LINAC4 45 keV PROTON BEAM MEASUREMENTS

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Abstract

Linac4 is a 160 MeV normal-conducting H⁻ linear accelerator, which will replace the 50 MeV proton Linac2 as injector for the CERN proton complex.

Commissioning of the low energy part - comprising the H⁻ source, a 45 keV Low Energy Beam Transport line (LEBT), a 3 MeV Radiofrequency Quadrupole (RFQ) and a Medium Energy Beam Transport (MEBT) - will start in fall 2012 on a dedicated test stand installation.

In preparation to this, preliminary measurements were taken using a 45 keV proton source and a temporary LEBT setup, with the aim of characterising the output beam by comparison with the predictions of simulations. At the same time this allowed a first verification of the functionalities of diagnostics instrumentation and acquisition software tools.

Measurements of beam profile, emittance and intensity were taken in three different setups: right after the source, after the first and after the second LEBT solenoids respectively. Particle distributions were reconstructed from emittance scans and used as input to simulation studies of the beam transport through the line (forward and backward tracking). Comparison of the results with the measurements at different locations allowed an experimental validation of the LEBT (in terms of misalignments and calibration points) and qualification of the beam at the source output.

INTRODUCTION

The Linac4 [1] 3 MeV frontend is presently in the process of being assembled for the start of commissioning on a dedicated test stand in autumn 2012. While waiting for completion of the RFQ construction and final developments on the H- ion source, a preliminary campaign of measurements was carried out in 2011 to characterise the performance of a prototype Low Energy Beam Transport (LEBT) section of Linac4 and provide first validation of the beam simulation models used in the design of Linac4 as well as of the beam diagnostics and software acquisition tools functionality.

The LEBT is a critical part of the machine in the control of beam emittance and parameters for optimised matching into the RFQ acceptance of the beam extracted from the source. It consists of two solenoids, two steerers, a beam current transformer (BCT) and a diagnostics box containing a Faraday cup, a profile monitor, a moveable iris device for the production of lower intensity beams [2] and a pre-chopper (not operational at the time of the measurements). The layout has been kept as compact as possible in its 1.8 m length, to minimise space charge effects, predominant at these low energies. Beam

dynamics simulations studies carried out with the PATH code [3] show that in the case of nominal beam parameters (45 keV, 80 mA, 90% space charge compensation, ε=0.25 mm mrad), and using a uniform input particle distribution, we can achieve almost lossless transmission through the LEBT and good matching to the RFQ. The LEBT acceptance is largely determined by the distance between the source output plane and the first solenoid, together with the first solenoid aperture.
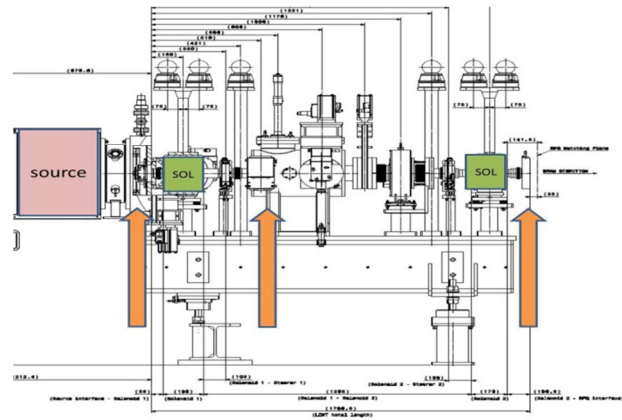

Figure 1: LEBT prototype setup (orange arrows indicate measurement positions).

MEASUREMENTS

A prototype version of the H- ion source was used for the measurements, in proton operation mode. Different neutralisation effects have to be expected, but beam dynamics in the LEBT is overall charge state insensitive, making the results of this pre-commissioning still meaningful for the final setup of the machine. Goal of the campaign was to calibrate the response of solenoids and steerers in the LEBT layout, and study the dependence of beam transport conditions and final parameters on the source settings (extraction voltage, RF power and gas pressure). The output beam was characterised via beam current and emittance measurements taken with the aid of a Faraday cup and a slit-and-grid device respectively at three distinct locations along the LEBT: at the source exit, between the two solenoids and downstream of the RFQ matching plane (see Figure 1).

Source Exit

Figure 2 shows the measured total beam current at the exit of the source when varying the RF power at a constant pulsed hydrogen gas flux. The beam consists of protons (about 70% of the total), as well as H_2^+ and H_3^+ ions (15% each), overlapped at this point, and which will

only later become separated in the transverse phase space. A representative beam distribution in the x-x' plane is shown in Figure 3, for the case of 40 kW applied RF power to the source: emittance was reconstructed by applying a 0.1% threshold of the maximum signal on the profile monitor. Near symmetry exists between the x and y plane (not shown here). The beam turned out to be considerably more divergent than expected on the basis of some extrapolations, with direct consequence on the transmission through the LEBT.
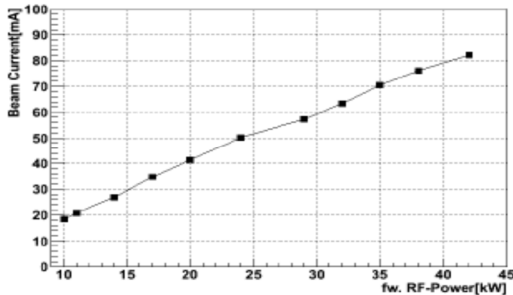

Figure 4: Beam transmission through the LEBT.

Figure 2: Measured beam current vs source RF power

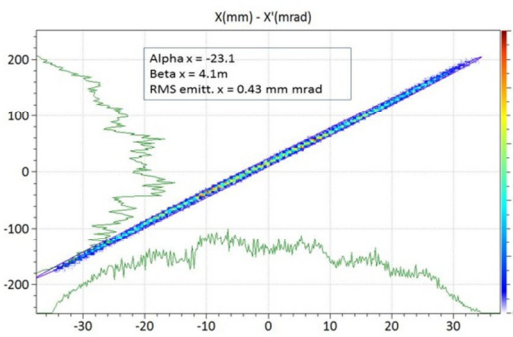Figure 5: Beam envelopes and transmission for 685A-350A solenoid currents.

Figure 3: Beam emittance after the source at 40kW RF power.

LEBT

Several measurements at the source output were superimposed to produce a representative beam input distribution to be used in tracking simulation studies. Phase space measurements were used to calibrate the solenoid field maps generated with the code SUPERFISH/POISSON [4] and the response of the steerers. The LEBT transmission is mostly determined by the settings of the first solenoid: Figure 4 (left) shows measurements (red dots) taken at the exit of the LEBT while scanning the current fed to the first solenoid. Agreement with simulated values (superimposed) is very good. Maximum transmission of 60% is achieved for a 600 A setting. Figure 5 shows beam dynamics envelopes resulting from simulations with the reconstructed beam as measured at the source exit (red and blue lines) compared to the case of lossless transport for a uniform particle distribution input (green line). The aperture of the first solenoid is the main bottleneck for transmission, with 40% of the beam lost.
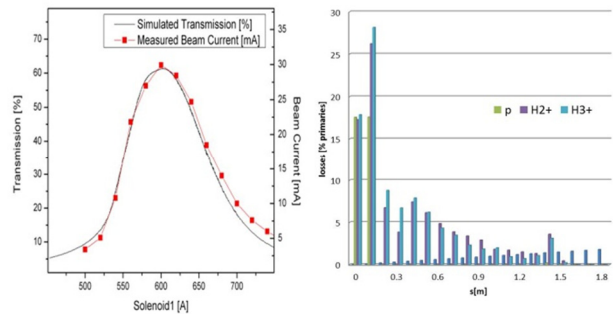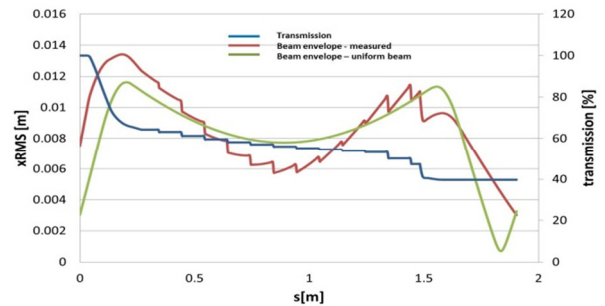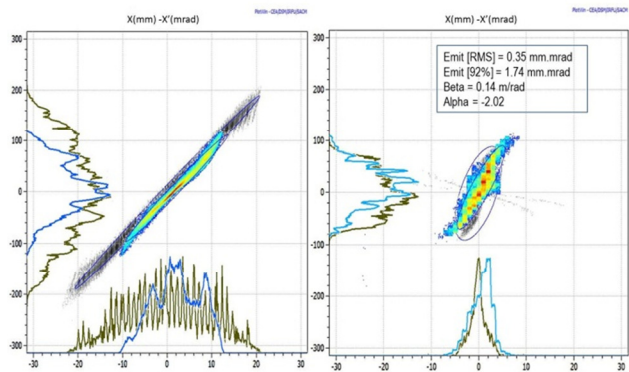

Figure 6: LEBT acceptance and output (600A-330A solenoid currents).

Figure 4 (right) shows a histogram of losses for the three distinct particle species: $H2+$ and $H3+$ losses are more evenly spread out along the LEBT structure, whereas all proton losses are concentrated at the first solenoid. Figure 6 (left) shows a comparison between the beam phase space measured after the source (in the background in grey) and the LEBT acceptance for the maximum transmission solenoid settings of 600 A and 330 A (as results from backtracking the LEBT output beam to the source measurement plane, in the foreground in colour). Only particles with a divergence within 100 mrad are transmitted through the structure. The right hand side shows the beam measured at the LEBT output for these configuration settings, in the foreground in colour, overlapped with the output beam distribution (in grey in the background) resulting from tracking the beam

measured at the source exit through the LEBT structure with the PATH code. Again, a very good agreement between measurements and simulations is obtained.

RFQ Matching Plane and Acceptance

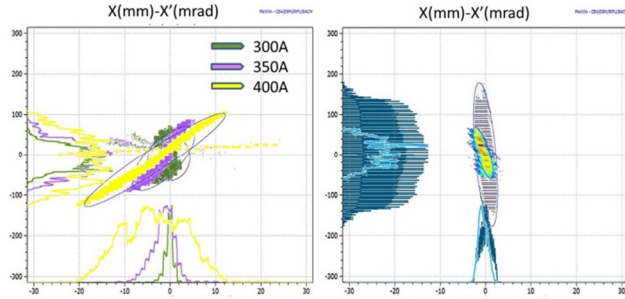The second solenoid allows flexibility in finding best matching conditions to the RFQ.

Figure :7 Phase space plots of the LEBT output beams (left) and RFQ acceptance (right).

Figure 7 on the left shows the measured beam phase space distributions at the LEBT output when varying the current settings on the second solenoid (300 A, 350 A and 400 A respectively) while keeping the first solenoid current fixed at 665 A. Figure 7 on the right illustrates a good matching case to the RFQ. Shown in grey in the background is the zero current acceptance of the RFQ in the x-x' plane, as obtained from Parmteqm [5] simulations; overlapped in colour is a beam distribution measured at the profile monitor at the LEBT output and backtracked by 83 mm to the point corresponding to the RFQ input plane. The settings used in this configuration are 685 A and 350 A for the first and second solenoid respectively. Assuming that measured offsets can be re-absorbed through some steering, the beam can be tracked to the end of the RFQ with >95% transmission (see Figure 8).
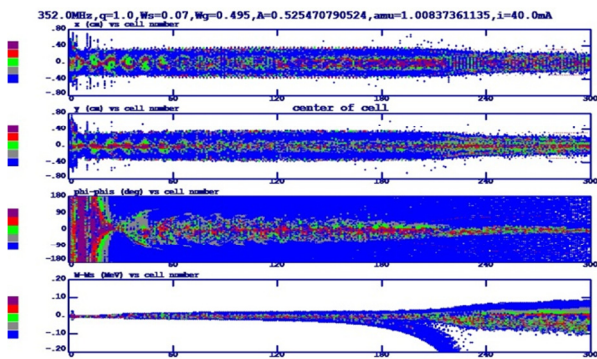

Figure 8 Transport through the RFQ: beam profiles in x, y, $\phi - \phi_s$, and $W - W_s$ vs cell number.

For different settings (non-optimised matching), RFQ transmission can drop to 60-70%, as indicated in Table 1, where simulation results for different LEBT configurations are shown. That matching to the RFQ is a

critical point of the beam dynamics in Linac4 is otherwise illustrated in Figure 9, which shows the results of zero space charge acceptance studies, whereby a very large input beam distribution is tracked through each single structure at one time in a nominal machine setup. The plot shows that the RFQ and MEBT chopper line present the most stringent limitations in both transverse planes.

Table 1: Transmission Results for Different Solenoid Settings

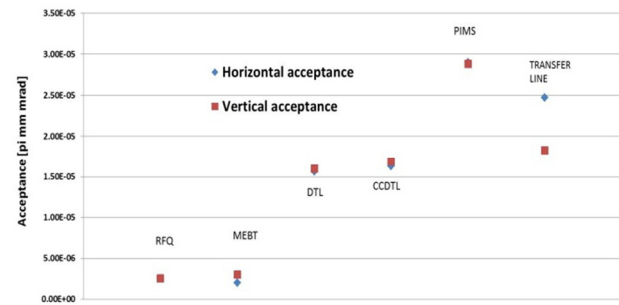| Solenoid settings		Beam current [mA]		Transm.
Sol1	Sol2	LEBT	RFQ	RFQ
600	330	31	22.3	72%
600	350	31	19.2	62%
620	340	30	18.5	62%
640	350	26	22.1	85%
665	350	17	15.2	89%
685	350	14	13.3	95%

Figure 9 : Linac4 structures zero space charge acceptance (π mm mrad).

CONCLUSIONS

The 2011 pre-commissioning campaign at the Linac4 test stand has provided a means of detailed investigation of the LEBT optics using proton beam transport through prototype versions of the source and LEBT. Characterisation of the beam at the source output was made to cross-check measurements against simulation, as well as test beam diagnostics performance and software acquisition tools. Results were overall very satisfactory and a maximum proton beam current of 30 mA was successfully transported to the RFQ matching plane.

REFERENCES

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[3] A.Perrin,J.F.Amand,Travelv4.06user manual, CERN(2003)
[4] J Billen and L. Young, "SUPERFISH/POISSON Manual", LA-UR-96-1834.
[5] J Billen, "RFQ design codes", LA-UR-96-1836.