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Status and plans for Linac4 installation and commissioning

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Keywords : Linac4 ; PS Booster (PSB) ; Drift Tube Linac

Abstract

Linac4 is a normal conducting 160 MeV H^- linear accelerator presently being installed and progressively commissioned at CERN. It will replace the ageing 50 MeV Linac2 as injector of the PS Booster (PSB), increasing at the same time its brightness by a factor of two thanks to the higher injection energy. This will be the first step of a program to increase the beam brightness in the LHC injectors for the needs of the High-Luminosity LHC project. After a series of beam measurements on a dedicated test stand the 3 MeV Linac4 front-end, including ion source, RFQ and a beam chopping line, has been recommissioned at its final position in the Linac4 tunnel. Commissioning of the following section, the Drift Tube Linac, is starting. Beam commissioning will take place in steps of increasing energy, to reach the final 160 MeV in 2015. An extended beam measurement phase including testing of stripping equipment for the PSB and a year-long test run to assess and improve Linac4 reliability will take place in 2016, prior to the connection of Linac4 to the PSB that will take place during the next long LHC shut-down.

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Linac4 is a normal conducting 160 MeV H^- linear accelerator presently being installed and progressively commissioned at CERN. It will replace the ageing 50 MeV Linac2 as injector of the PS Booster (PSB), increasing at the same time its brightness by a factor of two thanks to the higher injection energy. This will be the first step of a program to increase the beam brightness in the LHC injectors for the needs of the High-Luminosity LHC project. After a series of beam measurements on a dedicated test stand the 3 MeV Linac4 front-end, including ion source, RFQ and a beam chopping line, has been recommissioned at its final position in the Linac4 tunnel. Commissioning of the following section, the Drift Tube Linac, is starting. Beam commissioning will take place in steps of increasing energy, to reach the final 160 MeV in 2015. An extended beam measurement phase including testing of stripping equipment for the PSB and a year-long test run to assess and improve Linac4 reliability will take place in 2016, prior to the connection of Linac4 to the PSB that will take place during the next long LHC shut-down.

INTRODUCTION

The Linac4 project was started in 2008 with the goal of building a new H^- linear accelerator going up to 160 MeV energy to increase the injection energy into the PS Booster (PSB) from the 50 MeV provided by Linac2. The main motivation was the need for higher brilliance beams in the PSB and in the LHC injector complex to fulfil the requirements of the High-Luminosity LHC upgrade program [1]. Additionally, injection into the PSB of H^- ions instead of protons would reduce beam loss increasing the operational flexibility; at the same time, the modern construction technology of Linac4 would remove the concerns for the reliability of Linac2, which in the last years has seen recurrent vacuum problems.

Linac4 is a normal-conducting linac of 90 m length (Fig. 1); a 3 MeV injector composed of ion source, RFQ and transport and chopping line is followed by three accelerating sections, all at 352 MHz frequency. The first Drift Tube Linac (DTL) section brings the energy to 50 MeV; it is followed by a Cell-Coupled Drift Tube Linac (CCDTL) section reaching 102 MeV and finally by a section made of Pi-Mode Structure (PIMS) cavities [2].

Figure 1: Linac4 block diagram.

The main Linac4 design parameters are reported in Table 1. The beam out of the ion source is chopped at the RFQ exit to create particle-free intervals in the beam pulse corresponding to the edges of the PSB RF bucket with the goal of reducing capture losses. About 35% of the beam is chopped in this way and sent to a conical dump located in the 3 MeV transport line.

Table 1: Main Linac4 beam parameters

Particles	H-
Energy	160 MHz
Ion source current (max.)	80 mA
Chopping factor	65 %
Output current (max.)	40 mA
Beam pulse length (max.)	400 μs
Output transv. Emittance	0.4 π mm mrad
RF Frequency	352 MHz

LINAC4 STATUS

After completion of the building and tunnel at the end of 2010, the infrastructure including all piping and cabling was installed in 2011 and 2012. In 2013 started the installation of accelerator equipment (klystrons, modulators, power supplies and electronics) while the 3 MeV injector was being tested and commissioned on a dedicated test stand. Initial commissioning of the RF volume ion source showed problems related to the excess of electrons co-extracted with the H^- ions and forced to develop a new source design intended to initially operate in volume mode and finally in surface mode after the addition of a Caesium injection [3]. The new volume source and the RFQ were ready at beginning of 2013, and after ion source beam testing and RF conditioning of the RFQ the first 3 MeV beam was accelerated in March 2013. Commissioning of the chopper and transport line followed, and finally the 3 MeV injector was dismounted from the test stand, transported to its final location in the Linac4 tunnel (Fig. 2) and recommissioned with beam in November 2013.

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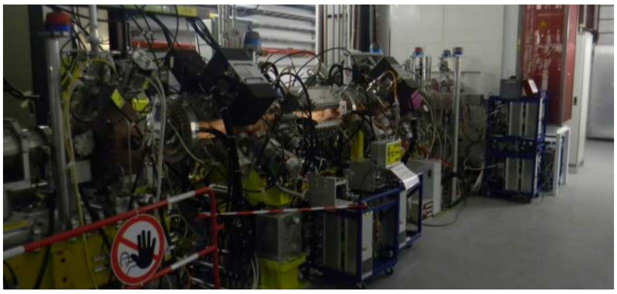

Figure 2: The 3 MeV injector in the Linac4 tunnel. From the right, ion source, RFQ, chopper line.

The 3 MeV beam tests in the tunnel were completed in March 2014 and preparation for the installation of the other accelerating structures started. In parallel, the new caesiated ion source was commissioned in the test stand; an H$^-$ current up to 60 mA was obtained and a series of reliability tests at 40 mA showed an excellent stability and reproducibility of the ion beam. The first DTL tank is ready to start RF conditioning and beam tests at 12 MeV will immediately follow.

The remaining two DTL tanks are in the final assembly phase, while the CCDTL modules have been already completed and are being installed in the tunnel. Construction of the PIMS modules is progressing and all elements of the transport line to the PSB are in an advanced construction phase.

3 MEV BEAM COMMISSIONING

Linac4 is commissioned in 5 stages of increasing energy, making use of some temporary diagnostics installed on a movable test bench. The bench used at 3 and 12 MeV (about 4 m in length) includes a slit-and-grid emittance measurement, a spectrometer, a time of flight measurement via pick-ups, a halo monitor, a bunch shape monitor and a laser to strip the H$^-$ into H^0 and measure their profile with a diamond detector [4]. The scope of the low energy measurement is primarily to characterise the beam but also to cross calibrate some redundant diagnostics (spectrometer vs time of flight, laser stripping vs conventional profile measurements).

The commissioning of the low energy end of Linac4 started in 2012 in the test stand with a thorough characterisation of 45 keV beam from the source. Although the ion source was not the final one, a campaign of emittance measurements dedicated to mapping the behaviour of the beam as a function of LEBT solenoid settings and gas pressure yielded very precious information for the future commissioning, in particular a particle distribution representing the actual beam coming out of the source. This was achieved by back-tracking a number of measurements to the source output plane after having populated a beam of macro-particles according to the slit-and-grid emittance experimental data. The emittance from the temporary source turned out to exceed the acceptance of the RFQ and a maximum transmission of 75% was expected with these parameters.

After injecting the beam into the RFQ, the beam was rapidly matched and the expected transmission was obtained almost immediately. The characteristics curve of transmission vs RF power was measured and compared with simulations (Fig. 3). The emittance after the RFQ was measured both with a slit-and-grid and by reconstruction from profile measurements and turned out to be about 20% smaller than expected, an effect not yet explained.

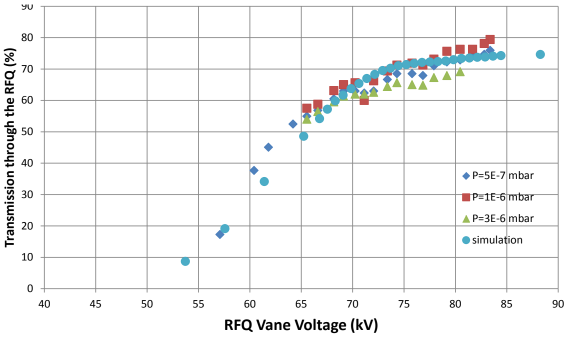

Figure 3: Transmission through the RFQ as a function of RF power.

The following step consisted in transporting the beam through the 3.6 m long line which houses 11 quadrupoles, 3 RF cavities and two fast choppers (meander lines).

The beam went rapidly through the line with the nominal quadrupole settings and the general response of the beam to changes of the focusing was confirmed by measuring the profile and emittance with varying quadrupole values, with kick measurements, and with transmission measurements. All measurements present a satisfactory agreement with predictions from the tracking code. At a second stage the buncher phase and amplitude were cross-calibrated with beam based measurements: the amplitude and phase of the three bunchers were progressively scanned and the movement of the beam centre was observed after the spectrometer. The longitudinal plane was further studied with the bunch shape monitor: the phase spread of the beam at a fixed location was measured as a function of varying RF amplitude settings and the longitudinal emittance was reconstructed with the same technique widely used in the transverse plane, giving results consistent with the spectrometer measurements (energy dispersion rms of about 20 keV) and comparable to expectation, Fig. 4.

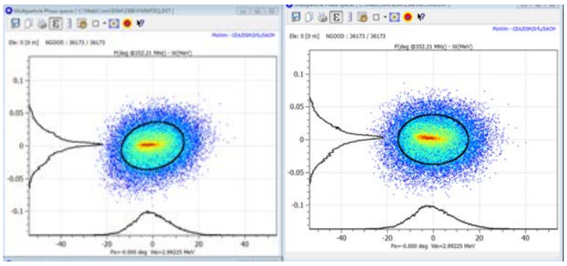

Figure 4: Longitudinal phase space (left expected, right reconstructed) after the RFQ.

The fast chopper was then turned on and the beam passing through the line was extinguished, thus confirming the integrated chopper dynamics [5]. The Linac4 chopper system is unique in that it is composed of a meander line housed in a FODO system. The combination of the chopper kick and the phase advance given by the quadrupoles has to be balanced exactly so that the chopped beam is fully extinguished and the un-chopped beam is fully transmitted without degradation of the emittance. This choice, which allowed keeping the line compact and reducing the chopper voltage, relied on a well-defined beam dynamics configuration. Both the chopper extinction factor and the quality of the through beam were confirmed during measurements (Fig. 5). The chopper rise and fall times measured on a fast beam transformer are shorter than the transformer resolution, 10 ns.

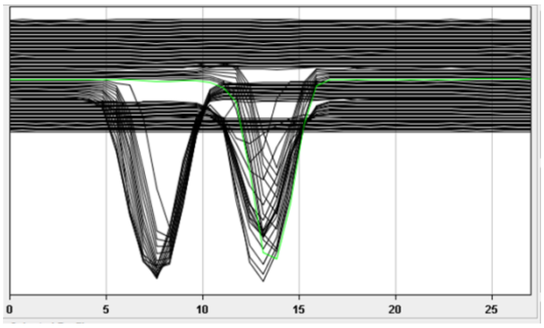

Fig. 5: Transverse beam profile along the beam pulse after the chopper; chopped and main beam are fully separated.

DRIFT TUBE LINAC COMMISSIONING

The Linac4 DTL mechanical construction follows a new design based on achieving precise tolerances on the drift tube supporting elements and on a simple installation of the drift tubes without any alignment step. Assembly of the first tank (Fig. 6) with the new mechanism was straightforward; RF measurements and tuning of post-couplers followed, resulting in a residual field error within ±1.5%. The measured Q-value of 42’120 is 86 % of the simulated one. The tank is now installed in the Linac4 tunnel and RF conditioning is expected to start soon.

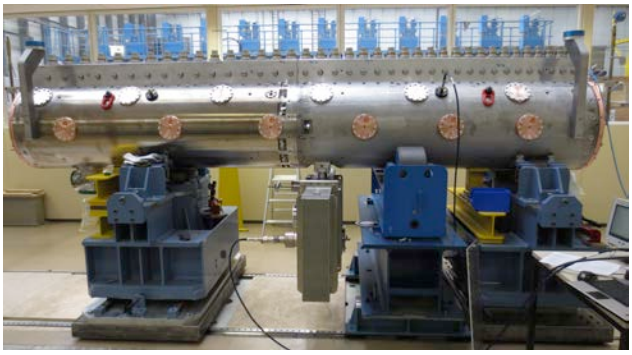

Figure 6: Drift Tube Linac Tank 1.

FUTURE PLANS

After commissioning of the first DTL tank at 12 MeV in June 2014, it is foreseen to install the caesiated version of the ion source at the end of summer and then repeat the 12 MeV beam measurements at higher current. Installation and commissioning of the remaining DTL tanks will take place at the end of 2014, while during 2015 first the CCDTL and then the PIMS sections will be commissioned with beam. After reaching the final energy, the beam from Linac4 will be used to test a part of the new stripping section that will be installed in the PSB. The following step will be a year-long reliability run sending a short beam pulse on the main dump, intended to identify initial problems and in general terms to assess the reliability of Linac4 prior to its connection to the CERN accelerator complex. The goal of Linac4 is achieving more than 95% availability.

The new injection system in the PSB will be installed during the next LHC Long Shutdown foreseen in 2018-19 and from that moment Linac4 will be the only proton injector of CERN. Before the H^- connection it is foreseen that Linac4 could inject protons at 50 MeV in the PSB in case of a long Linac2 fault. Protons can be produced directly by the ion source or obtained by stripping the H^- at the end of the linac; powering only the DTL tanks and detuning the other accelerating structures would allow acceleration at 50 MeV. The Linac4 design current is lower than what is presently provided by Linac2, the advantages in terms of number of particles for an H^- linac coming from the longer pulse. For proton operation, the Linac4 current has to be increased up to the limit of the available klystron power, between 50 and 60 mA. With this proton current all the LHC beams could be produced, while simulations are ongoing to show the possible impact on other users.

REFERENCES

[1] K. Hanke, H. Damerau, A. Deleu, A. Funken, R. Garoby, S. Gilardoni, N. Gilbert, B. Goddard, E.B. Holzer, A.M. Lombardi, D. Manglunki, M. Meddahi, B. Mikulec, E. Chapochnikova, M. Vretenar, Status of the LIU Project at CERN, this conference.

[2] F. Gerigk et al., Design and Construction of the Linac4 Accelerating Structures, LINAC2012, Tel Aviv, September 2012, p. 778 (2012).

[3] J. Lettry et al, Status and operation of the Linac4 ion source prototypes, Rev Sci Instrum. 85 02B122, 2014.

[4] S. M. Gibson et al., A Fibre Coupled, Low Power Laserwire Emittance Scanner at CERN LINAC4, this Conference.

[5] G. Bellodi, A. Akroh, O. Andreassen, J.-F. Comblin, V. Dimov, J.-B. Lallement, A. M. Lombardi, C. Martin, O. Midttun, E. Ovalle, U. Raich, F. Roncarolo, C. Rossi, J.-L. Sanchez Alvarez, R. Scrivens, J. Vollaire, M. Yarmohammadi Satri, F. Zocca, 3 MeV Test Stand commissioning report, CERN-ACC-2013-025.