FIRST BEAM TESTS OF THE CLIC POWER EXTRACTION STRUCTURE IN THE TWO-BEAM TEST STAND*

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Abstract

The two-beam acceleration scheme foreseen for CLIC and the associated radio-frequency (RF) components will be tested in the Two-beam Test Stand (TBTS) at CTF3, CERN. Of special interest is the performance of the power extraction structures (PETS) and the acceleration structures as well as the stability of the beams in the respective structures. After the recent completion of the TBTS, the first 12 GHz PETS has been tested with beam, using so-called recirculation of the RF power inside the PETS. The TBTS allows precise measurement of beam parameters before and after the PETS as well as RF power and phase. Measurements of transverse kick, energy loss and RF power with recirculation are discussed and compared with estimations, including first measurements of pulse shortening probably due to RF breakdown.

INTRODUCTION

The Two-beam Test Stand (TBTS) is a unique and versatile facility devised to test key components of the two-beam acceleration concept that is the basis of the CLIC project [1]. Worldwide it is the only facility where CLIC type power production (PETS) and accelerating structures can be tested with beam. The TBTS is part of the CTF3 complex at CERN [2] that creates a high power drive beam which is then decelerated in order to generate the RF power needed to accelerate a second, probe, beam which is provided by a another linac. The drive beam has a time structure suitable for power generation at all harmonics of 1.5 GHz but is optimised for the nominal CLIC frequency of 12 GHz. It can reach beam intensities up to 30 A, pulse lengths up to 1500 ns and beam energies up to 150 MeV. The probe beam can reach beam intensities up to 0.9 A, pulse lengths up to 150 ns and beam energies up to 170 MeV.

Commissioning of the TBTS drive beam line started last year. As the available drive beam current will be some four times lower than in the CLIC design, the installed PETS has a modified design. It has increased length to 1 m from 0.215 m and is equipped with external RF recirculation [3]: the PETS operates as an amplifier feedback ring driven by the drive beam power. Up to 30 MW of 12 GHz RF power has been produced from a 5 A beam.

THE TWO-BEAM TEST STAND

The TBTS consists of two parallel beam lines for the drive and probe beam and a two meter long test area in each. The layout of the two beam lines is almost identical [4]. The experiments described in this report are performed on the drive beam line. The layout of the line with PETS installation is shown in Figure 1.

Two quadrupole triplets are used to vary and optimise the beam size inside the PETS and on an OTR screen following a spectrometer dipole in order to maximise the energy resolution. Moreover, four steering magnets are available to adjust the orbit inside the PETS with a closed bump. Five inductive BPMs [5] are installed for intensity and position measurements. Their bandwidth allows to observe the position within a bunch train and this is used to determine kicks and energy loss of the beam during normal operation and when a RF breakdown occurs inside the PETS. The achievable resolution to determine the kicks is in the order of a few micro radians and 4×10^{-4} for the energy [6].

The PETS RF recirculation loop contains a variable splitter to control the amount of power in the loop and a phase shifter to tune the loop's length. The RF power and phase are measured through directional couplers connected to 12 GHz diodes and I&Q demodulators.

RECIRCULATION

In the recirculator a fraction of the field g (product of the splitter ratio κ and the round-trip ohmic losses) is coupled

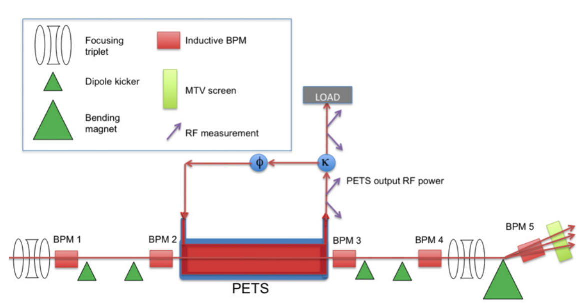

Figure 1: Sketch of the Two-beam Test Stand's drive beam line (not to scale).

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back into the PETS with an eventual phase-shift ϕ with respect to the beam generated field [7–9]. For a rectangular pulse, neglecting system bandwidth limitations, and keeping all parameters constant one can calculate the peak electric field at the PETS output after M full recirculation cycles, E_M, as [9]

$$E_M = E_{beam} \sum_{m=0}^{M} g e^{j\phi} \tag{1}$$

where E_{beam} is the peak electric output field generated by the beam before the recirculation starts to act. Using the same assumptions the beam energy loss, $\langle U_M \rangle$, can be calculated as [10]

$$\langle U_M \rangle = \Re(E_M) L F(\lambda) - \frac{1}{2} E_{beam} L F(\lambda) \tag{2}$$

where L is the structure length and $F(\lambda)$ the form factor.

RECONSTRUCTION

Extending Eq. (1) to arbitrary beam pulse intensities, while keeping other parameters constant, we use BPM intensity measurements to reconstruct the PETS output peak field, E, the phase of the total field with respect to the beam generated field, θ, and the output power, P. The relative field phase was measured using I and Q demodulator channels on the signal from the PETS output RF window, indicated in Figure 1.

For the 2008 run the recirculator parameters g and ϕ were unknown, and as part of the reconstruction process these parameter had to be identified. A continuous series of 200 logged pulses were used to fit the unknown parameters by comparing the power and phase reconstruction with the RF measurements yielding $g = 0.75$, ϕ = -18 deg [9]. No precise bunch length measurements were available for the run, and an overall scaling factor had therefore to be fitted as well.

The rms difference of the measured and reconstructed power pulses lies within 10% for 75% of the pulses in the series used for the fit. Figures 2 and 3 show examples of reconstructed and measured power and phase.

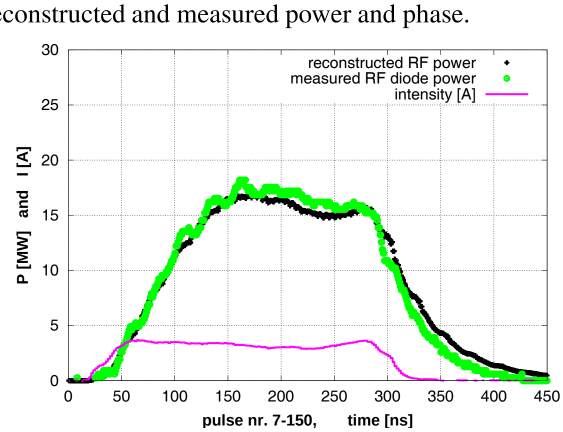

Figure 2: Reconstructed RF power from intensity measurements in black (+), measured RF power in green (o), BPM intensity in magenta (-), for a nominal pulse.

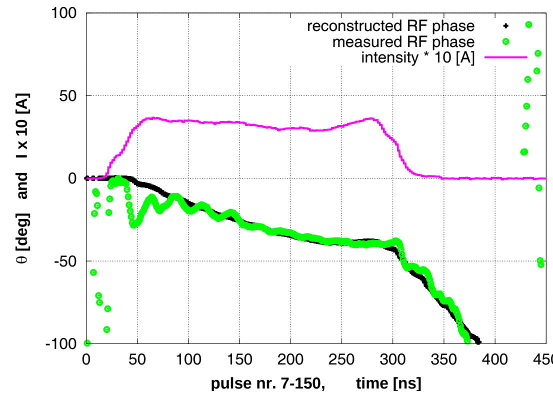

Figure 3: Reconstructed relative field phase from intensity measurements in black (+), measured relative field phase in green (o), BPM intensity in magenta (-), for a nominal pulse.

The beam intensity was gradually increased during the 2008 run, and in specific time intervals the measured RF power pulse was significantly shorter than the power reconstructed from the intensity measurements for a given pulse, as shown in Figure 4. The dynamics of such pulses can be modelled by varying the recirculation gain and phase [8] during the pulse, or, alternatively, by varying the bunch arrival phase [11]. This work is ongoing and the instrumentation of the TBTS proves to be very useful for the understanding of the dynamics of the PETS. The analysis software will be incorporated in the on-line analysis software and will serve as an indicator for breakdown, such that interesting pulses can be automatically stored for further post-processing at a later time.

ENERGY LOSS MEASUREMENTS

The PETS transfers part of the drive beam energy into RF power. In [10] three different approaches for estimating of corresponding beam energy loss are presented. First, we can determine the energy loss from the BPM in the spectrometer [6]. Second, the loss can be deduced from the power measurements in addition to the intensity measure-

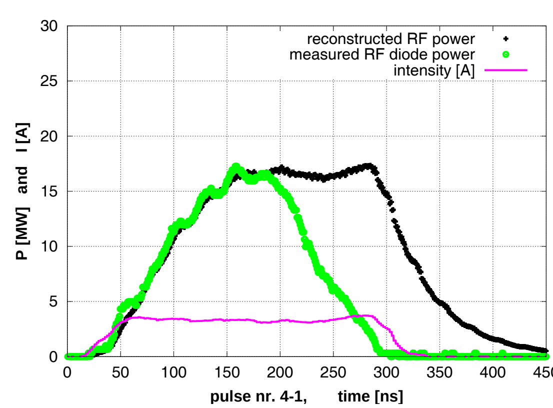

Figure 4: Reconstructed RF power from intensity measurements in black (+), measured RF power in green (o), BPM intensity in magneta (-), for a shortened pulse.

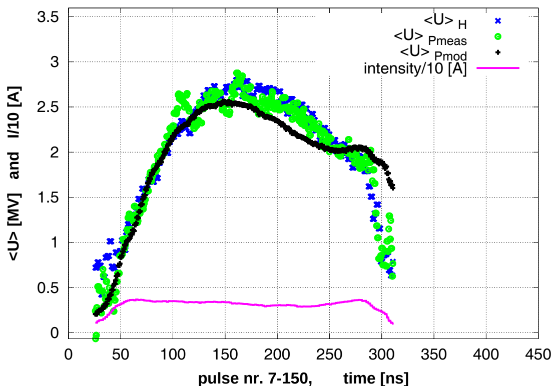

Figure 5: Energy loss estimates based on spectrometer measurements, $\langle U\rangle_H$, in blue (x), PETS power combined with BPM intensity measurements $\langle U\rangle_{P\mathrm{meas}}$, in green (o) and BPM intensity measurements alone, $\langle U\rangle_{P\mathrm{mod}}$, in black (+).

ments. Third, we can can use the intensity measurements alone, combined with Eq. (2). The rms difference between the three estimates lies within 20% for 75% of the pulses in the series used for the fit. Figure 5 shows an example of the mean voltage seen by the beam, along the pulse, estimated using these three approaches.

KICK MEASUREMENTS

For the design of a future two-beam accelerator and its stability it is also important to know if the beam receives any kick on its way through the PETS. Any such kick can be determined using the horizontal and vertical BPM measurements. For simplicity in the commissioning phase we assume here that such a kick would originate in the longitudinal centre of the PETS. From simulations we expect that the kick due to transverse dipole wakes in the PETS should be less than 100 μrad if the incoming beam offset is 1 mm parallel along the PETS centre line. Due to mechanical and electrical BPM offsets, not yet precisely identified, it was not possible to resolve the absolute angle and kick measurements accurately at this stage of operation. We therefore consider only relative changes along the pulse.

Figure 6 shows the estimated vertical offset (y), angle (yp) and kick in the middle of the PETS, for the pulse presented in Figure 4. During the time period that corresponds with the build up of the RF field in the PETS and the external RF power, the kick angle changes with approximately 0.5 mrad. From 250 ns on the kick angle changes with more than 1 mrad in the opposite direction. This could possibly indicate a relation between the beam kick and the field inside the PETS when pulse shortening is observed, and will be studied further during the next run. The horizontal measurements of the same pulse do not show a significant change in kick angle.

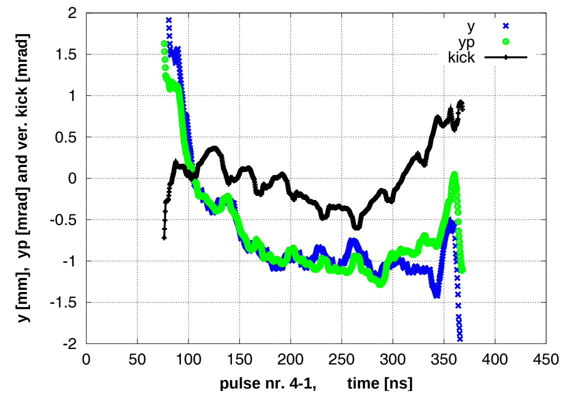

Figure 6: Estimated beam centroid offset, y, in blue (y), beam angle in the PETS, yp, in green (o) and kick angle, in black (+). All quantities are estimated in the middle of the PETS.

CONCLUSIONS

The first beam tests of a PETS in the TBTS have proven the extensive possibilities to correlate beam and RF measurements. Using a simple constant parameter model, a good agreement has been reached between estimations and measurements of the RF power production and beam energy loss. Being in the commissioning phase, work is ongoing to improve the quality of the modelling and measurements and extend their scope. The first results presented here demonstrate already that the TBTS is an excellent tool for studying the PETS dynamics.

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