BEAM COMMISSIONING OF LINAC4 UP TO 12MeV

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Abstract

CERN Linac4 is made of a 3 MeV front end including a 45 keV source , a 3 MeV Radio Frequency Quadrupole (RFQ) and a fast chopper, followed by a 50 MeV Drift Tube Linac (DTL), a 100 MeV Cell-Coupled Drift Tube Linac (CCDTL) and a 160 MeV Pi-Mode Structure (PIMS). The Linac4 beam commissioning is performed in 6 stages of increasing energy. Movable beam diagnostics benches, with various instruments, are used at each step to allow the detailed characterisation of operational parameters that will play a key role in the overall future performance. The first three stages of the commissioning, up to 12 MeV beam energy, have been completed at the end of 2014. The RFQ and the chopper line at 3 MeV, as well as the first tank of the DTL at 12 MeV were fully characterised, using permanent diagnostic instruments and a movable diagnostic bench equipped with a spectrometer, a slit-grid emittance meter, a Bunch Shape Monitor, Beam Position Monitors and a laser-emittance device. This paper reports on the strategy and the results of the commissioning up to 12 MeV. It also presents the validation of the set-up strategy, which is essential for the next stages of commissioning.

INTRODUCTION

Linac4 is a normal conducting, 160 MeV H- ions accelerator that is being constructed within the scope of the LHC Injectors Upgrade project. Linac4 will be connected to the Proton Synchrotron Booster during the next long LHC shutdown and it will replace the current 50 MeV proton linac, Linac2. Linac4 is being commissioned progressively with the installation of the accelerating structures into the Linac4 tunnel.

The first three stages of commissioning, which focused mainly on the characterisation of the RFQ (3MeV), the validation of the chopping system and the characterisation of the first DTL tank (12MeV), have been successfully performed by the end of 2014. A temporary version of the ion source, which gives about 20mA of beam current, was used during each stage.

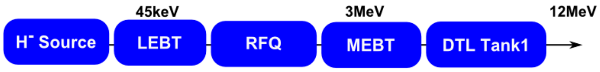

Figure 1: The Linac4 basic architecture up to 12MeV.

Figure 1 shows the Linac4 basic architecture up to 12MeV and Fig. 2 shows the movable diagnostic bench, which was used for the beam commissioning at 3MeV and 12MeV. The bench was consecutively used for the beam measurements after the RFQ, the Medium Energy Beam Transport (MEBT) line and the DTL tank1. In addition to the temporary diagnostic instruments on the bench, the permanent diagnostic instruments of the MEBT line and between the DTL tank1 and tank2 were also used where necessary.

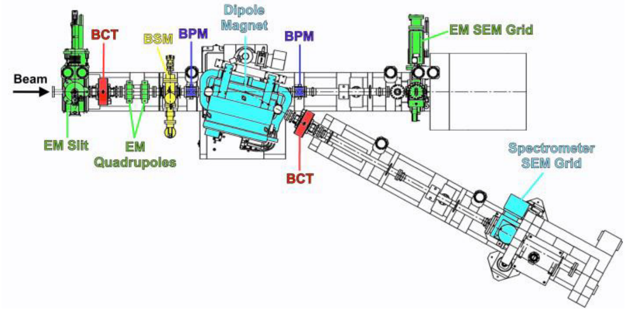

Figure 2: Movable diagnostic bench for 3MeV and 12MeV beam measurements.

During the 3MeV and 12MeV commissioning periods, the same beam properties were measured using different methods and instruments and then compared. In addition to the characterisation of the accelerating structures, these commissioning stages were particularly important for cross-calibration of the permanent diagnostic instruments with the temporary ones and validating the measurement methods, which are crucial for the high energy beam commissioning stages.

The following sections summarize the significant results of the 3MeV commissioning stage, with relevant references, and explain the measurement process and the results of the 12MeV commissioning in detail.

3MeV COMMISSIONING

During the 3MeV commissioning stage, many issues were addressed. The major ones were: confirming the RFQ performance, validating the chopping system operation and finding the RF phase and amplitude setting of the cavities on the MEBT line.

The performance of the RFQ and the calibration of the RF amplitude were confirmed by varying the power in the RFQ and measuring the transmission [1].

The chopping system is composed of four plates, followed by a cone shaped in-line dump. The correct operation of the chopping system was confirmed by measuring the transmission of the main and the chopped beam through the in-line dump, under different optics conditions. The spatial separation of the main beam and the chopped beam was also confirmed through the wire scanner measurements [1].

The MEBT line houses three RF cavities, which are used for the longitudinal matching of the beam to the DTL. The RF phase and the amplitude settings of each cavity were determined by varying the cavity parameters and measuring the beam centre position after the spectrometer on the diagnostic bench shown in Fig. 2 [2].

The beam transverse emittance was measured using three different methods: slit-grid emittance meter (EM) and laser-emittance device, as direct methods, and forward method [3], as an indirect method, which is based on the beam profile measurements. The comparison of the measurement results validated the forward method, which is the only emittance measurement method at high energy commissioning stages, [4] and proved the feasibility of laser-stripping emittance measurement [5]. Using an RF cavity and the Bunch Shape Monitor (BSM), the forward method was successfully applied to the longitudinal emittance reconstruction as well [4].

After the MEBT line, several transverse emittance measurements were taken with the slit-grid EM. Based on the measurement data, multi-particle beams were generated and then backtracked to the RFQ output plane using the multi-particle tracking code, PATH[6]. The agreement between the backtracked beams confirmed the correct calibration of 11 quadrupole magnets on the MEBT line. The backtracked beam was also used for cross-checking the wire scanner measurements with the emittance measurements [7].

After fully characterising the machine and the beam properties, the MEBT quadrupole magnet and RF cavity settings, which match the beam to the DTL tank1, were found using the code PATH. The transverse matching was confirmed through the slit-grid EM measurement. The longitudinal properties of the matched beam were also confirmed using the BSM and the spectrometer [1].

12MeV COMMISSIONING

The first DTL tank was installed in the tunnel in July 2014 and the diagnostic bench (in Fig. 2) was moved to the injection point of the DTL tank2. The intertank between the tank1 and the tank2 houses a Beam Position Monitor (BPM), a horizontal and vertical steering magnet and an electromagnetic quadrupole. These elements were also used during the commissioning. The main goals of the 12MeV commissioning were to determine the operational values of the tank1 cavity phase and the RF amplitude, as well as to confirm the correct beam dynamics through the DTL tank1 permanent magnet focusing system.

The DTL tank1 commissioning started with the MEBT buncher cavities turned off and detuned. The cavities were turned on one by one. At each step, the MEBT quadrupoles were adjusted to satisfy the transverse matching of the beam to the DTL tank. Figure 3 shows a sketch of the MEBT line and the first DTL tank.

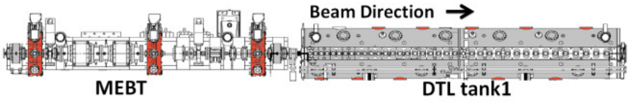

Figure 3: The sketch of the MEBT with the three buncher cavities (in orange) and the DTL tank1 (in grey).

The longitudinal bunch size at the tank1 injection plane depends on the setting of the cavities. Figure 4 shows the comparison of the simulated beam longitudinal phase spaces with the tank1 longitudinal acceptance plot for different settings of the buncher cavities. The acceptance plot was obtained by simulating a multi-particle beam, which has a big longitudinal emittance, through the tank and checking the initial coordinates of the transmitted and accelerated particles[8].

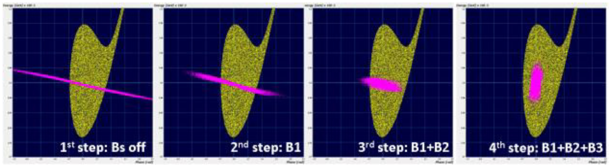

Figure 4: Comparison of the beam longitudinal phase space (in purple) with the tank1 longitudinal acceptance plot (in yellow). From left to right: all bunchers off, first buncher on, first two bunchers on, all bunchers on. For each plot, the axes are Δφ and ΔE with the range of ±200° and ±0.3MeV respectively.

For each step shown in Fig. 4, the tank1 RF phase was scanned over a range of 360° and the transmission was measured. This is similar to scanning the longitudinal acceptance plot of the tank across the phase space of the beam (in Fig.4) and counting the number of particles inside the intersection area of the two.

The operational RF phase is determined by comparing the measured phase profile of the transmission with the simulation results. The comparison between the measured and the expected profile of transmission from phase scans is given in Fig.5, for the cases when all the MEBT cavities were turned off and when they were all turned on.

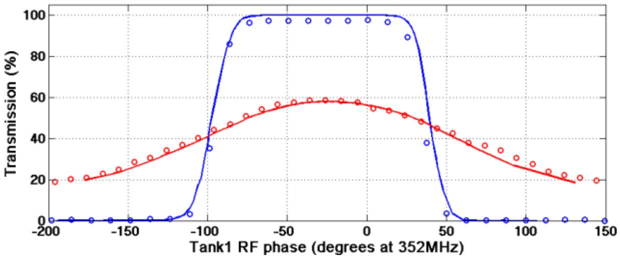

Figure 5: Transmission through the tank1 vs. RF phase of the tank. Red: all the MEBT cavities are off, blue: all the MEBT cavities are on, dotted lines: measurement, solid lines: simulation.

After the determination of the RF phase of tank1, the MEBT cavities were kept operational for the rest of the commissioning.

The measurement of the tank1 output beam energy was the key for setting the RF amplitude and confirming the RF phase found by the acceptance scans. By varying the RF phase, the tank1 output energy was measured both by the time-of-flight (ToF) and the spectrometer. While the trend of the energy vs. tank1 RF phase curves agreed very well, the results from the ToF were consistently higher by 60keV.

The tank1 output energy was measured by ToF for different RF amplitudes by scanning the RF phase. The curve of energy vs. RF phase was observed to be unique for each RF amplitude. By comparing the measured curves with the simulations, the setting of the RF phase was confirmed and the operational level of the RF amplitude was identified with an accuracy of ±1%. Figure 6 compares the measured curves (dots) with the simulated curves (solid lines) for the nominal RF amplitude and 5 % above the nominal.

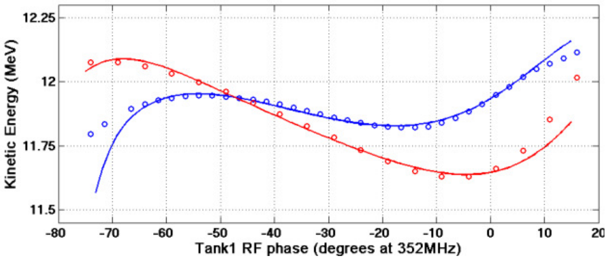

Figure 6: Energy vs. tank1 RF phase. Blue: nominal RF amplitude, red: 5% above the nominal. Dotted lines: measurement, solid lines: simulation. (The measured data are shifted by -60keV for a better comparison of the trend).

Extensive transverse emittance measurements were taken with the slit-grid EM, by varying last MEBT line quadrupole and the intertank quadrupole after the tank1. The measurement results agreed well with the simulations and, when the beam was matched to tank1, no emittance growth was observed through the tank. The agreement between the measurements and the simulations confirmed the beam dynamics design through the tank1 permanent magnet focusing channel, the calibration of the intertank quadrupole and the accuracy of the beam dynamics simulations.

The operation of the chopper in the MEBT line should not cause any perturbations on the main beam (un-chopped bunches). In order to test this, with the same optics condition, two emittance scans were taken: one with the chopper turned off and the other with the chopper on. The comparison of the measured phase spaces along the pulse showed no effect of the chopper on the main beam.

As a last step of the 12MeV commissioning, the machine parameters were set to the operational values in order to match the beam to the second DTL tank. The parameters of the matched beam were confirmed with the slit-grid EM, the BSM and the spectrometer. Figure 7 shows a comparison between the measured and the simulated transverse phase spaces with an excellent agreement in orientation (the measurements were cut because of the limited angular acceptance of the EM).

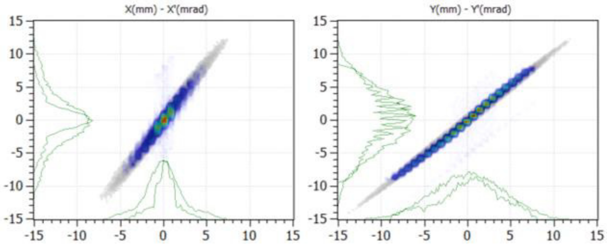

Figure 7: Transverse phase spaces of the beam matched to the second DTL tank. Colour scale: measurement, grayscale: simulation.

The rms energy spread and the longitudinal particle distribution of the matched beam were confirmed with the spectrometer and the BSM, respectively. Figure 8 shows the comparison between the measured and the simulated longitudinal particle distribution in a bunch.

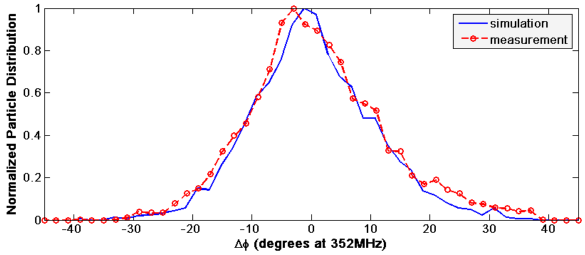

Figure 8: Comparison between the simulated (blue) and the measured (red) longitudinal particle distribution at the BSM location.

CONCLUSIONS

The Linac4 was successfully commissioned up to 12 MeV with a temporary version of the ion source. A movable diagnostic bench was used at several locations for the detailed characterisation of the structures and for setting the operational parameters.

During the 12MeV commissioning, the RF phase of the DTL was set using the acceptance scans. The ToF, which will be the sole energy measurement method at the next commissioning stages, was successfully commissioned and used for setting the RF amplitude and for confirming the RF phase of the first DTL tank. The beam dynamics design through DTL tank1 with the permanent magnet focusing channel was confirmed by the emittance measurements.

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