CTF3 PROBE BEAM LINAC COMMISSIONING AND OPERATIONS

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Abstract

The probe beam Linac, CALIFES, of the CLIC Test Facility (CTF3) has been developed by CEA Saclay, LAL Orsay and CERN to deliver trains of short bunches (0.75 ps) spaced by 0.667 ns at an energy around 170 MeV with a charge of 0.6 nC to the TBTS (Two-beam Test Stand) intended to test the high gradient CLIC 12 GHz accelerating structures.

Based on 3 former LEP Injector Linac (LIL) accelerating structures and on a newly developed RF photo-injector, the whole accelerator is powered with a single 3 GHz klystron delivering pulses of 45 MW during 5.5 µs to a RF pulse compression cavity and a network of waveguides, splitters, phase-shifters and an attenuator.

We relate here results collected during the various commissioning and operation periods which gave stable beam characteristics delivered to the TBTS with performances close to nominal.

Progress has been made in the laser system to improve the beam charge and stability, in the space charge compensation to optimize the emittance, in RF pulse shape for energy and energy spread. The installation of a specially developed RF power phase shifter for the first accelerating structure used in velocity bunching allows the control of the bunch length.

INTRODUCTION

The objective of CALIFES (figure 1) is to 'mimic' the main beam of CLIC in order to qualify the performances of the 12 GHz accelerating structures installed in the TBTS [1].

Figure 1: CALIFES Linac inside the CLEX room.

The stringent beam characteristics detailed in table 1 are measured with a set a diagnostics composed of: a beam current monitor, 6 reentrant cavity BPMs [2], 3 beam profiles monitors based on OTR and/or YAG screen with in situ calibration test pattern [3], a triplet for quadrupole scan, a dipole for energy measurements and a RF deflecting cavity for bunch length measurement.

Table 1: CALIFES Specified Beam Parameters

Parameters	Specified	Tested
Energy	200 MeV	178 MeV
Norm. rms emittance	< 20 π mm.mrad	8 π mm.mrad
Energy spread	< ± 2 %	± 1 %
Bunch charge	0.6 nC	0.65 nC
Bunch spacing	0.667 ns	0.667 ns
Number of bunches	1-32-226	from 1 to 300
rms. bunch length	< 0.75 ps	1.42 ps

The beam characteristics have continuously been improved from its first run in December 2008 owing to a better understanding of the settings of the accelerator and improvements in various sub-systems [4] shown in figure 2. However some difficulties remain to ensure all these goals simultaneously and reliably.

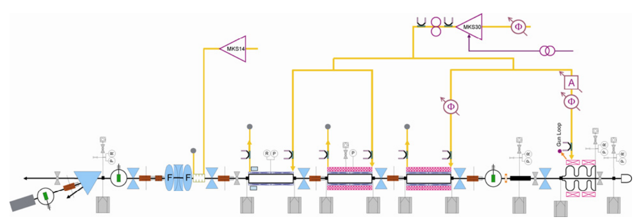

Figure 2: CALIFES layout.

BUNCH CHARGE

The nominal bunch charge produced by the photo-injector [5] is 0.6 nC as foreseen for the CLIC main beam. However for trains longer than 32 bunches the total beam charge is limited to 19.2 nC due to the beam loading in the LIL structures. This performance goal was difficult to fulfill and was only obtained during few days after the photocathode was regenerated by depositing Cs and Te on its surface. During these first days of operation its quantum efficiency (QE) decreases from approx. 1% to 0.25% and then stabilizes at this value (figure 3). Phase scanning of the RF power delivered to the gun permits to find the optimum charge collection phase.

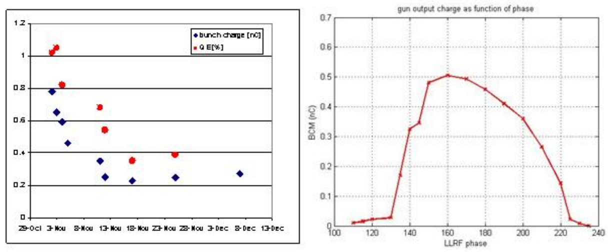

Figure 3: evolution of QE and of bunch charge during 6 weeks and gun RF phase scan.

The major limitation on the charge production is the laser. The fast pulse-pickers in the IR capable to deliver single pulses and the long transport line ~70m in the UV (262 nm) introducing losses, the maximum energy/pulse in the full laser beam is 270 nJ. A hard aperture is used to shape the laser beam profile for optimum characteristics of the electron beam, further reducing the available pulse energy to ~75 nJ (figure 4). This energy would provide a charge per bunch of 0.6nC only when QE is 3.8 % that is beyond the present capability of the in situ cathode preparation.

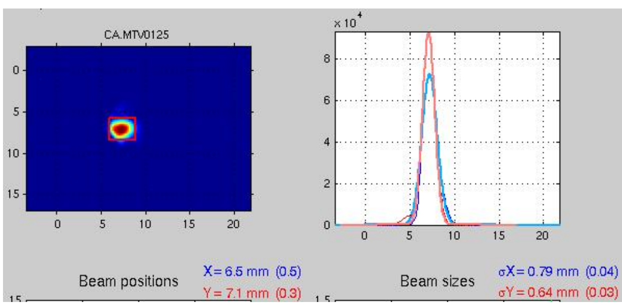

Figure 4: Laser pulse on the virtual cathode after shaping.

Consequently, recently we operated with a bunch charge of only 0.05 nC and long trains. To circumvent this limitation a new laser system dedicated to CALIFES, and not shared with the PHIN photo-injector as at present, is under development to provide pulse energy over 1 μJ in the UV. It will be installed closer to the gun to avoid losses in the long transport line.

ENERGY AND ENERGY SPREAD

Only a single klystron providing pulses of 45 MW is available to power the gun and the 3 accelerating structures. Using a compression cavity the pulse power is increased to 130 MW peak during the 1.2 μs necessary to fill the structures.

The phase of the first accelerating structure can be independently controlled thanks to a specially developed power phase shifter in order to use it close to the zero crossing and to shorten the bunch length via velocity bunching.

When this structure, also called buncher, is used this way the maximum energy reached at the end is 140 MeV, while when tuning its phase to full acceleration the final energy obtained is 177 MeV. On the other hand considering the RF power feeding each structure and the gun (figure 5), the theoretical beam energy should exceed 200 MeV. Phase distributions along the structure are suspected but the reason of this discrepancy remains to be investigated.

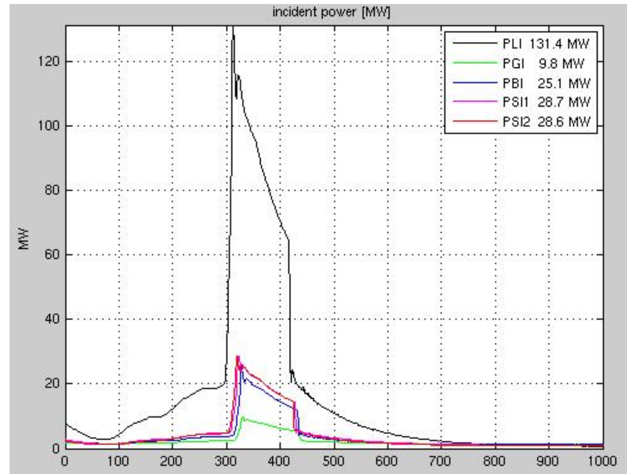

Figure 5: Power after pulse compression: *PLI*, at gun input: *PGI*, at buncher input: *PBI*, at accelerating structures inputs: *PSI1 and PSI2*

The energy spread can be easily tuned to less than 2%, but it can also be increased on purpose by changing the timing of the laser pulse versus the RF pulse in order to produce a train of pulses scaled in energy (figure 6)

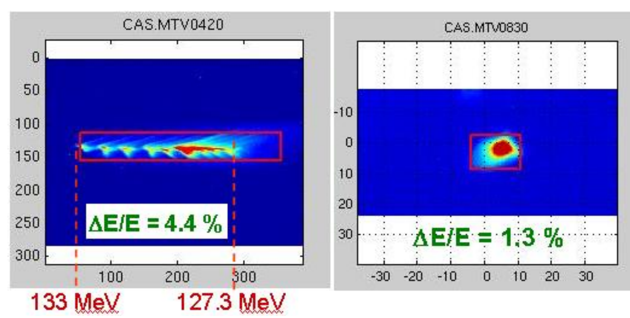

Figure 6: Energy spread for a pulse of 10 bunches. Laser timing vs. RF pulse governs its value.

BUNCH LENGTH

The bunch length has been measured using a deflecting cavity powered by an additional klystron delivering 7 MW. The measured value of 1.43 ps, compared to the 6 ps laser pulse length, shows the efficiency of the velocity bunching method. However the power phase shifter was not yet installed at that time and accurate tuning of the buncher phase was not possible. Later the klystron was no longer available and the bunch length has been measured with the energy dispersion provided by the 12 GHz accelerating structure installed in the TBTS by setting its phase at zero crossing with respect to the bunch (figure 7). The increase of energy spread measure on the spectrometer can be related to the phase extension of the bunch with respect to the 12 GHz period to derive the bunch length.

$$\Delta\sigma_{[MeV]} = \sqrt{\sigma_{ON}^2 - \sigma_{OFF}^2} \cdot cal_{screen} = 1.35\ MeV$$

$$\sigma_{[bunch\ length]} = \frac{T_{[12\ GHz]}}{2\pi} \cdot Arc\sin\frac{\Delta\sigma_{[MeV]}}{E_{\max}} = 4.2\ ps$$

with cal_{screen}= 0.4 MeV/mm: MTV0830 screen calibration and E_{max}= 4.33 MeV: energy gain on crest of 12 GHz

The buncher was adjusted to provide full acceleration not bunch compression; consequently the bunch length is longer than in the previous test.

A study of the bunch length as function of the buncher phase and cross checking result with both diagnostic methods remains to be completed.

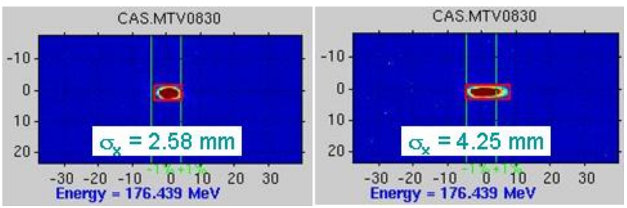

Figure 7: energy spectrum with 12 GHz CLIC structure switched OFF (left) and ON (right) at zero crossing.

EMITTANCE

The emittance is measured via quadrupole scan method at the end of the linac. Measurements have for a long time given results larger than 100 mm.mrad, well above the specifications. Eventually it was understood that the problem was caused by a ceramic phosphorescent screen in which light diffusion enlarges the beam size as small as 50µm at the waist. Using an OTR screen and a higher optical magnification, despite the difficulties associated to a much lower light yield, has produces emittance measurements around 20 mm.mrad. Lately, with a reduced bunch charge (0.05 nC) and using an improved OTR screen with an aluminum layer deposited on its surface, emittance around 10 mm.mrad have been measured (figure 8). The method being quite sensitive to beam size measurement errors a propagation of the uncertainties is to be computed.

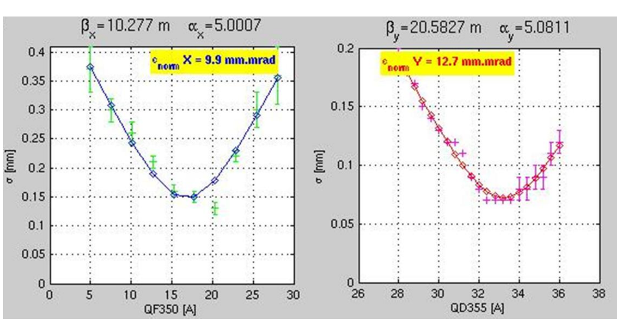

Figure 8: Horizontal and vertical transverse Twiss parameters reconstructed from quadrupole scan.

BEAM TRANSPORT

Despite the care taken by the survey team to align the various equipments it is still necessary to use the numerous correctors to ensure an efficient beam transport. Solenoids around the RF gun and the two first structures prevent space charge to dilute the beam. Eventually, practically 100% of the beam charge produced by the photo-injector is delivered to the TBTS as can be shown on the BPMs current history (figure 9).

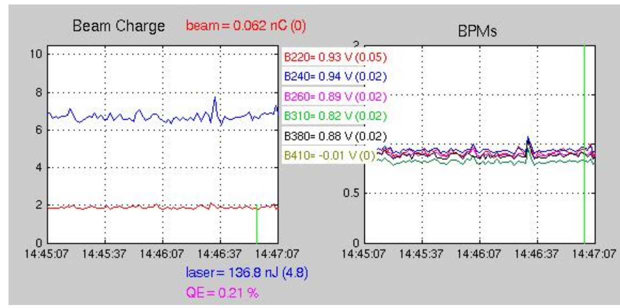

Figure 9: Time records of beam charge, laser energy and BPMs intensity.

CONCLUSION

After a long period of commissioning and improvements from July 2010 the CALIFES probe beam is used to test the 12 GHz CLIC structure installed in the TBTS [6 and 7]. Analysis of results, in addition to characterize the CLIC structure behavior also provides interesting information about the probe beam itself and drive further improvement on CALIFES and on the flexibility of its command/control. Moreover, some preliminary plans are studied to use the probe beam on a line dedicated to the test of beam diagnostics.

REFERENCES

[1] A. Mosnier et al., “The Probe Beam Linac in CTF3” Proceedings of the EPAC 2006, Edinburgh, Scotland.
[2] C. Simon et al., “Beam Position Monitors using a Re-entrant Cavity” Proceedings of DIPAC 2007, Venice, Italy.
[3] W. Farabolini et al., “Video Profile Monitors Development for the CTF3 Probe Beam Linac”, Proceedings of EPAC 2008, Genoa, Italy.
[4] F. Peauger et al., “Status of the CTF3 Probe Beam Linac CALIFES” Proceedings of LINAC08, Victoria, Canada.
[5] J. Brossard et al., “Construction of the Probe Beam Photo-Injector of CTF3” Proceedings of EPAC 2006, Edinburgh, Scotland.
[6] R.J.M.Y. Ruber et al., “The CTF3 Two-beam Test-stand Installation and Experimental Program”, Proceedings of the EPAC 2008 Genoa, Italy.
[7] R.J.M.Y. Ruber, “CLIC Feasibility Demonstration at CTF3”. These proceedings.