CTF3 PROBE BEAM LINAC COMMISSIONING AND OPERATIONS

Wilfrid Farabolini, Claire Simon, Franck Peauger, Aline Curtoni, Daniel Bogard, Patrick Girardot, CEA / Saclay, F-91191 Gif-sur-Yvette, France
Marta Csatari, Nathalie Lebas, Massimo Petrarca, Eric Chevallay CERN, 1211 Geneva 23, Switzerland
Roger Ruber, Andrea Palaia, Volker Ziemann, Uppsala University, Sweden

Abstract

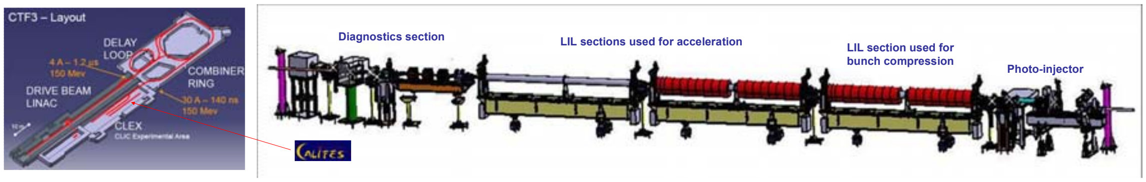
The probe beam Linac, CALIFES, of the CLIC Test Facility (CTF3) has been developed by CEA Saclay, LAL Orsay and CERN to deliver trains of short bunches (0.75 ps) spaced by 0.667 ns at an energy around 170 MeV with a charge of 0.6 nC to the TBTS (Two-beam Test Stand) intended to test the high gradient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

CALIFES location and design



Command control

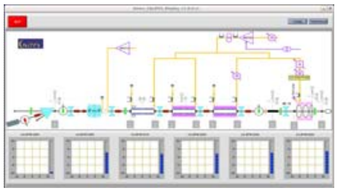
A flexible, reliable and easy to operate command control, in addition to a fully operational set of diagnostics, is a key factor for the success of the commissioning and further operations. CALIFES/TBTS command control has been continuously improved from the early days where many commands were accessible on local mode only.


CTF3 control room


The early days control room


Very local control at the beginning


Basic C/C classically used

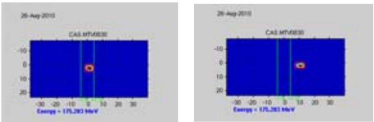

Active synoptic recently developed at CERN

Commissioning results and first operations with the TBTS

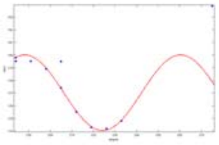
Beam characteristics have been continuously improved from the first run in December 2008. Performance has now reached the specifications. However some difficulties remain to ensure all the performances simultaneously and along the time.
From August 2010, the probe beam is used in the Two Beam Test Stand (TBST) where first results of acceleration with the 12 GHz accelerating structures have been achieved.

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	1.4 ps

Main CALIFES beam parameters

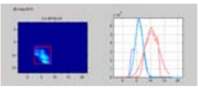


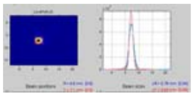
First evidence of acceleration by the 12 GHz CLIC structure (left RF Off – right RF On)


Scan of the phase between probe beam and drive beam showing acceleration provided to the probe beam

Laser and bunch charge

The laser used to drive the photoinjector is shared with another photoinjector foreseen to be installed in the drive beam Linac. It produces long trains of pulses (5 μs) of which a short slice (from 0.6 ns up to 100 ns) is extracted with 2 pulse pickers. Pulses are then frequency converted from IR to UV (262 nm) using 2 stages of KDP crystals before being transported via a 70 m long vacuum line to the Califes photoinjector. Due to the complexity of this scheme and the necessity to use a hard aperture to shape the laser beam profile, the energy per pulse is limited below 100 nJ. This is not sufficient to ensure a bunch charge of 0.6 nC except during the very first days after the photo-cathode has been regenerated. To overcome this limitation a new dedicated laser is under development that will be installed close to the photoinjector and deliver pulses over 1 μJ.


Laser transverse profile without shaping: 230 nJ


Shaped laser transverse profile : 78 nJ


CALIFES photoinjector

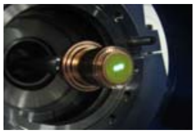
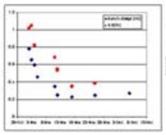
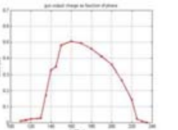
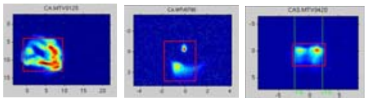


Photo-cathode


Evolution of quantum efficiency


RF gun phase scan

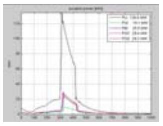


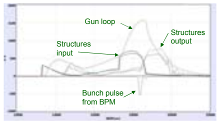
Badly shaped laser profile severely affects the beam

Energy and energy spread

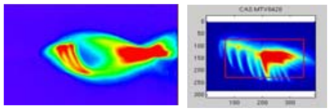
The photo-injector and the 3 accelerating structures are powered with a single klystron delivering pulse of 45 MW during 5.5 μs. These pulses are sent to a pulse compressor that transform them in pulses of 130 MW peak during the 1.2 μs necessary to fill the structures. The RF power distribution is achieved through a network of waveguides, splitters, circulator, phase shifters and an attenuator.
When the first structure is used as a buncher to shorten the bunch length the maximum energy reached is 145 MeV, while when used in full acceleration the maximum energy raises to 177 MeV. However, in this latter case the theoretical energy obtained should be in excess of 205 MeV. The reason of such a discrepancy is not yet understood but phase distribution along the structures is suspected.

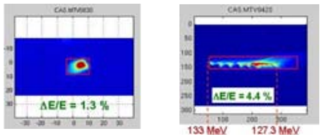
The energy spread is below ±1% rms by carefully setting the bunch time (laser pulses) vs. the RF pulse. Setting the laser pulses on the slope of the RF pulse leads to a much higher energy spread where each bunch has a distinct energy.


Incident powers distributed to the structures



Structures input / output signals, gun loop and bunch position


Some fishy beams



Energy spectrum governed by the bunches positions vs. the RF pulse

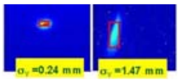
Bunch length

Bunch length has been measured using a deflecting cavity powered by a dedicated klystron at 3 GHz as well as using the 12 GHz accelerating structure installed in the TBTS. The laser pulse length is 6 ps that leads to approximately the same bunch length produced by the photoinjector. Downstream, the first accelerating structure can be used to shorten the bunch via velocity bunching by setting its phase close to the zero crossing thanks to a specially developed power phase shifter.


3 GHz RF deflecting cavity

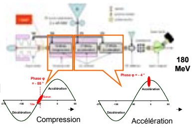

Power phase shifter for the buncher


12 GHz CLIC Accelerating structure



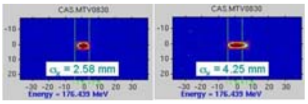
RF deflector OFF RF deflector ON

$$\Delta\sigma = \sqrt{\sigma_{ON}^2 - \sigma_{OFF}^2} = 1.45\ mm$$



CALIFES phase scheme

Calibration of the RF deflector on the screen:
0.94 mm per degree at 3 GHz, so for 0.925 ps (333 ps for 360 deg)
→ Bunch length (1σ) = 1.43 ps (buncher phase close to zero crossing)



ACS 12 GHz OFF (left) / ON (right) at zero crossing

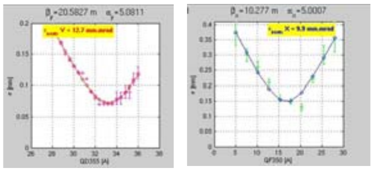
$$\Delta\sigma_{[MeV]} = \sqrt{\sigma_{ON}^2 - \sigma_{OFF}^2}\cdot cal_{screen} = 1.35\ MeV \quad \text{with } cal_{screen} = 0.4\ MeV/mm$$

$$\sigma_{[bunch\ length]} = \frac{T_{[12 GHz]}}{2\pi}\cdot Arc\sin\frac{\Delta\sigma_{[MeV]}}{E_{crest}} = 4.2\ ps \quad \text{with } E_{crest} = 4.33\ MeV$$

→ Bunch length (1σ) = 4.2 ps . The buncher was set on crest

Emittance

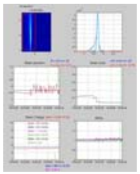
Emittance is computed at the end of the linac with the quadrupole scan method. Beam size is measured on a video beam profile monitor fitted with 2 types of screen (phosphorescent and OTR) and with 2 optical magnifications. Emittance have for a long time be computed around 100 mm.mrad well above the requirements. It was eventually understood that the problem lied in using a ceramic screen in which light diffusion enlarges the beam size, as small as 50 μm at the waist. Using OTR screen and a higher optical magnification emittance around 10 mm.mrad have been measured. The method being quite sensitive to beam size measurement errors a propagation of the uncertainties is to be computed. In situ calibration patterns are used to calibrate the pictures.

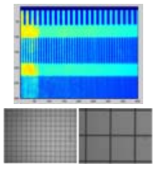


Results of quad scan


Diagnostic section


Multi-screen carrier


Quad scan control during acquisition


Various types of patterns used for calibration