EFFECT OF BEAM-LOADING ON THE BREAKDOWN RATE OF HIGH GRADIENT ACCELERATING STRUCTURES*

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Abstract

The Compact Linear Collider (CLIC) is a study for a future room temperature electron-positron collider with a maximum center-of-mass energy of 3 TeV. To efficiently achieve such high energy, the project relies on a novel two beam acceleration concept and on high-gradient accelerating structures working at 100 MV/m. In order to meet the luminosity requirements, the break-down rate in these high-field structures has to be kept below 10 per billion. Such gradients and breakdown rates have been demonstrated by high-power RF testing several 12 GHz structures. However, the presence of beam-loading modifies the field distribution for the structure, such that a higher input power is needed in order to achieve the same accelerating gradient as the unloaded case. The potential impact on the break-down rate was never measured before. In this paper we present an experiment located at the CLIC Test Facility CTF3 recently proposed in order to quantify this effect, layout and hardware status, and discuss its first results.

INTRODUCTION

The CLIC project [1] aims to collide electrons and positrons accelerated in two opposing linacs using normal conducting high-gradient accelerating structures. The main limitation for the achievable gradient is the RF breakdown effect which results in luminosity loss due to the transverse kick on the beam. In order to limit luminosity loss due to this effect to less than 1%, a maximum breakdown rate of $3 \cdot 10^{-7}$ BD/(pulse·m) is specified for CLIC at 3 TeV, at the nominal gradient of 100 MV/m [1]. During the last years an extensive program has been carried out to understand and control the RF breakdown rate in prototype CLIC accelerating structures. Results [2] demonstrate that such low breakdown rates are achievable.

In contrast, all breakdown high-gradient tests so far have been performed without the presence of an accelerated beam inside the structure. CLIC is designed to run with a high RF-to-beam efficiency (the fraction of RF power converted to beam kinetic energy), reaching around 30%. This high level of beam loading is accomplished with the high beam current of approximately 1A, which unavoidably modifies the longitudinal field profile (Fig. 1).

The effect of the changing field profile on the breakdown behaviour is hard to predict. While the whole-structure breakdown rate varies approximately with electric field as E_{acc}^{30} when input power is varied [2], the longitudinal dependency of the breakdown rate with the surface electric field is linear [3]. In order to experimentally measure the effect of beam loading on breakdown rate, an experiment is running at CTF3 using a 12 GHz klystron connected to a CLIC prototype accelerating structure loaded by the drive beam of the facility.

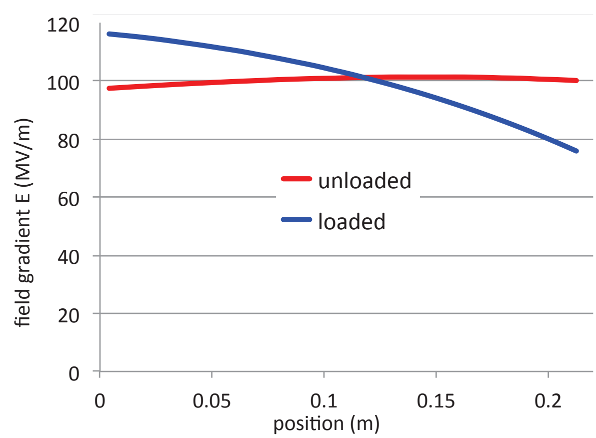

Figure 1: Longitudinal field gradient profile for an unloaded (red line) and 1.2 A of beam loaded (blue line) CLIC travelling wave structure at 100 MV/m average gradient.

EXPERIMENT LAYOUT

CTF3 was built to probe the main feasibility issues of the two beam acceleration concept [1]. In the past, a dogleg line branching off midway the drive beam linac was used to divert the beam and send it through an RF generating Power Extraction and Transfer Structure (PETS) to produce 30 GHz RF power conveyed to CTF2 [4]. The line has been reused to install a 24 cell CLIC prototype accelerating structure (Fig. 2) connected to a 12 GHz RF source. The iris radius of the structure cells are tapered to reduce the group velocity and provide a constant distribution of the unloaded gradient (Fig. 1). The forward, reflected and transmitted RF powers are sampled by logarithmic detectors and measured by the

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acquisition system. Two Beam Position Monitors (BPMs) located upstream and downstream the structure measure the beam current sent through. An upstream collimator prevents damage in the case of beam losses. In addition, two beam loss monitors that are based on diamond and optic fibre detection have been recently installed. They will check the potential of this technology to detect particles scattered or created by the breakdown. The basic layout of the installation is shown in Fig. 3.

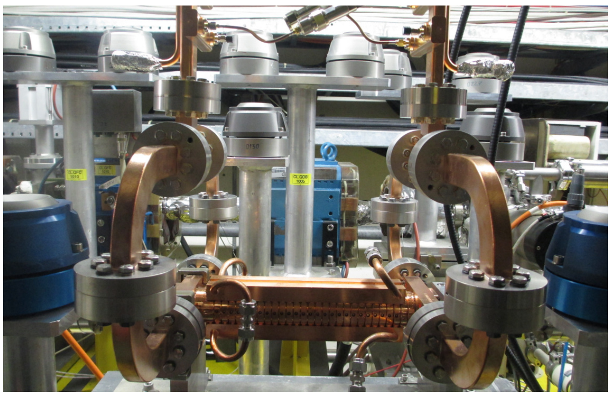

Figure 2: T24 structure installed in the CTF3 Dogleg line.

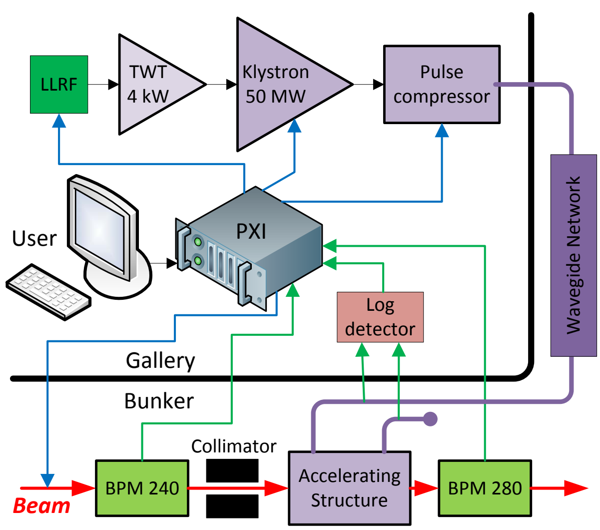

Figure 3: Simplified scheme of the hardware installation, control and acquisition system.

12 GHz *RF Source*

The 12 GHz test stand (Xbox-1 [5]) is comprised of a klystron, pulse compressor cavity and an RF network to transport the RF to the structure. The LLRF produced is pre-amplified using a 3 kW TWT before injecting it to the klystron. The klystron is capable of producing 50 MW of 12 GHz RF pulses of 1.5 μs at 50 Hz repetition rate [6] driven by a Scandinova solid state modulator [7]. The pulse compressor is a SLED I type able to compress the klystron output into a 250 ns 140 MW pulse [8], enough to feed the loaded structure accounting for waveguide losses. The RF power is transported through a complex waveguide line, which includes overmoded waveguides and components. The measured RF transport efficiency from klystron to the structure is 0.67, with 115 ns group delay time, which approximately correspond to about 35 m of waveguide system length.

Beam Source

The beam for loading the accelerating structure is provided by the CTF3 linac. It is generated from a thermo-ionic gun and can be coded into 1.5 GHz or 3 GHz bunch frequency using a system of subharmoic bunchers, prebuncher and buncher cavities. A magnetic chicane with a slit can be used to reduce the energy spread, and acceleration is provided by 8 travelling wave accelerating cavities at 3 GHz connected to 4 klystrons equipped with pulse compression system. Further down the linac after the dogleg start a spectrometer and a screen allow to measure energy and Twiss parameters of the beam by a quadrupole scan. This configuration offers enough flexibility to provide beam pulses of 1.2 A, 250 ns and up to 130 MeV with a pulse repetition frequency up to 25 Hz compared with the 4 A, 1120 ns at 0.8 Hz of the standard beam operation conditions.
The optic inside the dogleg line has been designed to provide minimum beam size and maximum transmission through the structure under test [9].

Acquisition System

The acquisition system checks all signals in real time and stores events periodically as well as breakdown events. The breakdown events use a buffer which contains the two previous pulses in addition to the breakdown pulse itself. This approach allows the breakdowns to be compared with normal events and to check for potential evidence of breakdowns triggers. The breakdown identification is based on the observation of reflected RF power and the loss of transmitted signal through the structure compared to the incident pulse. Regarding the safety of the equipment, the system inhibits the operation of the 12 GHz klystron to avoid damage to the structure and the klystron itself if conditions on the beam, RF signal or vacuum are not appropriate. Since the operating rate varies from 10 to 50 Hz, we use a powerful NI PXIe-8133 controller equipped with a high-performance NI FlexRIO FPGA-based digitizers (NI 5761 – 250MS/s – 4ch) [10] for power signal reading and interlocking complemented with serial buses, digital IO and the CERN control system, all controlled and interfaced to the user with an adapted version of the Labview program used in [11].

FIRST RESULTS

The experiment was divided in two stages, first a period of installation and calibration and then conditioning and full tests period.

During the first period the structure was loaded with beam and RF production was observed. Figure 4 shows that the measured power (corrected for calibration errors) fits very well the expected RF calculated from the incident beam current. On the other hand, the steady-state output power as function of beam current can be calculated for both BPMs surrounding the structure. The shadow area in Fig. 5 shows the measured dependency which fits with the theoretical prediction (black line). Uncertainties come from both beam losses and calibration errors of the RF power which, in the worst case, is better than 1.3 dB for a total attenuation of 79 to 87 dB.

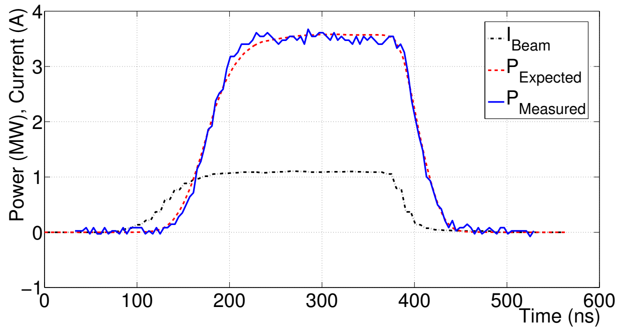

Figure 4: Forward RF output power of the accelerating structure calculated from the measured beam current profile along the pulse together with measurement (scaled in power level).

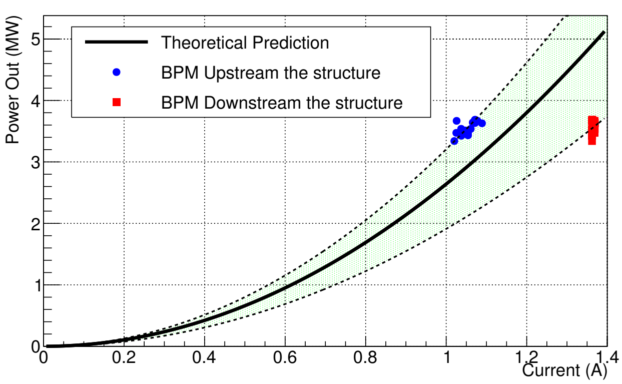

Figure 5: Steady-state forward RF output power of the accelerating structure as function of beam current, for the theoretical prediction and for experimental results (shadow area) bounded by measurements of current upstream and downstream the accelerating structure.

For the second stage the structure was connected to the 12 GHz source. The conditioning process began in middle of July 2014. Figure 6 shows the conditioning history of the structure with RF for a pulse length of 50 ns. It is performing as expected and it will be loaded with beam by end of August, once the nominal pulse length has been achieved.

CONCLUSION

An experiment has been set up to measure the effect of beam loading on the break down rate. The hardware and acquisition channels have already been installed and calibrated. RF conditioning of the structure is progressing successfully and will continue until an unloaded breakdown rate of ~ 10^{-5} is reached for the nominal pulse length. From

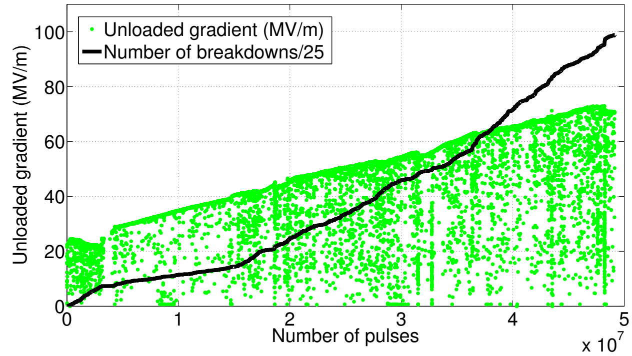

Figure 6: Evolution of gradient (green) and accumulated breakdowns (black) for the dogleg structure.

that point on, the loaded and unloaded operation will be alternated during the conditioning procedure in order to compare the evolution of the breakdown rate for the two states. This will be complemented by a complete program of measurements with different beam and RF conditions.

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