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CLIC – Note – 983

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A. Palaia, M. Jacewicz, T. Muranaka, R. Ruber,
V. Ziemann, Uppsala University, Uppsala, Sweden
W. Farabolini, CEA/DSM/IRFU, Saclay, France

Abstract

The measurement of the effects of RF-breakdown on the beam in CLIC prototype accelerator structures is one of the key aspects of the CLIC two-beam acceleration scheme being addressed at the Two-beam Test Stand (TBTS) at CTF3. RF-breakdown can randomly cause energy loss and transverse kicks to the beam. Transverse kicks have been measured by means of a screen intercepting the beam after the accelerator structure. In correspondence of a RFbreakdown we detect a double beam spot which we interpret as a sudden change of the beam trajectory within a single beam pulse. To time-resolve such effect, the TBTS has been equipped with five inductive Beam Position Monitors (BPMs) and a spectrometer line to measure both relative changes of the beam trajectory and energy losses. Here we discuss the methodology used and we present the latest results of such measurements.

CERN-OPEN-2013-038
20/05/2012

Presented at: 3rd International Particle Accelerator Conference 2012, New Orleans, LA, USA, 20 - 25 May 2012

Geneva, Switzerland
Date 20/05/2012

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INTRODUCTION

RF-breakdown in accelerator structures can affect the accelerated beam, modifying its orbit and energy. Simulations and measurements of breakdown in X-band accelerator structures have shown that transverse momentum transfer can occurr such that the beam orbit is modified, or kicked [1]. Moreover it has been suggested that simply dark currents can kick the beam even if no breakdown happens [2].

Besides the general interest related to any accelerator based on high-gradient technology, the study and measurement of RF-breakdown effects on the beam are an extremely relevant aspect in the development of future high-energy linear colliders as the Compact Linear Collider (CLIC). Moreover such study represents one of the main goals in the experimental program of the Two-beam Test Stand (TBTS) at the CLIC Test Facility 3 (CTF3) [3].

Here we present the results of a first measurement of transverse kicks to the beam due to RF-breakdown in a CLIC prototype accelerator structure, carried on at TBTS during the CTF3 2011 run. We first describe our experimental setup. Then we focus on the description of our measurements based on the detection of the beam spot on a scintillating screen. Finally we describe the methods used in the analysis of the data and we discuss the results obtained so far.

EXPERIMENTAL SET-UP

The TBTS is part of CTF3 and is the only existing experimental facility where the two-beam acceleration concept on which CLIC is based on can be tested [4]. It consists of two parallel beam lines designed to test power extraction from a high-current beam (drive beam) and its transfer to a low-current beam (probe beam) to be accelerated. The drive beam is decelerated in a Power Extraction and Transfer Structure (PETS) which provides multi-MW 12 GHz radio frequency at expense of the beam energy. The RF is transferred through a waveguide network to a CLIC prototype accelerator structure (ACS) in which the probe beam is accelerated in a gradient of 100 MV/m. Both lines consists of a 10 m long straight section ending with a 1.6 m long spectrometer line where the beam energy can be measured before the beam dump. Both lines are equipped with five inductive Beam Position Monitors [6] (BPMs) - two upstream and three downstream of each structure - the last one being in the spectrometer line. Finally both lines are equipped with removable imaging screens which are used to measure the beam spot either just before of after the dipole magnet which bends the beam in the spectrometer line.

Transverse kicks to the beam orbit can be determined by using the beam position measurements [5] or by measuring the beam spot before the spectrometer line. Any change in the beam trajectory on a single beam pulse during a RF-breakdown in the accelerator structure is in fact expected to show up as a step in the BPM signals or as a double spot on the screen intercepting the beam.

The measurements of RF-breakdown kicks to the beam presented here are based on measurements of the beam spot with a YAG:Ce scintillating screen situated just in front of the spectrometer line dipole, about 4.8 m downstream of the ACS.

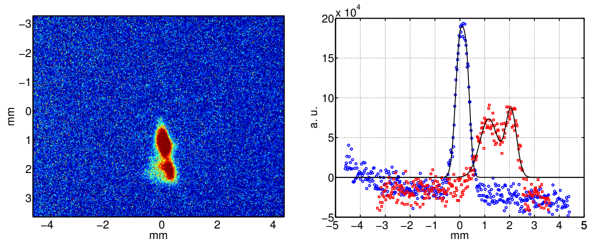
MEASUREMENTS, ANALYSIS AND RESULTS

Double spots were occasionally measured as shown in Fig. 1(a) which are explained as resulting from a change of the beam orbit during the pulse. Part of the pulse is kicked on the transverse plane, travels on a different orbit and hits the screen on a different point.

To verify that these double spots were not due to breakdown current hitting the screen, the measurement was repeated without the beam and this always led to a less bright, wider, and blurred image as shown in Fig. 2. It is worth noting that the gain of screen images in Fig. 2 is higher than the one normally used in presence of the beam (see for example Fig. 1(a)).

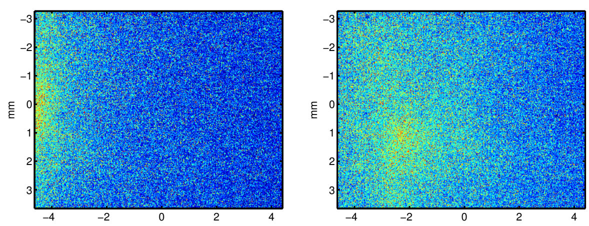
A photomultiplier directed towards one of the empty damping slots of the ACS was used as trigger. We observed in fact that despite it is sensitive to the dark current emitted from the ACS and shows a moderate activity during the

ISBN 978-3-95450-115-1



(a) (b)

Figure 1: Example of a double beam spot detected for the same beam pulse in correspondence of a RF-breakdown in the accelerator structure. (a) The beam spot is measured on a scintillating YAG:Ce screen. (b) The centroid of the two beam spots can be calculated by means of a 2-Gaussian fit on both the horizontal and the vertical projections of the screen image.



(a) (b)

Figure 2: Example of breakdown current detected on a YAG:Ce imaging screen downstream of the accelerator structure.

RF pulse, it shows a stronger signal whenever a breakdown occurs.

For each and every triggered event we recorded the corresponding beam spot measured on the scintillating screen. Due to beam jitter which is of the same order of the measured kicks to the beam, we are only able to detect kicks happening along a beam pulse and resulting in two distinct beam spots on the screen. The analysis presented here is based on such events.

Most of the recorded images show a double beam spot, although it is not always as clear as the case shown in Fig. 1(a), because often the two spots are very close. Therefore, under the assumption that the beam is Gaussian, for each image we calculated the centre of the two beam spots by means of a 2-dimensional 2-Gaussian fit, as shown in Fig. 3. A 2-dimensional fit is preferred to separate fits of vertical and horizontal image profiles because it includes information on the correlation between the two dimensions. Nevertheless the initial guess of the fit parameters is calculated with a 2-Gaussian fit on the horizontal and vertical profiles of the screen image, separately (see Fig. 1(b)). When only one beam spot was measured on the screen - either because the beam was not kicked or because the kick was smaller than the screen resolution - the 2-Gaussian fit does not converge or converge to a non-acceptable solution. In both cases the event is discarded.

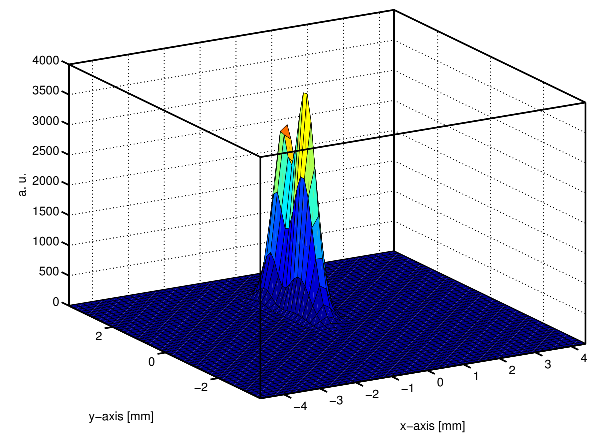


Figure 3: (a) Examples of 2-dimensional 2-Gaussian fit on the imaging screen data shown in Fig. 1(a).

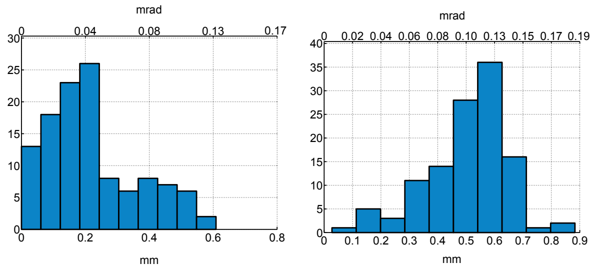
Given the distance $d_{x,y}$ between the two beam spots detected on the screen and the distance L between the center of the accelerator structure and the same screen, we calculated the corresponding kick angle $\phi_{x,y} \simeq d_{x,y}/L$ respectively on the horizontal and vertical planes, and the total kick angle $\phi = \sqrt{d_x^2 + d_y^2}/L$ (see Fig. 4). It is worth noting that we switched off all quadrupoles in the beam line to have only a drift space.

We also estimated the transverse electrical field $\mathcal{E}$ accounting for the measured kick angle, given the beam energy plus half of the energy gained in the accelerator structure as we do not have any time information of where the breakdown happened along the beam pulse. The electrical field is then $e\mathcal{E} \simeq E_{beam} \cdot \phi$ (see. Fig. 5(a)).

The magnitude of the measured kicks is about 0.13 mrad, which corresponds to a transverse momentum of about 25 keV/c in the accelerator structure. This estimation is consistent with previous measurements performed at SLAC [1].

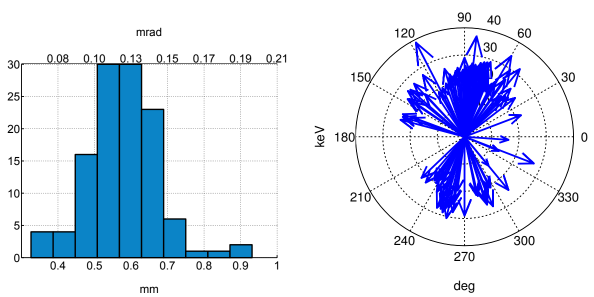
In Fig. 5(b) we present the measured kicks in a compass plot, where each arrow has a length corresponding to the transverse momentum transferred to the beam and a direction corresponding to the direction of the kick as it is measured on the screen.

We did not detect transverse kicks to the beam having a small or no vertical component, as shown in the compass plot in Fig. 5(b) and from the distribution in Fig. 4(a). Further studies are needed to exaplain that although the symmetry of the distribution suggests effects other than geometrical limitations. For instance, a misalignment of the accelerator structure with respect to the beam line would result in an asymmetric distribution.



(a) (b)

Figure 4: Distribution of horizontal and vertical kicks to the beam. The distribution of the horizontal distances and angles between the two beam spots is shown in (a) whereas the distribution of the vertical distances and angles between the two beam spots is shown in (b).



(a) (b)

Figure 5: Distribution of transverse kicks to the beam. The distribution of the distances between the two beam spots is shown in 5(a) whereas the distribution of the corresponding transverse electric field in the accelerator structure accounting for such effect is shown in 5(b).

CONCLUSIONS

We measured the magnitude of transverse momentum transferred to the beam during a RF-breakdown in a CLIC prototype accelerator structure. We call this effect "beam kick" and we measured its typical magnitude to be 25 keV/c. Our result is consistent with previous measurements in accelerator structures driven at lower power. The worst place where a kick can happen in CLIC is at the beginning of the main linac where the beam energy is 9 GeV. For such energy a transverse kick of 25 keV/c corresponds to a kick angle of about 32 μrad. It is worth noting that such angle is one order of magnitude bigger than the nominal CLIC beam divergence of about 0.2 μrad, assuming a vertical normalized emittance of 10 nm mrad and a beta function of 10 m at the beginning of the main linac.

ACKNOWLEDGMENTS

The authors thank the whole CTF3 team, especially J. Barranco, B. Constance and T. Persson for their support during the running of the experiment. A greatful acknowledge to D. Gamba for his fundamental help in the data acquisition. This work is supported by the 7th European Framework program EuCARD under Grant number 227579, the Knut and Alice Wallenberg foundation and the Swedish Research Council.

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ISBN 978-3-95450-115-1