BEAM OPTICS STUDIES AND COMMISSIONING STATUS OF CTF3

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Abstract

The objective of the CLIC Test Facility CTF3 is to demonstrate the feasibility issues of the CLIC two-beam technology. CTF3 consists of an electron linac followed by a delay loop, a combiner ring and a two-beam test area. One issue studied in CTF3 is the efficient generation of a very high current drive beam, used in CLIC as the power source to accelerate the main beam to multi-TeV energies. The beam current is first doubled in the delay loop and then multiplied by a factor four in the combiner ring by interleaving bunches using transverse deflecting rf cavities. The combiner ring and the connecting transfer line have been put into operation in 2007, and the remaining parts, namely decelerating section, probe beam linac and test beam line in 2008. In this paper we give the status of the commissioning, present the results of the combination tests and illustrate in some detail the beam optics measurements, including response matrix analysis, dispersion measurement and applied orbit correction algorithms. We discuss as well the observation of a vertical beam break-up instability which is due to the vertical transverse mode in the horizontal RF deflectors used for beam injection and combination. We outline the attempted methods to mitigate the instability and their effectiveness.

THE CTF3 COMPLEX

The CLIC technology [1] is believed to be the only practical 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 build at CERN by an international collaboration which at present includes 24 institutes from 14 countries [4]. Its construction is almost completed and a large part of the facility is already commissioned. It re-uses the infrastructure and most of the hardware of the former LEP Pre-Injector, LPI (see Fig. 1).

CTF3 consists of a 70 m long drive-beam linac followed by two rings, where the beam current is multiplied by a factor eight: a 42 m delay loop and an 84 m combiner ring. The drive beam is then delivered to the CLic EXperimental area (CLEX) to produce 12 GHz RF power for structure tests. In the same area, the CALIFES linac provides a probe beam for a Two-Beam Test Stand (TBTS) and a decelerator (Test Beam Line – TBL) will be used for drive beam stability studies. The detailed description of the facility can be found in [2,5].

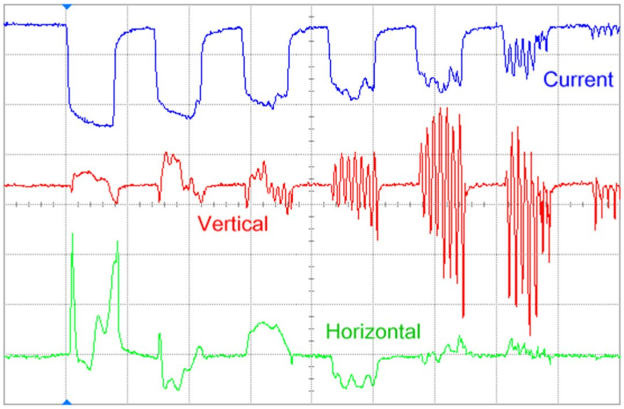

Figure 1: Traces of the beam current (upper line), vertical position (middle) and horizontal position (lower) in the ring, a clear indication of the vertical instability.

COMMISSIONING STATUS

In 2003-2004 the injector, the linac, the mid-linac power station and the end-of-linac magnetic chicane were installed and commissioned. Full beam-loading operation was established [6]. The resulting beam is remarkably stable, with no sign of beam break-up. An RF-to-beam efficiency of 94 % has been experimentally verified later on [7]. The first part of the linac is routinely used since 2005 as a source of 30 GHz RF power. Up to 100 MW can be produced in the PETS, and transported to the test stand with ~ 70 % efficiency. The delay loop was installed during 2005 and commissioned in 2006. Five 140 ns long bunch-trains were injected into the delay loop and combined with the following train, thus doubling the beam current [8]. In 2006 a short period was dedicated to the commissioning of the newly installed TL1. Short pulses of 200 ns were used. The beam was rapidly transported to the end of the line and a current of 3 A could be injected in the ring first straight section.

The combiner ring installation was completed at the beginning of 2007. Commissioning of the combiner ring began in 2007, with several interruptions for repairs and installation work [9], and still continues with the goal to reach nominal beam parameters. Several problems in the hardware and in the optics model were identified, mainly through beam measurements, and eventually fixed, including wrong BPM calibration and connections, quadrupole cabling errors, switched polarities and wrong current calibrations. The alignment of magnets and vacuum chamber elements was also re-checked and corrected when necessary. During 2007 we could finally obtain a beam circulating for several turns in the ring, albeit with non-negligible losses. A fast beam instability in the vertical plane (see Fig.1) was indeed discovered

[10], which gives rise to growing vertical beam oscillations and eventually to beam loss.

The instability is believed to be caused by the vertical deflecting mode in the RF deflectors, excited by the beam [11]. This mode is shifted in frequency by 48 MHz with respect to the horizontal deflecting mode by polarising rods in the deflector cells, but it is not damped. New RF deflectors are being built, to be installed in October 2008. At the end of the 2007 run, a recombination test over four turns was performed anyway, bypassing the delay loop (see Fig. 2). In 2008 the ring commissioning restarted.

In August this year the last part of the drive beam installation was completed. Currently the TL2 line, which transports the beam to CLEX area and also TBTS are being commissioned. The beam was already successfully transported to the end of TBTS, however, with only half of the initial current. More detailed study is ongoing which aims to find the remaining problems.

The construction of the probe beam linac was also completed in August. Currently its CALIFES gun and accelerating structures undergo the RF conditioning process. The start of CALIFES commissioning is foreseen for November this year.

MEASUREMENTS

Detailed beam optics measurements had to be performed in order to identify discrepancies between the model and the real machine. Furthermore, they were necessary to try to control the vertical instability by a proper choice of the vertical tune in the ring and of the β-function in the RF deflectors [10]. Indeed, we have found that bringing the vertical tune close to half integer reduces the instability growth time. However, we have not yet managed to damp it enough to achieve nominal beam parameters. During these machine studies, we were severely limited by beam jitter induced by gun voltage fluctuations. Recently we have ameliorated the performance of the gun, and at present further studies on this subject are being performed.

Among others, the following optics measurements were done:

1. Standard quadrupole scans, used to check the optics and perform re-matching of the different beam lines.
2. Determination of transverse response matrix elements by orbit measurements with kick excitation. The data obtained were paramount in order to identify and correct errors in the quadrupole families and also insufficiently precise modelling of combined function magnets, in which magnetic lengths of dipolar and quadrupolar components are different.
3. Dispersion, typically measured by varying the strength of all magnetic elements over a 1% range and taking the orbit difference. Such technique is simpler then a beam energy change and has the additional advantage that dispersion can be measured locally, not being sensitive to incoming residual dispersion. A good agreement was found in all machine areas (see an example in Fig. 3).

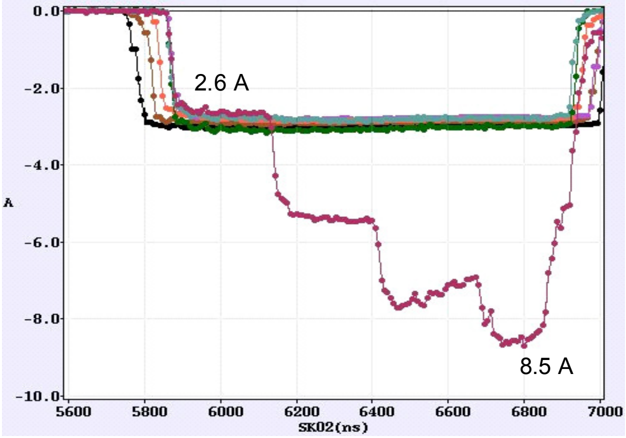

Figure 2: Beam current multiplication in the combiner ring. The traces show the beam current measured in several BPMs in the linac and TL1, and in one ring BPM. The incoming pulse has four times the ring length (4×280 ns). Losses from instability in the last two turns don't allow to reach a full factor four in current gain.

Additionally we have implemented on-line dispersion monitoring by means of beam energy jitter measurement. We can perform such a measurement since the precision and sensitivity of our beam monitors is high enough to observe beam displacement induced by the energy jitter from shot to shot, which is in our case the primary factor of the beam position variation. Dispersion is directly proportional to the position spread at a given location. The calibration is made at a chicane in the linac where dispersion is well known and controlled.

4. Tune measurements, by FFT of horizontal and vertical signals of the ring BPMs (see Fig.4). Together with dispersion and kick-orbit studies this enabled us to find, and later correct, disagreements with the MAD model.

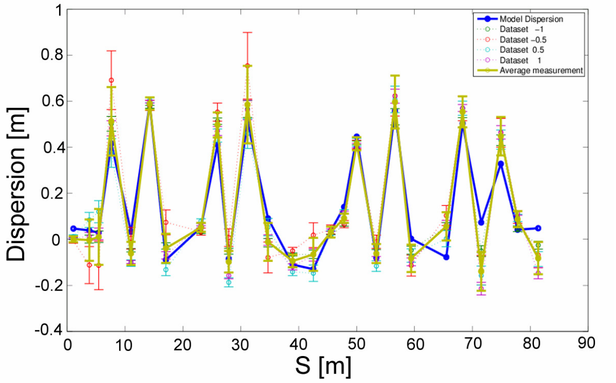

Figure 3: Results of dispersion measurements in the combiner ring (yellow line) compared with predictions from the MAD model (blue line).

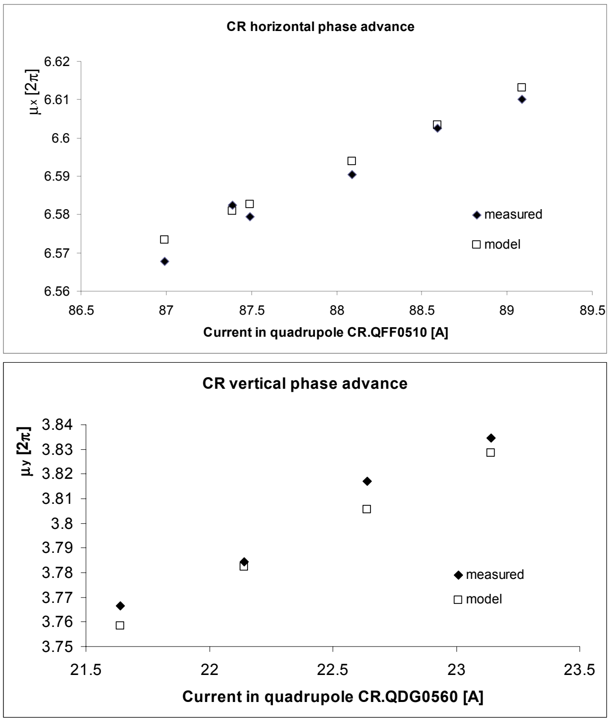

Figure 4: Example of tune measurement results for different setting of a quadrupole current compared with the predictions of the model.

5. Determination of the closed orbit. A first estimate is done by averaging the first few turns. The injection is then optimized to minimize the turn-to-turn difference. An automatic closed orbit correction program is still under test. The main limiting factor is low number of turns which is again related to the instability.
6. Measurement of the ring length, fundamental since the recombination process relies on a precise control of the revolution time, to the 10^{-5} level. The measurement was done using a 3 GHz RF phase monitor. An FFT of the signal gives the ring length modulo the RF wavelength (see Fig.5). The ring was found to be 1.5 mm longer than nominal. A good closed orbit correction (not applied then) may in principle reduce the discrepancy, which is however within the limits of the needed operational range (corresponding to 4-turn to 5-turn recombination). The path length variation as a function of the path length tuning wiggler current behaved exactly as expected.

CONCLUSIONS

The CTF3 project is the main facility to demonstrate feasibility of the CLIC scheme, in particular the generation of the high-current drive beam. A number of issues have already been addressed, such as full beam loading operation and the bunch phase coding and interleaving scheme. Commissioning of the combiner ring is in progress and a full combination test is expected after installation of the new RF deflectors, needed to damp the fast vertical instability which is the present limiting factor. The construction of the facility is completed now and commissioning of the newly delivered parts is ongoing.

We have summarized the optics measurements that we performed in order to find the discrepancies between the model and the machine.

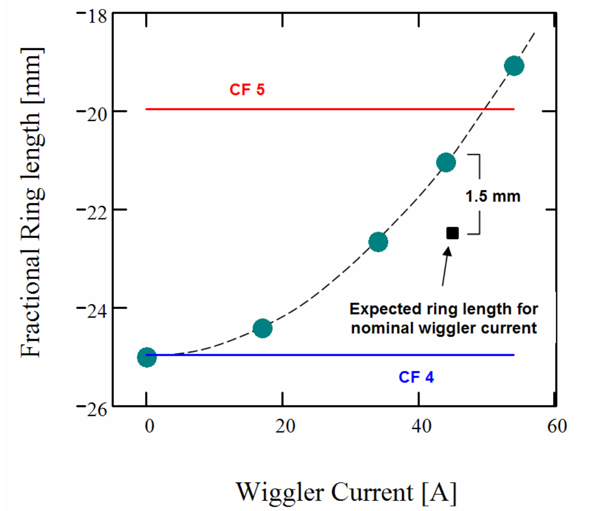

Figure 5: Ring length as a function of the tuning wiggler current. The actual length is an integer number of 3 GHz wavelengths, plus the fractional part shown here. The circles are measured values and the dashed line the expected variation. The black square is the nominal value and the horizontal lines mark the operational range.

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