RF-BREAKDOWN EXPERIMENTS AT THE CTF3 TWO-BEAM TEST-STAND

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Abstract

The Two-beam Test-stand (TBTS) in the CLIC Test Facility CTF3 offers unique possibilities to conduct RF-breakdown related experiments on the accelerating structures and the power extraction and transfer structures with beam. We report on the set-up of two such experiments, one for the measurement of the transverse kick and the other for the measurement of positive ion currents. The purpose of the transverse kick measurements is to determine the effects of a RF-breakdown event on the beam. Five BPMs in the TBTS will be used to study the trajectory of a pulse train after a RF-breakdown event, with important implications for the operation of CLIC. Ion currents ejected from accelerating structures during RF-breakdown events have already been observed at the 30 GHz test stand at the present test facility. Results and their implications for RF-breakdown physics are presented, as well as plans for similar measurements at the TBTS.

INTRODUCTION

The vacuum breakdown phenomena have been known for a long time and have been studied both in DC and RF conditions [1]. Results from experiments have been diverse and not seldom contradictory. We propose to utilize the unique possibilities of the TBTS to study the RF breakdown phenomena in the perspective of the two following questions:

- How big of a problem might RF breakdown become for CLIC operations?
- What are the conditions in a breakdown site, such as temperature and number of particles?

Two experiments conducted at the TBTS will try to provide clues to help answer these important questions. The first question will be investigated by the so called kick measurement, and the second will be addressed by ion current measurements.

The unique feature of the TBTS is that the set-up consists of two beamlines, in order to test the CLIC power generation scheme. A high-current low-energy beam (drive-beam) will be decelerated in special power extraction and transfer structures (PETS) in order to generate RF-power which will be used to power fully loaded accelerating structures. The high-gradient accelerating structures will accelerate a low-current beam (probe-beam). While RF-breakdown can be studied at other experimental set-ups, there are few which have an actual beam in the accelerating structures, and none which will test PETS. A overview of the TBTS with equipment can be found in [2]. The remainder of the paper will describe a set-up focused on experiment on breakdowns in the accelerating structures in the probe-beam, but the PETS in the drive-beam have breakdowns as well, which can be instrumented in the same fashion, with small modifications to the set-up.

KICK MEASUREMENT

The question of how much breakdown events affect the beam will be answered by the kick measurement. It has been observed and simulated at SLAC [3] that RF breakdown might affect the beam by electromagnetic interactions directly between the bunches and breakdown currents. The magnitude of the kick on the beam due to RF breakdown will help to decide on the tolerable breakdown rate in CLIC. Small kick magnitudes affects the luminosity when the bunch trains are kicked out of collision. Larger magnitudes might lead to beam dumping in the collimators or other sensitive equipment in the beam path, with extensive damage and downtime as one conceivable outcome.

In order to estimate how severe these effects are for CLIC, we plan to measure the breakdown kick at the TBTS in CTF3. An overview of the kick measurement experiment is displayed in figure 1, displaying five beam position monitors (BPM), one dipole magnet and two chicanes, which are a pair of small dipole steerer magnets. The readouts of the first two BPM's, allow for determining the incoming bunch train offset x^1 and angle x'^1. Breakdown occurs in the accelerating structures between the BPM's 2 and 3. The bunch train angle is changed with θ, and affects the readout on the last three BPMs. The last monitor (5) is placed after a dipole magnet. This magnet will add dispersion allowing BPM5 to measure the bunch train relative change in energy due to breakdown δ. A RF breakdown will cause the accelerating field in the structures to collapse, thus reducing the energy gain depending on when in the pulse and where in the structure the breakdown occurs.

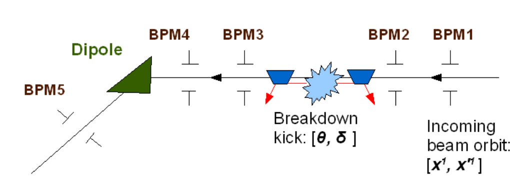

Figure 1: Overview of the kick measurement

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Note that a breakdown produces a high quantity of electrons, which are ejected almost simultaneously with the bunch train. This could potentially "blind" the BPM's near the accelerating structures. To remedy this problem a pair of small dipole magnets were added both up and downstream of the accelerating structures in order to divert the low-energy high-current breakdown electrons.

If the transfer matrix between every BPM are known, a least-square fit can be performed of the kick parameters θ and δ and incoming beam parameters x^1 and $x^{'1}$ to the BPM readout. Further, with knowledge of the transfer matrices as well as the accuracy in BPM readout σ, the accuracy of kick and incoming beam parameters can be determined, as investigated in [4].

The accuracy with which the kick angle θ can be measured was found to be on the order of 10 μrad for a BPM resolution of 10 μm [4]. The relative energy change which can be resolved was found to be in the order of 4×10^{-5} of total bunch train train energy, given the BPM accuracy stated above. The results of [3] suggest breakdown kicks up to 100 keV/c, which translates to a kick angle of 0.67 mrad in the TBTS. If this prediction can be applied to some degree of certainty to the CLIC accelerating structures, the kick should be resolvable with the BPMs present in TBTS [5].

The possibility to resolve the longitudinal position of the breakdown in the accelerating structures was investigated as well in [4], but the accuracy was found to be too poor (several cm) to be of practical use.

ION CURRENT MEASUREMENT

It was noted in 2006 that RF breakdowns are accompanied with not only a burst of electrons (breakdown current) but also with a burst of positively charged particles, identified as ions on account on the relative slow arrival time after a breakdown event (μs as compared to the ns arrival time of breakdown electrons). An extensive measurement of the ion currents was performed at the 30 GHz test stand [6] in CTF3 [7] in 2007. A paper describing this experiment is currently under review [8].

Results from 30 GHz Test Stand

Assuming that the ions originate from a small sphere of charged particles with an initial velocity determined by the thermal motion of the particles, the arrival time of the particles at a detector some distance away is determined by three parameters as shown in [9]:

- $\tilde{N}_0$: the effective amplitude factor. [1]
- t_s: the arrival time of a majority of the particles,
- α: a parameter describing the relative importance of thermal motion versus Coulomb interactions in the breakdown event.

In 2007, 6700 ion currents were recorded at the 30 GHz test-stand. Ion currents were detected on average in one out of every four breakdown events. Different pulse lengths, amount of RF power and level of conditioning seemed to influence the occurrence rate of ion currents, but the dependence is not obvious. The simple model outlined above fits some of the data very well, as displayed in figure 2. The fit parameters for this ion current event were found to be: $\tilde{N}_0 = 7.9 \times 10^9$, $\alpha = 0.47$, and $t_s = 4.6\mu$s.

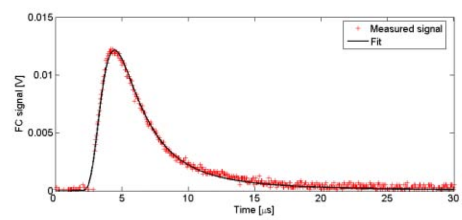
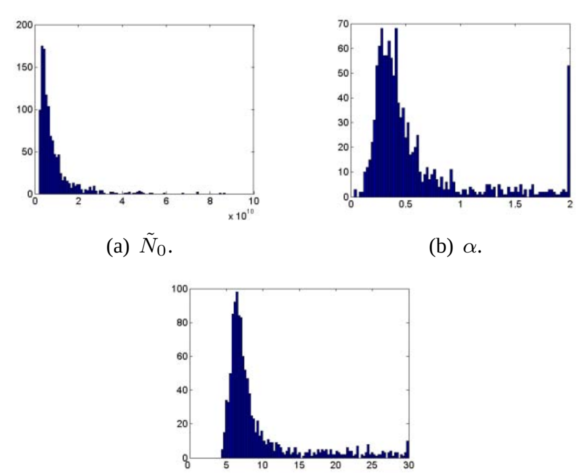


Figure 2: A sample ion current event with fit. The breakdown electrons have been removed from this plot.

If the distance between the detector and the breakdown is known, as well as the ion masses, the temperature T of the breakdown can be calculated from t_s and α. The median values for 1146 selected "good" fits were: $\tilde{N}_0 = 5.86 \times 10^9$, $\alpha = 0.41$ and $t_s = 7.1\mu$s, which yields a median temperature $T = 5.1 \times 10^5$ [K] (assuming copper ions). A histogram of the fit-parameter t_s from the 1146 selected ion current event is displayed in figure 3.

The model in [9] fits some of the data very well, but other ion current events showed multiple peaks as displayed in figure 4. The peaks seem to fall into three categories with



(a) $\tilde{N}_0$. (b) α. (c) t_s.

Figure 3: Fit parameters from 1146 selected ion current events.

[1] The total number of particles in the breakdown event N_0 is given by $\tilde{N}_0/\eta$, where η is the acceptance efficiency of the FC, including solid angle coverage [9].

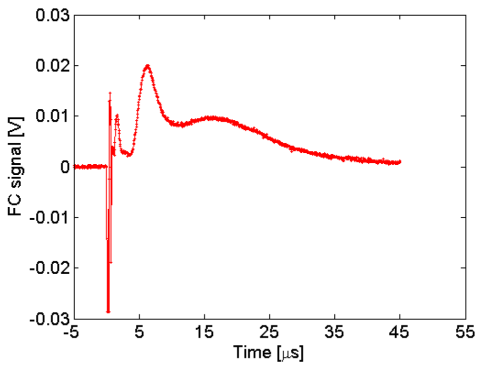


Figure 4: A multiple peak ion current event.

a specific arrival time:

- ”Fast” peaks, almost overlapping with the breakdown electrons, occurs around one μs after a breakdown and are generally narrow,
- ”medium” peaks arrive between 5 and 10 μs, as is the case of the ion current event displayed in figure 2, and
- ”slow” peaks arrive after 15 μs, and are generally wider than the ”medium” ones.

While many of the ion current events seems to have only one peak, the majority of events seem to be a mix of all three categories of peaks with different amplitudes. The ion current event in figure 4 is an example where all three types of peaks are clearly visible. Multiple peaks possibly indicate either several breakdown sites or multiple ionization states of the ions or possibly both.

Planned Measurements at TBTS

In order to measure the degree of ionization or the mass-to-charge ratio of the particles from a breakdown event, an electric or magnetic field is needed. The ions are slow, but have a large momentum due to their large mass compared to electrons. The small chicane dipole steerer magnets foreseen for the kick measurement will have little effect on the ions, and thus a electric field should be added to the TBTS, along with a spatial resolved detector. The straightforward choice of detector would be a Faraday-cup, due to the easy design and manufacturing of such device, as well as the insensitivity to radiation (as opposed to e.g. silicon detectors).

Design has begun on such detector, the so-called ”Flashbox”. The exact design of the Flashbox is work in progress, and it is foreseen to be completed and installed in time for phase 2 (March 2009) or sooner in TBTS.

SUMMARY

The TBTS offers unique possibilities to study the RF breakdown phenomena. We have outlined two such experiments, the kick measurements and the ion current measurements. The result of the experiments will provide some clues to help answer important questions about RF breakdown.

ACKNOWLEDGMENTS

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