EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN – ACCELERATORS AND TECHNOLOGY SECTOR

CERN-ACC-2014-0327

Linac4 Low Energy Beam Measurements with Negative Hydrogen

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Abstract

Linac4, a 160 MeV normal-conducting H- linear accelerator, is the first step in the upgrade of the beam intensity available from the LHC proton injectors at CERN. The Linac4 Low Energy Beam Transport (LEBT) line from the pulsed 2 MHz RF driven ion source, to the 352 MHz RFQ has been built and installed at a test stand, and has been used to transport and match to the RFQ a pulsed 14 mA H- beam at 45 keV. A temporary slit-and-grid emittance measurement system has been put in place to characterize the beam delivered to the RFQ. In this paper a description of the LEBT and its beam diagnostics is given, and the results of beam emittance measurements and beam transmission measurements through the RFQ are compared with the expectation from simulations.

Presented at : 15th International Conference on Ion Sources ICIS13, 9-13 September 2013, Chiba, Japan

Linac4 Low Energy Beam Measurements with Negative Hydrogen Ions[a)]

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(Presented XXXXX; received XXXXX; accepted XXXXX; published online XXXXX)

Linac4, a 160 MeV normal-conducting H^- linear accelerator, is the first step in the upgrade of the beam intensity available from the LHC proton injectors at CERN. The Linac4 Low Energy Beam Transport (LEBT) line from the pulsed 2 MHz RF driven ion source, to the 352 MHz RFQ has been built and installed at a test stand, and has been used to transport and match to the RFQ a pulsed 14 mA H^- beam at 45 keV. A temporary slit-and-grid emittance measurement system has been put in place to characterize the beam delivered to the RFQ. In this paper a description of the LEBT and its beam diagnostics is given, and the results of beam emittance measurements and beam transmission measurements through the RFQ are compared with the expectation from simulations.

I. INTRODUCTION

Linac4 is a project to construct at CERN a 160MeV H^-, pulsed, normal conducting Linac as part of the improvement of the injection chain for the LHC[1]. In the low energy stage, the beam is produced by a pulsed (500 µs, <2 Hz) 2 MHz RF ion source[2] delivering the beam at 45 keV to a 352 MHz Radiofrequency Quadrupole (RFQ). The transfer between the two is made with a two solenoid Low Energy Beam Transport (LEBT).

The LEBT has been installed as part of a test stand, including a source, RFQ and post RFQ chopper line. All these systems underwent a first commissioning with beam in the second quarter of 2013, before the RFQ was moved to its final position in the Linac4 tunnel.

II. LAYOUT AND EQUIPMENT

The overall layout of the LEBT is shown in Fig. 1, and the subsystems of the LEBT are listed, with more details, in the following paragraphs.

The source outlet aperture is positioned 305mm upstream of the entrance to the LEBT, with the extraction gap, electron dumping system and an Einzel lens between the source and LEBT. In the LEBT, the beam focusing is provided by two water cooled, DC solenoid magnets with external magnet shielding. The internal radius of the magnet is 70 mm, whereas the beam pipe has an internal radius of 50 mm and the external yoke length is 340 mm. An integrated magnetic field of 0.13 Tm, can be supplied whereas for normal beam matching to the RFQ, this value should be approximately 0.08 Tm. The solenoid magnetic axis has been measured using the stretched wire technique[3], after which the magnet supports were shimmed in order to align the solenoid magnetic axis to the theoretical beam axis.

Correction of the beam trajectory is made with 2 sets of horizontal and vertical dipole window DC magnets placed between the two solenoids, which could normally deflect the beam up to 54 mrad (6.0 mrad/A).

Several beam instruments are permanently installed in the LEBT, namely a Faraday Cup, profile harp and beam current transformer (BCT). An emittance meter can be temporarily installed in, or at the end of the line, in place of other equipment.

The Faraday cup uses a conical collector and a suppressor ring biased to -1 kV, all inside a shield which has an input aperture of 80 mm. The beam current transformer is installed to allow non-destructive monitoring of the beam current.

The profile harp contains two planes of 20 wires each, covering a total of 51 mm. They are more densely spaced in the harp centre, to allow the profile of a focused beam to be measured.

[a)]Contributed paper published as part of the Proceedings of the 15th International Conference on Ion Source, Chiba, Japan, September, 2013.
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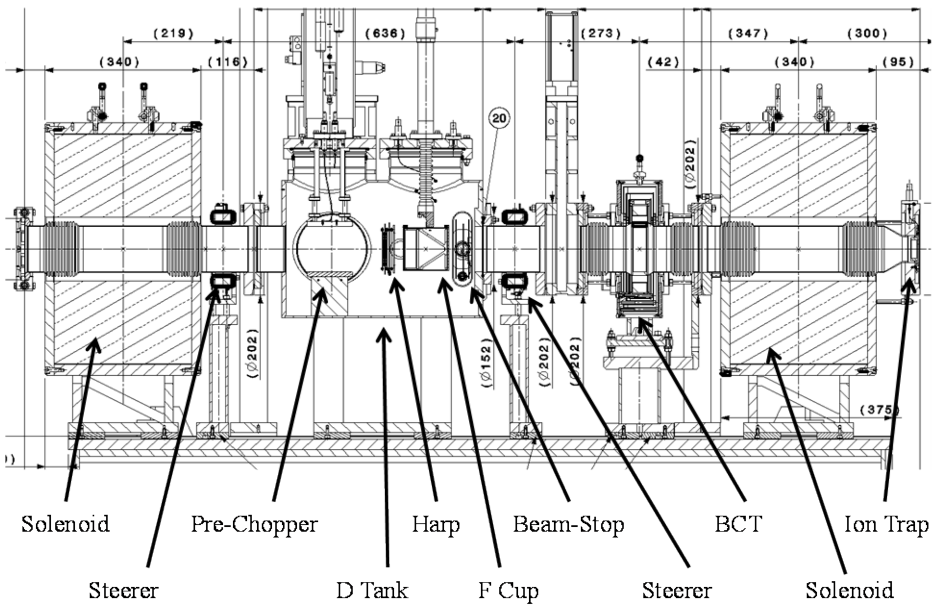

FIG. 1. Layout of the LEBT as installed at the 3MeV test stand. D Tank=Diagnostic Tank, F Cup=Faraday Cup. Harp = Harp profile monitor. BCT=Beam Current Transformer. Beam travels from left to right.

The slit and grid emittance meter[4] has been designed to measure the low energy H^- ion beam. The slit consists of one single plate translated at 45 degrees between the horizontal and vertical axes, with single horizontal and vertical slits (0.1 mm) cut into the plate. The profile grids use 40 µm tungsten wires spaced at 0.75 mm on separate horizontal and vertical linear translators. The spacing between slit and grids is 200 mm, and a series of collector plates behind the grids can be biased to avoid secondary electrons from returning to the grids. The signal from the grids is sampled at 6µs intervals, allowing the phase space to be sampled as a function of time during the pulse.

In order to have some control over the space-charge neutralization in the LEBT, the vacuum level can be controlled using a gas dosing valve, allowing some independent control from the gas already present from the injection of hydrogen gas into the source. The dosing valve, along with a cold cathode gauge and turbo pump is located on a tank in the centre of the LEBT. A commercial gas dosing valve is used, whose controller can be configured to maintain a constant vacuum level as measured with a vacuum gauge. As the source gas is pulsed, the pressure read out from the vacuum gauge is sampled and held just before beam production, and this control value is regulated by the controller, which improves the independence of the potentially coupled regulation circuits of the source and LEBT. The sampling point in time is also consistent with the fact that the gas injected into the source does not arrive into the LEBT until after the beam is produced. However this injected gas from the source is not fully pumped away before the following beam pulse, and leads to a residual H_2 pressure of approximately $5x10^{-7}$mbar when the source is running with a 1.2 s cycle time, which is therefore the minimum pressure that can be set in the LEBT. Hydrogen gas is supplied to this system with a pressure regulated circuit, which typically is set to 1.3 bar absolute pressure.

III. BEAM MEASUREMENTS AND SIMULATIONS

During the first beam commissioning phase, the emittance meter was inserted into the LEBT in place of the beam current transformer and the second solenoid, and emittance measurements were made as a function of the solenoid setting for a beam of 14 mA of H^- delivered by the source, at a cycle rate of 1.2 seconds. The source plasma generator was of the type designed by DESY, coupled to an extraction system using a magnetized Einzel lens for electron dumping[5].

When this first solenoid was set for the correct value for matching to the RFQ, the measured phase-space, averaged over the beam pulse and measured with a slit step of 0.4mm, is shown in Fig. 2, where the normalized rms emittance is 0.60 mm.mrad averaged over the horizontal and vertical planes. For the calculation of the rms emittance, all measurement signals below 1 % of the peak intensity have been set to zero. The beam Twiss parameters are very similar in the two planes, confirming the beam symmetry. The total normalized acceptance of the RFQ is 2.6 mm.mrad, but Linac4 aims to produce a beam within an rms emittance of 0.4 mm.mrad at the Linac exit, and the next generation of the ion source (using cesium) should help this emittance reduction from the source. The beam has been injected into the RFQ, and a beam transmission of 75% has been reached[6].

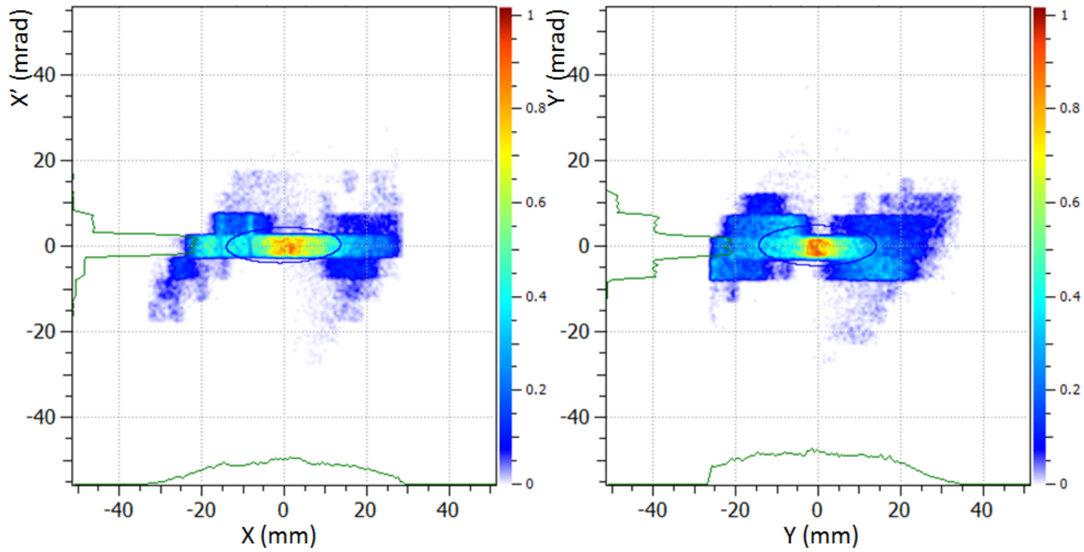

FIG. 2. Phase space measured in a position between the two solenoids of the LEBT, the colour scale represents the local particle density (Color online).

Two methods have been explored for the simulation of the beam through the LEBT.

In one method the beam emittance measurements are used to create a distribution of simulation macro particles, which are then tracked backwards through the first solenoid. This is repeated for several emittance measurements at different solenoid settings, and the beam current used for the beam transport simulations (to mimic the effect of space-charge compensation) is adjusted to converge to a single input beam into the LEBT. This has shown to work for the case of a proton beam, but does not lead to a unique LEBT input beam when attempted for the H^- beam.

The second method uses the beam extraction simulations from the ion source input, and then tracks the beam forward with IBSimu[7], a Vlasov solver, including the generation of secondary particles to simulate space-charge compensation. They have shown a very good correspondence with the measured phase space, but are computationally expensive and have more input parameters that require tuning. More details of the results of these simulations are given in Ref. 8.

IV. SUMMARY AND OUTLOOK

The Low Energy Beam Transport line for Linac4 has matched a low current beam from the source to the RFQ, within the limitations of the larger measured emittance compared to the acceptance of the RFQ.

Some items are yet to be fully commissioned, including the pre-chopper to deflect the beam from the RFQ and the profile harp still needs final commissioning with an H^- beam.

Improving the space-charge compensation with injection of H_2 gas needs to be supplemented with tests of other gas types, for example Kr and N_2.

The next versions of the ion source should lead to higher beam currents, and probably different beam parameters, which will require re-investigation in the LEBT. For Linac4, a duplicate system has been installed, so the original source and LEBT are still available as a test stand for these studies.

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