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THE LINAC4 PROJECT AT CERN

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Abstract

As the first step of a long-term programme aiming at an increase in the LHC luminosity, CERN is building a new 160 MeV H^- linear accelerator, Linac4, to replace the ageing 50 MeV Linac2 as injector to the PS Booster (PSB). Linac4 is an 86-m long normal-conducting linac made of an H^- source, a Radio Frequency Quadrupole (RFQ), a chopping line and a sequence of three accelerating structures: a Drift-Tube Linac (DTL), a Cell-Coupled DTL (CCDTL) and a Pi-Mode Structure (PIMS). The civil engineering has been recently completed, and construction of the main accelerator components has started with the support of a network of international collaborations. The low-energy section up to 3 MeV including a 3-m long 352 MHz RFQ entirely built at CERN is in the final construction phase and is being installed on a dedicated test stand. The present schedule foresees beam commissioning of the accelerator in the new tunnel in 2013/14; the moment of connection of the new linac to the CERN accelerator chain will depend on the LHC schedule for long shut-downs.

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LINAC4 AND THE LHC UPGRADE

The peak luminosity of the LHC has been constantly increased during its first two years of operation, reaching in 2011 about 2×10^{33} cm^{-2}s^{-1}. Some additional steps will be required to reach the nominal value of 10^{34} cm^{-2}s^{-1} and possibly exceed it, but it is clear that in a few years LHC performance will saturate because of the injectors and because of the collider itself. To overcome this limitation and extend the physics reach an intensive luminosity upgrade programme has been recently launched, aiming at important hardware modifications in the LHC interaction regions and in the injectors that have to provide beams of higher brightness and intensity [1]. Space charge effects represent a first obvious limitation, which is addressed by increasing the injection energy in the first two synchrotrons in the injection chain, starting from the PS Booster (PSB) presently fed by the 50 MeV Linac2. Because of the lack of space and of its obsolete technology an energy upgrade of Linac2 has been ruled out and instead the construction of a new linac injector for the PSB with a final energy of 160 MeV has been approved by the CERN Council in June 2007. The new linac, called Linac4 because it is the 4th hadron linac to be built at CERN, will bring other advantages related to the injection in the PSB of H^- instead of protons, to a modern construction technology exempt from the reliability concerns of Linac2, and to the possibility of increased beam intensity for non-LHC users. The project started in January 2008 and will be completed in 2014.

DESIGN AND MAIN PARAMETERS

Linac4 is dimensioned to double the maximum intensity from the PSB with the same transverse emittances, providing up to 10^{14} protons per pulse; this charge will be supplied by 400 μs long pulses at 40 mA current. The pulse repetition frequency is limited to a maximum of about 1 Hz by the PSB magnetic cycle and the duty cycle will be only 0.04%. However, in case Linac4 would be used in a future high-intensity facility for neutrino physics, the accelerating structures have been designed for a maximum duty cycle of 10%, leaving infrastructure and power supplies dimensioned only for the low duty cycle; they will have to be replaced in case the high-intensity programme is approved. Chopping of about 35% of the beam at 3 MeV is foreseen to allow low-loss injection in the PSB, bringing the required current out of the ion source to 80 mA. The 3 MeV Front end (source, LEBT, RFQ and chopper line) is followed by three normal-conducting accelerating structures all at 352 MHz, for a total linac length of 86 m (Fig. 1).

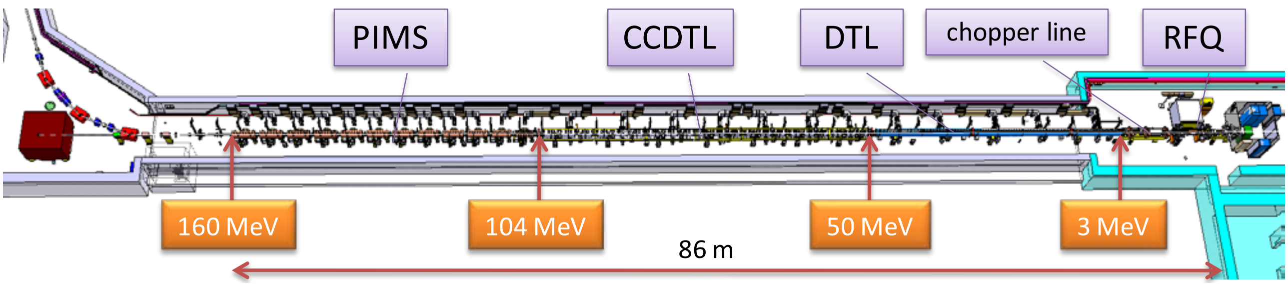

Figure 1: Linac4 layout.

Three different accelerating sections allow maximising the RF efficiency minimising at the same time the construction costs; the use of superconductivity is not economically justified in this range of energy and duty cycle. A single RF frequency allows standardising the RF system with important cost savings; moreover, it is the same as in the previous LEP machine, from which a stock of klystrons, circulators and waveguides is still available.

THE 3 MEV FRONT END

A test stand has been set up to allow commissioning of the 3 MeV Front-end before completion of the building. The source, LEBT and chopper line are completed and under test; the RFQ will be installed at end 2011.

Operation at 45 kV of the original RF volume type H^- source has been prevented by the high power of the co-extracted electron beam. As a consequence, this source has been converted to protons and will be used for the initial commissioning of the RFQ. Two more source assemblies are under construction, an RF volume unit with improved electron dumping to commission the RFQ with H^- from summer 2012 and a cesiated RF source to be eventually used in the final linac configuration. A magnetron source is also being investigated.

The 3-m long RFQ of the brazed-copper 4-vane type is entirely built in the CERN Workshop. A sequence of machining steps and thermal treatments allowed keeping vane position errors after brazing within the 30 μm tolerance. Figure 2 shows the third 1-m long segment ready for assembly.

Figure 2: 3rd RFQ module.

Fast chopping will be provided by two 40-cm long meander-line electrostatic deflectors mounted on a ceramic substrate and inserted into a quadrupole. Pulses of >650 V with rise times of 1.5 ns (10 to 90%) have been produced during testing [2]. The deflected beam is sent on a conical dump that acts like a collimator for the non-deflected beam. Three rebunching cavities, 11 quadrupoles and diagnostic equipment complete the 3.6 m long chopper line and allow transporting, measuring and matching of the beam before injection into the DTL.

ACCELERATING SECTION

A Drift Tube Linac (DTL) divided in three tanks accelerates the beam up to 50 MeV. Focusing in the DTL is provided by 108 Permanent Magnet Quadrupoles (PMQ) placed in vacuum inside the drift tubes. The DTL is based on a new mechanical design allowing precise positioning of the drift tubes inside the tank, without the need for bellows or rubber vacuum joints to align the drift tubes after assembly. The principle has been tested on a 1.2 m long high-power prototype (Fig. 3) which has been conditioned up to the design voltage. Construction of the DTL has started; the components are being produced in industry, in collaboration with the ESS-Bilbao project. Assembly and tuning will be done at CERN.

Figure 3: DTL prototype.

The Cell-Coupled DTL is made of 7 accelerating modules for a maximum RF power of 1 MW each, accelerating the beam to 102 MeV; a module is composed of 3 tanks housing two drift tubes each and connected by coupling cells. Focusing is provided by a combination of PMQs (between tanks) and electromagnetic quadrupoles (between modules). After the successful high-power test of the prototype, construction assembly and tuning have been taken over by a collaboration of Russian laboratories (VNIITF Snezinsk and BINP Novosibirsk). The first two modules are expected to be completed end of 2011.

The Pi-Mode Structure (PIMS) section is made of twelve 7-cell cavities operating in pi-mode. The cells are made of copper and electron-beam (EB) welded. The first cavity (Fig. 4) built at CERN, intended as a prototype, has been completed and conditioned up to 1.25 times the design voltage [3]. Construction of the other cavities has started in collaboration with the Soltan Institute (Poland), with part of the EB welding done at FZ Jülich (Germany).

Figure 4: PIMS first cavity under high-power tests.

Additional contributions to the construction of the Linac4 accelerating cavities come from CEA (France, RF design and measurements of the RFQ), INFN (Italy, all RF tuners) and RRCAT (India, alignment jigs and sections of the RF couplers).

OTHER LINAC COMPONENTS

The Linac4 Radio-Frequency system in its initial configuration (Fig. 5) will use thirteen 1.3-MW-klystrons, previously used in the CERN LEP accelerator, and six new klystrons of 2.8 MW, all operating in pulsed mode. The power out of the 2.8 MW klystrons is divided in two, allowing to either feed two couplers on the DTL tanks 2 and 3 or at high energy to feed two PIMS cavities in parallel. It is foreseen that as the stock of LEP klystrons runs out, pairs of LEP klystrons will be replaced by new klystrons equipped with a power splitter, leaving the waveguide network unchanged and progressively increasing the number of RF stations feeding two cavities [4]. The 110 kV modulators, equipped with a HV pulse transformer and a droop compensation bouncer, have a modular design that allows feeding of either one high-power klystron or two LEP-type units. A digital Low-Level RF derived from the LHC system and equipped with feed-forward capability is being completed and will soon be tested in the 3 MeV test stand.

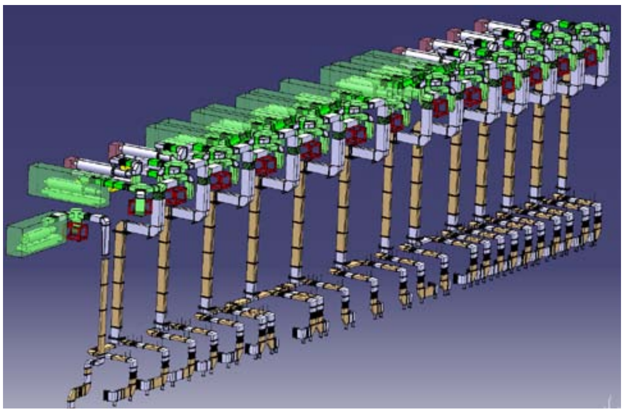

Figure 5: 3-D layout of the Linac4 RF system.

The beam diagnostics is based on standard devices used in other machines at CERN, albeit adapted for the reduced longitudinal space and the specific beam parameters of a linac. The 27 beam position monitors are based on strip-line detectors; beam profile along the machine will be measured by 16 SEM-grids and 6 wire scanners. Beam intensity is measured with 15 beam current transformers. Additional diagnostics equipment placed on movable temporary measurement benches will be used during commissioning [5].

Linac4 will be terminated in a beam dump, preceded by a bending magnet which can send beam pulses into the 70-m long transfer line connecting to the present Linac2-PSB transfer line. A PIMS-type cavity in the line acts as a debuncher, matching the beam energy spread to the PSB acceptance.

CIVIL ENGINEERING AND INFRASTRUCTURE

Linac4 will be located in an underground tunnel placed 12 m below the surface building housing klystrons and other machine equipment. Because of the natural slope of the site next to the present Linac2, the beam line is only 2.5 m lower than the PSB.

The civil engineering works started in October 2008 and were completed in October 2010. After reception of the building and tunnel, the installation of electrical, cooling and ventilation infrastructure has started and will progress until June 2012. Part of the waveguides has been already installed in the surface building (Fig. 6); the cabling campaigns will start in autumn 2011.

Figure 6: Linac4 equipment hall (May 2011).

SCHEDULE AND COMMISSIONING

After completion of the infrastructure installation, the accelerator components will be progressively installed between June 2012 and the first months of 2013. The 3 MeV section will be moved to the Linac4 tunnel at beginning of 2013; it is foreseen to progressively commission the accelerator in steps of increasing energy between May 2013 and April 2014. From that moment on Linac4 will be ready for the connection to the PSB; the latter has to take place during a shut-down of all CERN accelerators lasting a minimum of 7 months, to allow for the conversion of the PSB injection to H^- at higher energy. This long shut-down will have to be coordinated with the overall CERN schedule.

REFERENCES

[1] R. Garoby, S. Gilardoni, B. Goddard, K. Hanke, M. Meddahi, M. Vretenar, “Plans for the Upgrade of the LHC Injectors”, this Conference.
[2] M.Paoluzzi, “A fast 650V chopper driver”, this Conf.
[3] F. Gerigk, P. Ugena Tirado, J.M. Giguet, R. Wegner, “High Power Tests of the first PIMS Cavity for Linac4”, this Conference.
[4] O. Brunner, N. Schwerg, E. Ciapala, “RF Power Generation in Linac4”, Proc. of 2010 Linac Conf., Tsukuba.
[5] F. Roncarolo et al., “Overview of the CERN Linac4 Beam Instrumentation”, Proc. of 2010 Linac Conf.