Geneva, Switzerland
E. Bressi, CNAO, Milano, Italy
C. Biscari, A. Ghigo, INFN, Frascati, Italy
A. Ferrari, Uppsala University, Sweden

Abstract

The CLIC Test Facility 3 (CTF3) has the objective to demonstrate the remaining feasibility issues of the CLIC two-beam technology for a future multi-TeV linear collider.

One key issue is the efficient generation of a very high current 'drive beam' that serves as the power source for the acceleration of the main beam to high energy. This large current beam is produced by interleaving bunches in a combiner ring using transverse deflecting RF cavities.

The 84 m long CTF3 combiner ring and the connecting transfer line have been recently installed and put into operation. The latest commissioning results will be presented.

INTRODUCTION

The aim of the CLIC (Compact Linear Collider) study is to demonstrate the feasibility of a high luminosity, multi-TeV linear e+ e- collider [1]. The CLIC design is based upon normal-conducting accelerating structures operating at a very high gradient (100 MV/m) at an RF frequency of 12 GHz, using a two-beam-acceleration concept [2]. A high current electron beam (drive beam) runs parallel to the main beam and is decelerated to generate the RF power. The production of the high-intensity drive beam pulses with the right time structure is one of the main challenges in CLIC.

Initially, a long electron beam pulse is accelerated in a low frequency normal-conducting linac. Funnelling techniques in delay lines and rings are subsequently used to obtain the desired structure while increasing the beam intensity. Transverse RF deflectors interleave the bunches, hence the bunch spacing is reduced and the beam current is increased. The principle of this bunch train combination by transverse RF deflectors in a ring has been already demonstrated at low current [3] (this reference also describes the principle in detail).

Several critical issues still need to be addressed to demonstrate the CLIC technology. The experimental program of the CLIC Test Facility (CTF3) [4] addresses the main issues, i.e., the generation and use of the drive beam and the testing of high frequency structures and components, with the goal of demonstrating the CLIC feasibility before 2010, when the first LHC results should be available.

CTF3 is presently being built and commissioned at CERN by an international collaboration, including 22 institutes from 11 different countries.

* tecker@cern.ch

The facility is situated in the buildings of the former LEP pre-injector complex, whose hardware is partly re-used, and is designed to work at a lower beam current and a lower energy than the CLIC drive beam (4 A at 150 MeV instead of 5.2 A at 2.4 GeV). It includes a 70 m long drive-beam linac followed by two rings, where the bunch train combinations will be carried out: a 42 m delay loop and an 84 m combiner ring. After such manipulations the drive beam will have a current of 30 A and will be transported to an experimental area to produce 12 GHz RF power for structure tests. In the same area, another linac will provide a main beam for a CLIC two-beam module and a test decelerator will be used for drive beam stability studies.

In 2003-2004 the injector, the linac, a mid-linac power station and an end-of-linac magnetic chicane with variable momentum compaction factor were installed and commissioned. The installation of the delay loop, under full responsibility of INFN-LNF (Italy), was completed during 2005. The commissioning of the delay loop has been essentially completed in May 2006. The first stage of the bunch combination was successfully demonstrated [5].

During autumn 2006, the transfer line TL1, linking the delay loop to the combiner ring was constructed and an essential part of the combiner ring installation took place. Fig. 1 shows the layout of TL1 and the combiner ring.

Since not all components were available for the instal-

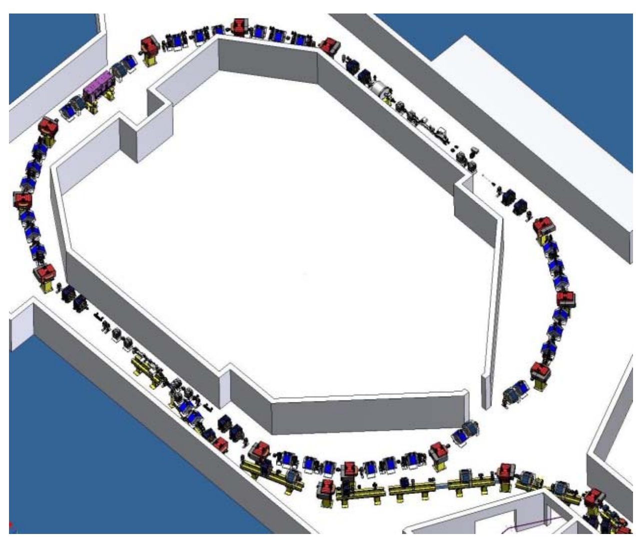

Figure 1: Layout of the TL1 transfer line and the combiner ring. The beam arrives after the delay loop (not visible) from the bottom right into TL1.

lation, the whole ring could not be completed but the injection region and a measurement line after the first bend were installed. The injection region includes the transverse RF deflector needed for the bunch train combination, the measurement line contains a screen for optics studies and a beam dump.

The combiner ring installation was continued after a short commissioning run for TL1 (see below). The ring was finished including a short extraction line opposite the injection area by March 2007 except for a number of beam position monitors that were not yet available. These were finally installed during two weeks in April, together with modifications on the front-end electronics of the BPMs.

TRANSFER LINE TL1

2006 Run

The initial commissioning period of the transfer line TL1 in 2006 was only three weeks with an effective beam time of about 80 hours. During this time, the delay loop was bypassed, and short pulses of 3 GHz beam with up to 200 ns length and a current of 3.5 A were used for the commissioning. The beam energy was about 125 MeV. To keep radiation levels low, the whole commissioning was performed with a repetition rate of only 0.8 Hz.

The commissioning started on 21 November. Already on 23 November, the beam was transported to the end of the line with the nominal isochronous optics, only using trajectory steering. After some optimization, a current of 3 A could be injected into the combiner ring. The first injections were done by using dipole corrector magnets to bring the beam on the closed orbit, but the nominal injection with the transverse RF deflector could be established quickly afterwards with the same transmission.

Dispersion measurements were performed by scaling all magnet currents in the line by up to $\pm 1\%$ (see Fig. 2). The dispersion pattern measured agreed very well with the calculated dispersion for the first part of the line but there were some differences in the injection region at the end. Quadrupole scans for Twiss function determination were performed at the beginning of the line. The line was rematched for the measured initial conditions and a quadrupole scan was performed at the end of the line. The

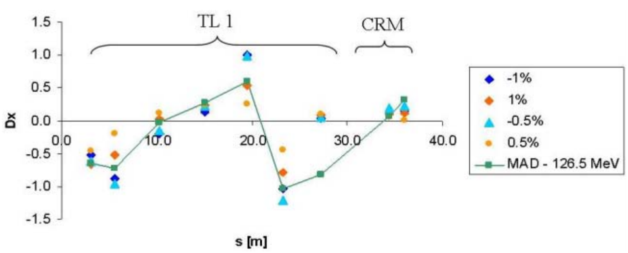

Figure 2: Dispersion measurement in TL1 and ring injection region. (The difference at the end of TL1 (s=27 m) is due to a defective pick-up.)

measured rms emittances were all in the range of 40 – 80 π mm mrad in both planes (100 π mm mrad nominal). The measured Twiss values differed somewhat from the MAD optics model expectations (as for the dispersion) indicating that there could be an error in the model description or problems with a quadrupole magnet in the line.

2007 Run

A short, 7 day run was scheduled initially at the beginning of April. The goal was to transport the beam to the combiner ring and make a turn in order to discover main obstacles and identify problems which have to be solved in the subsequent two week installation period. During this time, no particular emphasis was put on TL1.

During the last commissioning period starting at the end of April, the line was again rematched based on quadrupole scans at the beginning of the line. The beam could be transported through the line and injected into the combiner ring without problems. Still further measurements will be required to verify the proper functioning of the line in agreement with the optics model.

COMBINER RING

During the short initial 2007 run, it was envisaged to make a turn in the combiner ring. The beam could be transported half way through the ring to the extraction line with about 25% losses. It was difficult to obtain this transmission and the optics was not the design optics but empirically optimized. Due to the short time, no further studies could be performed.

After the two week installation break in April, another 10 weeks of commissioning are scheduled. The final objective for this period is the demonstration of the bunch recombination in the combiner ring by a factor 4. The first step was to establish full transmission in the ring over several turns with a 3 GHz beam, bypassing the delay loop. A first way of achieving circulating beam is by using a short RF pulse in only the transverse RF deflector that directs the injected beam on the closed orbit. When the RF pulse is stopped just after the passage of the injected beam, the RF field is not present any more when the beam returns after one full revolution and the injection is similar to an injection by a kicker.

Since the beam losses in the second arc persisted, the quadrupole currents were verified and it was found that the control cables for two of the quadrupole families in this region of the ring had been swapped.

Unfortunately, the commissioning was interrupted for almost two weeks due to a vacuum leak in the CTF3 linac that could only be repaired after a waiting time to allow for radiation level decay. When the commissioning restarted, it was still difficult to pass the beam through. The best result could be obtained with a beam optics that had one of the arc quadrupole families switched off, and the beam made up to three turns with losses. Following these results, it was decided to re-check the quadrupole polarities again. This had been previously done but no control was made after inverting the magnets that had had a wrong polarity. Indeed, it was found that one quadrupole (from the family that was off in the best-performing optics) in the region with losses had the wrong polarity.

After having corrected the polarity, it was possible to get the beam circulating with the nominal isochronous optics. Initially, the beam was lost over about 10 turns. Eventually the ring could be optimized such that after some losses over the first turns, the remaining beam was circulating up to 180 μs, corresponding to more than 600 turns.

While the setting up so far was done with a 3 GHz beam, a 1.5 GHz beam is required for the nominal recombination. When putting the 1.5 GHz subharmonic bunching (SHB) system in operation (only 2 of the 3 SHB cavities could be used due to a failure of a travelling wave tube), the same transmission could be immediately be obtained after optimization of the different cavity phases.

After achieving reasonable transmission, the pulse length of the transverse RF deflector was extended so that the RF field is still present after one turn. With the correct path length in the combiner ring, the beam should arrive at the zero-crossing of the RF field so that the beam is not deviated by the deflector. The geometry of the combiner ring was carefully chosen in the design, taking into account the path length in the arc dipole magnets, calculated based on the measured field distribution. A wiggler magnet in the ring allows a fine tuning of the path length within a total range of 9 mm.

The wiggler magnet current was changed and the beam was observed in the second turn after the deflector. A good transmission and trajectory could be obtained for a relatively low current of the wiggler. This shows that the length of the combiner ring has been designed correctly and that the correct path length for a combination by a factor four is experimentally accessible.

With the correct path length in the ring it is possible to obtain a combination by a factor two. A beam pulse of twice the combiner ring time of flight (2 x 280 ns) is injected with the RF deflector field on during this time. The bunches of the first 280 ns pass the RF deflector at the zero-crossing after one turn and are combined with the next 280 ns of incoming beam, increasing the beam intensity. Fig. 3 shows the result of this first combination by a factor two. The beam current could be increased from 3.5 A to about 6.5 A.

Beam losses are still present over the first turns and will have to be further minimized. The next steps will be to adjust the second RF deflector in amplitude and phase to produce a time-dependent local closed orbit bump in the injection region. This will make the nominal combination by a factor four possible. Furthermore, optics and dispersion studies of the ring will be performed. Finally, the first stage of combination by a factor two in the delay loop has to be set up again to demonstrate the nominal combination by a factor eight, when both the delay loop and combiner ring operate nominally.

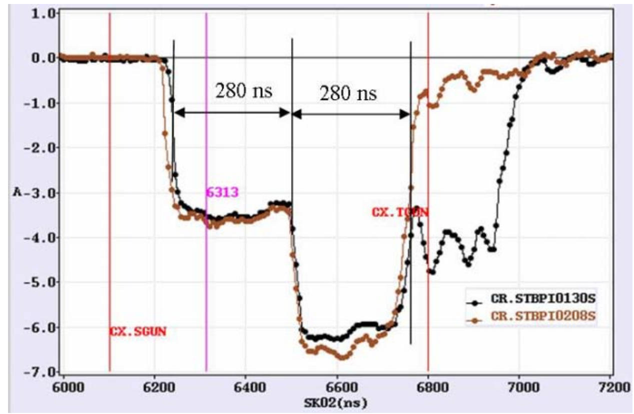

Figure 3: First recombination in the Combiner Ring. The traces show the beam current measured by 2 beam position monitors. The incoming beam pulse has twice the length of the CR (2 x 280 ns). During the second 280 ns, the bunches are interleaved with the bunches that made one revolution in the ring.

CONCLUSIONS

Beam through the newly installed transfer line TL1 could be quickly established with good transmission at the end of 2006. The CTF3 combiner ring commissioning has been ongoing since end of March 2007 with some interruptions for further installation work and due to equipment failures.

It took a certain time to set up properly circulating beam because of undetected errors in the quadrupole magnet cabling. After fixing these, a reasonable beam was finally obtained and a first preliminary bunch train combination by a factor two could be demonstrated.

Further optics and combination studies will continue in the following weeks of the running period, to confirm and extend the first observations with the goal to show the nominal bunch train combination with delay loop and combiner ring.

REFERENCES

[1] The CLIC Study Team (edited by G. Guignard), “A 3 TeV e+/e- Linear Collider Based on CLIC Technology”, CERN Report 2000-008

[2] H. Braun, R. Corsini (Ed.), “The CLIC RF Power Source: a Novel Scheme of Two-Beam Acceleration for Electron-Positron Linear Colliders”, CERN 99-06 (1999)

[3] R. Corsini et al., “Experimental Results on Electron Beam Combination and Bunch Frequency Multiplication”, Phys. Rev. ST Accel. Beams 7, 040101 (2004)

[4] G. Geschonke and A. Ghigo (Eds), “CTF3 Design Report”, CERN/PS 2002-008 (RF)

[5] R. Corsini et al., “Commissioning Status of the CTF3 Delay Loop”, EPAC ’06, 2006

