CERN – EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CLIC – Note – 897

THE CLIC FEASIBILITY DEMONSTRATION IN CTF3

P.K.Skowroński, J.Barranco, S.Bettoni, R.Corsini, M.Divall Csatari, A.E.Dabrowski, S.Doebert,
A.Dubrovskiy, O.Kononenko, M.Olvegaard, A.Rabiller, F. Tecker, (CERN, Geneva),
Wilfrid Farabolini (CEA/DSM/IRFU, Saclay),
T. Persson (CERN, Geneva; Chalmers University of Technology,
Gothenburg), R.L.Lillestol (CERN, Geneva; NTNU, Trondheim),
E.Adli (University of Oslo, Oslo), A.Palaia, R.Ruber, (Uppsala University, Uppsala)

Abstract

The objective of the CLIC Test Facility CTF3 is to demonstrate the feasibility issues of the CLIC two-beam technology: the efficient generation of a very high current drive beam, used as the power source to accelerate the main beam to multi-TeV energies with gradients of over 100 MeV/m, and stable drive beam deceleration. Results of successful beam acceleration with over 100 MeV/m energy gain are shown. Measurements of drive beam deceleration over a chain of Power Extraction Structures (PETS) are presented. The achieved RF power levels, the stability of the power production and of the deceleration are discussed. Finally, we give an overview of the remaining issues to be addressed by the end of 2011.

Presented at: 2nd International Particle Accelerator Conference, San Sebastian, Spain, 4 - 9 Sep 2011

Geneva, Switzerland
Date 15/09/2011

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN – ACCELERATOR AND TECHNOLOGY SECTOR

CERN-ATS-2011-177

THE CLIC FEASIBILITY DEMONSTRATION IN CTF3

P.K.Skowroński, J.Barranco, S.Bettoni, R.Corsini, M.Divall Csatari, A.E.Dabrowski, S.Doebert,
A.Dubrovskiy, O.Kononenko, M.Olvegaard, A.Rabiller, F. Tecker, (CERN, Geneva),
Wilfrid Farabolini (CEA/DSM/IRFU, Saclay),
T. Persson (CERN, Geneva; Chalmers University of Technology,
Gothenburg), R.L.Lillestol (CERN, Geneva; NTNU, Trondheim),
E.Adli (University of Oslo, Oslo), A.Palaia, R.Ruber, (Uppsala University, Uppsala)

Abstract

The objective of the CLIC Test Facility CTF3 is to demonstrate the feasibility issues of the CLIC two-beam technology: the efficient generation of a very high current drive beam, used as the power source to accelerate the main beam to multi-TeV energies with gradients of over 100 MeV/m, and stable drive beam deceleration. Results of successful beam acceleration with over 100 MeV/m energy gain are shown. Measurements of drive beam deceleration over a chain of Power Extraction Structures (PETS) are presented. The achieved RF power levels, the stability of the power production and of the deceleration are discussed. Finally, we give an overview of the remaining issues to be addressed by the end of 2011.

CERN-ATS-2011-177
15/09/2011

THE CLIC FEASIBILITY DEMONSTRATION IN CTF3

P.K.Skowroński, J.Barranco, S.Bettoni, R.Corsini, M.Divall Csatari, A.E.Dabrowski, S.Doebert, A.Dubrovskiy, O.Kononenko, M.Olvegaard, A.Rabiller, F. Tecker, (CERN, Geneva), Wilfrid Farabolini (CEA/DSM/IRFU, Saclay), T. Persson (CERN, Geneva; Chalmers University of Technology, Gothenburg), R.L.Lillestol (CERN, Geneva; NTNU, Trondheim), E.Adli (University of Oslo, Oslo), A.Palaia, R.Ruber, (Uppsala University, Uppsala)

Abstract

The objective of the CLIC Test Facility CTF3 is to demonstrate the feasibility issues of the CLIC two-beam technology: the efficient generation of a very high current drive beam, used as the power source to accelerate the main beam to multi-TeV energies with gradients of over 100 MeV/m, and stable drive beam deceleration. Results of successful beam acceleration with over 100 MeV/m energy gain are shown. Measurements of drive beam deceleration over a chain of Power Extraction Structures (PETS) are presented. The achieved RF power levels, the stability of the power production and of the deceleration are discussed. Finally, we give an overview of the remaining issues to be addressed by the end of 2011.

INTRODUCTION

The CLIC study aims to provide a design of a multi-TeV electron-positron collider [1]. The demonstration of its feasibility is carried out with the help of the CLIC Test Facility (CTF3) [2], in particular the generation and use of the high-current drive beam [3]. CTF3 was built at CERN by an international collaboration, which at present includes 41 institutes from 21 countries [4]. A detailed description of the facility can be found in [2,5].

CTF3 generates the drive beam from a 1.5 μs long electron pulse of 5 A intensity, see Figure 2. The injector, which includes a 1.5 GHz sub-harmonic bunching system, produces bunches spaced by 20 cm, twice the acceleration wavelength. Afterwards, bunches are compressed by a four bend chicane where off-energy electrons are also stopped by collimation slits. A pulse of 4 A intensity is injected into the linac and accelerated to about 120 MeV. Later, bunches are stretched by a chicane. The 42 m long Delay Loop (DL) converts the train to four 140 ns pulses of twice higher current, see Figure 2. They are transferred to the Combiner Ring (CR) where they are recombined producing a single 140 ns long pulse of eight times the intensity in the linac.

The CTF3 experimental area (CLEX) contains two lines where the beam is decelerated and 12 GHz power is produced. One is the Test Beam Line (TBL), where stable deceleration over several structures is studied. The other one is the Two-Beam Test Stand (TBTS), which provides power to accelerate the probe beam delivered by the CALIFES linac.

During previous runs, several feasibility issues of the CLIC design had already been shown and published: fully loaded acceleration with RF to beam efficiency of 95.3%, bunching with phase coding, bunch length control and beam recombination factor 8. The remaining issues are: 12 GHz RF power production with CLIC nominal pulse length (140 ns) and power level (135 MW), probe beam acceleration with a gradient of 100 MeV/m and stable deceleration.

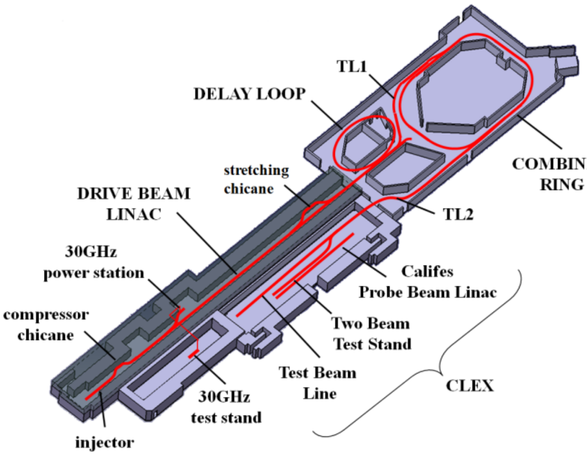

Figure 1: Layout of CTF3

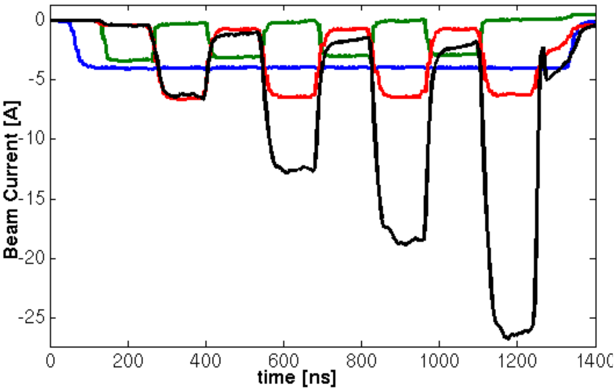

Figure 2: The beam current along the pulse at different parts of CTF3: blue – end of linac, green – in the DL, red – in between DL and CR, black – in the CR.

THE DRIVE BEAM

During recent runs the reproducibility and stability of the drive beam was significantly increased. This was possible thanks to development of specialized control and software tools monitoring all available signals. They permitted the most important sources of the beam drifts to be spotted. The acquired knowledge triggered development of adequate feedback systems, e.g. temperature of various RF systems [6], the gun current and the flatness of the compressed RF pulses. Additionally, the RF scheme for the drive beam was improved in the beginning of the 2010 run. The RF power compression mechanism introduces an inevitable phase variation of parabolic shape along the pulse with an amplitude of 7-10 degrees. In the previous setup, this led to bunch length, phase and energy variations along the pulse that made the beam optimization difficult. Since this year, the RF power compression is adjusted to give identical phase variation for all klystrons, and variable phase shifters controlled by arbitrary waveform generators are used to shape the phase variation of the bunching system to match the one from the RF power compression. This way the energy and also the bunch length along the pulse are constant. The variation of the bunch phase can be corrected with the help of the stretching chicane and appropriate energy modulation along the pulse in the last accelerating cavities.

STABLE BEAM DECELERATION AND RF POWER PRODUCTION

The Test Beam Line (TBL) was set up to verify the CLIC decelerator concept, and the main purpose is to produce 12 GHz RF power and to demonstrate the stability of a heavily decelerated beam [7]. It consists of 8 FODO cells, and will eventually house 16 PETS which will extract 55 % of the beam energy. The design power produced per PETS is up to 139 MW. So far, 4 PETS have been installed and commissioned. The maximum achieved RF power has been 55 MW, for a beam current of 19 A. The PETS power scales as $P \propto F^2(\lambda)\ I^2$, where $F(\lambda)$ is the charge distribution form factor and I is the beam current.

The energy lost by the beam in the deceleration process can be calculated from the produced power, which in turn can be also inferred from the beam current. The deceleration is also measured directly in spectrometers with time resolution located at the beginning and the end of the TBL. Figure 3 contains a comparison between the three methods, which show a good agreement when the power measurements are scaled down by 10% which is within the uncertainty of the measurements. The current of the combined main pulse amounted to 18 A, preceded by satellites. A form factor of 0.85 was used for the prediction, consistent with recent bunch length measurements in CLEX.

The TBL has also been used as a diagnostic for the bunch combination in CTF3, by comparing BPM readings and RF measurements to estimate the form factor variation along the pulse [8]. Estimations over a large number of pulses, as well as phase signals, have been used to optimize the combination.

The quadrupoles in the FODO lattice are mounted on mechanical movers with a precision of 5 µm [9]. These have been used to investigate beam-based alignment techniques and steering algorithms including dispersion-free steering [10].

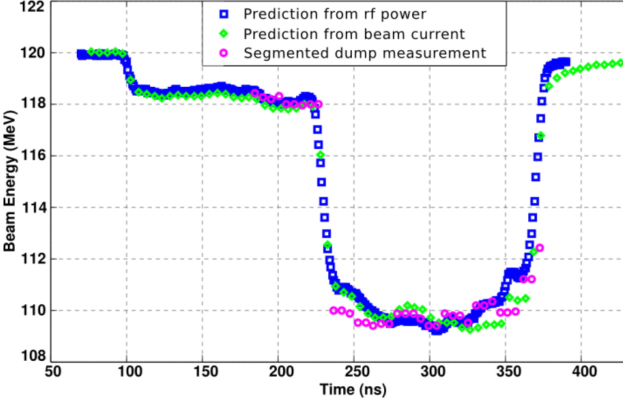

Figure 3: Measured deceleration in the spectrometer and predictions from the beam current and the PETS RF power.

TWO BEAM ACCELERATION

The Power Extraction Structure in the Two Beam Test Stand is longer than the TBL ones and is equipped with an RF power recirculation loop, thus allowing power levels up to and beyond 150MW, even with lower than nominal drive beam current.

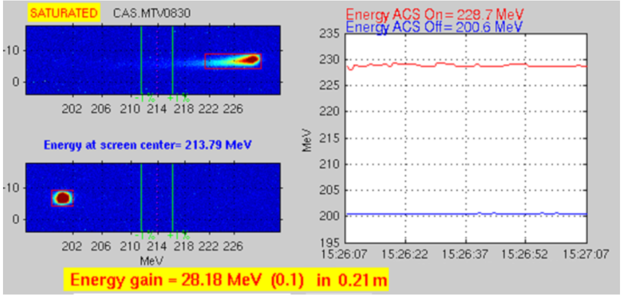

Figure 4: Screenshot of online acceleration measurement in the Two Beam Test Stand

The probe beam delivered by the CALIFES injector has 190-200 MeV kinetic energy and a bunch charge of 0.12 nC. Its energy is measured with help of an optical transition radiation monitor placed in spectrometer line at the end of the line. Its repetition rate is twice that of the drive beam and in this way the energy gain from the two beam acceleration is measured in a truly online manner, see Figure 4.

Already in 2010 we have achieved an acceleration of 100 MeV/m. However, the required power levels were considerably higher than expected. A detailed examination of the structure revealed that the frequency of the accelerating cavity was 10 MHz too high due to accidental mechanical stress experienced during its assembly. Over the last winter shutdown the cavity was re-tuned and its performance was validated during the last run, reaching an energy gain of 150 MeV/m. Figure 5 shows measured acceleration versus input power of the structure, together with the predicted curve. We believe that the observed discrepancy is mainly due to imperfect accuracy of the RF power measurements. Other possible sources for a lower gradient are drive-beam/probe-beam synchronization and phase but these were carefully optimized.

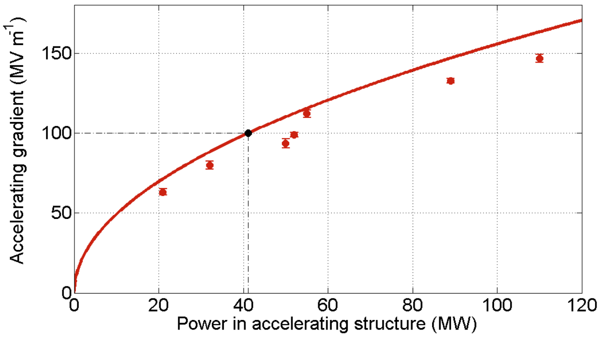

Figure 5: Accelerating gradient as function of measured RF power. The line represents the theoretical curve.

Figure 6 presents the measured break down rate as a function of accelerating gradient. The repetition rate of the beam is only 0.8 Hz at present in CTF3 therefore the structure processing is much more aggressive in CTF3 compared to a klystron driven experiment. As a consequence this kind of data can't be easily compared and only an upper limit can be determined form the CTF3 experiments. The total conditioning time in CTF3 is equivalent to less than 24 hours of a klystron based processing at 60 Hz. The CLIC study managed to demonstrate breakdown rates below 3 10^{-7} corresponding to the CLIC target value after more than 1000 hours of processing at 60 Hz [11].

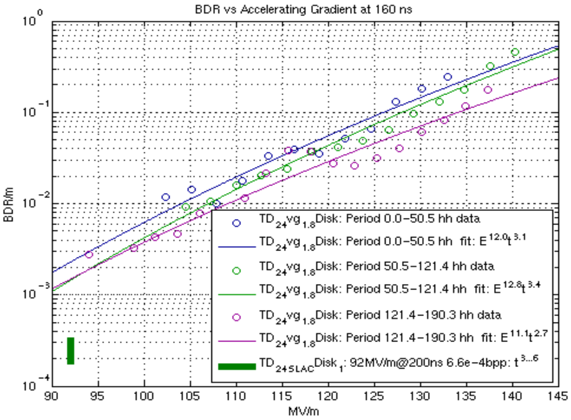

Figure 6: The break down rate versus accelerating gradient measured in the Two Beam Test Stand of CTF3

CONCLUSIONS AND OUTLOOK FOR FUTURE

CTF3 has already shown most of the feasibility issues of the drive beam generation scheme. Fully loaded acceleration is routinely used since 2004. The bunch length is well controlled. Stable acceleration with the nominal CLIC gradient of 100 MV/m was accomplished and maximum gradients of 150 MV/m were reached. The dependence of acceleration as a function of delivered RF power is in very good agreement with the predicted curve.

We have plans to continue the CTF3 operation at least until 2016. TBL will be equipped with a total of 12 PETS before the 2012 run, and up to 16 structures shall be installed before the end of 2012. This will allow for more detailed beam deceleration studies. Eventually, the produced RF power will be used to condition and test the accelerating structures. Full-fledged CLIC modules will be installed in the TBTS area in order to validate their design with beam measurements. A prototype of the phase feed forward system will be used to demonstrate the phase stabilization concept to the precision needed in CLIC. A dedicated monitor will measure the phase of the beam at the end of the linac. A fast kicker system located in the transfer line between CR and CLEX will then correct eventual phase jitter. This should also improve the operational stability of the facility.

REFERENCES

[1] G.Guignard (Ed.), "A 3 TeV e+e- linear collider based on CLIC technology", CERN 2000-008, 2000.

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

[3] R.Corsini (Ed.), "The CLIC RF power source", CERN 99-06, 1999.

[4] http://clic-meeting.web.cern.ch/clic-meeting/CTF3_Coordination_Mtg/Table_MoU.htm

[5] R.Corsini et al., "Experimental studies on drive beam generation in CTF3", Proc. EPAC'08.

[6] A.Dubrovskiy, F.Tecker, "RF pulse compression stabilization at the CTF3 CLIC test facility", Proc IPAC'10.

[7] E.Adli, Ph.D. Thesis, University of Oslo, Oslo, 2009

[8] R.Lillestol, M.Sc. Thesis, Norwegian University of Science and Technology, Trondheim, 2010.

[9] F. Toral et al., "Design, manufacturing and tests of a micrometer precision mover for CTF3 quadrupoles", Proc. EPAC'08

[10] E.Adli, D.Schulte, "Beam-Based Alignment for the CLIC Decelerator", CERN-AB-2008-013, EPAC08,

[11] T. Higo et al., 'Various observables of the TW accelerator structures operating in 100 MV/m or higher at X-band Facility, NEXTEF of KEK', IPAC 2010, Kyoto, Japan.