ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEOCA02

RECENT RESULTS FROM CTF3 TWO BEAM TEST STAND

Wilfrid Farabolini, Franck Peauger, CEA/DSM/IRFU, France
Roberto Corsini, Davide Gamba, Alexej Grudiev, Muhammad Asif Khan, Stefano Mazzoni, Jose Luis Navarro Quirante, Rui Pan, Jack Raymond Towler, Niki Vitoratou, Kashif Yaqub, CERN, Geneva, Switzerland
Christopher Borgmann, Jim Oegren, Roger Ruber, Uppsala University, Uppsala, Sweden

Abstract

From mid-2012, the Two Beam Test Stand (TBTS) in the CTF3 Experimental Facility is hosting 2 high gradient accelerating structures powered by a single power extraction and transfer structure in a scheme very close to the CLIC basic cell. We report here about the results obtained with this configuration as: energy gain and energy spread in relation with RF phases and power, octupolar transverse beam effects compared with modelling predictions, breakdown rate and breakdown locations within the structures.
These structures are the first to be fitted with Wake Field Monitors (WFM) that have been extensively tested and used to further improve the structures alignment on the beam line.
These results show the unique capabilities of this test stand to conduct experiments with real beams.

INTRODUCTION

The CLIC two beam acceleration *scheme* has been successfully demonstrated in 2011 at CERN in the CTF3/CLEX facility [1, 2]. After having obtained an accelerating gradient up to 145 MV/m and developed tools to investigate the breakdowns and their consequences on the beam orbit, the next step was to install two X-band accelerating structures (ACS) powered by a single Power Extraction and Transfer Structure (PETS) according to the elementary CLIC cell design. In addition these ACS are for the first time equipped with WFMs adapted on the High order mode (HOM) waveguides fitted with silicon carbide (SiC) damping material (Fig. 1).

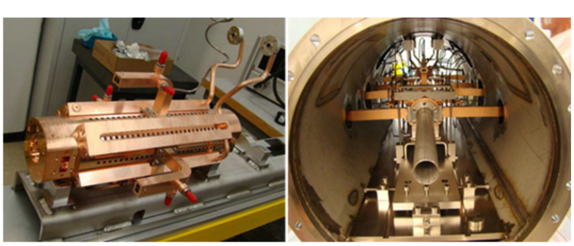

Figure 1: ACS with its WFM waveguide in the middle cell and vacuum test tank with 2 ACS inside.

In the aim to enlarge the small circle of institutes/industries capable of producing such mechanically challenging devices the realisation of these ACS was attributed to the CEA Saclay which in turn commissioned Mecachrome for the precise machining and Thales for the diffusion bonding under 1 bar hydrogen pressure [3].

ACCELERATING PERFORMANCES

The two ACS require a RF power of 85 MW combined to reach unloaded gradient of 100 MV/m within their 24 regular cells. Due to the limited CTF3 drive beam current (24 A) compared to the CLIC one (101 A) a recirculation of RF power inside the PETS is adopted to increase the output peak power using a variable phase shifter at the ACS input coupler and a variable splitter at its output (Fig. 2). To ensure larger flexibility an additional phase shifter is installed on the waveguide to the second ACS.

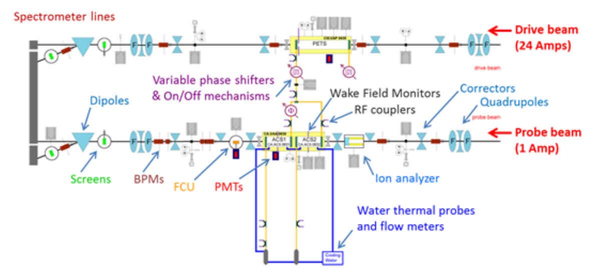

Figure 2: Scheme of the TBTS in CLEX.

The power pile-up produced by the recirculation makes the RF pulse shape rather triangular and implies an accurate synchronisation of the Califes probe beam versus the Drive beam to experience the maximum accelerating gradient taking into account the ACS filling time of 63 ns (Fig. 3).

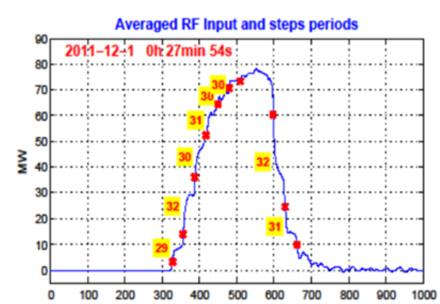

Figure 3: Power pile-up at the PETS output evidencing the recirculation group delay (yellow labels in ns).

Accurate phasing between the 2 ACS is ensured by first regulating the phase of the second ACS towards a set point where not beam acceleration is measured (ACSs in anti-phase), and then shifting its phase by 180°. For setting the ACSs common crest accelerating phase their phase is first positioned where the beam is not accelerated

5th International Particle Accelerator Conference IPAC2014, Dresden, Germany JACoW Publishing
ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEOCA02

(zero crossing) and then the probe beam phase is shifted by 90°.

Energy gain recorded on few hundreds RF pulses during phase scan is very close to the theoretical performances of the ACSs, the difference could be explained by RF power calibration uncertainties (Fig. 4).

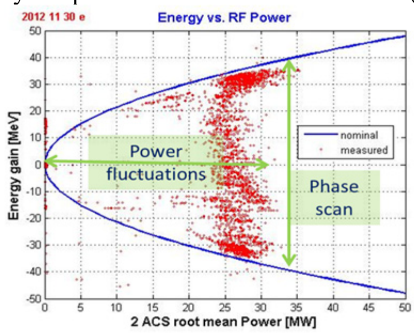

Figure 4: Energy gain obtained with 2 ACS as function of RF phase and power.

OBSERVATION OF THE OCTUPOLAR COMPONENT OF THE FUNDAMENTAL ACCELERATING MODE

Beam shape and trajectory are affected when the beam is not well centred in the ACS. We applied a new method to investigate this effect by sending a large and parallel flat-profile beam that occupies the whole structures aperture (Fig. 5).

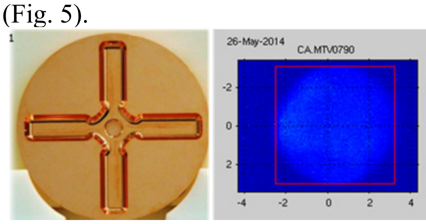

Figure 5: An ACS disk with its 4 HOM damping waveguides and the flat beam collimated by the smallest iris aperture with diameter 4.7 mm.

Downstream to the ACS the beam shape reveals an octupolar focusing effect caused by transverse field component generated by the four HOM waveguides in each cell. RF octupolar component is maximal at zero crossings (Fig. 6) and is null on crest. The effect was predicted by the RF model and measurements, in good agreement with expectations, confirm it will be negligible for CLIC operation [4].

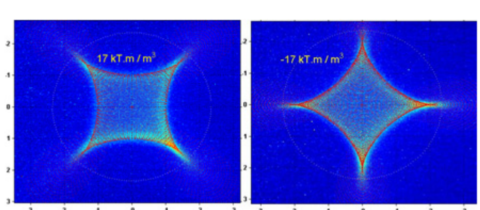

Figure 6: Large beam shape downstream to the ACS at zero crossing, left: towards accelerating phase, right: towards decelerating phase. The red superposed lines are the octupolar model fit.

BREAKDOWNS KICKS

The limiting factor for the accelerating gradient is the breakdown rate that for CLIC is requested to be lower than 4.10^{-7} events per pulse and per meter [5]. The risk with a breakdown (BD) is that the beam can be kicked out of its nominal trajectory inducing emittance growth or even beam loss. An extensive study of these phenomena has been conducted using time resolved cavity BPMs and beam profile diagnostics [6]. Long trains of bunches (200 ns) have been used in order to sample the ACS before and after the BD event (Fig. 7).

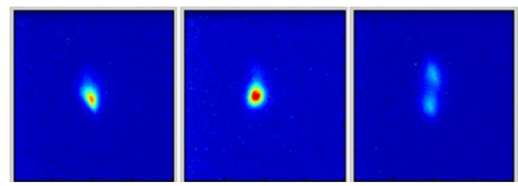

Figure 7: Sequence of 3 successive pulses, left: accelerated without BD, middle: non-accelerated (RF off), right: accelerated with a BD during the pulse.

Statistical results (Fig. 8) shows average kick strength around 25 keV/c in accordance with previous measurements [7] but the number of events was still too limited to conclude on a possible anisotropy in the kick direction.

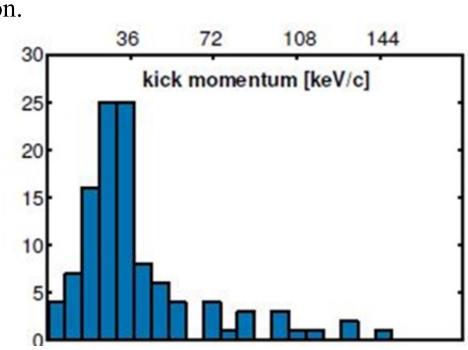

Figure 8: Histogram of the BDs kick momentum.

Further studies are to be conducted to figure out the kick mechanisms, like sending the probe beam after the RF pulse has vanished in order to investigate a possible plasma effect on the beam [8]. Investigating beam kicks for various accelerating phase is also foreseen as suggested in [7]

WAKEFIELD MONITORS

WFM are installed on the central cell of the ACS on which the HOM waveguides are extended by a bended waveguide terminated with SiC absorber (Fig. 9). Two dipolar modes are experimented, a TM-like at 18 GHz and a TE-like at 24 GHz [9]. Logarithmic detectors are used to rectify the signal with 50 dB of dynamic. The first results obtained by scanning the beam positions with correctors have shown a vertical misalignment of the two

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEOCA02

ACS as regard to the rest of the line elements (Fig. 10). This misalignment has been corrected resulting in a much easier beam transport.

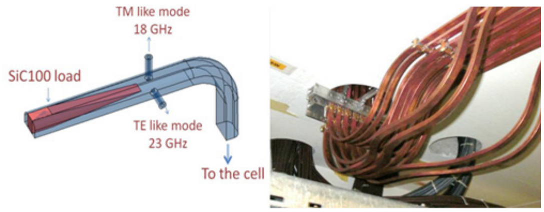

Figure 9: Extended waveguide with the 2 coupling antennas and the SiC absorber and waveguide network to the electronic gallery.

Studies are continuing to determine the WFM resolution when ACSs are powered with their nominal 42.6 MW RF power. Without external RF power the resolution has been measured to better than 25 µm with the 24 GHz mode and low bunch charge.

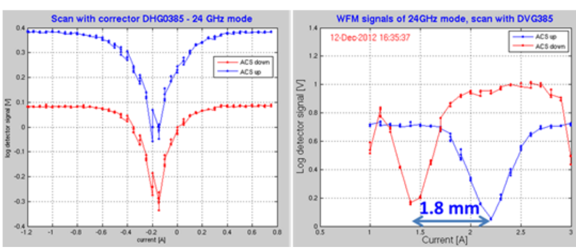

Figure 10: WFM response of the 2 ACS for a horizontal beam position scan (left) and a vertical scan (right). The ACSs were vertically misaligned.

TESTS OF BEAM DIAGNOSTICS

The Califes probe beam has been used to experiment a large variety of beam diagnostics related to the CLIC project, like high accuracy cavity BPMs, beam loss monitors and a longitudinal profile monitor based on electro-optical spectral decoding system (EOS) [10]

The EOS installation and the results are described at ref. [11]. Measures are cross-checked using a streak camera with a resolution of 200 fs (Figure 11).

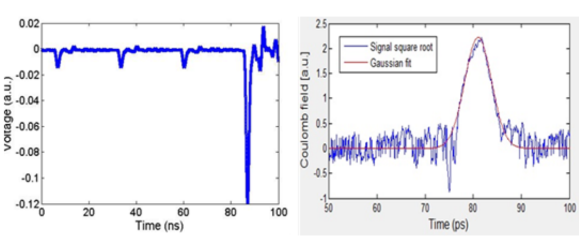

Figure 11: Left: 3 laser pulses though EOS system non synchronous with e$^-$ bunch followed by a synchronous one. Right: spectrum of the chirped laser pulse calibrated in ps corresponding to a bunch length of 6.9 ps FWHM.

CONCLUSIONS

The CTF3/TBTS has proven to be an essential facility to demonstrate the CLIC acceleration scheme validity. Testing X-band structures with beam allows accurate validation of their properties (accelerating gradient, beam characteristics) and understanding of key phenomena (kicks due to breakdown). Devices like WFMs can only be characterized in such a facility that also offers flexible test benches for experiencing various types of beam diagnostics.

In the near future (Sept. 2014), the first CLIC module will be installed in the TBTS. Being a real prototype of the CLIC lattice, it includes all the features to be tested simultaneously: Drive beam line with 2 PETS, 2 quadrupoles and 2 BPMs, Main beam with 4 ACS and 2 WFMs, and a complete set of instruments for active alignment of the girders.

After completion of the CLIC module program in CTF3, planned for 2016, a reflexion is open to maintain the CALIFES accelerator facility for beam instrumentation test and to couple it to a standalone test stand based on X-band klystron.

REFERENCES

[1] R. Ruber et al., “The CTF3 Two-beam Test Stand”, Nucl. Inst. Meth. A729 (2013) 546.

[2] W. Farabolini et al., “Two Beam Test Stand Experiments in the CLEX CTF3 Facility”, IPAC11, Sept. 2011, San Sebastian, (MOOCA02).

[3] F. Peauger, “Progress on TD24 Accelerating Structures Fabrication and Wakefield Monitor Experiment Preparation”, HG2012, Apr. 2012, KEK Tsukuba.

[4] W. Farabolini and A. Grudiev, presented at the CLIC RF Structure Development Meeting of 29th May 2013 - http://indico.cern.ch/event/245687/

[5] “CLIC Conceptual Design Report (CDR)”, CERN-2012-007 ; SLAC-R-985 ; KEK-Report-2012-1 ; PSI-12-01 ; JAI-2012-001, Geneva, 2012.

[6] Andrea Palaia, “Beam Momentum Changes due to Discharges in High-gradient Accelerator Structures”, PhD Thesis, Uppsala University, Nov 21, 2013.

[7] V. A. Dolgashev, T. Raubenheimer, “Simulation of RF Breakdown Effects on NLC Beam” SLAC-PUB-10668, Aug 2004.

[8] A. A. Sahai, T. C. Katsouleas, “Refraction of e$^-$ beams due to plasma lensing at a plasma-vacuum interface applied to CLIC beam”, ECE, Duke University, Durham, June 14, 2013.

[9] F. Peauger et al, “Wakefield Monitor Development for CLIC Accelerating Structure”, LINAC 2010, Tsukuba, Japan (TUP098).

[10] M. Wendt et al. “Status of the CLIC/CTF3 beam instrumentation R&D”, IPAC14, these proceedings.

[11] R. Pan, “Timing Design of a Bunch Profile Monitor Based on Electro-Optic Spectral Decoding”, BIW12, Apr. 2012 (MOPG034).