TRANSIENT BEAM LOADING COMPENSATION IN CTF3

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Abstract

In the CLIC Test Facility 3 (CTF3), the strong coupling between the beam and the accelerating cavities (full beam loading) induces transient effects such that the head of the pulse is accelerated almost twice as much as the steady-state part of the pulse. The beam optics in the machine is tailored for the steady-state and not for the higher energy electrons, which are gradually lost. This can lead to inefficiency and contributes to the activation of the machine. A beam loading compensation scheme has been proposed to minimize this effect. By delaying appropriately the arrival time of the rf pulse in accelerating cavities with respect to the beam, the transient energy can be brought close to (within a few percent of) the steady-state one. This paper presents the measurements done on CTF3 using time resolved energy measurements.

INTRODUCTION

In CTF3 an electron pulse of 3.5 A and 1.5 µs is accelerated using fully loaded 3 GHz accelerating structures [1]. The resulting energy spectrum shows a strong time dependency with higher energies in the first 50 nanoseconds of the pulse, followed by the steady state. Time-resolved spectrometry is therefore an essential beam diagnostic tool to correctly set the phase of the accelerating structures. Several spectrometer lines are installed along the CTF3 linac for this purpose. They consist of a bending magnet, which provides horizontal deflection to the electrons, followed by a transverse profile monitor measuring the beam position and its transverse width. The spectrometer lines are equipped with an optical transition radiation (OTR) screen [2] observed by a CCD camera with good spatial resolution and at the end of the line a novel segmented beam dump [3] for time resolved energy measurements.

This paper is devoted to the commissioning and utilization of the segmented beam dump. This device is composed of parallel metallic plates designed to measure a current, proportional to the number of stopped incident particles. By measuring the deposited charge in each segment, the beam energy profile can be reconstructed. The material and the dimension of the segments were chosen based on considerations of the beam parameters, in particular the beam energy and the energy spread, but also on the beam power absorbing efficiency and the radiation hardness requirements. The segments need to be deep enough to stop the particles; on the other hand, the segment thickness must be chosen to optimize the spatial resolution, which is eventually limited due to multiple Coulomb scattering [4]. After simulation studies with the Monte Carlo code FLUKA [5] as described in [3], the design was chosen as consisting of two devices; a passive 4 cm thick multi-slit (400 µm wide vertical slits) collimator made of iron which stops about 75% of the electrons and the active detector, which we refer to as the segmented dump that is installed just behind the collimator. It consists of tungsten plates of 2 mm transverse thickness, 5 cm depth and 5.5 cm height spaced by a 1mm thick radiation hard ceramic insulator as shown in Fig. 1. The role of the collimator is to capture as much beam power as necessary to ensure a good signal in the segmented dump, but to keep the deposited power low enough so that the segmented dump does not require water cooling.

The electronics, used to read the current drawn from each segment, consists of a direct connection to the segment with a 50 Ω impedance to ground. These signals are attenuated by 8 dB, and then digitised by a 100 MSa/s sampling ADC, which limits the time resolution of the post digitised signals to 10 ns, see Fig. 2.

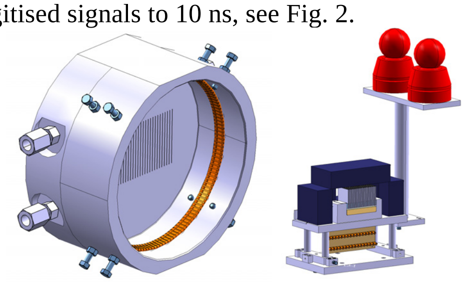

Figure 1: (a) Multi-slit collimator, (b) segmented dump.

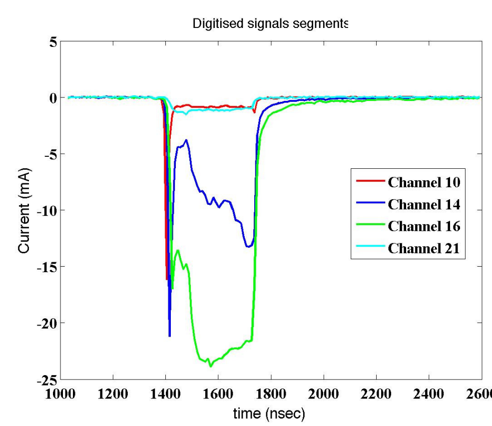

Figure 2: Typical digitised signals from segmented dump.

COMMISSIONING OF THE SEGMENTED DUMP

The first part of the CTF3 drive beam linac is shown in the schematic of Fig. 3. The injector consists of a dc gun followed by a 3GHz bunching system. Two 3 GHz accelerating structures boosts then the beam energy up to approximately 20 MeV. A magnetic chicane equipped with a collimator provides the proper beam cleaning to get rid of the remaining low energy particles produced in the bunching cavities. The linac continues with standard accelerating modules composed of two 3 GHz accelerating structures fed by a single klystron. Two segmented dumps were installed in the spectrometer lines 4 and 10.

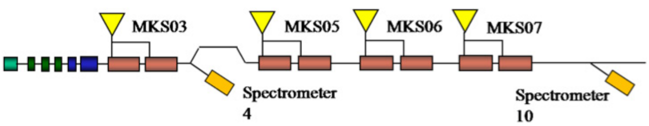

Figure 3: A schematic of the layout of the first part of the CTF3 injector and linac and the locations of the spectrometer lines used for energy measurement diagnostics.

The design of the two spectrometer lines are essentially the same with an acceptance in energy spread of about 15% for the spectrometer line 4 and 10% for the spectrometer line 10, as shown in Fig. 3.

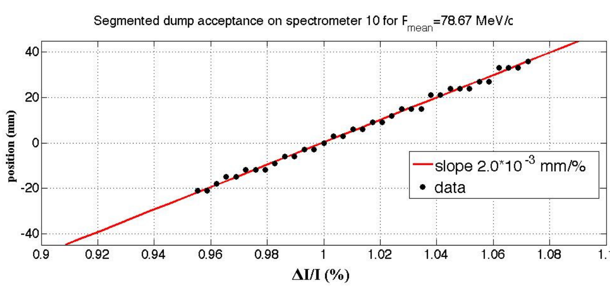

Figure 4: The horizontal dimension ±48 mm for the segmented dump in spectrometer 10 corresponds to an energy spread acceptance of about 10%.

The response of the segmented dump was measured by comparing the current read in each segment, with the beam current measured by the beam position monitor installed in front of the spectrometer line. By comparing the two devices, the amount of charge absorbed by the collimator can be estimated and also the response of each active segment. The total amount of absorbing material in front of each segment with respect to the beam path and any imperfections in the alignment of the detector with regard to the collimator and the beam axis could be measured and thus provide a calibration response for the detector. The calibration curve for each channel of the segmented dump installed in spectrometer line 10 is shown in Fig. 5. The triangular shape of the curve was expected based on Monte Carlo simulations [3], given that the segments, and the slits in the collimator are aligned parallel to the spectrometer axis. The calibration of the detector is implemented in the online analysis code used routinely in operation.

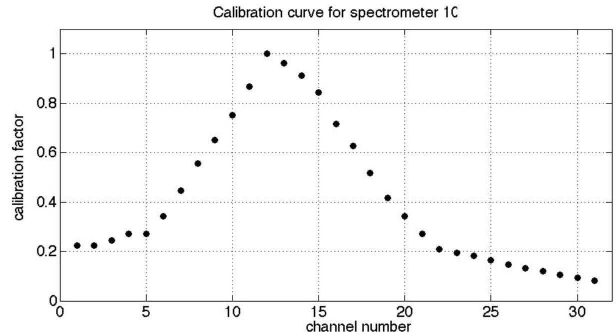

Figure 5: The calibration curve for the response of each segment of the segmented dump on spectrometer 10.

MEASUREMENT OF TRANSIENT COMPENSATION USING THE SEGMENTED DUMP

The eight 3 GHz acceleration sections in the beginning of the CTF3 linac are fed by four klystrons, namely MKS03, MKS05, MKS06 and MKS07. In "full beam loading" [1] operation, the strong coupling between the beam and the accelerating cavities, generates transient effects such that the head of the pulse is accelerated almost twice as much as the steady-state part of the pulse, see Fig. 6.

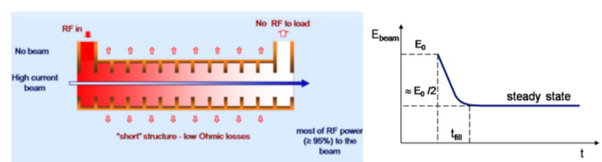

Figure 6: A schematic of the full beam loading concept.

Without compensating for the transient, the first 50 ns of the pulse experiences a much higher accelerating field than the steady state part of the beam. This effect can be seen in Fig. 7(a), which is the time resolved energy spectrum as measured by the segmented dump in spectrometer line 10. The transient is measured to have about a 40% higher energy than the steady state. In addition, since there was some residual dispersion in the linac, the transient was also seen reflected in the horizontal beam position monitor signals, just upstream of the dipole magnet used to bend the beam to the spectrometer line, see Fig. 7(c).

In order to reduce the transient, a technique has been proposed in order to accelerate the beam head less than the steady part of the pulse. It relies on the adjustment of the arrival time of the rf power in the accelerating structures with respect to the beam. The beam transient is initially generated in the first two accelerating structures on girder 3. The transient compensation is achieved by moving the timing of the next 3 klystrons pulses, namely MKS05, MKS06 and MKS07. The measurement of the evolution of the reduction in the transient is performed in the spectrometer line 10 and the results are depicted in Figs. 7-8.

The timing of MKS05 was adjusted to have the arrival of the rf, on the very edge of the arrival of the beam. Due to the filling time of the structure this meant that the transient saw less rf than the steady state, and hence was not accelerated as much as the steady state. The transient was reduced from 40% to approximately 20% of the steady state energy. Finally the arrival of the rf of MKS06 and MKS07 each were delayed by 550 and 250 ns, See Fig. 8(b) with regard to the nominal RF timings in Fig. 7(b). The final resulting transient was reduced to about 15%; see Fig. 8(a).

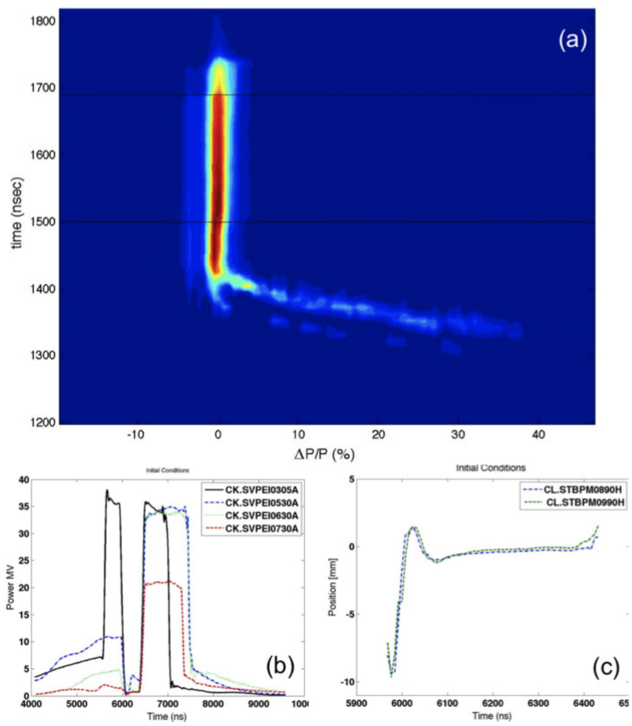

Figure 7: Initial Conditions. (a) The time resolved energy profile as measured with the segmented dump on spectrometer 10. (b) Output rf power measured from the accelerating structures (c) The horizontal position as measured with a beam position monitor on girders 8 and 9.

CONCLUSION

A new radiation hard segmented dump was installed, calibrated and commissioned successfully with beam. Two devices have been installed in the CTF3 facility, and measure the time resolved beam energy and energy spread along the pulse with a 10 ns resolution. The devices are used routinely in CTF3 to optimise the beam energy along the pulse. By manipulating the arrival time of the rf, it has been shown that the transient can be reduced from an initial spread of 40% to a final spread of about 15%.

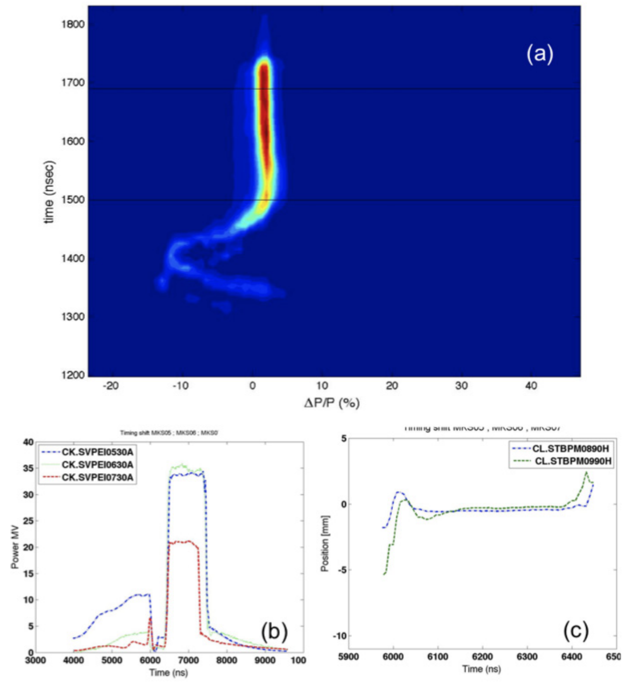

Figure 8: Delay arrival of rf from MKS05 by 400 ns; MKS06 by 550 ns and MKS07 by 250 ns with respect to the nominal conditions in Fig. 7. (a) The time resolved energy profile as measured with the segmented dump on spectrometer 10. (b) The output power measured from the accelerating structures. (c) The horizontal position as measured with a beam position monitor on girders 8 and 9.

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