CALIFES: A MULTI-PURPOSE ELECTRON BEAM FOR ACCELERATOR TECHNOLOGY TESTS

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Abstract

The Compact Linear Collider (CLIC) project aims to accelerate and collide electrons and positrons up to 3 TeV center-of-mass energy using a novel two-beam acceleration concept. To prove the feasibility of this technology the CLIC Test Facility CTF3 has been operated during the last years. CALIFES (Concept d'Accélérateur Linéaire pour Faisceau d'Electron Sonde) is an electron linac hosted in the CTF3 complex, which provides a flexible electron beam and the necessary equipment to probe both the two-beam acceleration concept and novel instrumentation to be used in the future CLIC collider. In this paper we describe the CALIFES Linac and its beam characteristics, present recent test results, outline its future program on two-beam module testing and finally discuss about possible future applications as a multi-purpose accelerator technology test facility.

INTRODUCTION

The CLIC project relies on a novel two beam acceleration concept where 12 GHz RF power produced in the deceleration of a high current (~100 A) beam is used to accelerate a low current (~1 A) beam up to an energy of 3 TeV [1]. CTF3 was constructed with the aim of addressing the key issues of the concept. The facility contains the necessary elements to produce the high current beam, so called drive beam, as well as its recombination by interleaving bunches using a delay loop and a combiner ring to multiply bunch frequency up to 12 GHz and current up to 28 A. Finally, in the CLIC Experimental Area (CLEX) the deceleration can be done in specific Power Extraction and Transfer Structures (PETS) to produce 12 GHz high power RF. Additionally, CLEX hosts the CALIFES injector (section 7.2.6 in [1]) which provides the low current probe beam that is accelerated and successfully demonstrates the two beam acceleration concept.

CALIFES LAYOUT

The main goal of the CALIFES injector (Fig. 1) is to mimic the main beam of CLIC. This probe beam is produced in a Cs_2Te photo-injector pulsed by an UV (262 nm) laser which delivers up to 270 nJ/pulse. This energy can be reduced using a hard aperture to produce a bunch charge up to 0.6 nC with a bunch frequency of 1.5 GHz [2]. Trains ranging from 1 to 300 bunches have been tested successfully. The acceleration is provided by a single klystron delivering pulses of 45 MW to power the gun, a buncher structure and two accelerating structures. Using a compression cavity the pulse peak power is increased to 130 MW during 1.2 μs, the necessary time to fill the accelerating structures. An attenuator and a phase shifter located before the gun provide flexibility tuning bunch extraction from the photo-cathode. The phase of the buncher can be independently controlled using a specially developed power phase shifter thereby operating the structure close to the zero crossing, thus shortening the bunch length via velocity bunching. The measured bunch length of 1.4 ps compared with the 6 ps of the laser shows the efficiency of the system. The whole acceleration system of the injector can provide a beam with kinetic energy up to 210 MeV with an energy spread <2%. The energy spread can be increased on purpose by changing the timing of the laser pulse versus the RF pulse to produce a train of pulses scaled in energy if needed. A system of solenoids around the accelerating cavities allow to keep the beam emittance below $10\,\pi \cdot mm \cdot mrad$; which can be measured by quadrupole scan using a quadrupole triplet and a screen downstream the last accelerating cavity. An electro-optical system and a streak camera located after the triplet, allow to measure bunch length with a 200 fs resolution. Finally a spectrometer line located downstream the injector enables energy measurements.

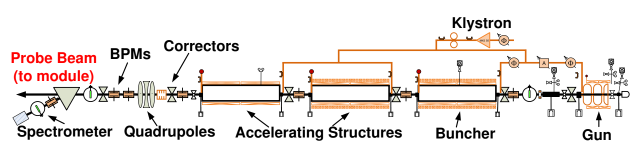

Figure 1: Layout of the CALIFES injector installed in CLEX.

This layout provides a flexible electron beam which can be used not only as CLIC probe beam, but also as a line for accelerator technology tests.

Downstream the CALIFES injector, the Two Beam Test Stand (TBTS) [3] was installed with the aim to demonstrate the two beam acceleration concept. The facility has successfully demonstrated the feasibility of the concept achieving up to 145 MV/m of gradient using one PETS and powering two X-band accelerating structures

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(ACS) according to the CLIC cell design [4]. Additionally, breakdowns and their effect on the beam orbit have been investigated [5].

After the successful experiments, TBTS was dismantled in July 2014 to be substituted by a CLIC Two Beam Module. Being a real prototype of the CLIC lattice, it contains all the features to be tested simultaneously: namely drive beam line with two PETS, two quadrupoles and two Beam Position Monitors (BPMs), probe beam line with four ACS and two wakefields monitors, and a complete set of instruments for active alignment of the girders. A sketch of the new installation, to be finished in September 2014, is show in Fig. 2.

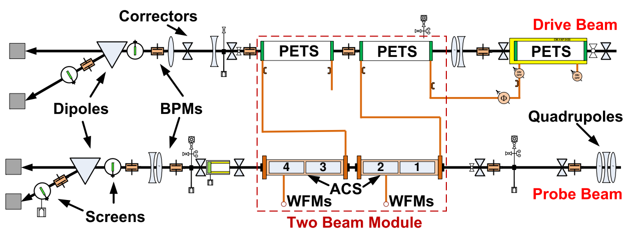

Figure 2: Layout of the module installation downstream the CALIFES injector.

RECENT RESULTS

The aim of the CALIFES accelerator is not only to provide a probe beam for the two beam acceleration concept but also to experimentally check the performance of the accelerator technology associated with the CLIC project and eventually offer an electron facility for external users. In this respect, high accuracy cavity BPMs, breakdown detection systems, beam loss monitors and longitudinal profile devices are some examples of the variety of instrumentation that has been tested in recent years. The latest systems tested before the module installation and the results are summarized in the following.

Octupolar Effect in Accelerating Structures

The ACS installed in TBTS had four High Order Modes (HOM) waveguides around each cell to damp wakefields produced by the beam. Nevertheless, due to this HOM waveguides, the radio frequency model predicts an octupolar transverse field produced by the 12 GHz RF which can affect shape and trajectory of the beam if it is not well centred in the ACS. A novel technique was used to observe and eventually quantify the effect of the octupolar field. The optics before the accelerating structure was set to have quasi-paraxial trajectories of the bunched electrons. Additionally, a long train of high charge bunches with high emittance was used such that the beam fully covered the iris of the ACS with an isotropic azimuthal and radial distribution (Fig. 3 left). This approach allows to sample the radial and azimuthal dependency of the octupolar effect for each beam shot using a screen downstream the ACS. Fitting the observed shape (Fig. 3 right) with the model described in [6], the octupolar field strength can be calculated.

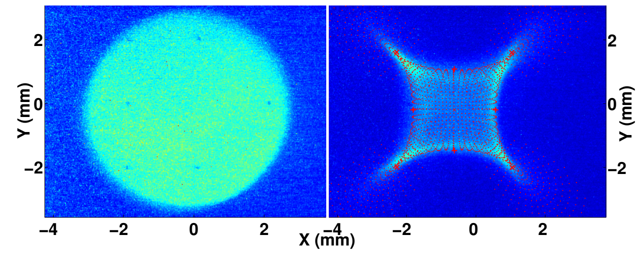

Figure 3: Transverse beam shape observed downstream the ACS without RF (left) and with 12 GHz RF at 306° phase (right).

The integrated octupolar field strength sampled for different 12 GHz RF phases follows the expected sinusoidal behaviour as shown in Fig. 4. Further measurements are planned for the newly installed module in CLEX.

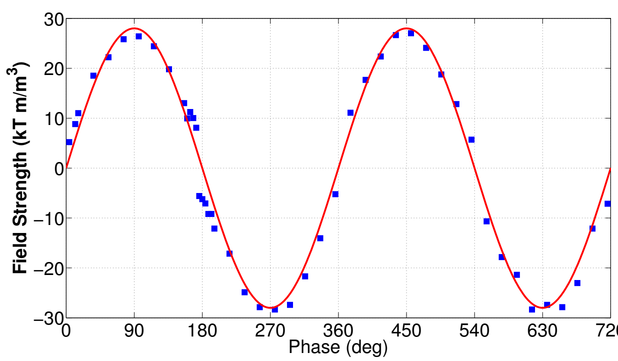

Figure 4: Reconstructed octupolar strength as function of the 12 GHz accelerating phase.

Wakefield Monitors

Wakefield monitors were installed on the central cell of the ACS on which the HOM waveguides are extended by a waveguide terminated with a SiC absorber. Two dipolar modes are sampled by 50 dBm logarithmic detectors, a TM-like 18 GHz and a TE-like 24 GHz [7]. The beam position inside the ACS can be scanned using vertical and horizontal correctors upstream the ACSs. Figure 5 shows the wakefield dependency for a vertical position scan. Similar results were obtained for horizontal scans.

An absolute calibration of beam position versus wakefield was done using the information of a screen located downstream the ACSs. The independent measurements provided by the two ACSs were used to determine the resolution in beam position of the wakefield monitors by fitting the calibrated beam offset of one ACS against the other and correcting for longitudinal displacement (Fig. 6). The resolution defined as the standard deviation of the measurements to the fitted dependency is $<10\,\mu$m for 1 mm beam offset improving to $<5\,\mu$m for beam offsets <0.4 mm.

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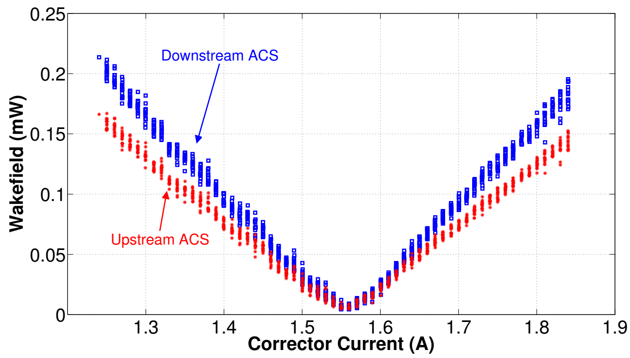

Figure 5: TE-like 24 GHz wakefield excited as function of the upstream vertical corrector current for the upstream (red) and downstream (blue) ACSs installed in TBTS.

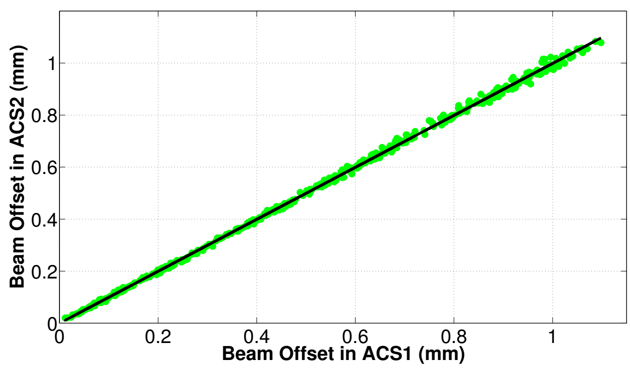

Figure 6: Correlation of measured beam position from 24 GHz excited wakefields (green dots) in downstream ACS with respect to position measured in upstream ACS and the expected lineal behaviour (black line).

Electro-Optic Spectral Decoding System

A longitudinal profile monitor based on electro-optic spectral decoding (EOSD) has been developed, installed and tested in CALIFES. Using such technique the longitudinal profile of an electron bunch is encoded into a chirped laser pulse using a 4 mm ZnTe crystal and decoded with a spectrometer, providing a non destructive tool with a resolution of ~1 ps [8, 9].

Single bunch lengths of 5.3, 6.4 and 9.0 ps have been measured for a 0.17, 0.3 and 0.7 nC bunch charge respectively (Fig. 7). The differences in bunch length are explained by the space charge effect. The results are consistent with earlier measurements done with a streak camera, even though the latter provides bunch length values that are systematically higher. After the success demonstrating the technique, further tests will be done to probe the system with shorter bunch lengths.

CONCLUSIONS

The CALIFES injector has proved to be an efficient facility to provide beam to demonstrate the CLIC acceleration concept in TBTS. After a period of successful operation and results, TBTS has been dismantled in favour of the in-

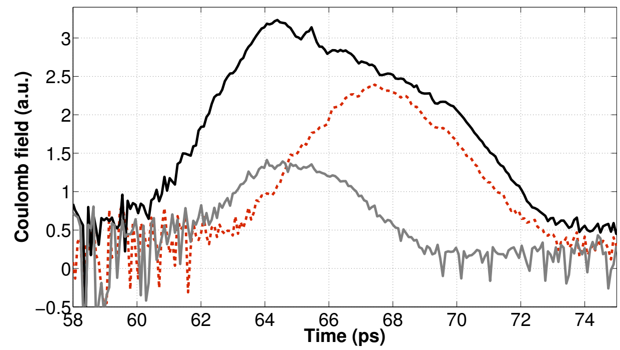

Figure 7: Temporal structure of the measured Coulomb field for 0.17 (grey solid), 0.3 (red dashed) and 0.7 nC (black solid) bunch charge.

stallation of a real prototype CLIC module. The scientific program in the new installation is expected to last until the end of 2016. Given the flexibility of the injector, a discussion is open to maintain CALIFES as an electron facility for beam instrumentation tests after completion of the module program.

ACKNOWLEDGMENT

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