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EXPERIMENTAL VERIFICTION OF THE CLIC TWO-BEAM ACCELERATION TECHNOLOGY IN CTF3

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Abstract

The Compact Linear Collider international collaboration is pursuing an extensive R&D program towards a multi- TeV electron-positron collider. In particular, the development of two-beam acceleration technology is the focus of the CLIC test facility CTF3. In this paper we summarise the most recent results obtained at CTF3: the results of the studies on the drive beam generation are presented, the achieved two beam acceleration performance is reported and the measured breakdown rates and related observations are summarised. The stability of deceleration process performed over 12 subsequent modules and the comparison of the obtained results with the theoretical expectations are discussed. We also outline and discuss the future experimental program.

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The Compact Linear Collider international collaboration is pursuing an extensive R&D program towards a multi-TeV electron-positron collider. In particular, the development of two-beam acceleration technology is the focus of the CLIC test facility CTF3. In this paper we summarise the most recent results obtained at CTF3: the results of the studies on the drive beam generation are presented, the achieved two beam acceleration performance is reported and the measured breakdown rates and related observations are summarised. The stability of deceleration process performed over 12 subsequent modules and the comparison of the obtained results with the theoretical expectations are discussed. We also outline and discuss the future experimental program.

INTRODUCTION

A leading contender for the next generation of high energy lepton colliders, the Compact Linear Collider [1] (CLIC) is one of the two machine designs being pursued by the many international partners of the Linear Collider Collaboration. Integral to the verification of many aspects of the CLIC design is the work carried out at the CLIC Test Facility [2] (CTF3) located at CERN. In particular, a drive beam complex consisting of a 120 MeV e^- linac followed by a stretching chicane, a 42 m Delay Loop (DL) and an 84 m Combiner Ring (CR) is used to generate a high-current drive beam using a system of bunch frequency multiplication and pulse compression. This drive beam is then transported to the CLIC Experimental Area (CLEX) where it is used as a source of 12 GHz RF power.

A 3 GHz, 4 Amp beam from the linac, initially 1.5 μs long, can be injected directly in the CR using 3 GHz transverse deflecting RF cavities. Here it is stacked to produce a 12 GHz pulse of 16 Amps and 280 ns duration. This mode of operation is referred to as factor 4 combination.

Alternatively, a sub-harmonic bunching system may be used to reduce the linac bunch frequency to 1.5 GHz. By coding the beam phase with a series of 180° phase shifts, 140 ns sections of the pulse may be alternately injected or allowed to bypass the DL. On exiting the DL, the delayed sections interleave with those sections bypassing. This results in a train of four 140 ns sub-pulses, separated by 140 ns, with a current of some 8 A and a 3 GHz bunch frequency. These four sub-pulses are then stacked in the CR before extraction to CLEX, where the final 12 GHz pulse is 140 ns long. The typically expected combined current is around 28 A before transport, since some fraction of the charge is lost to satellite bunches in the unused RF buckets. This is similarly referred to as factor 8 combination.

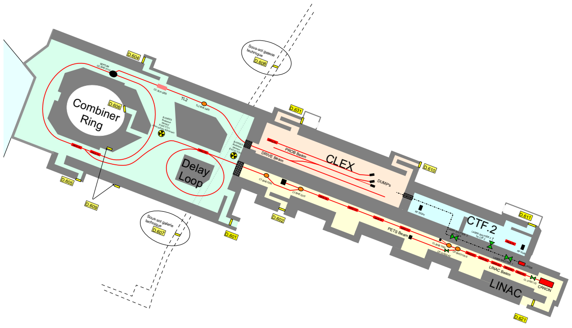

Figure 1: Layout of the CTF3 complex at CERN.

In CLEX, 12 GHz RF power is extracted from the drive beam using resonant Power Extraction and Transfer Structures (PETS). The drive beam may be directed to one of two beamlines: the Test Beam Line [4] (TBL) or the Two-Beam Test Stand [5] (TBTS). In TBL the stability of the drive beam under deceleration is assessed experimentally, and the produced RF power is compared to theoretical models. Two-beam acceleration studies are carried out in the TBTS, which is also served by a 200 MeV injector (CALIFES) to be used as a probe beam. RF power from the PETS is fed into two accelerating structures in the probe beam line.

STATUS OF DRIVE BEAM GENERATION

Recent drive beam studies have included the addition of software feedbacks to help improve beam stability and the commissioning of new stretching chicane optics to allow control of bunch length and beam phase. By careful closure of the CR orbit, it has also been possible to achieve emittances in both planes close to the design value of 150 πμm

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for a factor 4 combined beam

New feedback tests

Unlike at CLIC, CTF3 relies on klystron pulse compression to generate the RF power necessary to accelerate the drive beam to 120 MeV. RF pulses of 5.5 µs are compressed down to around 1.5 µs using resonant cavities, increasing peak power by a factor of 2 to over 30 MW. This necessarily introduces a phase sag into the linac RF, which by design is transferred to the beam phase in such a way as to maintain constant acceleration along the beam pulse. In addition, despite temperature stabilisation of the compression cavities and RF phase feedback loops, this procedure has an adverse impact on the beam stability in both energy and phase. Two new feedbacks have been implemented to combat these effects.

In the first, a feedback loop is closed between a beam phase monitor at the end of the linac and the phase of the second 3 GHz bunching cavity. As the phase of the beam is seen to drift with respect to a more stable local oscillator, the beam bunching is adjusted to compensate. This ensures a more static working point against which to tune the rest of the machine, with the resulting improvement in beam phase at the end of the linac shown in figure 2 (a).

The second feedback loop is closed between the horizontal position read from the first dispersive BPM in the transfer line to the CR, and the power of the compressed RF fed to the last two accelerating cavities in the linac. Energy drifts leading to position drifts in the dispersive pickup are thus compensated, giving a factor 2 improvement in stability as shown in figure 2 (b).

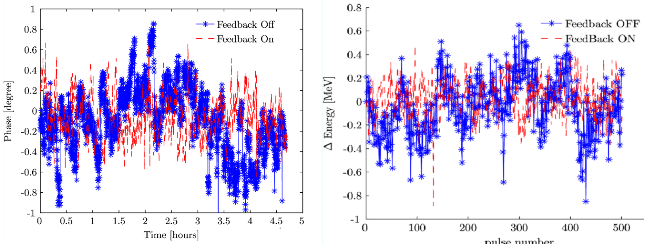

Figure 2: Effect of injector phase (a) and beam energy (b) feedbacks.

Control of the stretching chicane R_{56}

In previous runs, the stretching chicane at the end of the linac has been operated in its 'natural' state, with quadrupoles within the chicane off and with $R_{56} = 0.45$. In this configuration, an increase in RMS phase variation along the pulse of around a factor 5 was observed. Energy variations are coupled to beam phase by the large R_{56} value. Two new sets of optics were designed, with $R_{56} = 0.2$ and $R_{56} = 0$, to help control this effect, and the improvement is clearly visible in the data of figure 3 [3]. The new optics are also expected to affect the bunch length, though streak camera measurements have not yet been conclusive and require further study. The chicane is now regularly operated with a low R_{56}.

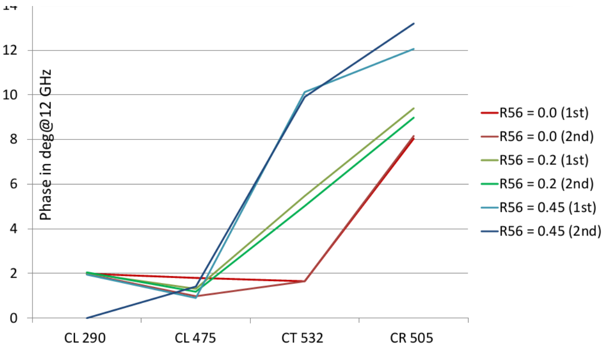

Figure 3: Growth in RMS phase variation for different chicane R_{56} values.

Factor 8 combination

One outcome of the drive beam generation studies has been an increase in maximum current obtained by factor 8 combination to 25 Amps, with a good current stability along the pulse. Figure 4 shows the current over the four successive turns in the CR during such operation as measured in a BPM. The second half of each turn shows the current lost to satellite bunches due to imperfect subharmonic bunching, in this case around 4 Amps. CTF3 has 3 sub-harmonic bunchers each driven by a separate 1.5 GHz travelling wave tube (TWT), yet so far only 2 have been operated simultaneously. This has been due to limited TWT availability. It is anticipated that with 3 TWTs available, the satellite current will be reduced and the maximum current achieved likewise increased.

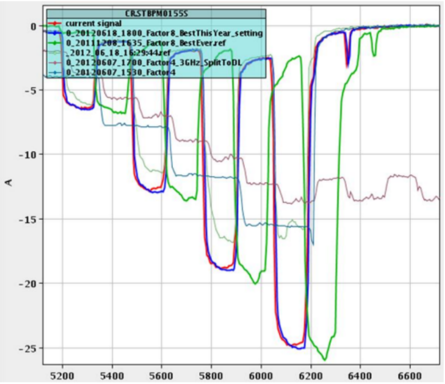

Figure 4: CR current over 4 turns during factor 8 combination.

STATUS OF THE TBL EXPERIMENT

Since the number of PETS in TBL was increased to 12 in the summer of 2012, a factor 4 combined beam has been successfully decelerated by 25% from 125 MeV. The decelerated beam was stably transported along the entire beam

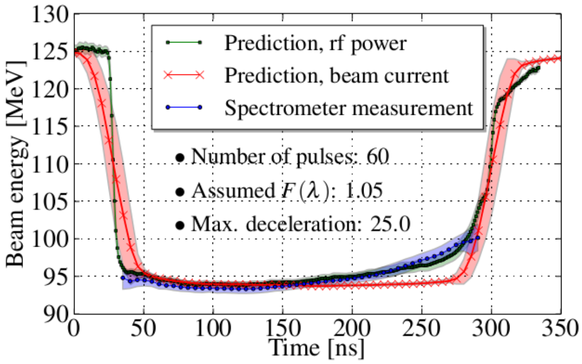

Figure 5: Beam energy along the factor 4 pulse at the end of TBL along with theoretical predictions. Coloured bands represent measured standard deviations

line to dump, and the final energy compared to theoretical predictions. See [4] in these proceedings for further details. Figure 7 shows the energy along the pulse as measured in a spectrometer at the end of TBL, along with the predictions from beam current and produced RF power. In the near future, the experiment will be repeated with a higher beam current using a factor 8 combined beam.

STATUS OF THE TBTS EXPERIMENT

Two accelerating structures are now installed in the TBTS and powered from a single PETS. With the nominal accelerating gradient (100 MV/m), the energy gain experienced by the probe beam will be 43.4 MeV for an input power of 42.2 MW each. Accurate checks of the structures' acceleration have been made for various powers and phases, and the performance is very close to expectation.

Concerning the breakdown rate, the structures are still in their very first period of conditioning. However, the location of the particular cell where breakdowns occur is quite evenly distributed for both structures. Conversely, the previous structure tested in the TBTS presented a hot spot around cell number 6 [5].

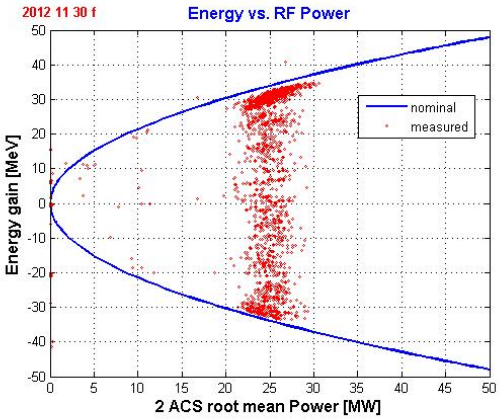

Figure 6: Measured probe beam energy gain vs. RF power for various relative phases. Predicted curves are shown for in phase and in antiphase acceleration.

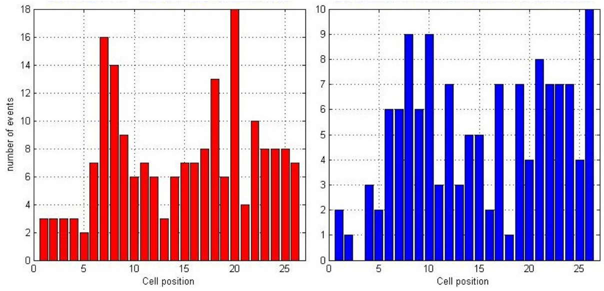

Figure 7: Frequency of recorded breakdowns in each cell of the two TBTS accelerating structures.

FUTURE PROGRAM

In addition to the consolidation of the drive beam development studies discussed here through software automation, and the demonstration of stable deceleration of a factor 8 beam through 12 PETS, there are several additional studies planned at CTF3 in the coming months.

In the TBTS, the two new structures will be conditioned with drive beam RF and the breakdown rates measured. Two-beam acceleration experiments with a factor 8 beam will be performed, and new instrumentation to measure the drive beam wakefield tested.

A dogleg halfway down the linac allows the drive beam to be directed to the CTF2 experimental hall, where a test accelerating structure has been installed. This structure is being driven by a 12 GHz X-Band klystron [6]. By delivering a 1 Amp beam from the linac, the intention is to compare breakdown rates in the cavity with and without beam loading.

Finally, a novel phase feed-forward system has been designed to correct the beam phase profile and jitter. First tests of this system are foreseen for the summer of 2013, and further details may be found in [7] in these proceedings.

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