# ACHIEVEMENTS IN CTF3 AND COMMISSIONING STATUS

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*Abstract*

The aim of the latest CLIC test facility CTF3, built at CERN by an international collaboration, is to prove the main feasibility issues of the CLIC two-beam acceleration technology. Several of the main goals have been already achieved in the past years, like the full-loading linac operation mode and the delay loop principle. During 2008 also the combiner ring concept has been experimentally proven and the recombined beam has been used to generate the RF power. In parallel in the fall of the year also the probe beam line commissioning had started.

## CTF3 LAYOUT

The CLIC technology, based on the two-beam acceleration scheme [1], is believed to be the only practical strategy to build a multi-TeV e+/e- collider. To prove the feasibility of this scheme several tests facilities have been built at CERN by an international collaboration. The schematic layout of the most recent one, CTF3 (CLIC Test Facility 3), is shown in Fig. 1.

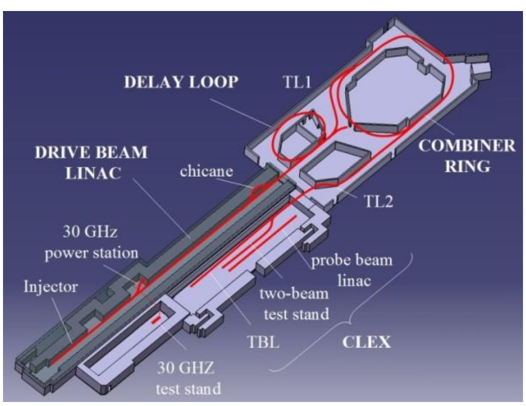


Figure 1: Schematic view of the CTF3 layout.

A 70 m long linac is followed by a 42 m delay loop (DL) and an 84 m combiner ring (CR), used to multiply the current by a factor 2 and 4, respectively. The high current beam (almost 30 A for 140 ns pulse length) is then transported through a tuneable $R_{56}$ transfer line into the CLic EXperimental area (CLEX), where two lines were fully installed in 2008 and another one will be completed at mid-2009. In the Test Beam Line (TBL) the stability of the drive beam during the deceleration will be experimentally characterized and in the Two Beam Test Stand (TBTS) the 12 GHz RF power is produced by the Power ExTraction Structures (PETS). In the same area the probe beam, which corresponds to the CLIC main beam, produced and accelerated in the CALIFES injector, will be accelerated further by 12 GHz high-gradient structures. A more detailed description of the machine can be found in [2].

## DRIVE BEAM COMPLEX

The commissioning of the different areas of the drive beam complex was completed quite smoothly (2003-2006) up to the transfer line 1 (TL1). Kick response and dispersion measurements played a major role, allowing to identify discrepancies between the MAD model and the real machine. The fully-loaded operation mode in the linac was established [3] and 94 % RF-to-beam efficiency was measured [4]. Since 2005 the first part of the linac is also routinely used as a source of the 30 GHz RF power production, mainly at nights and during week-ends. Up to 100 MW power was produced and transported to the test stand with 70 % efficiency.

In 2006 five 140 ns length bunch trains have been successfully combined with the following ones, thus doubling the current from 3 A to 6 A and experimentally demonstrating the DL principle validity.

The beam was therefore quickly transported to the CR, where a long commissioning started at the beginning of 2007 and not completed yet. Several hardware problems were identified and fixed. Wrong beam position monitors (BPM) calibration and alignment, quadrupole cabling errors, switched polarities and erroneous gradient versus current calibration factors were identified by using high precision and multi-turn response matrix measurements. The response of the machine to two symmetric steering magnets is compared with the model prediction to identify the possible discrepancies in a single quadrupole (like a short circuit or a bad cabling). Once this comparison is satisfactory the orbit variation induced by a single kick is compared to the model prediction over several turns to magnify the effect of the possible model-machine disagreements. After the model is corrected to have the best accordance with the machine response, other independent measurements (dispersion and tunes) are performed to further verify the model modifications.

In Fig. 2 an example of the very satisfactory comparison between the machine response and the MAD predictions obtained after the tuning of the model is shown.

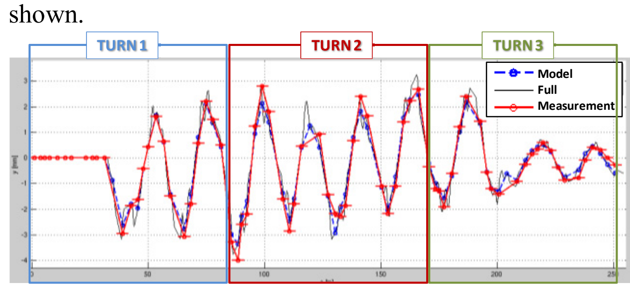


Figure 2: Kick measurement example. The multi-turn comparison is shown.

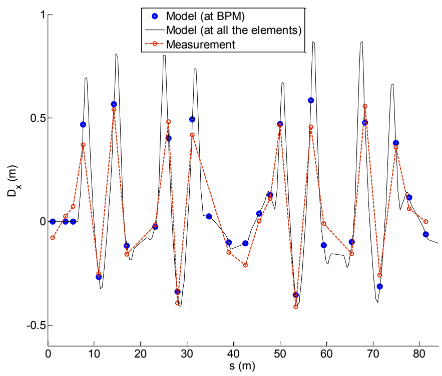


Figure 3: Comparison between the predicted and the measured dispersion in the CR.

The dispersion is locally measured from the orbit variation induced by scaling all the magnets of the part of the machine to be measured. This method is easier from the operational point of view with respect to more standard ones and it allows also to perform independent measurements in different part of the machine, neglecting the contribution of the incoming residual dispersion. In Fig. 3 the good agreement of the model predictions with the measurements is shown.

A further check of the model is given by the horizontal and vertical tune measurements. These are done by analysing the FFT of the horizontal and vertical beam position in one or more BPMs as a function of a quadrupole family current. The quite nice agreement of the model predictions with the measurements is shown in Fig. 4.

Part of the running time in 2009 will be used to further refine the model by comparing the optics functions measured by quad scans before the injection and immediately after the ring extraction using a new screen installed during the 2008/2009 winter shut-down.

Even the initial model was in any case already accurate enough to set up the beam and obtain a first recombination by-passing the DL in the fall of 2007 [5]. This test was not completely successful, because starting from 2.6 A 280 ns train length only 8.5 A instead of more than 10 A have been obtained. The cause of this limitation was rapidly identified in a vertical instability induced by the RF deflector at the injection bump (necessary for the recombination) excited by the beam itself [6, 7].

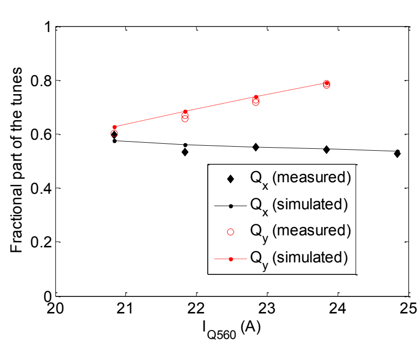


Figure 4: Comparison between the predicted and the measured horizontal and vertical tune.

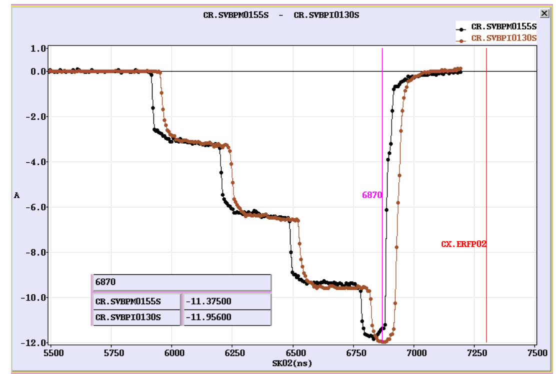


Figure 5: Factor 4 recombination in the CR. The beam current in the first two BPMs is shown.

A new RF deflector, including RF damping, was designed, built and finally installed and tested at the end of September 2008. More details about it can be found in [8]. Once this new deflector has been put in operation the expected factor 4 of multiplication was immediately demonstrated and 12 A were obtained starting with about 3 A injected beam, as shown in Fig. 5.

The length of the fourth turn recombined train is shorter with respect to the other ones because of the large phase variation in one of the RF pulse in the linac. To eliminate this effect the first weeks of the start-up of this year have been dedicated to the optimization of the phase variation in all the RF pulses.

In the second half of 2008 the transfer line from the CR to the CLEX area (TL2) and TBTS were installed and the commissioning started. At the end of the last year the drive beam was transported up to the end of TBTS, but with large losses. New BPM electronics, improved in several weeks, were used in TL2 and in the CLEX area and it was necessary to rematch the machine from a quad scan in TL1, tracking the Twiss parameters through TL1 and CR (using a model that at that time didn't fit so well the measurements). A new screen has now been installed in the first part of TL2, so a more systematic commissioning of this part of the machine will be possible this year.

A fundamental element of the CLIC two-beam acceleration scheme is the PETS structure, which in 2008 was tested for the first time with the drive beam coming from the CR. Beams with several length and intensities can be sent through the structures by operating CTF3 in several ways, as shown in Table 1.

Table 1: CTF3 possible scenarios: #1: all the rings are used, # 2: DL is by-passed and only the CR is used, # 3: DL is by-passed and CR is used as a transfer line For completeness also the CLIC nominal is reported.

| Mode | # 1 | # 2 | # 3 | CLIC |
|---|---|---|---|---|
| Current (A) | <30 | 14 | 4 | 101 |
| Pulse length (ns) | 140 | <240 | <1200 | 240 |
| Bunch frequency (GHz) | 12 | 12 | 3 | 12 |
| PETS power (MW) | <280 | 61 | 5 | 135 |

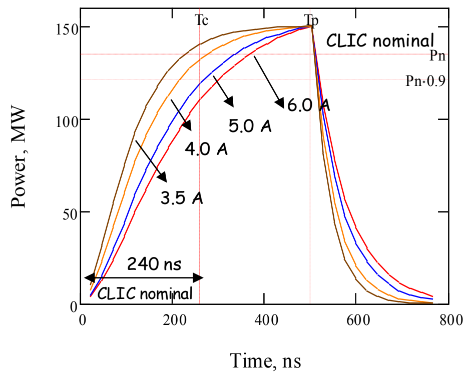


Figure 6: Expected power at several train currents as a function of the pulse length.

To produce the CLIC nominal power a 22 A drive beam current would be necessary (possible only in operation mode #1 using DL), but, after 2007, the DL has not been put in operation anymore to speed up the commissioning of the rest of the machine. A new concept, which can be eventually used also in CLIC, has therefore been developed to obtain the CLIC nominal power with only 5 A of drive beam current. To obtain such a result part of the power produced by the PETS is sent back in the same structure. In Fig. 6 the expected maximum power for several beam currents and different settings for the recirculation as a function of the train length is shown.

The tests, made in the short time available (from mid-November to mid-December 2008), were very promising in spite of several hardware problems (splitter and phase shifter were stuck and not remotely controllable) and allowed to produce - with the splitter in a fixed position - 30 MW of RF power with a 5 A drive beam, instead of the 5 MW expected without re-circulation. The measurements fit very well with the predictions by a specially developed model, as can be seen in Fig. 7. More details about the measurements and the model can be found in [9].

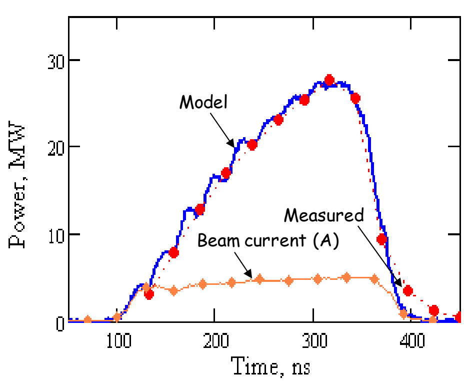


Figure 7: Comparison between the measured and the expected power.

At the end of 2008 and in the first weeks of the run in 2009 the measurements on a new 3 GHz (1908 bunches train, 1.5 GHz bunch spacing) photo-injector (PHIN) under study for the drive beam generation had started. The 2.3 nC nominal beam charge per bunch was achieved in early 2009, and the emittance measurements agreed well with the simulations [10].

## PROBE BEAM COMPLEX

The commissioning of the probe beam linac (CALIFES) started in mid-December 2008 and resumed in April 2009. The beam reached already the end of TBTS with an energy of 140 MeV and a bunch charge of 0.2 nC instead of the nominal 0.6 nC, because of a not optimal quantum efficiency and some power loss in the laser transport system.

## CONCLUSIONS

CTF3 has already experimentally demonstrated the full-loading operation mode in the linac and the delay loop current multiplication principle in the past years. During the 2008 run also the combiner ring mechanism was demonstrated, after having cured the vertical instability which limited the circulating beam current. For the first time the drive beam was sent into 12 GHz PETS producing the power predicted by the theory. Also the re-circulation concept, which allows to increase the produced power for a given beam current, has been experimentally demonstrated. The drive beam reached the end of the final transport lines, albeit with some loss due to the uncertainty on the optics functions at the beginning of TL2 and some diagnostics problems. A new screen has been installed during the shut-down, such that a more systematic campaign of measurements will be done this year. In parallel also the probe beam line was installed and its commissioning, started at the end of last year, is under progress.

## REFERENCES

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