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BEAM DIAGNOSTICS MEASUREMENTS AT 3MEV OF THE LINAC4 H^- BEAM AT CERN

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Abstract

As part of the CERN LHC injector chain upgrade, LINAC4 [1, 2] will accelerate H^- ions to 160 MeV, replacing the old 50 MeV proton linac. The ion source, the Low Energy Beam Transfer (LEBT) line, the 3 MeV Radio Frequency Quadrupole and the Medium Energy Beam Transfer (MEBT) line hosting a chopper, have been commissioned in the LINAC4 tunnel. Diagnostic devices are installed in the LEBT and MEBT line and in a movable diagnostics test bench which is temporarily added to the MEBT exit. The paper gives an overview of all the instruments used, including beam current transformers, beam position monitors, wire scanners and wire grids for transverse profile measurements, a longitudinal bunch shape monitor and a slit-and-grid emittance meter. The instrumentation performance is discussed and the measurement results that allowed characterizing the 3 MeV beam in the LINAC4 tunnel are summarized.

INTRODUCTION

The first phase of the LINAC4 3 MeV H^- beam commissioning was performed in a dedicated Test Stand [3]. The ion source, the LEBT line, the RFQ and the MEBT line were then installed in the LINAC4 tunnel and went through a second longer commissioning phase. A movable temporary diagnostics test bench was first used at the Test Stand, while plugged at the RFQ and MEBT exit in two different stages, and was then installed in the tunnel at the MEBT exit. It contains Beam Current Transformers (BCTs), Beam Position Monitors (BPMs), a Bunch Shape Monitor (BSM), a halo monitor, a slit-and grid Emittance Meter (EM) and a spectrometer line [4]. Before the installation in the tunnel, the halo monitor and one position monitor were replaced by two quadrupole magnets added downstream the slit, with the purpose of better focusing the beam on the emittance meter grids. This is required when the beam is setup to match the first DTL (Drift Tube Linac) cavity, which is supposed to accelerate the beam from 3 MeV to 12 MeV. The new test bench structure, as installed in the LINAC4 tunnel, is shown in Fig. 1.

BEAM INTENSITY AND POSITION

Two Beam Current Transformers are used for intensity measurements in the MEBT line and two more in the movable test bench. All have significant magnetic shielding in order to reduce the electro-magnetic coupling with the pulsed quadrupole magnets placed downstream or upstream the transformers. Their read out electronics is based on 200 MHz ADCs, with the output of consecutive samples averaged over a software programmable period ranging from 10 ns to a few μs. As the output buffer on the acquisition card has a limited size, this averaging period is normally set such that the 400 μs Linac4 beam pulse is completely acquired as well as a subsequent BCT calibration pulse.

The BCTs in the MEBT line were the first instruments to see the 3 MeV H^- beam accelerated through the RFQ and were extensively used to optimize both the RFQ and the MEBT transmission. The second BCT in the MEBT line is placed downstream of the chopper and gave the first evidence of the chopper operation, by showing the “hole” due to the “chopped” beam, as shown in Fig. 2. By setting the highest sampling resolution of 100 MHz, and by adjusting the time window around the kicker start and stop times, it could be clearly seen that the chopper rise and fall times were faster than 10 ns.

Beam Position Monitors (BPMs) are located in the straight line of the movable test bench, upstream and downstream the spectrometer magnet. The BPMs are designed to measure beam position and intensity with ~ 45 ns time resolution. In addition, by a comparison of the phase of two BPMs, the time of flight and hence the energy of the particles can be determined. Simulations and tests with Linac2 beams [5] predict a resolution better than 0.1 mm on the beam position and 0.1 mA on the beam intensity. A very good agreement was found between the BPM intensity measurements when compared to the BCT signals, as shown in Fig. 3. The possibility for validation of the position measurements was unfortunately limited since only two BPMs out of three were left in the diagnostics bench when installed in

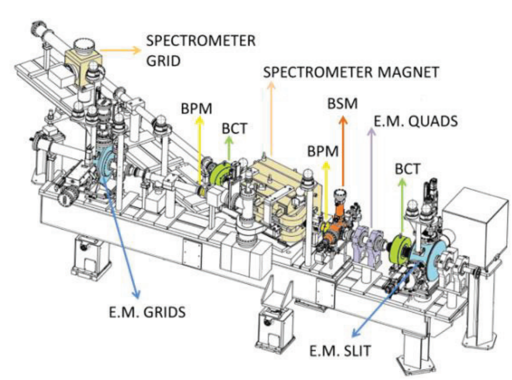

Figure 1: The 3MeV movable diagnostic test bench.

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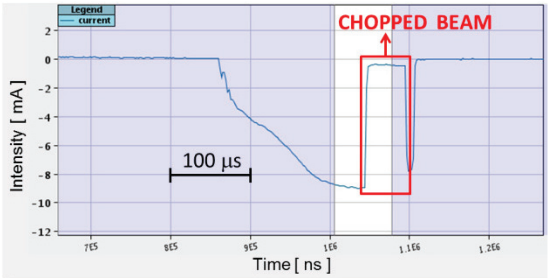

Figure 2: Typical BCT acquisition of the chopped beam.

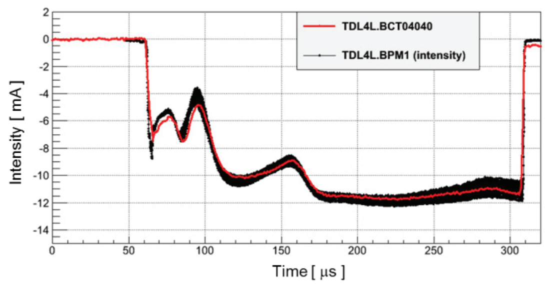

Figure 3: Comparison between BCT (red trace) and BPM (black trace) beam intensity measurement.

the tunnel. The absence of one BPM due to the addition of temporary focusing quadrupoles meant that a final validation with a three-point trajectory measurement was not possible at 3 MeV. This is now foreseen in the next commissioning phase at 12 MeV.

TRANSVERSE PROFILE AND EMITTANCE

The transverse profile and emittance measurements performed at the 3 MeV Test Stand were extensively described in [4]. Hence this paper will be focused on the improvements and the results achieved during the commissioning in the tunnel.

Two wire scanners are located in the MEBT line. They both consist of two 33 µm graphite wires, one horizontal and one vertical, mounted on the same fork support which scans the beam under a 45 degree angle. The second MEBT wire scanner allowed measurements of the chopped beam displacement, being located between the deflecting magnets and the chopper dump [3]. Thermal effects due to the 3 MeV beam load were extensively studied at the Test Stand and reported in [4]. Although no evidence of cross-talk between the two wires was identified at the 3 MeV Test Stand, the wire scanner cross-shape geometry was changed into an L-shape geometry before the installation of the MEBT line in the tunnel. The typical horizontal and vertical profiles acquired with the L-shaped wire scanners are shown in Fig. 4 as a function of the fork support position, which is obviously common for both wires. When the wires were not polarized, as in Fig. 4, no significant cross-talk could be seen. When the gain was highly increased, so that the main beam profile was deeply saturated, a cross-talk signal below 0.3 % appeared in the same position of the beam peak intensity on the other plane. This cross-talk is due to the stripped H$^-$ outer electrons that are scattered from one wire onto the other one, in agreement with what was predicted by Fluka simulations [6]. When the wires were polarized with a positive voltage, up to the maximum available 120 V, an increase in the main signal intensity was seen due to secondary emission suppression, but a significantly higher cross-talk signal (10-20 %) was also measured. As discussed in [6] for the case of a wire grid, the electric field generated by wire polarization is only partially able to suppress secondary electrons, so that part of the emitted secondaries are captured by the neighbouring wires due to the shape of the electric field lines. The wire scanners were hence used with no polarization.

The emittance meter installed on the movable test bench consists of a slit-and-grid system for a direct sampling of the transverse phase space. For both planes, the slit is made of two graphite blades mounted with a 15° angle with respect to the beam axis in order to dilute the energy deposition. The wire grids, placed about 3 m downstream the slit, consist of 48 graphite wires with a diameter of 33 µm and a pitch of 0.75 mm. The emittance measurements performed during the Test Stand commissioning were described in [4]. Three upgrades were implemented before the installation in the tunnel: (i) the slit aperture was increased from 200 µm to 300 µm, in order to achieve higher beamlet intensities with a beam current of only about 10 mA (compared to the nominal 60 mA); (ii) read-out electronics channels were connected to all the 48 grid wires in order to increase the emittance meter acceptance in the presence of large beamlet divergences; (iii) biasing voltages were provided to the metallic frames placed upstream and downstream of each grid, at about 5 mm distance, in order to suppress secondary emission from the wires and to repel secondary electrons emitted by the downstream beam dump. The biasing voltage level and polarity were carefully optimized through extensive tests, supported by CST Particle Studio tracking simulation. A negative polarization of -700 V, applied to the grid frames, was found to be essential in order to get the correct phase-space reconstruction. The measurements obtained were in

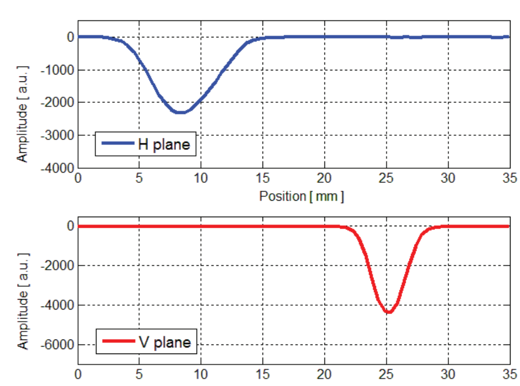

Figure 4: Typical horizontal (blue) and vertical (red) beam profiles acquired by the L-shaped wire scanner.

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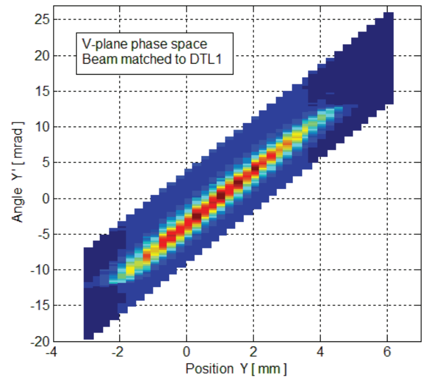

Figure 5: Typical vertical transverse phase space of the 3MeV H$^-$ beam when matched to DTL1 tank.

good agreement with phase-space simulations and confirmed by the agreement between the measurements performed with different field values of the quadrupole magnets placed downstream of the slit. As already mentioned in the Introduction, the additional quadrupoles were introduced to measure the emittance of the 3 MeV beam when set-up to match the DTL1 tank acceptance. An example of the phase space acquired by the emittance meter in this case, and reconstructed according to the quadrupole field correction, is shown in Fig. 5 for the vertical plane. This measurement was considered fundamental for the final 3 MeV beam validation [2], as it could then be considered ready for acceleration to 12 MeV by the DTL1 tank.

LONGITUDINAL DISTRIBUTION

A Bunch Shape Monitor (BSM), developed at INR in Russia [7], was used in the test bench to measure the longitudinal intensity distribution of a micro-bunch (one of the bunches filling the 352.2 MHz RF buckets within the 400 µs linac pulse). In this device the secondary electrons generated by the interaction of the H$^-$ beam with a 100 µm tungsten wire are accelerated by the polarization voltage applied to the wire, deflected by an RF deflector whose RF pulse is synchronized with the accelerating RF, and finally amplified by an electron multiplier. By scanning the phase of the deflecting field, the longitudinal intensity distribution of the incoming beam was measured with a phase resolution of one degree. The BSM was extensively used to set-up the bunching phase of the three bunching cavities of the LINAC4 chopper line. The method relied on the fact that at the correct bunching phase the measured bunch size is modified by a change in RF amplitude, but the bunch position (the average phase) is not affected. A typical BSM acquisition is shown in Fig. 6, where the three MEBT bunchers are all phase tuned. The bunch shape is shown all along the beam pulse while sampled with a time resolution of 1 µs.

The buncher phase tuning procedure performed with the BSM was validated by extensive measurements performed in parallel using the spectrometer magnet and

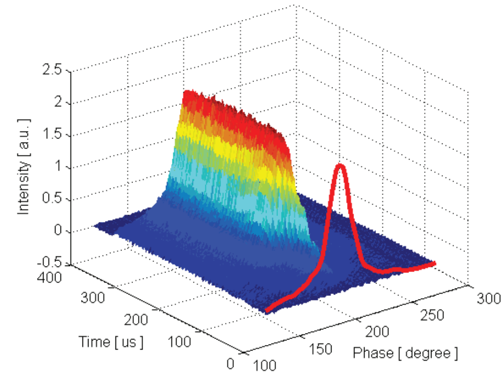

Figure 6: Typical longitudinal distribution acquired by the BSM when the three MEBT bunchers are phase tuned.

the horizontal-plane wire grid placed at the end of the spectrometer line. While varying the buncher phase, the dipole magnetic field needed to keep the beam centered on the grid was recorded. As the change in the dipole field is proportional to the change in the average beam energy, the sinusoidal modulation of the beam energy could be reconstructed as a function of the RF phase. A negative polarization of -700 V applied to the grid frames proved to be fundamental in order to suppress secondary emission from the wires and from the downstream dump, as was the case for the emittance meter grids.

CONCLUSIONS AND OUTLOOK

The beam instrumentation devices used to characterize the LINAC4 3 MeV H$^-$ beam, installed both in the MEBT line and in the temporary movable test bench, have all been successfully commissioned in the LINAC4 tunnel. Their very good performance was essential in order to validate the 3 MeV H$^-$ beam dynamics. The beam is now ready to be accelerated to 12 MeV by the first DTL cavity.

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