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DAΦNE LINAC: BEAM DIAGNOSTICS AND OUTLINE OF THE LAST IMPROVEMENTS

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Abstract

The LINAC of the DAΦNE complex is in operation since 1996, both as injector of the $e^+ e^-$ Φ-factory, and, since 2003, for the extraction of electron beam to the Beam Test Facility. In the last years, many improvements have been developed in different sub-systems of the LINAC, aiming at a wider, tuneable range of beam parameters, in particular the pulse time width and the pulse charge. A long term measurement campaign has been recently started to characterize the LINAC performance after that many sub-systems has been overhauled and improved, starting from RF power (i.e. klystron substitution, modulator renewal, RF driver layout, SLED tuning) as well as the timing system, magnets, cooling, vacuum, control system and energy/position diagnostics. This work reports the latest results on the optimization of the fully consolidated system.

LINAC DESCRIPTION

The electron-positron LINAC of the DAΦNE collider complex is a ~60 m long, S-band (2856 MHz) linear accelerator, and has been in operation since 1997. It includes a thermionic gun[1], four 45 MW SLEDed klystrons (Thales TH-2128C) and 15, 3 m long travelling-wave accelerating sections[2].

With reference to figure 1, it is possible to see that 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 klystron power into four equal parts, feeding each one an accelerating section. The fourth klystron has a different configuration: half the power is sent to the capture section (CS), the first section downstream the positron converter (PC), while the second half is equally divided between two branches feeding the accelerating section P1 the first one, the prebuncher, the buncher and the accelerating section E1 the second one.

All the 15 accelerating sections (E1-E5, CS, P1-P9) are of the same type: the well known 3 m long, 2/3 π travelling wave, constant gradient, SLAC design structures. In our configuration, with 45 MW coming out the klystron, the nominal accelerating component of the electric field is 24 MV/m in the CS and 18 MV/m in the remaining accelerating sections.

The phase adjustments between the sections are performed by means of low power 360° phase shifters upstream the RF amplifiers of each klystron, and by a high power 360° phase shifter that uncouples the CS from E1. The relative phasing between accelerating sections belonging to the same klystron network were regulated once and for all by properly adjusting the rectangular waveguides upstream the section inputs.

The above described configuration allows changing arbitrarily the phase of the CS with respect to E5, and this is an important feature in the positron mode of operation.

The four modulators are able to produce a pulse of 4.5 μs flat top with a repetition rate at 50 Hz, with a HV power supply with resonant circuit charging the pulse forming network (PFN), composed by 9 LC cells up to 50 kV, and a switching thyratron (type EEV CX2168).

The positron converter subsystem is based on the SLAC scheme. The conversion is obtained by interposing to the electron beam a metallic target and collecting the produced positrons by a flux concentrator jointly with DC solenoid magnets, generating a 5 T peak magnetic field. The system allows the choice of three different targets, with thickness varying around 2 radiation lengths, built with an alloy of 75% of tungsten and 25% of rhenium. A remotely controlled actuator permits to extract the target from the beam path during the electron mode of operation.

The focusing system is configured according to the requirements of the interested LINAC portion. An easy way to describe this system is to follow a particle beam from the gun to the LINAC end. The first coil that the beam finds is the bucking coil, used for reducing the presence of magnetic field in the gun cathode region, followed by a 'thin lens' with a solenoid driving the beam to the pre-buncher. The pre-buncher, buncher and the accelerating section E1 are immersed in a solenoidal field produced by 14 Helmholtz coils. A quadrupole doublet between E1 and E2 allows matching between the solenoidal focusing system with the FODO that transports the beam to the positron converter.

The FODO is composed by two quadrupoles per each of the four accelerating sections (E1-E4). A high gradient quadrupole triplet upstream the positron converter is used for focusing the beam into a 1 mm (RMS) radius spot on the converter target. The focusing system on the positron converter area and on the accelerating sections CS and P1 has been already described.

Downstream this part is placed the positron/electron separator which, in the positron mode, separates secondary positrons and electrons in 2 different paths and eliminates the electrons by means of a beam stopper. In the remaining part of the LINAC, from section P2 to P9, a FODO, composed by 26 quadrupoles with steps tapered according to the beam energy, completes the focusing scheme.

A network of vertical and horizontal correctors, in general a couple on each of the accelerating sections, is used for LINAC orbit correction.

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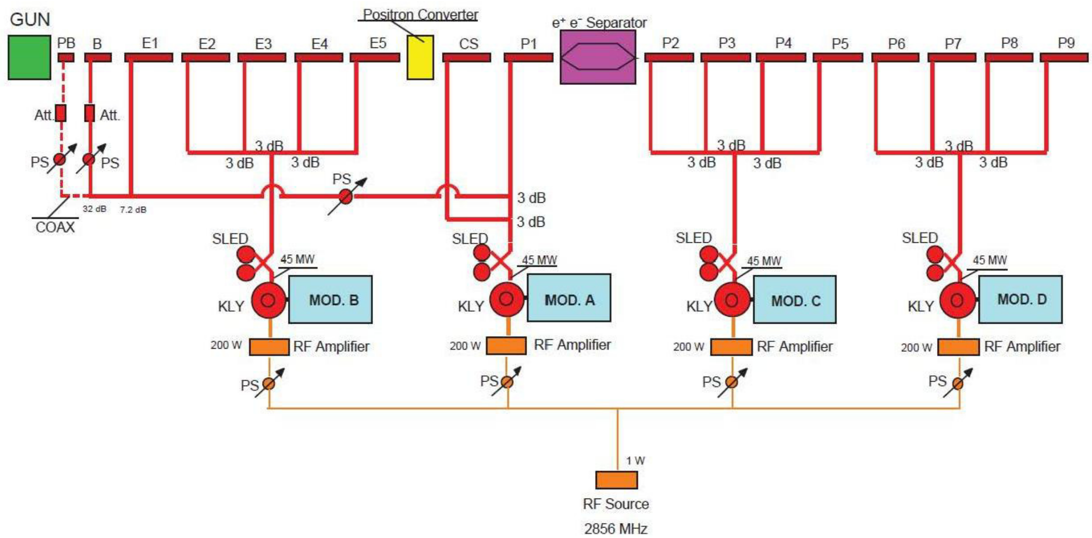

Figure 1: DAΦNE LINAC RF LAYOUT.

The main parameters of the LINAC are summarized in Table 1.

Table 1: DAΦNE-LINAC Parameters

Parameters	**Design**	**Operational**
e^- energy (max)*	800 MeV	750 MeV
e^+ energy (max)*	550 MeV	530 MeV
RF frequency	2856 MHz	
e^+ conversion energy	250 MeV	220 MeV
Beam pulse length	10 ns	1.4 to 40 ns
Gun current	8.0 A	8.0A
RMS energy spread e^-	0.5 %	0.56%
RMS energy spread e^+	1.0%	0.95%
e^- current on e^+ converter	5.0 A	5.2 A
Max output e^- current (10 ns)	>150 mA	180 mA
Max output e^+ current (10 ns)	36 mA	85 mA
Trasport efficiency from capture section to linac end	90%	90%

*the final energy for electron/positron beam during the DAΦNE operation is fixed at 510 MeV.

Beam Diagnostics includes 14 beam position monitors, one at the end of each of the accelerating sections, four fluorescent screens placed at the end of E5 section, on the converter target, at the separator output and at the LINAC end. Finally, four wall current monitors of the resistive type placed at the gun output, at the PC, at the separator output and at the LINAC end, allow measuring the beam current along the LINAC. Other important quantities like energy, energy spread and emittance are measured by dedicated devices placed on the transfer line downstream the LINAC.

UPGRADE OF THE SYSTEM

During the last long shutdown (January-May 2013), all the LINAC components have been overhauled in particular the four RF power stations. Several components such as filter capacitors, thyratrons and high power pulse discrete elements have been replaced, and a newly designed RF driver system has been installed, in order to achieve a better stability of the delivered power. In critical parts, like waveguides downstream the SLEDs, additional pumps with higher pumping speed have been added, in order to reduce discharge occurrences. All the ceramic windows, placed downstream the klystron ones to decouple the LINAC vacuum, have been preventively substituted.

Concerning the RF-vacuum devices in the LINAC accelerating sections, the residual pressure considerably improved by replacing all the RF loads, reaching a stable operation at the level of 10^{-9} mbar. In the meantime, we have completely replaced the entire vacuum safety system, the gating valves and the four old fluorescent screens (obtained by oxidizing the surface of a thin aluminum plate) and new screens with higher sensitivity (YAG:CE crystal) have been installed. The cooling subsystems of the accelerator waveguides network, have been upgraded (new PLC control system), and all components underwent an accurate revision involving water ducts, flux-meters and water pumping system, leading to replacement of many equipments.

The LINAC control system has been revised and upgraded in order to be compliant with the renewed Ethernet architecture (new routers relying on fiber connections) and to profit from new network features. The control system and diagnostic data acquisition is now running on four virtual machine subsystem (VMS, both Linux and Windows), hosted by four physical machines (2.80Ghz Intel Xeon E5, 16GByte RAM, DELL PowerEdge R320) with CentOs6 distribution, in KVM based environment. The LabView software is interfaced through CAMAC to the hardware of the LINAC. In this context a new control application, based on dedicated multiplexed DAQ, has been designed and implemented for the 14 LINAC BPMs. A new electron gun system has been also developed and put into operation [1].

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OPERATION EXPERIENCE

Since June 2013 intense activities have been performed to find the best setup of the LINAC, especially for the upgraded subsystems. First of all RF measurements and tune-up of the RF system, including klystrons characterization, SLED's retuning, monitors recalibration, check of the phase relation between sections have been performed. In order to increase the stability and the RF power at the klystron output, power measurements have been acquired by using a calibrating peak power meter (type Boonton4540[3]) at different set point of the klystron (focusing coils and filament voltage) but at fixed drive power input and modulator HV. As a summary of this klystron characterization the maximum output power values measured are showed in Table 2.

Table 2: Klystron Output Power Values Acquired with Maximum Input Drive Power and HV = 297kV

Klystron A	40.5 MW
Klystron B	38.8 MW
Klystron C	39.7 MW
Klystron D	41.5 MW

The value for the energy during DAΦNE injections is fixed at 510 MeV, so the present value of output power (modulators at 90% of the maximum) is sufficient for the positron operations.

In dedicated BTF[4] operation a maximum energy of 750 MeV (electron) and 530 MeV (positron) has been achieved increasing the high voltage value of the klystron. In this configuration the optimal setup of RF phases, magnet settings and correctors has been found. During these tests, the diagnostics (fluorescent screen and BPMs) were also commissioned and put into stable operation.

Concerning the timing, all the signals (modulator, RF subsystem and electron gun) have been synchronized and the old timing control chassis has been replaced with digital delay generators (Stanford DG535, BNC 575[5]). During these runs, different LINAC operational settings have been tested with high efficiency and reliability.

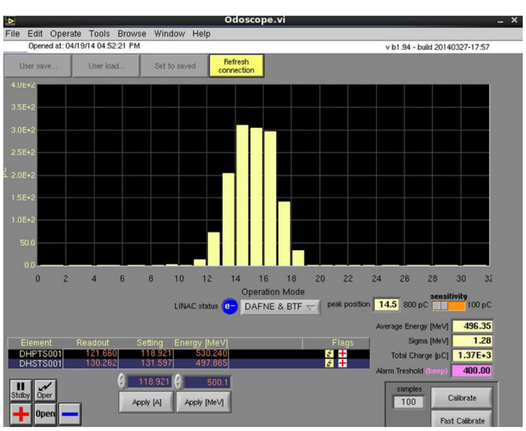

Figure 2: 500 MeV Electron beam with a pulse length of 10 ns. Energy spread in order of 1%

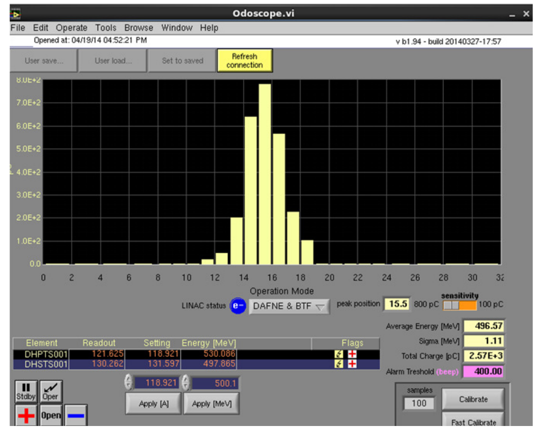

Figure 3: 500 MeV Electron beam with a pulse length of 40 ns. Energy spread in order 1%.

With the new electron gun system, measurements of beam energy spread (electron) have been performed at different beam pulse length. With the same LINAC configuration setup at 500 MeV electrons, beam with pulse lengths increasing from 10 to 40 ns has been transported at LINAC end, essentially with the same energy spread (actually, slightly improving, see figures 2-3).

CONCLUSIONS

In order to increase the performance and the stability of the DAΦNE LINAC, many improvements have been developed, tested and characterized. The latest results on the optimization of the LINAC parameters have been presented.

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