HIGH-GRADIENT TEST RESULTS FROM A CLIC PROTOTYPE ACCELERATING STRUCTURE: TD26CC

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Abstract

The CLIC study has progressively tested prototype accelerating structures which incorporate an ever increasing number of features which are needed for a final version ready to be installed in a linear collider. The most recent high power test made in the CERN X-band test stand, Xbox-1, is of a CERN-built prototype which includes damping features but also compact input and output power couplers, which maximize the overall length to active gradient ratio of the structure. The structure's high-gradient performance, 105 MV/m at 250 ns pulse length and low breakdown rate, matches previously tested structures validating both CERN fabrication and the compact coupler design.

INTRODUCTION

One of the highest priorities for the CLIC collaboration has been the development of accelerating structures for the facility's main linac. The most important specifications for the structures are a high accelerating gradient, 100 MV/m, a normalized average beam aperture radius a/λ above 0.11 and very strong high-order transverse mode suppression. Details of the origin of these specifications and the optimization that led to the current design can be found in the CLIC Conceptual Design Report [1].

Different versions of structures have been tested in the course of the development program – first simplified structures without high-order-mode (HOM) damping waveguides and later with them included. The structure described in this report, named TD26CC, takes the next step in this process and is the first to also include compact input and output power couplers. Compact couplers allow the structures to be installed as close together as possible in the linac, in order to maximize filling factor and average accelerating gradient. They replace the so-called mode-launcher couplers used in previous test structures.

Prototype accelerating structures have been successfully produced and high-gradient tested over the past few years in a close collaboration between CERN, KEK and SLAC [2]. CERN has made the RF designs, the structures have been manufactured jointly by KEK and SLAC and tested at both KEK and SLAC. The structure described in this report is the first to be both fabricated and tested at CERN, and thus also represents an important step in broadening the availability of X-band infrastructure and technology.

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RF DESIGN

The RF design of the TD26CC prototype is the one of the CLIC accelerating structure for the CDR and is described in detail in [3]. In summary, the accelerating structure consists of 26 regular cells with iris radius tapered from 3.15 mm down to 2.35 mm to reduce the group velocity from 1.65% down to 0.83% of the speed of light. This tapering provides constant distribution of the unloaded gradient along the structure.

Four waveguides are attached to each regular cell for damping higher order modes. The outer wall of each cell is optimized in order to reduce surface magnetic field enhanced by the coupling aperture to the damping waveguides. In addition to the 26 regular cells there are input and output coupler cells. These are essentially double-feed magnetic couplers with two additional damping waveguides attached to each coupler cell to maintain good HOM damping also in the coupler cells. The coupler cells provide the same accelerating gradient as the regular cells due to their compactness. This is the first CLIC structure prototype tested with these compact couplers.

The prototype needs 42.6 MW input power for an unloaded gradient of 100 MV/m averaged over the 230 mm active length (26 regular + 2 coupler cells). At this gradient, the maximum surface electric field is constant along the structure at the level of 200 MV/m, the pulsed surface temperature rise for 100 ns rectangular pulse is going from 22 K in the first cell down to 18 K in the last cell and the modified Poynting vector S_c [4] is also going down from 3.9 MW/mm^2 in the first cell to 2.9 MW/mm^2 in the last cell.

STRUCTURE FABRICATION AND TUNING

CLIC accelerating structures are composed of micron-precision diamond-machined OFHE copper disks which are etched, bonded together in a hydrogen atmosphere at 1025 °C and finally vacuum-fired at 650 °C. This procedure was adopted from that developed during the NLC/JLC linear collider project. Details of the procedure can be found in [1, 5]. Structures are tuned after bonding and vacuum-firing is done just before testing. The structure was tuned to have very small phase errors and little residual standing wave pattern as shown in Fig. 1.

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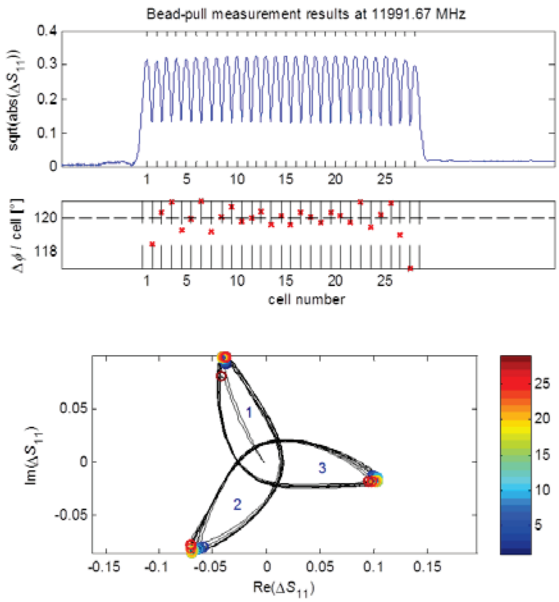

Figure 1: Bead-pull measurement results after tuning the structure; from top to bottom: the electric field distribution along the beam axis, the phase advance per cell and the change of the input reflection due to the perturbing bead in complex plane.

HIGH-POWER TESTING

The TD26CC structure was high-power tested in the Xbox-1 test stand at CERN, which is described in detail in [6]. The structure was instrumented and interlocked for breakdown with incident, transmitted and reflected RF signals, Faraday cups and vacuum. A photograph of the structure installed in Xbox-1 is shown in Fig. 2.

The conditioning process was computer controlled using the newly-developed algorithm described in [6]. Overall the structure was conditioned first at a short pulse length, 50 ns, up to the target gradient of 105 MV/m. The

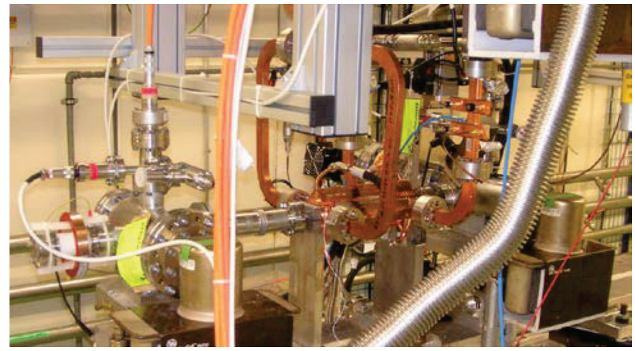

Figure 2: Structure installed in Xbox-1.

pulse length was then increased to 250 ns in 50 ns steps. After each pulse length change, the input power to the structure was reduced to compensate for the increased pulse length and then progressively ramped up in power while maintaining the set target breakdown rate. This rate was chosen to be $7 \cdot 10^{-5}$ initially and was later (after 10^{8} pulses) reduced to $2 \cdot 10^{-5}$.

The structure test history is summarized in Fig. 3. The figure shows the gradient profile, the cumulated number of RF breakdowns, the peak value of dark current measured on the downstream Faraday cup during normal pulses and the logarithm of the breakdown rate (BDR). The structure has been tested for more than 1800 hours at 50 Hz corresponding to $3.3 \cdot 10^{8}$ pulses. The change in target breakdown rate can be seen in the change of slope of the accumulated breakdowns curve (green) in Fig. 3.

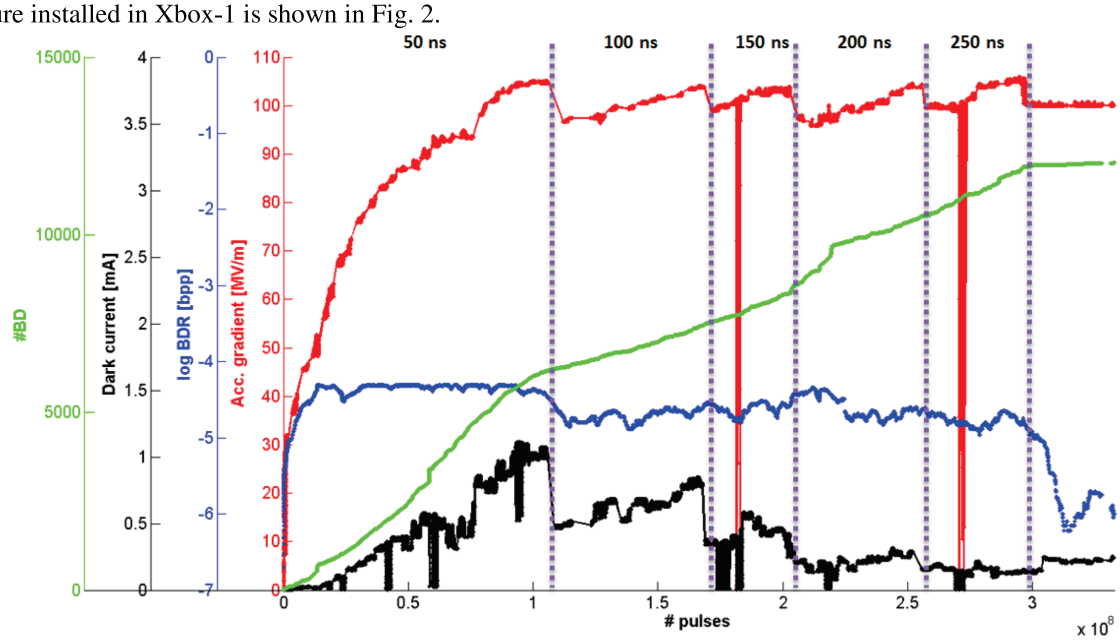

Figure 3: Summary of the TD26CC test history.

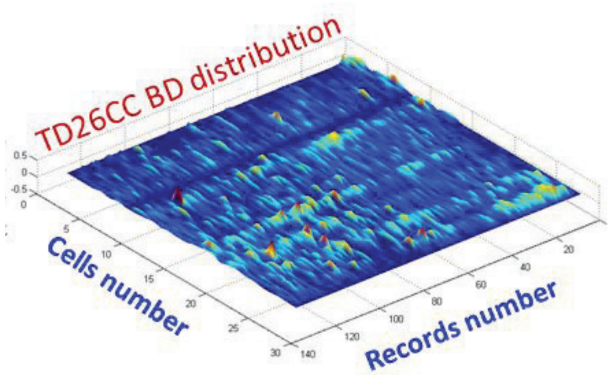

Figure 4: Breakdown distribution as a function of cell number and of time, in 8 hour records.

The structure performed well during high power operation and conditioned steadily throughout the run. The breakdown rate was however strongly influenced by pulse compressor tuning. Typically the structure showed an increased BDR pulse when compressor cavities were tuned both too high and too low in frequency.

Breakdown rates were measured for the structure as a whole. In addition the position of each breakdown was determined using the timing of breakdown-induced features in incident, transmitted and reflected RF signals. A summary of the evolution of the distribution of breakdowns along the structure length is shown in Fig. 4. There is no evidence of the development of any 'hot' cell.

At the time of this writing, operation of the structure has been suspended due to the reconfiguration of Xbox-1 for an experiment of the effect of beam-loading on breakdown rate [7]. Testing is expected to resume later this year (2014).

COMPARISON TO PREVIOUS STRUCTURES/RESULTS

The performance of the structure at the end of the testing period covered in this report was 105 MV/m average unloaded accelerating gradient at a flat-top pulse length of 250 ns and a breakdown rate of $2 \cdot 10^{-5}$. After the initial conditioning period, a measurement of breakdown rate evolution at fixed gradient of 100 MV/m was started. The high gradient performance of the structure was still improving and had already exceeded all previously tested damped structures as shown in Fig. 5.

ACKNOWLEDGMENT

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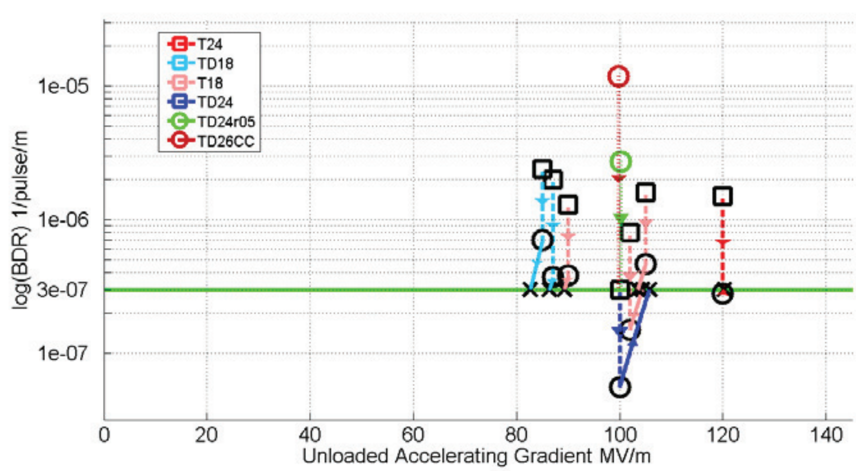

Figure 5: Summary of high-gradient test results of prototype CLIC accelerating structures.

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