Measurements of Linac4 H⁻ Ion Source Beam with a Magnetized Einzel Lens Electron Dump

Ø. Midttun^{1,2,b)}, J. Lettry², R. Scrivens²

¹ University of Oslo, P.O. Box 1072 Blindern, 0316 Oslo, Norway

² CERN, 1211 Geneva 23, Switzerland

Abstract

Linac4 is a part of the upgrade of CERN's accelerator complex for increased luminosity in the LHC. A new system to extract the ion beam from the plasma generator has been designed and tested, in order to improve the reliability and beam optics of the pulsed H⁻ ion source. This paper presents the successfully implemented extraction system and three different beam measurements. The simulations compare well to the measurements and show that the plasma density was too low for the extraction system design during the measurements.

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

Measurements of Linac4 H^- Ion Source Beam with a Magnetized Einzel Lens Electron Dump^{a)}

Øystein Midttun,^{1,2, b)} Jacques Lettry,² and Richard Scrivens²

¹⁾ *University of Oslo, P.O. Box 1072 Blindern, 0316 Oslo, Norway*

²⁾ *CERN, 1211 Geneva 23, Switzerland*

(Dated: 20 September 2013)

Linac4 is a part of the upgrade of CERN's accelerator complex for increased luminosity in the LHC. A new system to extract the ion beam from the plasma generator has been designed and tested, in order to improve the reliability and beam optics of the pulsed H^- ion source. This paper presents the successfully implemented extraction system and three different beam measurements. The simulations compare well to the measurements and show that the plasma density was too low for the extraction system design during the measurements.

I. INTRODUCTION

Linac4 is a 160 MeV negative hydrogen linear accelerator that will replace the ageing 50 MeV proton accelerator, Linac2, as an injector to the Proton Synchrotron Booster (PSB). This upgrade is the first step of a long-term program aiming for an increase in the LHC luminosity.¹ The specification for the ion source is a pulsed H^- beam of 500 μs , 45 keV beam energy and 80 mA beam current within a normalized rms emittance of 0.25 mm mrad at a repetition rate of 2 Hz.

The ion source, based on the non-caesiated, 2 MHz DESY H^- volume source, has been designed with a new extraction system to provide a more flexible and reliable operation, where co-extracted electrons are safely dumped with an energy below 10 keV.²⁻⁴ At the present stage of the ion source development program, the extraction system is designed for a maximum H^- beam current of 30 mA with an electron to H^- (e/H^-) ratio of 50.^{5,6}

II. ION SOURCE DESIGN

The ion source, as shown in Fig. 1, consists of two independent parts: the plasma generator and the front end. These two parts are exchangeable, and the ion source has been designed with sufficient flexibility to host plasma generators based on different ion production modes:⁶

1. A DESY type RF-driven plasma generator (volume production).
2. A version of the DESY plasma generator upgraded to high RF-power - IS01 (volume production).
3. A RF-driven plasma generator with a caesiated Molybdenum surface - IS02 (surface production).

4. A magnetron type plasma generator - IS03 (arc discharge).

The measurements presented in this paper have been made with the DESY plasma generator.

FIG. 1. Layout of the Linac4 ion source and the first part of the LEBT.

The plasma generator is kept at -45 kV during operation, and the newly implemented multi-stage extraction system sits inside the front-end.⁵ A puller electrode gives the first acceleration from the plasma generator and shapes the plasma meniscus, which depends on the electric extraction field and the ion density in the plasma. The electrons are dumped inside a magnetized Einzel lens kept at high voltage to reduce the electron energy and to distribute the electrons over a large surface. A second Einzel lens ensures suitable beam size to enter the Low Energy Beam Transport (LEBT).

The extraction system has been designed with IBSimu, a general-purpose three-dimensional simulation code for charged particle optics with space charge.⁷ In IBSimu, the input values for the H^- and electron beam currents are given as uniform current densities (A/m^2) within the plasma volume, and the extracted beam consists of those particle trajectories that are caught by the electric field at the plasma aperture. These input values are estimated from the final measured beam current and the outlet aperture size, but this can lead to a significant error when beam loss is involved, and also depend on the setting of the plasma generator. The simulation results presented in this paper use input current densities of H^- and electrons that give the best match to the results of

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

^{b)} Author to whom correspondence should be addressed. Electronic mail: oystein.midttun@cern.ch

electrical currents measured on all the electrodes in the extraction region.

III. MEASUREMENTS

In this paper, three sets of measurements are presented, each as a function of a different ion source parameter.

1. RF-power: changes the H^- density in the plasma.
2. Puller voltage: defines the electric extraction field.
3. Plasma aperture potential: modifies the ion and electron densities close to the plasma aperture.

The comparison with simulations is made by using the currents measured on the plasma generator, puller and electron dump using Pearson transformers, and the H^- beam current measured in the Faraday cup.

A. RF-power

In this measurement, the RF forward power was varied from 20 kW to 30 kW. Increased RF-power should lead to a higher degree of ionization in the plasma, which means a higher plasma density, and higher extracted beam current. The results are shown in Fig. 2. For measured currents, the x-axis corresponds to the current density linearly scaled from the RF-power transmitted to the source (i.e. the incident minus the reflected power). The extraction system electrodes are illustrated in Fig. 3.

The measurement shows an expected increase in extracted beam current, and the simulated values correspond well. Included in the simulation are secondary electrons emitted from the electron dump by the impacting H^- and electron beam, illustrated in black in Fig. 3. Since these negative charges leave the electron dump, the measured current here is lower than the simulation output without secondary electron emission. Likewise, the measured puller current is higher because of these electrons. The few secondary electrons that follow the H^- to the LEBT are lost on the walls of the beam pipe in the solenoid and do not affect the Faraday cup measurement.

B. Puller voltage

The extraction system has been designed with a tunable puller voltage to change the electric field near the plasma aperture, and modify the shape of the plasma meniscus. With this option, it is then possible to tune the ion beam optics without changing the final energy of the ion beam.

Figure 4 shows that there is good agreement between simulations and measurements. We make two observations of the total current extracted from the plasma generator: (1) it increases with higher extraction voltage,

FIG. 2. Comparison between measurements and simulation with varying RF-power. The RF-power on the x-axis has been linearly scaled to match the H^- density used as input in the simulations.

FIG. 3. Image from a simulation. The beam is over-focused and parts of the H^- beam (red/dark grey) scrape the inside of the electron dump. Secondary electrons from the electron dump are shown in black.

and (2) the measured current increases slightly more than the simulated one.

The first observation is explained by the plasma meniscus that becomes more curved with higher extraction field. The meniscus surface is then increasing, allowing more particles to be extracted for a constant plasma density. The second observation suggests that when the plasma meniscus is being pushed further into the plasma, the plasma density increases. This effect is then causing a higher extracted beam current than the expected simulation value when the H^- density in the plasma is assumed to be constant. This variation of density as a function of depth of the plasma has previously been reported from Langmuir gauge measurements with a similar plasma generator.⁸

FIG. 4. Comparison between measurements and simulation with varying puller voltage.

C. Plasma aperture voltage

The DESY plasma generator is equipped with two electrodes close to the extraction hole that can be biased individually relative to the plasma generator (Fig. 5(a)). The collar is the largest electrode and will locally change the reference potential, whereas the plasma aperture electrode can be used to change the potential close to the extraction hole. In one way, we can treat the plasma aperture as a Langmuir probe measuring the charges in the plasma with respect to the plasma potential set by the collar. This behavior is clearly visible on the plot in Fig. 5(b), where the plasma aperture current looks similar to a Langmuir I-V curve, when plotted as a function of the voltage difference between the plasma aperture and the collar. The plot shows measurements made on two different days, and the plot shape is conserved even when connecting either of the electrodes to the plasma generator potential.

The e/H^- ratio, plotted in Fig. 5(b), has been estimated from the measured ratio between the plasma generator current minus the Faraday cup current (electrons) and the Faraday cup current (H^-). This ratio shows a similar shape as the plasma aperture current which can be explained as follows: When the plasma aperture is biased negatively, negative charges are repelled away from the extraction hole reducing the density of H^- and electrons in this region. Since the electrons have significantly less mass than the H^- , they are much more affected by this voltage difference, whereas the H^- current remains nearly unchanged. By applying a voltage difference of -30 V, the e/H^- ratio is reduced by 20 %. With a higher voltage difference, the plasma aperture current is in the

positive ion saturation region, and there is no more gain.

FIG. 5. (a) Detail of the extraction region. (b) e/H^- ratio and plasma aperture current measured at two different days as a function of the voltage difference between the plasma aperture and collar electrodes.

IV. CONCLUSION

The new extraction system has been implemented with success and has improved the ion source reliability drastically. During the first three months of operation, the source was running 24 hours per day without high voltage breakdowns, and the electron dump has no visible spots from the electron beam.

The simulations compare well with the measurements. These results show that the plasma is lower in density than the extraction system is designed to handle, causing secondary electron emission from beam scraping in the electron dump.

- ¹R. Garoby *et al.*, “Status and plans for the upgrade of the lhc injectors,” Tech. Rep. CERN-ATS-2013-059 (CERN, Geneva, 2013).
- ²J. Peters, AIP Conference Proceedings **1097**, 171 (2009).
- ³D. Küchler, T. Meinschad, J. Peters, and R. Scrivens, Review of Scientific Instruments **79**, 02A504 (2008).
- ⁴Ø. Midttun, T. Kalvas, M. Kronberger, J. Lettry, H. Pereira, C. Schmitzer, and R. Scrivens, Review of Scientific Instruments **83**, 02B710 (2012).
- ⁵Ø. Midttun, T. Kalvas, M. Kronberger, J. Lettry, H. Pereira, and R. Scrivens, AIP Conf. Proc. **1515**, 481 (2013).
- ⁶J. Lettry *et al.*, AIP Conference Proceedings **1515**, 302 (2013).
- ⁷T. Kalvas, O. Tarvainen, T. Ropponen, O. Steczkiewicz, J. Árje, and H. Clark, Review of Scientific Instruments **81**, 02B703 (2010).
- ⁸J. Peters, AIP Conference Proceedings **639**, 42 (2002).