COMMISSIONING STATUS OF THE DECELERATOR TEST BEAM LINE IN CTF3

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Abstract

The CLIC Test Facility (CTF3) at CERN was constructed by the CTF3 collaboration to study the feasibility of the concepts for a compact linear collider. The test beam line (TBL) recently added to the CTF3 machine was designed to study the CLIC decelerator beam dynamics and 12 GHz power production. The beam line consists of a FODO lattice with high precision BPM's and quadrupoles on movers for precise beam alignment. A total of 16 Power Extraction and Transfer Structures (PETS) will be installed in between the quadrupoles to extract 12 GHz power from the drive beam provided by the CTF3 machine. The CTF3 drive beam with a bunch-train length of 140 ns, 12 GHz bunch repetition frequency and an average current over the train of up to 28 A will be injected into the test beam line. Each PETS structure will produce 135 MW of 12 GHz power at nominal current. The beam will have lost more than 50 % of its initial energy of 150 MeV at the end of the beam line and will contain particles with energies between 65 MeV and 150 MeV. The beam line is completely installed and the PETS structures will be successively added until the end of 2011. The paper will describe the first results obtained during commissioning of the beam line and the first PETS prototype.

INTRODUCTION

In CLIC decelerator a 101 A beam will be decelerated from 2.4 GeV down to 240 MeV converting 85 % of its energy into 12 GHz microwave power. The power will be extracted by power extraction and transfer structures (PETS). In order to demonstrate the feasibility of the CLIC decelerator a special test beam line (TBL) has been implemented into CTF3 at CERN. The line will have 16 PETS installed in its final stage. Table 1 lists the parameters of the CLIC decelerator and of TBL in CTF3 for comparison. Each PETS in TBL will produce the nominal CLIC power of 135 MW with a beam current of 28 A . The PETS in TBL are a factor 4 longer compared to CLIC to compensate for the lower drive beam current in CTF3. The initial energy for the decelerator of CTF3 is even lower than the final energy for CLIC which makes the experiment more difficult in this respect. On the other hand wakefield effects will be less pronounced in TBL due to the much shorter beam line. The emphasis for the experimental program of TBL [1] will be on 12 GHz power production and the transport of the decelerated beam. It is essential for CLIC that the 12 GHz power production is efficient and stable. Therefore measurements of the energy balance of the produced rf power and the energy loss of the beam will be carried out. The stability of the produced power both in amplitude and phase will be determined. The beam transport is challenging because the beam develops a large energy spread during deceleration. The difference in deceleration for the most and least declerated particles amounts up to 85 MeV once the line is equipped with 16 PETS. The beam envelope is increasing along the beam line and will fill 2/3 of the aperture in the case of TBL assuming perfect alignment. The alignment of the quadrupoles of the FODO lattice and the PETS itself is critical for full transmission. The quadrupoles have been installed on moving tables developed by CIEMAT [2] which allow a positioning in the micrometer range. Beam based alignment studies are foreseen using the precision BPM's developed by IFIC Valencia and UPC Barcelona [3].

Table 1: Comparison of beam parameters for CLIC and TBL.

Parameter	Symbol	TBL	CLIC
Number of PETS [-]	N_{PETS}	16	1492
Length of PETS [m]	L_{PETS}	0.80	0.21
Initial average current [A]	I_0	28	101
Power per PETS [MW]	P	$\sim$138	135
Initial energy [MeV]	E_0	150	2400
Mean energy extracted [%]	η_{extr}	$\sim$54	84
PETS sync. freq. [GHz]	f_{rf}	12	12
Number of FODO cells [-]	N_{FODO}	8	524
Length of FODO cells [m]	L_{FODO}	2.82	2.01
Pulse length [ns]	t_{pulse}	140	240
Transient length [ns]	t_{fill}	3	1
Bunch rms length [mm]	σ_z	1.0	1.0
Init. norm. emittance [μm]	$\epsilon_{\mathrm{N\,x,y}}$	150	150
Beam pipe radius [mm]	a_0	11.5	11.5

The beam line has been installed in CTF3 comprising the FODO lattice, the precision BPM's and a PETS prototype. This first PETS has been developed and fabricated in collaboration with CIEMAT [4]. Each PETS consists of 8 copper bars machined to high precision which are clamped together with an extraction coupler and installed in a vacuum tank. So far only one prototype PETS tank has been installed and the production of a series of 8 more tanks is currently under way. A diagnostic section has been installed in front of and at the end of the line to measure transverse beam parameters and the energy spectrum. A time resolved spectrometer has been developed to observe the particular energy profile of the decelerated beam [5]. Figure 1 shows a photo of the TBL line installed in CTF3.

Figure 1: Photo of the test beam line in CTF3.

FIRST RESULTS

The commissioning of the beam line and the instrumentation started with a 3 GHz beam between 2 and 3 A. The energy of the beam was 113 MeV instead of the nominal 150 MeV planned for TBL. The Twiss-parameters of this beam have been measured using an OTR screen in front of TBL. The obtained beam parameters have been used to calculate a matching of the incoming beam to the FODO lattice. The matched beam could be transported through one PETS to the end of the line. A graphical user interface has been developed to ease this kind of operation. This application monitors the beam currents and positions along the line and calculates the matching for different phase advances of the lattice and sets the quadrupoles to their new values. The matching is done always for the particles with the lowest energy. A screen shot of the interface is shown in figure 2.

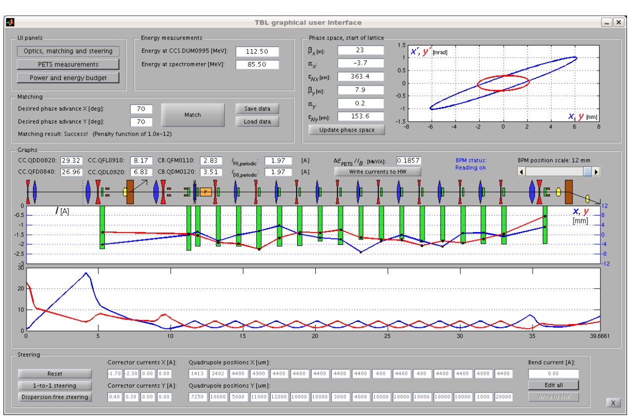

Figure 2: Graphical user interface showing the beam transmission and trajectory as well as the beta functions of the matched beam.

The beginning of the commissioning focused on the power production with the prototype PETS tank. The power produced in the PETS is proportional to the square of the beam current and the form factor determined by the bunch length $P \propto I^2F^2$. More details on the theory of the power production can be found in [6]. The power is extracted in a symmetrical coupler to two WR90 waveguides equipped with directional couplers and high power loads. The 12 GHz signal is subsequently mixed down to base band and detected by IQ-demodulators. The 12 GHz power produced by the beam agrees well with the theoretical predictions. Figure 3 shows an example of the measured rf signals together with the prediction from the BPM signal directly after the PETS as well as the phase of the rf signals. In this example a 12 GHz combined beam of 8 A was used and a form factor of 0.83 was used for the prediction. In CTF3 a 3 GHz beam from the linac can be combined using the combiner ring into a beam with a four times higher current and a 12 GHz bunch spacing [7]. The bunch length was not measured directly but is within the expected range for the CTF3 beam [8]. The phase measurement shows a dip along the bunch train which comes from the beam and is due to the rf pulse compression used in CTF3. The shape and phase of the extracted 12 GHz power is an excellent and very sensitive diagnostics for the quality of the drive beam production and combination. Shaping the rf power pulse correctly will be one of the experiments done in TBL to demonstrate the CLIC decelerator. The maximum power produced so far was 20 MW with a beam current of 10 A with no sign of breakdown.

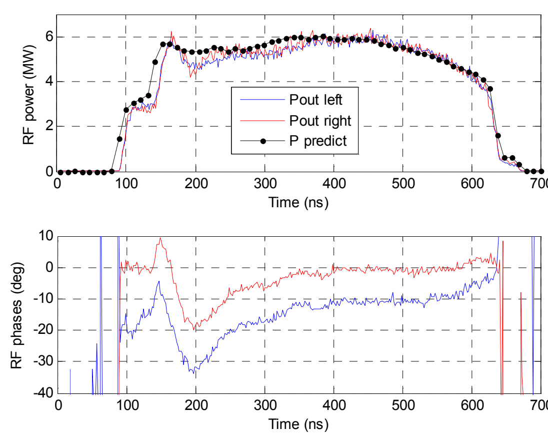

Figure 3: PETS output power measurement and prediction from the BPM signal (upper) and the corresponding phase of the rf signal (lower).

The inductive BPM's developed for TBL have been designed to have a 5 µm resolution in order to insure the beam-based alignment requirements. The quadrupoles have to be aligned within 10 µm by beam-based alignment to insure proper beam transport through the line once equipped with 16 PETS. A first measurement of the BPM resolution measuring the trajectory of the beam in three consecutive BPM's to take out the effects of beam jitter has been performed. For a beam with 2.3 A average current 57 µm resolution was measured corresponding well to the specified resolution of 5 µm for the nominal beam current of 28 A. The resolution was determined as the rms value of the difference distribution of the measured beam position in the middle BPM and the predicted beam position from the two other BPM's. However the BPM signals suffered from additional noise coming from beam losses.

Each quadrupole is mounted on a moving table allowing ±4 mm horizontal and vertical movement with a precision of 5 µm. The tables can be moved with a resolution of 1 µm. The movers have been used for kick measurements to verify the optics in the beam line systematically along the line. Figure 4 shows an example of such a measurement. Here the first quadrupole was moved to kick the beam and the measured trajectory was compared to the theoretical optics model. The first quadrupole was moved by 1 mm in horizontal direction for this example. The agreement is good and identifies a problem at the position of BPM 13 which will be corrected.

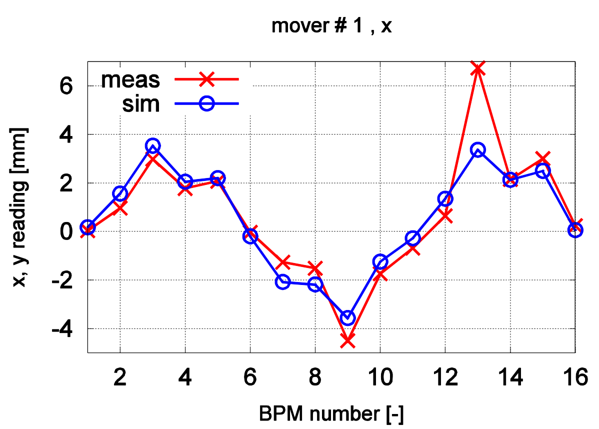

Figure 4: Kick measurement using the mover of the first quadrupole in the horizontal plane. The measured beam trajectory is compared to the optics simulations.

Finally the diagnostic sections in front of TBL and at the end of the beam line have been commissioned. Each diagnostic section is equipped with an OTR screen and a CCD camera allowing emittance and Twiss-parameter measurements using quadrupole scans. The energy and energy-spread can be measured before and after the line with a spectrometer dipole magnet and an OTR screen in the dispersive section. In addition the spectrometer at the end of the line is equipped with a slit dump which allows a time resolved energy spread measurement. This device will be replaced by a segmented dump which will enable single shot time resolved energy spread measurements. During commission the Twiss parameters of the beam have been measured and used to match the beam to the periodic FODO optics. The beam parameters have been measured subsequently at the end of the line and were found to be consistent with the predictions of the optics simulations. An energy spread of 2.5% FWHM was measured at the end of the line consistent with measurements in the CTF3 linac.

CONCLUSIONS

The commissioning of the test beam line in CTF3 dedicated to demonstrate the feasibility of the CLIC decelerator has been successfully started. A first PETS prototype has been manufactured and tested with beam. The produced 12 GHz output power corresponds well to the theoretical predictions. Until now a maximum of 20 MW of rf power could be extracted from the beam. The fully combined 28A drive beam of CTF3 is necessary to reach the goal of 135 MW extracted power. We plan to demonstrate the full power production by the end of this year. The series production of 8 more PETS tanks is underway and we plan to install those by the beginning of 2011.

The beam optics and diagnostics developed for TBL have been commissioned with different types of beams. The micrometer quadrupole movers have been used successfully for kick measurements to verify the beam optics. No major problems have been found with the optics.

A first resolution measurement of the inductive BPM gave a satisfactory result but can still be improved. At the end of the beam line a time resolved spectrometer using a slit dump has been installed and commissioned. This diagnostic will allow to bench mark the deceleration process in the PETS structures.

In 2011 the line will be used with 8 PETS installed and we plan to complete the line with a total of 16 deceleration structures in 2012.

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