THE PROBE BEAM LINAC IN CTF3

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Abstract

The test facility CTF3, presently under construction at CERN within an international collaboration, is aimed at demonstrating the key feasibility issues of the multi-TeV linear collider CLIC. The objective of the probe beam linac is to "mimic" the main beam of CLIC in order to measure precisely the performances of the 30 GHz CLIC accelerating structures. In order to meet the required parameters of this 200 MeV probe beam, in terms of emittance, energy spread and bunch-length, the most advanced techniques have been considered: laser triggered photo-injector, velocity bunching, beam-loading compensation, RF pulse compression ... The final layout is described, and the selection criteria and the beam dynamics results are reviewed.

INTRODUCTION

The probe beam will be an essential component for the two-beam acceleration experiments which are planned in the two-beam test-stand in CTF3 [1]. The required performances of the probe beam, as well as the motivations, are listed in Table 1. The main technical choices were driven by the beam requirements and, at a least extent, some economical considerations :

- *beam generation :* a laser triggered photo-injector is selected because it provides both better emittance and greater time flexibility than a thermo-ionic gun;
- *acceleration :* two 4.5 m long TW sections of the dismantled Lep Injector Linac (LIL) are used for economical reasons, despite a significant level of beam loading;
- *bunch compression :* the velocity bunching technique is chosen instead of a magnetic chicane because it is simpler, doesn't spoil emittance, and only requires one additional - and existing - LIL section.

The layout (Fig.1) then finally comprises: a photo-injector, designed by LAL-Orsay [2], including solenoids for a proper space charge compensation, one LIL section for bunch compression, two LIL sections for acceleration to ~200 MeV, and a transport beamline equipped with diagnostics to measure emittance, bunchlength and energy spread, before delivery to the two-beam test stand. First beam is expected at beginning of 2008.

Table 1: Main beam parameters and motivations.

Energy	200 MeV	Avoid beam disruption in high RF fields
Emittance rms	< 20 π mm.mrad	Fit in 30 GHz structure acceptance
Energy spread	< ± 2%	Measurement resolution
Bunch charge	0.5 nC	~ CLIC parameters
Bunch spacing	0.333 ns	
Number of bunches	1 – 64	Measure 30 GHz structure transients
bunchlength	< 0.75 ps	Acceleration with 30 GHz

The Cs_2Te photocathode will be elaborated in an adjecent to the gun existing preparation chamber. As the expected quantum efficiency will then be less than 1%, the bunch charge in a first step will likely be limited to ~0.2-0.3 nC.

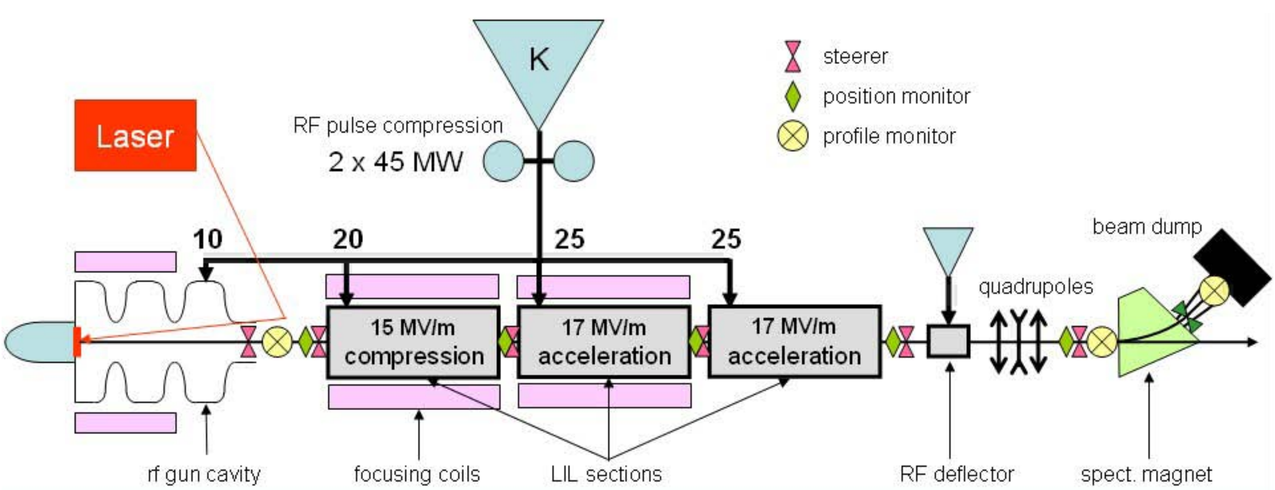

Figure 1: Schematic layout of the probe beam linac (Califes).

Later on, the photocathode can be elaborated in the Cern photo-emission laboratory, provided that a special transport carrier is available. Since both drive beam and probe beam have to be synchronous, a signal from the laser beam developed for the drive beam (DB) linac [3] will be derived and will then undergo the following operations: 1) appropriate windowing (in delay and duration) of the unused IR power pulses supplied by the DB laser 2) conversion of these laser pulses into UV by a fourfold frequency multiplier 3) increase of pulse frequency from 1.5 GHz to 3 GHz 4) transport of the UV light pulses to the photocathode, ~80 m away.

BEAM DYNAMICS

single bunch

The 1 mm rms long bunches delivered by the RF gun have to be compressed by a factor of ~ 4 before being injected into the 30 GHz CLIC structures. The "velocity bunching" method [4] consists in injecting the beam at the zero acceleration phase of the RF wave of the first LIL section. The bunch is then smoothly compressed while 'sliding' towards the crest of the wave. The minimal bunchlength is limited by the initial energy spread and space charge forces.

Numerical simulations, from the photocathode to the linac end, were performed using a modified PARMELA version [5]. Conservative parameters for the laser pulse (gaussian distribution, $\sigma_t = 4$ ps, $\sigma_r = 1$ mm) and RF gun (E_z = 80 MV/m, B_z < 0.22 T) and bunch charge of 0.5 nC have been assumed. With a gradient of 15 MV/m in the compression section, the optimum compression ratio reached a maximum value, larger than 8, with ~20 MeV energy gain. The evolution of the bunch length along the linac, from the photocathode to the exit of the third LIL section, is shown in figure 2. We also checked that the sensitivity of the bunchlength to the RF phase of the compression section is rather loose. With an accelerating gradient of 17 MV/m in the two accelerating sections and a magnetic field in the solenoids (~0.05 T), the beam energy at the exit of the linac reaches ~180 MeV with less than 1% energy spread and the normalized transverse emittance is less than 8 π mm.mrad .

multi bunch

Since the beam current in the macro-pulse is high (0.5 nC at 3 GHz ⇒ 1.5 A) the transient beam-loading in the probe beam linac is of main concern. That's why we developed a specific code, based on the coupled resonator model, to study the transient effects in the travelling wave sections, with the following features: space harmonics and dispersive effects of the structure included, any waveform of the RF input pulse, calculation of beam interaction from the propagation of the induced waves including dispersive effects. The LIL section is a quasi-constant gradient structure, composed of 9 constant impedance families linked by 4 linearly tapered transition cells. The space harmonics were inferred from Superfish calculations.

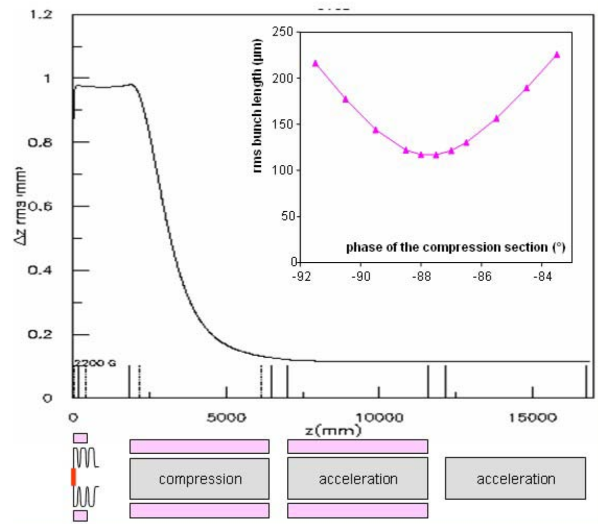

Figure 2 : rms bunch length along the linac and sensitivity to the RF phase (box).

The field pattern of the travelling wave in the n-th cell of length *d* is re-constructed at each time:

$$E_n(z) = E_0\, e^{i\omega t} \times A_n\, e^{i\phi_n} \times \sum_m a_m^n\, e^{i(\Delta\phi_n - 2\pi m)z/d}$$

where $A_n\, e^{i\phi_n}$ accounts for the cell excitation (steady-state or transient); $\Delta\phi_n$ is the phase shift of cell n and a_m^n is the m-th harmonic. Simulation results on the compression section at full beam-loading show too large energy and phase deviations (~3 MeV ~7°) between first and last bunch in the train (figure 3).

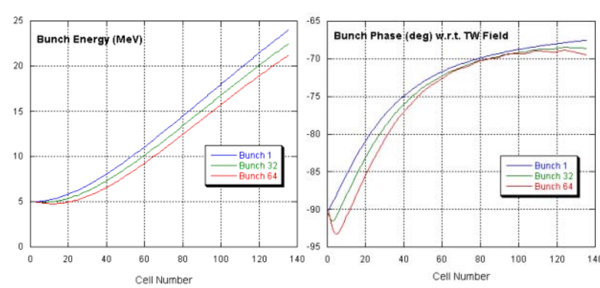

Figure 3 : Bunch energy and phase at the exit of compression section at full current.

Because of the very short current pulse (~20 ns for 64 bunches) with respect to the section filling time (1.3 µs) a conventional cure, like a beam injection before the end of the filling of the structure, is not suitable. Other methods, as a frequency detuning of the section or the use of a magnetic chicane, could efficiently compensate for the phase error, but of course not the energy drop of ~10%. In a first step, the bunch charge will then have to be linearly reduced with the number N of bunches, Qb < 5 nC / Nb, such that both energy and phase deviations meet the requirements (smaller than 1% and 1° at 3 GHz).

RF SYSTEMS

The RF system consists of one single klystron – modulator system, a RF pulse compressor controlled by a specific LLRF system, a distribution network to feed the gun cavity and the three TW sections.

The *RF source* is a 45 MW peak power klystron from Thales. The high voltage pulse has a usable flat top of 5.5 µs with ± 0.25 % voltage ripple and ± 0.1 % pulse to pulse stability. The repetition rate is 5 Hz.

The *RF pulse compression* system increases the power up to 90 MW while reducing the pulse width to about 1.3 µs. This system, designed for the drive beam linac [6], stores the energy in a high Q Barrel Open Cavity (BOC) working in a travelling wave mode. The 180° phase switch aimed at emptying the stored energy, as well as the phase modulation applied to shape the RF pulse, are supplied by the LLRF system.

The RF network divides the high power into four arms by means of one 3 dB and two 4.5 dB splitters. The standing wave RF gun arm includes a circulator, a phase shifter and an attenuator. The phase between the two acceleration sections is set by adjustment of waveguide length, whereas a new high power phase shifter is developed for the fine tuning of the compression section phase. This phase shifter is a 3 GHz scaling of the one studied at SLAC at 11.4 GHz [7] and consists of a circular waveguide operating in the TE_{01} mode and two wrap-around mode converters [8]. As shown in figure 4, the circular waveguide has a region with an expanded diameter, providing a reduction of the guide wavelength. A change of the length of this widened guide results then in a phase variation. The phase shifter is designed for 25 MW RF power, with a sensitivity of 1°/mm, maximum 200 mm variation, a precision of 0.5° and a stability of 0.1°.

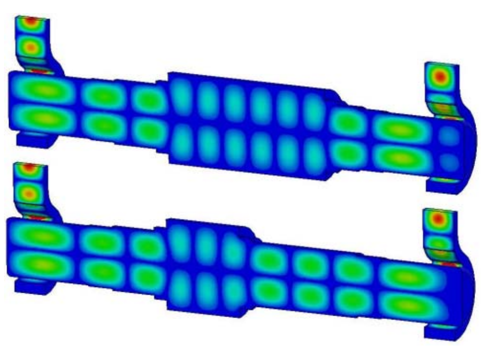

Figure 4: Electric field inside the power phase shifter for two lengths of the widened waveguide.

DIAGNOSTICS

Beam characteristics of CALIFES accelerator lead to challenging beam diagnostics.

Coaxial re-entrant cavities [9] have been chosen for the beam orbit measurement - single bunch or 3 GHz bunch trains - because of their mechanical simplicity and excellent resolution. A new design, with a large frequency separation between monopole and dipole modes, as well as a low loop exposure to the electric fields, has been developed (Fig. 5).

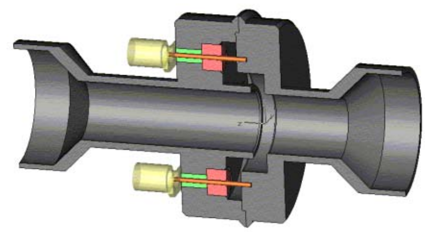

Figure 5 : BPM for the probe beam linac.

Transverse profiles are measured via beam imaging on a screen with a 1/3” CCD camera. Due to lower beam energy (5 MeV) and rather large beam size (1 mm), the first system located immediately after the gun is based on a phosphor movable screen. The second system, located after the triplet, is based on a back OTR movable aluminium screen. To comply either with the resolution and the range, two optics magnifications (1.7 and 0.4) are necessary. An optical filters wheel allows to cover the whole intensity dynamic from a single to 64 bunches. This profiler is also used for bunchlength measurement after deflection when passing at zero crossing through a transverse deflecting section. During standard operations the bunch length is tuned thanks to a RF pick-up providing non destructive information on the bunch spectrum [10]. Beam central energy and energy spread are measured on the third beam profile system located after a 15° bending magnet. Due to small energy density a phosphor screen is better suited. Last, time resolved measurements on beam central energy can be obtained thanks to the BPM located at the magnet exit.

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