TWO BEAM TEST STAND EXPERIMENTS IN THE CLEX CTF3 FACILITY

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Abstract

The CLEX building in the CTF3 facility is the place where essential experiments are performed to validate the Two-Beam Acceleration scheme upon which the CLIC project relies. The Drive Beam enters the CLEX hall after being recombined in the Delay loop and the Combiner Ring in intense beam trains of 24 A – 120 MeV lasting 140 ns and bunched at 12 GHz, although other beam parameters are also accessible. This beam is then decelerated in dedicated structures installed in the Test Beam Line (TBL) and in the Two-Beam Test Stand (TBTS) aimed at delivering bursts of 12 GHz RF power. In the TBTS this power is used to generate a high accelerating gradient of 100 MV/m in specially designed accelerating structures. To assess the performances of these structures a probe beam is used, produced by a second Linac. We report here various experiments conducted in the TBTS making use of the versatility of the probe beam and of dedicated diagnostics.

INTRODUCTION

After many years of development the CTF3 facility (Fig. 1) has now reached a completion state that has allowed achieving during this last year essential demonstrations for the CLIC project. Among them: measuring high gradient acceleration using the two-beam scheme, recording the breakdown rate evolution of an X-band structure, evaluating beam kicks during breakdowns as well as showing the efficiency of the RF power production with a high current drive beam.

CTF3 OPERATIONS

A Linac fitted with 16 fully loaded accelerating S-band structures [1] produces the drive beam composed of pulse trains bunched at 1.5 GHz. The bunches are then interleaved by a factor 8 using a Delay Loop followed by a Combiner Ring [2] that allows to increase the current from 4 A to 32 A and the bunch spacing to 12 GHz.

The drive beam enters the CLEX hall where it can either be directed to the TBL or the TBTS lines equipped with Power Extraction and Transfer Structures (PETS) [3]. In a PETS the beam is decelerated to produce RF power pulses at 12 GHz.

A second Linac called CALIFES [4] is installed inside CLEX to produce a probe beam aimed at testing the acceleration characteristics provided by the high gradient accelerating structures (ACS). Drive and Probe beam parameters are summarized in Table 1.

The TBTS is equipped with many diagnostic elements (Fig. 2) in order to carefully analyse the performance of the two-beam acceleration, among them beam profile monitors in the straight line and the spectrometer line, high resolution Beam Position Monitors (BPM) for beam kick measurements, RF directional couplers on various locations of PETS and ACS for amplitude and phase measurements, a Faraday cup and photomultiplier for breakdown detection, temperature and vacuum control and a dedicated device, called flash box, that allows to identify electrons and ions produced during breakdowns.

The TBTS offers a great flexibility for conducting the experiments: drive beam and probe beam can be produced with various characteristics in terms of charge, bunch length, size, position, respective timing and phase. In addition, a special mechanism called recirculation loop [5] allows the reinjection of the RF power at the input of the PETS through a variable phase shifter and splitter in order to further increase the produced power well above 150 MW.

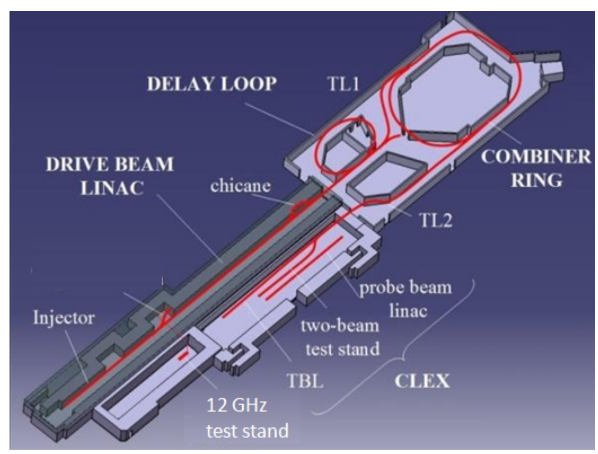

Figure 1: Layout of CTF3.

Table 1: Main Parameters of the CTF3 Beams

	Drive beam	*Probe beam*
Energy	120 MeV	200 MeV
Energy spread	2% (FWHM)	1% (FWHM)
Pulse length	140–1100 ns	0.6–150 ns
Bunch frequency	1.5–12 GHz	1.5 GHz
Bunch charge	up to 3 nC	0.085–0.6 nC
Intensity		
- short pulse	28 A	1 A
- long pulse	4 A	0.13 A
Repetition rate	0.8–5 Hz	0.8–5 Hz

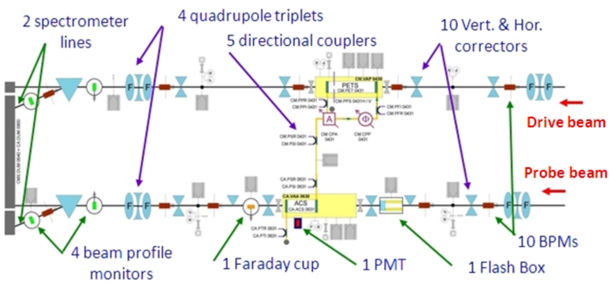

Figure 2: TBTS equipments.

HIGH GRADIENT ACCELERATION

The most important result obtained has proven the capability of the X-band accelerating structure installed in the TBTS to effectively accelerate the probe beam with a 100 MV/m accelerating gradient when powered with pulses of 42 MW – 12 GHz RF power produced by PETS.

The nominal accelerating gradient was achieved only after realising that the ACS was detuned by about 10 MHz. The cause attributed to a mechanical stress during the cooling circuit installation was not confirmed by dimensional control measurement (Fig. 3).

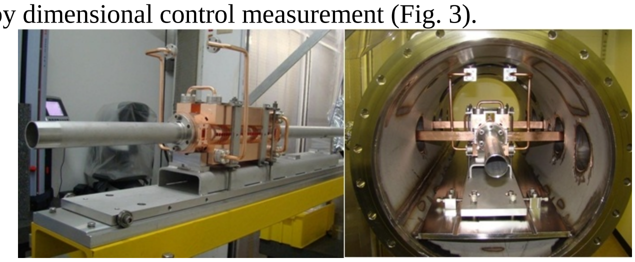

Figure 3: ACS in its vacuum tank.

To diagnose this problem, a single bunch probe beam was used in order to excite the ACS resonance frequency that was measured at the RF output coupler by mixing with the nominal frequency. Tuned to the correct frequency was achieved by warming it up to 60 °C using the cooling water circuits which permitted us to reach the design gradient.

During winter shutdown the ACS was mechanically retuned and a lot of effort spent to accurately calibrate the various 12 GHz RF power measurement channels that appeared to be very sensitive to the care invested in mounting the connectors.

Since then, energy gain up to 31.5 MeV obtained on the 21 cm ACS length has demonstrated accelerating gradient up to 150 MV/m (Fig. 4). To avoid errors due to possible probe beam energy drift the repetition rate of the CALIFES Linac is twice that of the drive beam, allowing a continuous monitoring of both accelerated and non-accelerated beams on the same spectrometer.

Scanning the RF power input by changing the drive beam parameters allows measuring the ACS gradient vs. power (Fig. 5) that is now close to nominal. The remaining discrepancy could be due to nonlinearity of the diode.

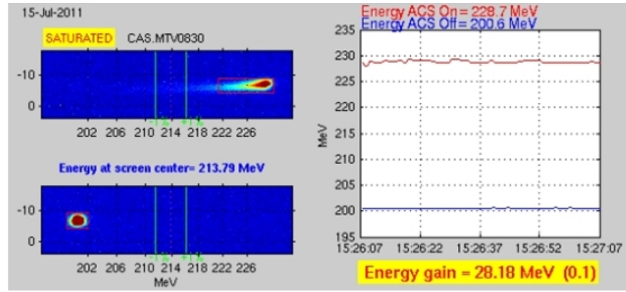

Figure 4: Spectrometer screen with tracking of accelerated (up) / not accelerated (down) beam.

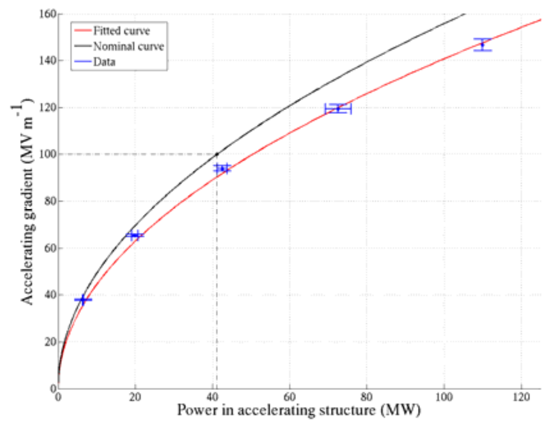

Figure 5: Accelerating gradient vs. RF power.

BREAKDOWN RATE MEASUREMENT

One of the main constraints that limits the accelerating gradient comes from the breakdown rate that for CLIC is requested to be lower than 3 10^{-7} breakdowns per pulse and per meter of structure. In the TBTS several diagnostic elements are aimed to localise the breakdowns based on missing energy at the ACS output, reflected energy at the input, detection of ion and electron current produced during breakdown and X-rays production (Fig. 6).

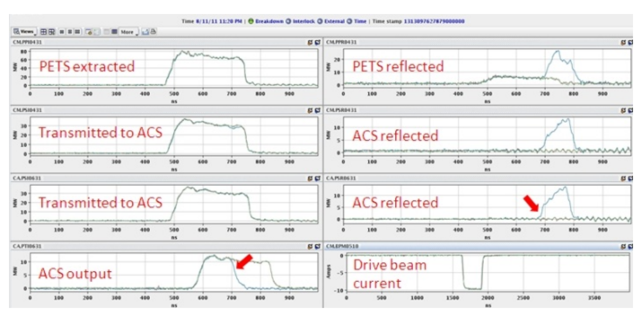

Figure 6: A breakdown in the ACS detected by cut in the output signal and rising of the reflected power.

ACS operation at low breakdown rate implies a long period of RF conditioning during which power is progressively increased. However, the repetition rate in the TBTS is limited to 5 Hz and presently to 0.8 Hz due to radiation protection constraints. For efficient ACS conditioning a stand-alone station based on a 12 GHz klystron that will operate with a repetition rate of 50 Hz is currently under construction within CTF3 [6].

Nevertheless, despite the low repetition rate, the breakdown rate improvement is already visible after a few hundreds of operating hours and is still improving (Fig. 7). It can be seen that the breakdown rate scales with the power of 12 to 13 of the accelerating gradient although a power of 30 is usually expected [7]. Studies are ongoing to understand this discrepancy.

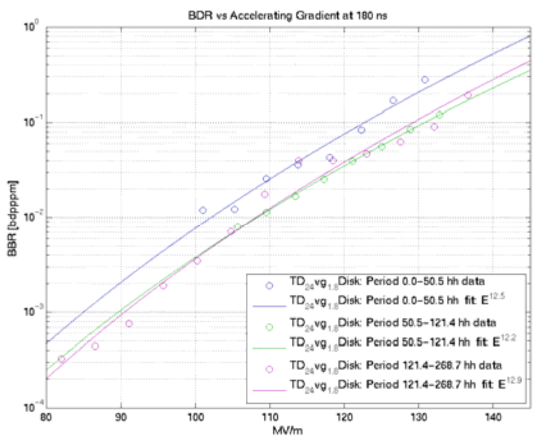

Figure 7: Breakdown rate vs. accelerating gradient for various periods of conditioning.

KICK MEASUREMENT

RF breakdown may produce a change of beam angle and energy, a so-called beam kick. The magnitude of the kick angle is expected between 15 μrad and 0.5 mrad given a beam energy of 200 MeV [8]. The probe beam line in the Two-beam Test Stand is equipped with 5 BPMs to measure both kick angle and energy change. A BPM resolution of 10 μm was calculated to be sufficient to resolve the smallest kicks of 15 μrad.

The presently achieved BPM resolution is about 0.4 mm. The limitation has been identified in a too small signal-to-noise ratio of the BPM signal given the probe beam current which is - at the moment - lower than 0.2 A, whereas initial BPM design was based on a 1 A probe beam current.

A very preliminary measurement of RF breakdown kicks has been recently obtained using the screen at the end of the straight section of the probe beam line, about 5 m downstream of the ACS (Fig. 8).

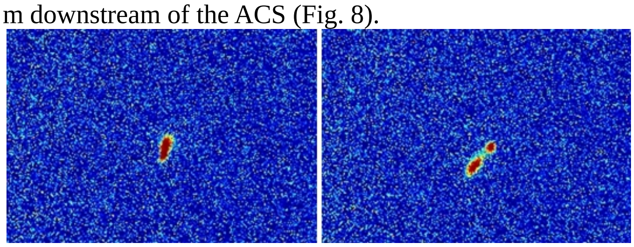

Figure 8: Beam profile without (left) and with (right) breakdown.

The beam profile on the screen corresponding to RF breakdowns in the accelerating structure shows a double spot demonstrating a kick for part of the beam pulse. The order of magnitude of such a kick is about 0.2 mrad.

FUTURE EXPERIMENTAL PROGRAM

Within the following months, an extensive program of experiments is foreseen on the TBTS in addition to confirm the data already obtained. A PETS equipped with On/Off mechanism device is presently under installation. During the next winter shutdown, two ACSs with integrated wake-field monitors will be installed. Data about ions emitted during breakdowns will be collected using the flash box mass spectrometer. Finally, three different types of CLIC modules including quadrupoles will be tested on the TBTS line [9].

CONCLUSION

The TBTS within the CLEX has demonstrated its effectiveness in performing essential experiments for the CLIC study. Such an efficient facility can only work thanks to the skill and dedication of the operating and technical teams, both from CERN and collaborating institutes. The completeness of its diagnostics, its flexibility in producing various beam and power characteristics as well as the easiness to install new devices is promising for its future applications.

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