PROGRESS TOWARDS THE CLIC FEASIBILITY DEMONSTRATION IN CTF3

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Abstract

The objective of the CLIC Test Facility CTF3 is to demonstrate the key feasibility issues of the CLIC two-beam technology: the efficient generation of a very high current drive beam and its stable deceleration in 12 GHz resonant structures, to produce high-power RF pulses and accelerate the main beam with an accelerating gradient of 100 MV/m. The construction and commissioning of CTF3 has taken place in stages from 2003. Many milestones had already been reached, including the first demonstration at the end of 2009 of a factor 2 x 4 re-combination of the initial drive beam pulse, thus reaching a beam current of 28 A. In this paper we summarize the commissioning highlights and the issues already validated at the earlier stages. We then show and discuss the latest results obtained, in view of the completion of the CLIC feasibility demonstration due for the end of 2010.

INTRODUCTION

The CLIC technology [1] is believed to be the only possible path to multi-TeV colliders. The experimental program of the present CLIC Test Facility (CTF3) [2] aims to confirm its feasibility, in particular the generation and use of the high-current drive beam [3].

CTF3 is built at CERN by an international collaboration, which at present includes 38 institutes from 19 countries [4]. Its construction is nearly completed and it is being commissioned. The facility re-uses buildings and most of the hardware of the former LEP Pre-Injector, LPI (see Figure 1). The detailed description of the facility can be found in [2,5].

A 5 A, 1.5 μs long electron pulse of is drawn from the gun. The injector, which includes a 1.5 GHz subharmonic bunching system, produces bunches spaced by 20 cm, twice the acceleration wavelength. A non-negligible current is captured in parasitic satellite bunches. Due to the unavailability of one of the three 1.5 GHz power sources, in the 2009 run satellite bunches contained about 12% of the total charge, rather than 7-8% as measured in past runs. Afterwards, the bunches are compressed by a four bend chicane where off-energy electrons are also cut by collimation slits, to get rid of the low energy tails and of the initial 0.1 μs transient of the train, which has higher energy. As a result, a 1.4 μs long train of 4 A is injected into the linac and accelerated to about 120 MeV. Later, bunches are stretched by a chicane where the transient is cut again. The 42 m long Delay Loop (DL) converts the train to four 140ns 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 bunches can be compressed again in the transfer line to the CLic EXperimental area (CLEX). 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 many structures is to be verified. The other one is the Two-Beam Test Stand (TBTS), which provides power to accelerate the probe beam delivered by the CALIFES linac.

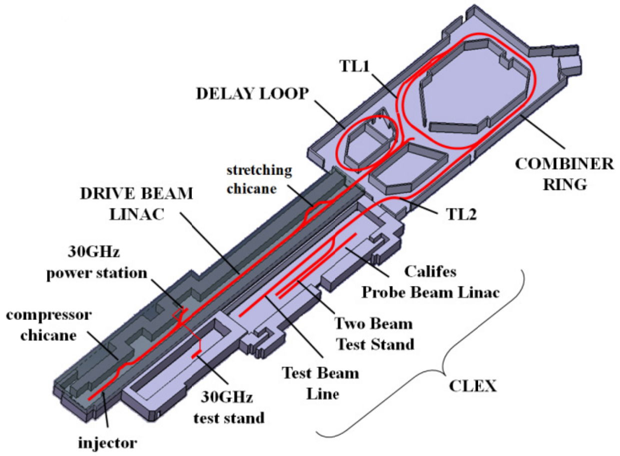

Figure 1: Layout of CTF3.

During previous runs, several feasibility issues of the CLIC design had been already shown and published: fully loaded acceleration with RF to beam efficiency of 95.3%, bunching with phase coding, bunch length control, beam recombination factor 2 with the DL and factor 4 with the CR. The remaining issues were: beam recombination factor 8 with DL and CR together, stable deceleration, 12 GHz RF power production of at least 135 MW, and probe beam acceleration with a gradient of 100 MeV/m.

BEAM RECOMBINATION

Recombination in the DL and CR alone were commissioned in 2005 and 2008, respectively. During early fall 2009, recombination with the DL and CR together was put in place. Figure 2 shows the beam intensity along the pulse as it is measured at different positions of CTF3: the current at the end of the linac (4 A), inside of the DL (3.3 A) and the current in the transfer line to the CR (6.6 A). The beam current in the DL is significantly lower compared to the end of the linac mainly due to the satellite bunches that are separated at injection to the DL. They are visible as the non-zero current observed before the peaks in Figure 2. The black line in Figure 2 shows the fully recombined pulse.

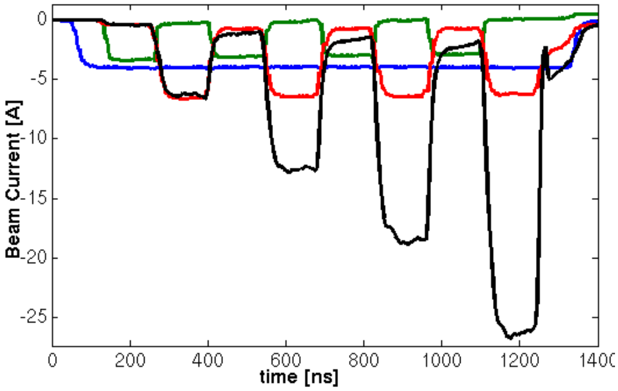

Figure 2: The beam current along the pulse at different parts of CTF3: blue – end of linac, green – inside the DL, red – TL1, black – inside the CR.

Figure 3 shows streak camera images of the recombined beams in the CR. The upper image is taken just after injection. The next three images show consecutive stages of the recombination. Detailed analysis of the streak camera images [7] revealed that bunches going around the DL are longer than the ones bypassing it. A wide set of detailed optics measurements was performed at the end of the run, which lead to a likely explanation of this effect: insufficient control of the DL dispersion. This finding will be verified at the beginning of the 2010 run, when a corrected optics is applied.

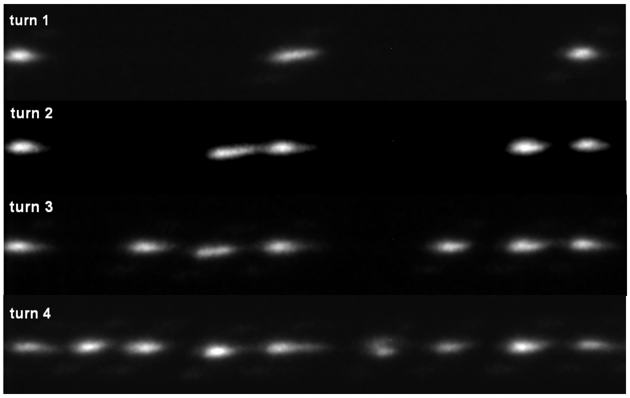

Figure 3: Streak camera images from the CR at different phases of the recombination.

The current stability of the combined beam is also an important point for the feasibility demonstration. The measured current stability is summarized in Table 1. The beam recombined with the CR only (factor 4, with the DL bypassed) reveals very small variations, while such variations are four times larger for the fully recombined beam. We believe that these variable losses are due to an imperfect matching between the DL and CR optics and orbits, including the error in the DL dispersion mentioned above. A more careful setting, to be studied at the beginning of next run, should increase the acceptance and improve the stability up to the same level of the DL or CR alone.

Table 1: Beam stability at different positions: behind the compressor chicane, in the CR for recombination factor 4, after the DL and in the CR for recombination factor 8.

Position	Mean [A]	Std. Dev. [A]	Variation [%]
Compressor	-4.078	0.005	0.13
CR (x4)	-15.097	0.038	0.25
DL	-6.277	0.014	0.22
CR (x8)	-25.210	0.254	1.01

During previous runs large beam energy jitter and drifts were observed. First, it was found that the gun electronics was unstable and could create up to 0.1 A pulse to pulse current variations, which in case of fully loaded on-crest acceleration translates to an energy jitter of over 1 MeV. The responsible hardware was replaced and the situation largely improved.

An energy drift was also observed, created by a slow variation of a few degrees of the RF power phase. Stabilisation based on a feed-back loop on the klystrons was put into operation and reduced of the slow phase variation down to around 0.5 degrees (rms). The short term relative energy jitter originating from RF is presently evaluated (based on RF measurements) to be about $0.6 \cdot 10^{-3}$.

Additionally, we periodically observed slow deterioration of the compressed RF pulses that badly influenced the beam quality. It was found to be caused by the ambient temperature drift around the pulse compression cavities. The temperature stabilization of those cavities is currently based on constant average temperature of input and output coolant. It is a sufficient solution if the temperature in the klystron gallery is kept stable. However, in CTF3 this is not the case during hot days, when the outside temperature exceeds 30 centigrade's and dramatically falls down during nights. A temperature feed-back that takes to the account the temperature inside the klystron gallery will be put in operation during 2010 run. More details on this topic can be found in [8].

TRANSPORT TO CLEX, TBTS AND TBL

The transfer line from the CR to CLEX is not yet fully commissioned. Beam was transported to the CLEX drive beam lines, but always with some losses. In the case of the fully recombined beam, these were as high as 60%. Equally, bunch lengthening and emittance growth were observed. The line commissioning was made more difficult by periodical malfunctioning of BPM readout system. Initial problems were partly solved, but radiation damage of the local DAQs was eventually observed, and it was decided to replace the system with a more standard one, used in the rest of the machine, which is much more reliable but more expensive. In spite of these problems, a pulse with up to 10A intensity was delivered for experiments in CLEX. The beam was successfully transported through both experimental lines: TBTS and TBL.

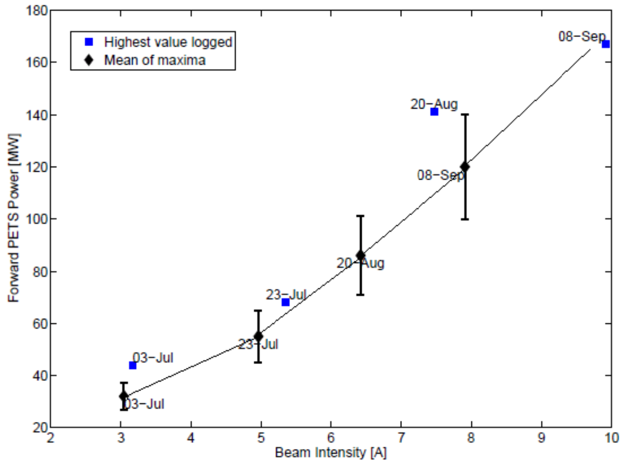

Figure 4: Time evolution of beam generated RF power.

The evolution of the power produced by the power generation structures (PETS) in TBTS is presented in Figure 5. The achieved value of 170 MW (peak) is well above the CLIC nominal one of 135 MW. This structure is equipped with a power recirculation loop which enabled us to achieve those power levels with 10 A, 280 ns beam pulse. The results are in very good agreement with the simulation. However, performance was limited by pulse shortening at high power levels, see Figure 5. At 280 ns pulse length, power production was stable only up to 80-90 MW peak power. Pulse shortening is caused by breakdowns occurring in the RF components of the recirculation loop outside the decelerating structure: a phase shifter and a variable attenuator. It became clear from the detailed analysis of the produced RF signals and it was confirmed by the visual inspection after those elements were removed and disassembled. New elements were fabricated with special cleaning procedure and heat treatment, to improve their high power performance.

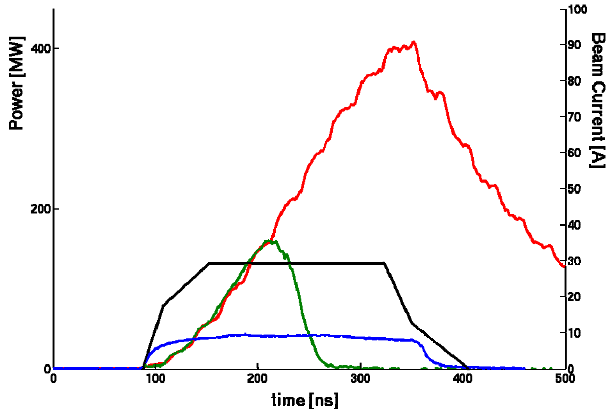

Figure 5: Example RF pulse produced in the PETS at TBTS during which a breakdown occurred. Blue line – beam current, green – measured RF power, red – the power expected from simulation. Black line shows the nominal CLIC pulse.

Additionally, a new less aggressive conditioning procedure of the system was prepared and will be applied during the 2010 run.

In the line for deceleration studies, TBL, only the first PETS structure was installed during 2009 run. The 10 A beam generated 20 MW of RF power in this PETS structure, which also follows expectations. Beam was transported to the end of the line without major problems.

During the 2009 run CALIFES (the probe beam photo-injector) was successfully commissioned. It delivered a 140 MeV beam with nominal bunch charge (250 pC) and normalized rms emittance (20 π mm·mrad). The beam was successfully transported to the end of the line. It delivered beam of sufficient quality to TBTS.

CONCLUSIONS AND OUTLOOK FOR FUTURE

CTF3 has already shown most of the feasibility issues of the drive beam generation schema. Fully loaded acceleration is routinely used since 2004. The bunch length is well controlled. During the last run, full bunch train combination 2x4 was achieved and stably operated over a few months, although the beam quality delivered to the decelerating structures needs to be improved. The power extraction cavities performance is on the expected level and exceeded the CLIC peak power requirement. The remaining issues were identified and will be addressed. Optimization of the machine in view of performance and stability has begun.

During next year we expect to achieve the two remaining major steps: two beam acceleration tests in TBTS and stable drive beam deceleration over several structures in TBL.

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