LONG BEAM PULSES WITH SLED COMPRESSION IN DAΦNE LINAC

M. Belli, B. Buonomo, R. Ceccarelli, A. Cecchinelli, R. Clementi, C. Di Giulio, L.G. Foggetta, G. Piermarini, L.A. Rossi, S. Strabioli, R. Zarlenga, INFN – Laboratori Nazionali di Frascati, Via Enrico Fermi 40, I-00044 Frascati (Rome), Italy
P. Valente, INFN – Sezione di Roma, P.le Aldo Moro 2, I-00185 Rome, Italy

Abstract

The DAΦNE LINAC is a ~60 m long, S-band (2856 MHz) linear accelerator, made up by four 45 MW klystrons with SLED compression, and by 15 travelling-wave, 2/3π, SLAC-type, 3 m long accelerating sections. It serves as injector of the DAΦNE e+ e- collider, providing 510 MeV, 10 ns long, electron and positron pulses of ≈1 nC, and to the Beam-Test Facility extraction line, with variable beam energy and intensity pulses, of length in the range 1.5 to 40 ns. A new pulsing system for the gun allows longer beam pulses, but the shape of the accelerating field in the sections due to the SLED compression has to be taken into account. We describe the tuning of the RF power, phase and delays in the pre-buncher, buncher and following accelerating sections, and the results of the tests performed in order to reach >200 ns, 500 MeV electron pulses and the characterization of the quality of the beam in terms of energy spread, time distribution, etc.

THE DAΦNE LINAC

General Layout

The DAΦNE LINAC is a ~60 m long, S-band (2856 MHz) linear accelerator, made up by four 45 MW klystrons (Thales TH-2128C) with SLED (SLAC Energy Doubler) compression, and by 15 travelling-wave, 2/3π phase advance, 3 m long accelerating sections of SLAC type. The RF distribution scheme is shown in Fig. 1: three of the klystrons have exactly the same configuration, consisting of an evacuated rectangular waveguide network with three 3 dB splitters arranged in order to divide the power into four equal parts, feeding each one an accelerating section. The configuration of the fourth klystron is different: half the power is sent to the capture section (CS), the first section downstream of the positron converter (PC), while the second half is equally divided between two branches, the first one feeding the accelerating section P1, the second one feeding the pre-buncher, the buncher and the accelerating section E1.

The phase between the sections (including pre-buncher and buncher) can be adjusted by means of low-power 360° phase shifters upstream of the RF amplifiers of each klystron, and by a high-power 360° phase shifter uncoupling the CS from E1.

The four modulators produce a pulse of 4.5 μs flat top with a repetition rate of 50 Hz: a HV power supply with resonant circuit charges the pulse forming network (PFN), composed by 9 LC cells up to 50 kV, and a switching thyratron.

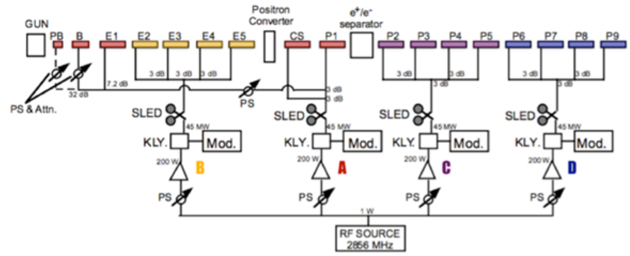

Figure 1: RF distribution scheme of the LINAC: four klystrons with SLED compression, powered by line modulators, feed a total of 15 accelerating sections.

The RF pulse from the klystron is then compressed by the SLAC system [1], in order to reach a higher energy with respect to the flat power: the RF power from the klystron is first stored in two resonant cavities, coupled by means of a 3 dB hybrid coupler, and then is discharged towards the accelerator by applying a phase inversion to the input power from the klystron.

This transforms the flat power from the klystron, 4.5 μs long, into the typical peaked shape at the output of the SLED, shown in Fig. 2.

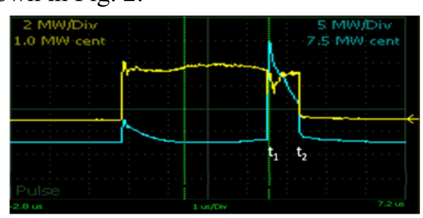

Figure 2: Klystron power (yellow trace) and SLED output power (cyan trace) for one of the DAΦNE four RF stations, measured by a power-meter.

The corresponding accelerating voltage will be approximately double with respect to the uncompressed case, but with a sharply peaked shape from the time of the phase inversion t_1, followed by an exponential decrease until the klystron pulse end time time t_2. One effect of the SLED compression is the fact that longer pulses accelerated close to the peak at t_1 will exhibit an energy spread due to the variation of the accelerating voltage during the pulse length.

Electrons are produced by a gridded electron gun with replaceable cathode, high-voltage deck with up to 150 KV power supply (operational 120 KV), isolation transformer and corona shielding, allowing to reach full voltage in air. The gun is pulsed at 50 Hz with a rectangular waveform of 10 ns length during DAΦNE injections. The system used up to Summer 2016 can adjust the beam pulse height in the 300-750 V range and the pulse length between 1.5 and 40 ns.

ISBN 978-3-95450-182-3

The focussing system, schematically shown in Fig. 3, varies its configuration along the length of the LINAC: in the first part the bucking coil reduces the field in the cathode region, while the so-called thin-lens solenoidal field focalize the electron current in the pre-buncher and buncher region; a FODO in the first accelerating sections transports the beam up to the converter region (matched with the up-stream solenoidal focussing by means of quadrupole doublet); downstream of the positron converter with the strong solenoids, a four-dipoles achromatic bump separates the electrons from the positrons; in the remaining part of the LINAC a FODO completes the focussing.

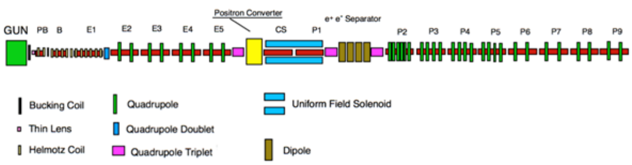

Figure 3: LINAC focusing system scheme.

Accelerating Voltage and Beam Loading

When the pulse is shorter with respect to the structure filling time, the effect of beam loading can be neglected and the beam is accelerated near the peak of the accelerating voltage at the output of the SLED (the small "flat top" close to the time t_2, as shown in Fig. 4, adapted from Ref. [2]).

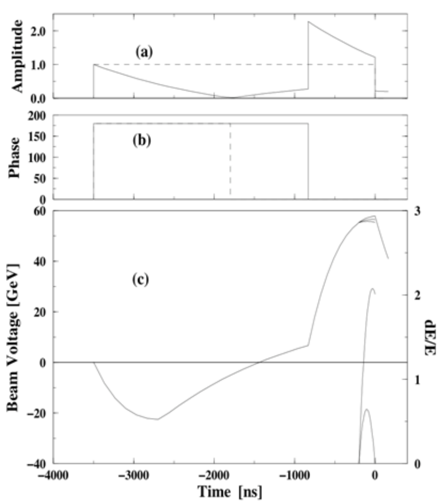

Figure 4: From the top: input (dashed) and output (solid) amplitude (a) and phase (b) of the SLED and (c) unloaded and loaded beam voltage and energy spread (lower curves), adapted from Ref. [2].

On the contrary, the beam loading can be used in order to compensate for the varying accelerating voltage when longer beam pulses are fed to the structures, by turning on the beam prior to the peak: the energy loss due to loading will be – at least partially – compensated by the still increasing energy gain curve, thus flattening the beam voltage and reducing the energy spread.

In addition to the beam loading effect, any shift between different RF phases or delays in the four stations feeding the four different portions of the DAΦNE LINAC can further increase the flat top of the beam voltage.

LONG BEAM PULSE RESULTS

New Gun Pulses

In order to produce electron pulses from the LINAC gun longer than 40 ns (for dedicated, low pile-up, high energy physics experiments [3]), a new pulsed power supply was necessary: the detailed specifications, the installation and commissioning is described in Ref. [4]: the new system is now routinely used since September 2016 in the standard DAΦNE operations with 10 ns long pulses.

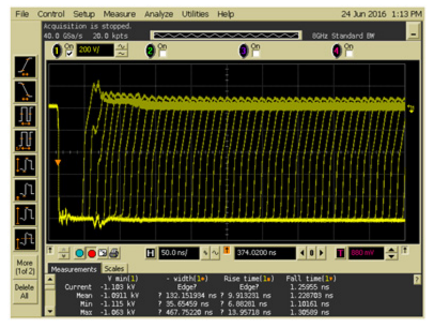

Figure 5: Test pulses of different width from the gun supply system.

Commissioning with beam and acceleration tests were performed on September 15-17, 2016.

First of all the pulse height for the square waveform to be applied to the gun has been optimized vs. the counter-potential of the stopping grid, in order to have a clean shape of the time profile of the electron current emitted by the cathode: increasing both the gun pulse and the grid potential has been useful for reducing the effect of the ringing of the output of the pulser, clearly visible in Fig. 5. While the pulse at the gun can be easily extended up to 300 ns, the time profile of accelerated electrons along the LINAC gets instead a triangular shape, with a FWHM of few tens of ns, shorter duration, due to the head-tail effect during acceleration, since the RF power stations (including the SLED's) were not modified.

Buncher Power

Referring to the scheme of Fig. 1, the distribution of RF power from the modulator "A" is the following: half of the power is fed to the "capture section" (CS), immediately following the positron converter (thus operating at a higher gradient of 26.5 MV/m, instead that 17 MV/m of all standard sections). The remaining half is further split: 25% of the modulator A power is fed to the P1 section (the first after the CS), while the last 25% can be phase-shifted and is distributed to the pre-buncher (PB), buncher (B) and first section (E1).

In order to get a significantly longer pulse width of the fully accelerated beam, the first parameter that we had to change was the relative power in the buncher with respect to the following first section E1: we have decreased the pre-buncher fraction from 49% to 32%, while increasing the overall power of modulator A from 64% to 76%, ob-

ISBN 978-3-95450-182-3

taining a triangular beam time distribution at the end of the LINAC with ≈150 ns base and 70 ns FWHM, when applying a 200 ns pulse to the gun (see Fig. 6).

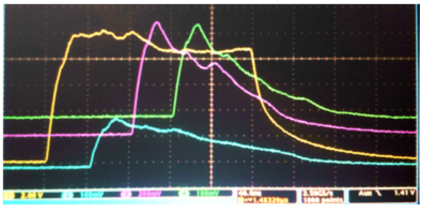

Figure 6: Beam pulse measured by the beam current monitors along the LINAC, from the exit of the gun (yellow trace) to the last accelerating section (green trace), for a gun pulse width set to 200 ns, buncher power at 32%.

RF Delay

In order to get a long flat top in the accelerated beam, the second important parameter that has been changed is the timing of the pulse with respect to the accelerating field inside the structures: if we move from the maximum of the field, in particular moving the head of the macro-bunch prior to it, towards the still increasing part of the accelerating potential (negative times in the reference of Fig. 4), we can get a smaller variation of the accelerating field of micro-bunches in the head and the tail of the pulse. This was done by changing the relative delay between the RF and the gun: 100 ns was the optimal value we found.

RF Power and Phase

In order to smooth the distribution of electrons at the end of the LINAC the other parameters that have been optimized were of course the power of the four modulators and the phase shifters. Of course changing the power and the phases of the modulators also affects the energy gain and thus the final energy at the end of the LINAC.

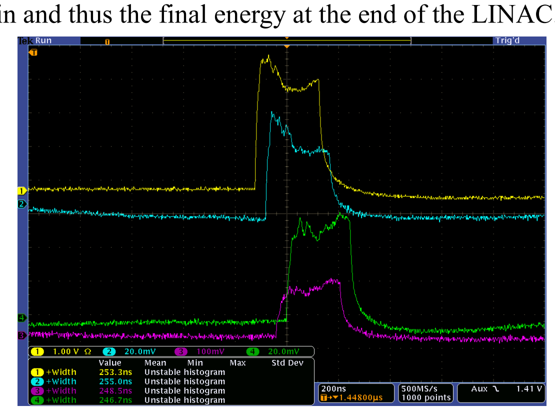

Figure 7: Beam current monitor signals after the gun (yellow trace), and at different positions along the LINAC (the green trace is right at the end of the accelerating sections): optimized 250 ns almost flat electron beam pulse, at 550 MeV final energy.

The best result, in terms of a long and flat beam pulse, is shown in Fig. 7: a 250 ns long distribution with a relative variation at the level of 25% (peak to peak) has been obtained, at a final energy of 550 MeV.

CONCLUSIONS AND FUTURE PLANS

At the end of 1990's at the SLAC LINAC – which indeed has been the model for the realization of the Frascati DAΦNE one – some studies for producing the longest possible, high-energy electron beam has been performed, in the framework to the experiment E-155.

By applying multiple phase inversion to the klystron power, a longer flat top in the SLED output can be obtained, in particular with a couple of additional phase inversions, a nearly constant, no-load accelerating voltage as long as 500 ns has been obtained, although at the price of a reduced beam charge (from 10^{11} down to $2.9{\cdot}10^{9}$ particles) and slightly higher energy spread [5-6].

Another possibility for getting even longer pulses is to modulate the low-level RF that is amplified by the klystron and fed to the SLED and from there distributed to the accelerating structure, in such a way to compensate the variation of accelerating voltage over a longer time. For instance, moving the beam pulse with even larger advance with respect to the flat top, a decreasing input RF power would compensate for the (larger) increase of voltage at the output of the SLED, of course at the price of a reduced energy gain.

ACKNOWLEDGEMENTS

This work is supported by the H2020 project AIDA-2020, GA no. 654168.

REFERENCES

[1] Z. D. Farkas, H. A. Hogg, G. A. Loew and P. B. Wilson, SLAC-PUB-1453 (1974).

[2] F.-J. Decker, Z. D. Farkas, L. Rinolfi and J. Truher, SLAC-PUB-7214 (1996).

[3] P. Valente *et al.*, "Linear Accelerator Test Facility at LNF. Conceptual Design Report", arXiv:1603.05651 [physics.acc-ph] (2016); INFN-16-04-LNF.

[4] B. Buonomo *et al.*, in *Proc. IPAC 2015*, paper TUPWA056 (2015).

[5] F.-J. Decker, Z. D. Farkas and M. G. Minty, SLAC-PUB-8111 (1999).

[6] F.-J. Decker, Z. D. Farkas and J. Turner, SLAC-PUB-8113 (1999).