LINAC4 COMMISSIONNING STRATEGY

J.B. Lallement, G. Bellodi, M. Eshraqi, M. Garcia Tudela, A.M. Lombardi, P. A. Posocco, E. Sargsyan, J. Stovall, CERN, Geneva, Switzerland

Abstract

Linac4 is a 160 MeV H^- ions accelerator, which will replace the 50 MeV proton Linac (Linac2) as injector for the CERN complex from 2016. The higher output energy together with charge-exchange injection will allow increasing beam intensity in the following machines. Linac4 is about 100 m long, normal-conducting, and will be housed in a tunnel, 12 m below ground, on the CERN Meyrin site. The low energy front-end, consisting of a 45 keV source, a 3 m long RFQ and a 3 MeV chopper line, will be commissioned starting next year in a temporary location. It will then be moved to the tunnel at the end of 2012 and the commissioning in situ will be done progressively with the installation of the accelerating structures. The preparation of 4 commissioning stages (12, 50, 100, and 160 MeV) is of key importance to meet the goals of beam performance and reliability. An extensive campaign of simulation is in progress to define the necessary measurements and the required diagnostics accuracy for a successful set-up of the transverse and longitudinal parameters of the machine. This paper presents the results of the simulations and the measurement strategy.

INTRODUCTION

Linac4 is a normal conducting, 160 MeV H^- ions accelerator, presently under construction at CERN which will upgrade the proton accelerator complex replacing the 50 MeV Linac2 and provide higher intensity beams [1]. The low energy front-end is composed of a 2 MHz rf volume source, a two solenoids Low Energy Beam Transport, a 3 MeV Radio Frequency Quadrupole resonating at 352.2 MHz and a Medium Energy Beam Transport, housing a beam chopper device. The acceleration up to 160 MeV is provided by three Drift Tube Linac tanks, a Cell Coupled Drift Tube Linac (21 tanks coupled in 3's) and 12 Pi-Mode Structure tanks. The first commissioning stage will start next year with the 3 MeV test stand. During this stage, the RFQ will be commissioned as well as the chopper-line. A dedicated detector, the Beam Shape and Halo Monitor, will characterize the performance of the chopper. The high energy part (from 3 to 160 MeV) will be commissioned in 2013, when the accelerating structures are installed in the tunnel. In the following we give some highlights of the simulation work done for the preparation of the commissioning.

COMMISSIONING STAGES

Linac4 will be commissioned in several stages, starting from the low energy end (3 MeV test stand) and after alternating phases of commissioning at intermediate energies (12, 50, 100,160 MeV) and installations. The different stages are detailed below:

- Stage1: 3 MeV test stand, commissioning of the source, LEBT, RFQ and chopper line. This stage of the commissioning, starting next year, will take place in the PS south hall and will last until installation in the tunnel will start at the end of 2012.
- Stage2: The LEBT, RFQ and chopper line will be re-commissioned in the tunnel (2013).
- Stage3: The DTL tank1 (12 MeV) will be installed and commissioned.
- Stage4: DTL tanks 2&3 are installed and commissioned.
- Stage5: CCDTL is installed and commissioned.
- Stage6: PIMS is installed and commissioned.

AVAILABLE DIAGNOSTICS

Besides the permanent diagnostics (listed in table 1), a movable diagnostic bench has been foreseen as part of the Linac4 commissioning plan to characterize the H^- beam properties at the exit of the front end (RFQ and MEBT) at 3 MeV and of the first DTL tank at 12 MeV. The low energy end is the most critical for beam quality control (50% of the emittance growth happens before 3 MeV) and also the most critical for housing diagnostics (free space for non-active equipment is limited to a minimum in order to avoid the effects of uncompensated space charge forces). The bench will be composed of two sections: a spectrometer and a straight line. The spectrometer line will be used for longitudinal plane measurements of the beam energy spread and average energy with the purpose of cross-calibrating the Time Of Flight measurements and to find the set point of the rf structures (buncher + DTL tank) characterisation. The straight line will be used to characterize the beam trajectory, its emittance with a slit and grid system and transverse profile, the intensity and the longitudinal shape. The layout of the bench is shown in Figure 1.

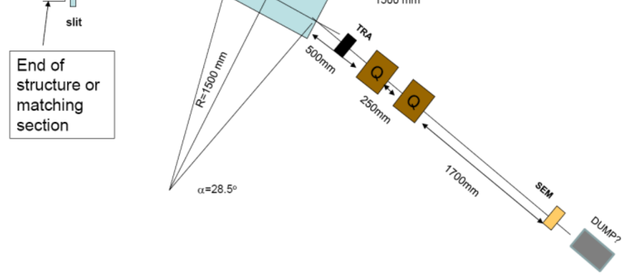

Figure 1: Diagnostic bench layout.

The permanent diagnostics which will be housed in the Linac between the rf tanks is mainly composed of:

- Beam Current Transformers.
- Pick Ups with four quadrants striplines to measure the beam centre position and the beam centre phase with respect to a reference rf phase.
- WireScanners to measure the profile at strategic locations.
- A Secondary EMission grid system to measure the transverse profile of a single bunch.
- Beam Loss Monitors placed at each tank transition.

A list of the number and location of the diagnostics permanently installed in the beam line is given in table 3.

Table 1: List of Permanent Diagnostics

	BCT	PickUp	WireSc	SEMGrid	BLM
LEBT	1	/	/	1	/
MEBT	2	/	2	/	/
DTL	1	3	/	1	3
CCDTL	1	7	2	2	1
PIMS	1	6	3	1	1

Some permanent diagnostics will also be installed in the beam line between the exit of the PIMS and the Linac dump (2 Pick-ups, 2 BCTs, 1 SEMGrid, 1BLM and 1 Feschenko monitor).

The test bench in its 3-12 MeV configuration (with the spectrometer line) will also be a test for the Time Of Flight measurements which will be the only tool for setting the rf parameters in the high energy part of the Linac. In fact, the DTL, CCDTL and PIMS tanks will be commissioned in the tunnel where we will not be able to have a spectrometer line. For the commissioning at 50 and 100 MeV, in the tunnel, the diagnostic bench will be only composed of 3 beam profile measurement devices and 2 pick-ups in a straight line section. In addition to the measurement bench, permanent diagnostics are installed in the beam line in the inter-tank and inter-structure areas.

Beam Intensity and Transmission

Three Beam Current Transformers will be installed on the diagnostic bench: two upstream and downstream of the dipole magnet in the inline part and one in the spectrometer line.

Beam Profile and Emittances

Transverse emittance measurements should be performed as close as possible to the exit points of the different structures to avoid effects of space charge. Independently of the test bench configuration (RFQ, MEBT, DTL tank1), the beam will have to be made parallel at the slit. For the RFQ measurements, two quadrupoles will be added between the cavity and the bench in order to make the beam parallel. For the MEBT and DTL tank1 measurements, we will use respectively the first and the last EMQs of the MEBT. According to simulations, the slit will be able to scan through the whole beam width, with an expected range of movement of ± 3 cm from the beam axis. The motor minimum step is 0.2 mm with a position accuracy of 50 µm. For the grid, the minimum wire spacing (especially for central wires) is 0.75 mm and the total travel range will cover the total width of the vacuum chamber. Taking all the diagnostics accuracy into account, the emittance measurements resolution should be around 0.5 mm/ 0.5 mrad.

Beam Position / Phase Monitors

Beam position and phase monitors will be essential instruments at the time of commissioning to measure:

- Absolute beam position.
- Relative beam intensity between pick-ups.
- Absolute beam intensity through calibration with BCT.
- Absolute beam phase.
- Average beam energy (TOF).

The monitors are located at positions along the bench where the beam is not completely debunched. Requested resolutions for the different types of measurements are given in table 2.

Table 2: BPMs Resolution

Beam position	0.1 mm
Beam intensity	1% of peak current
Beam phase	1 degree
Energy resolution	1 per mille

Energy Spread Measurements

The energy spread measurements will be carried out in the spectrometer line using a system dipole plus a screen located 3 m from the centre of the magnet. A slit located at the entrance of the bench, will reduce the space charge effect and the beam beta function. The energy spread will be derived from measurements of the beam size at the screen and the knowledge of the local dispersion.

Table 3: Beam Parameters for Energy Spread Measurements (5 rms Values)

	RFQ	MEBT	Tank1
ΔE at Slit [keV]	±41	±52	±72
Δx at dump [mm] (ΔE=0)	±1.6	±2.7	±2
Δx at dump [mm]	±7.7	±11	±4.5
Resolution [keV/mm]	±5.3	±4.7	±16

The line will also be used for beam average energy measurements as complement to the TOF technique and for the rf characterization of the MEBT bunchers. The following figure illustrates the use of the spectrometer line for setting up the first MEBT bunching cavity settings. It represents the beam centre displacement at the

SEMGrid as a function of buncher phase and amplitude [2].

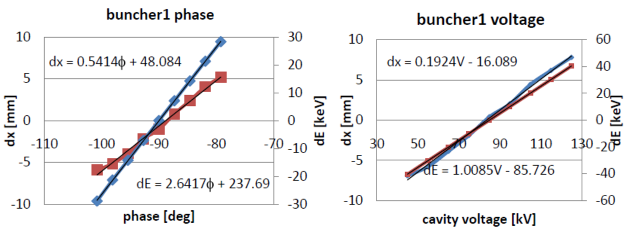

Figure 2: First MEBT buncher phase and amplitude characterization.

Bunch Shape Measurements

A Feschenko monitor [3] will be installed in the bench to measure the bunch profile giving useful information to assess the longitudinal quality of the beam and of the matching between the structures. The measurements will be performed on a pulse to pulse basis. The phase resolution is in the order of 1 degree.

PARAMETERS TO BE SET

Out of the 160 focusing elements in Linac4, 127 are Permanent Magnet Quadrupoles. The number of circuits to be set is therefore limited to 33. These include the settings of the two LEBT solenoids, 2 DTL intertank quadrupoles, 7 CCDTL quadrupoles and 11 PIMS quadrupoles. In addition to the magnets, we will have to set the rf parameters of the accelerating structures and buncher cavites. The following table summarizes the parameters to be optimized. Linac4 is equipped with 17 corrector magnets to steer the beam trajectory on axis and to compensate for alignment errors.

Table 4: Number of Parameters to be set in the Linac

	Magnets	RF Phase	RF Ampl	Steerer
LEBT	2 Solenoids	--	--	2
RFQ	--	--	1	--
MEBT	11 EMQs	3	3	2
DTL	2 EMQs	3	3	3
CCDTL	7 EMQs	7	7	4
PIMS	11 EMQs	12	8	6

Magnets Setting

For setting the transverse parameters, we will use a combination of transmission, beam size and emittances estimates. The following figure shows the relative transmission between the 2 beam current transformers installed in the MEBT as a function of gradients of the four first quadrupoles matching the beam from the RFQ to the chopper section.

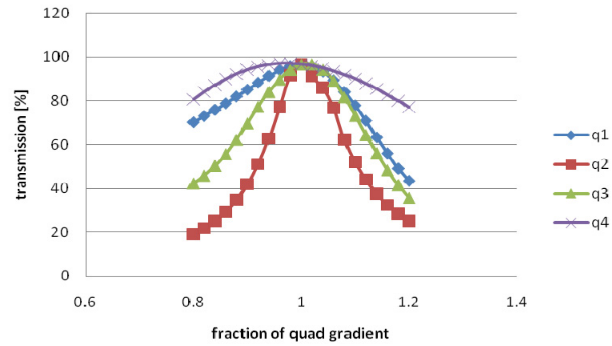

Figure 3: Transmission in the MEBT varying the 4 first quadrupoles.

From figure 3 we can deduce that transmission measurements are sufficient to find the optimized settings of the first four MEBT quadrupoles. The remaining quadrupoles instead act as well on the chopping efficiency and on the matching to the DTL. Therefore their optimized values can be found by looking at a more complex parameter space, including chopping efficiency (halo monitor) and matching through the DTL (measurements of profile at 12 MeV).

RF Parameters Setting

For longitudinal parameters, we will use the methods of the rf characteristics. In fact, varying cavities phase and amplitude will have an impact on the beam average energy, on its energy spread and transmission (mainly for the RFQ). Simulations were run to get all the tank characteristics. An example is given in the figure 4. It represents the first PIMS module output energy as a function of field amplitude and beam input phase. The first stage for setting the cavity parameters will be to find the two intersection points of the characteristic curve corresponding to the -90 and +90° phases. Being independent from the field amplitude, the beam energy is not modified. Once these characteristics points found, it will be straightforward to identify the 0° cavity phase and adjust the field amplitude to the required one. For the first PIMS module (close enough to the nominal amplitude) 5% of field offset lead to 300 keV beam output energy difference. For this particular example, the beam average energy will be measured with the TOF technique using Pick-Ups, housed in every other PIMS intertank.

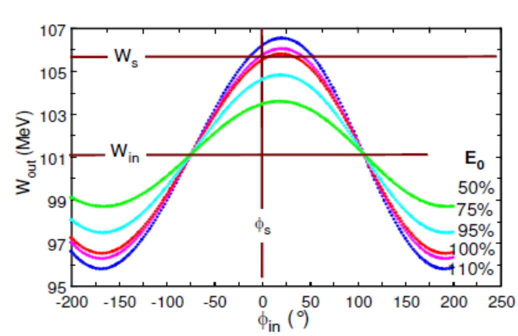

Figure 4: First PIMS module rf characteristics.

Another example of rf cavity characteristic is shown in figure 5. The plot represents the variation of the relative transmission between LEBT and MEBT beam current transformers as a function of the RFQ input power. In order to set the klystron power to the design value, we will vary the vane voltage in order to reproduce the following curve. The curve is really representative, being composed of two straight lines connected by a shoulder located around the nominal vane voltage.

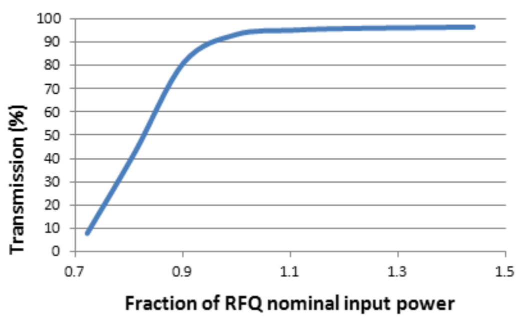

Figure 5: RFQ transmission vs. input power.

Steerer Setting

The corrector magnets will compensate the beam and machine alignment errors, reducing significantly the beam losses by improving the transmission [4]. In order to avoid any activation of the machine, the first stage of correction will be done using a pencil beam. Measurements from BLMs, profile and position beam diagnostics, together with an online Linac model will be used to correct the beam trajectory and recover the design performances. The online model was successfully validated during measurements on the Linac2 transfer line in 2007. The following figure shows the beam centre excursion the CCDTL (with beam and magnet alignment errors) before and after correction.

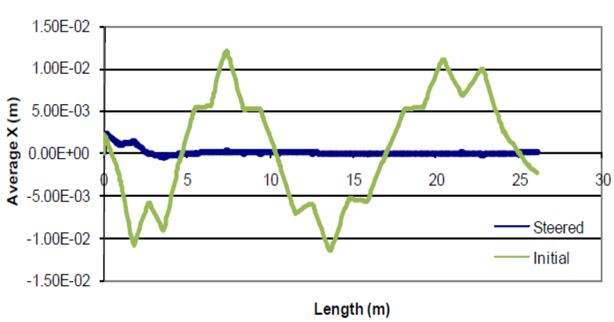

Figure 6: Beam centre excursion in CCDTL, before and after steering.

THE 3 MeV TEST STAND

The 3 MeV test stand is the first stage of the Linac4 commissioning. It is scheduled to start in mid 2011 at a temporary location. During this first stage, the RFQ and the chopper-line will be commissioned. One of the main goals of this commissioning stage is to set and validate the functioning of the chopper.

Beam Shape and Halo Monitor

The BSHM is a dedicated diagnostic developed to characterize the functioning of the chopper-line [5]. It has two objectives: 1) measure the transverse halo generated in the RFQ and in the MEBT; 2) detect and measure the partially chopped bunches. The layout of this detector is shown in Figure 6.

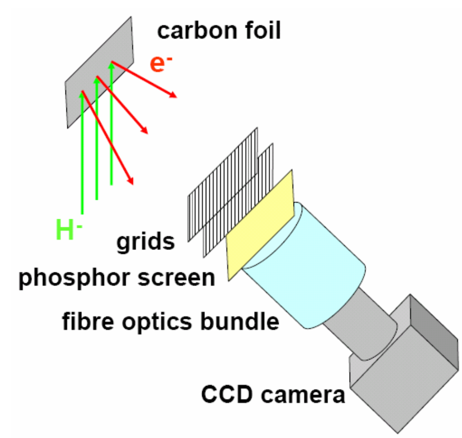

Figure 7: BSHM layout.

By hitting the carbon foil, H^- ions generate secondary electrons which are further accelerated towards a phosphore screen by an electric field applied between the grids. The emitted light is collected by a CCD camera through optic fibre. The BSHM has a spatial resolution of 1 mm and time resolution of 2 ns. Its dynamic range is in the order of 10^5.

NEED FOR A PENCIL BEAM

A pencil beam (low transverse emittance and low current) is needed mainly to avoid space charge effects and reduce significantly the potential losses. It can be generated for the Linac4 commissioning by placing an iris in the LEBT [6]. This beam will be used in order to characterize the different accelerating structures, the chopper section and to proceed to beam based measurements (alignment, acceptance scans). Thanks to the beam current flexibility of the Linac [7] as well as the transverse matching section we will be able to track the pencil beam, and keep its pencil characteristics up to 160 MeV. Depending on the iris size, we can vary the beam current and emittances. Currently, two different pencil beams were studied with current reduction from 80 to 1 and 7 mA. The transverse emittances are respectively reduced from 0.25 to 0.1 and 0.05 mm.mrad, reducing the beam size in the Linac by a factor of 1.6 and 2.2. The figure 8 represents the transverse and longitudinal envelopes of the pencil beam from in the DTL, CCDTL and PIMS.

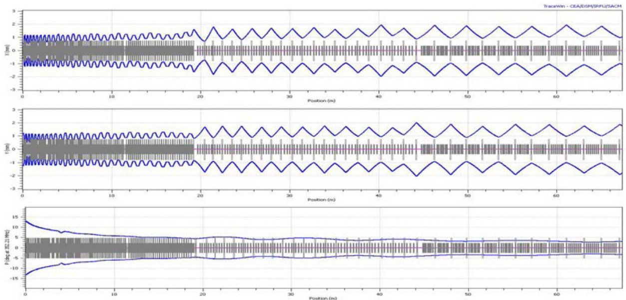

Figure 8: Pencil beam envelopes in DTL, CCDTL and PIMS.

Chopper Set up and Validation

Thanks to the low emittance and current of the pencil beam, we will be able to get a good transverse separation of chopped and non-chopped beams. We expect to observe the direct effect of the chopper field on the beam at the dump location by replacing it with a beam profile measurement device. The expected beam displacement induced by the chopper field is represented in the following figure.

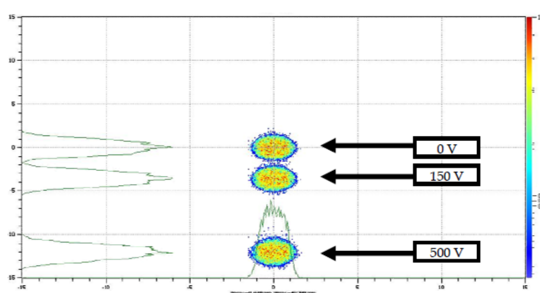

Figure 9: Beam displacement at the dump location for different effective voltage on chopper plates.

In addition to the direct effect of the chopper field, we will be able to validate the beam dynamics in the MEBT by observing the amplification of the chopper kick caused by the defocusing effects due to the quadrupole and the buncher cavity housed between the chopper and the dump.

Acceptance Scans

The pencil beam can also be used for other beam based measurements. Acceptance scans can be done displacing the pencil beam with steering magnets. Figure 10 shows the superimposition of the first DTL tank horizontal acceptance [8] and the 1 mA pencil beam from the MEBT (on axis). Looking at the relative transmission of the tank we could conclude if the pencil beam is or not inside the acceptance.

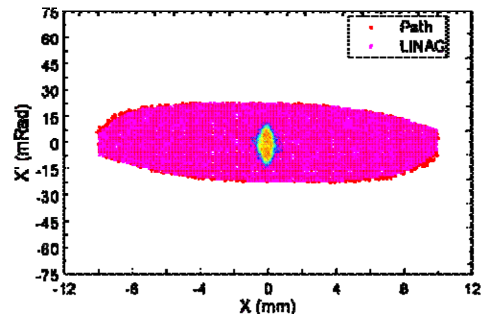

Figure 10: DTL tank1 X-X' acceptance plot and pencil beam.

CONCLUSION

With the permanent diagnostics and the temporary measurement bench we are confident that we have enough diagnostics elements to set the 33 magnets and the 47 rf parameters of the Linac. Starting next year, the 3 MeV test stand, will be the test bed for most of our commissioning strategy and calibration of diagnostics.

REFERENCES

[1] F. Gerigk editor, “Linac4 Technical design Report”, CARE-Note-2006-022-HIPPI.

[2] G. Bellodi et al, “Linac4 commissioning strategy”, CERN-sLHC-Report 0037.

[3] A.V. Feschenko, Methods and Intrumentation for Bunch Shape Measurements, Proceedings of PAC 01, Chicago, 2001.

[4] A.M. Lombardi et al, “Loss control and steering strategy for the CERN Linac4, CERN-AB-Note-2007-033.

[5] M. Hori, K. Hanke, Nucl. Instr. Meth. A 588 (2008) 359-374.

[6] JB. Lallement, A.M. Lombardi, “A pencil beam for Linac4 commissioning”, CERN-sLHC-Project-Note-0017.

[7] JB. Lallement, A.M. Lombardi, “Range of possible beam current in Linac4”, CERN-BE-Note-2009-017.

[8] J. Stovall et al, “Beam loss control in the Linac4 design”, CERN-sLHC-Project-Note-0009.