SPACE CHARGE COMPENSATION IN THE LINAC4 LEBT FOR THREE INJECTED GAS TYPES

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Abstract

The space charge of unbunched, high intensity beams can be compensated by the trapping of charged particles in the potential well of the beam. The source of these secondary charge particles can be the residual gas in the beam line. The effect is important in the Low energy beam transport (LEBT) regions. At CERN's Linac4, the LEBT transports a pulsed 45keV H- beam, which is compensated by the positive ions, created by collision of the beam with the neutral gas in the beam pipe. The rise time and amount of compensation may be varied by the density of neutral gas and the type of gas used (through the cross-section for ion production and the mass of the resulting ion). In this paper we present measurement results for the transport of the beam at the Linac4 LEBT with the addition of hydrogen, nitrogen and krypton gases into the line, and compare them with simulations of the beam dynamics including the effect of compensating positive ions. The H- beam is provided by a cesiated 2MHz RF ion source with an external solenoidal antenna, operating with 600 us pulses at 0.8Hz repetition rate.

INTRODUCTION

The Linac4 LEBT transports a high intensity H- beam at 45 keV, extracted from the source, to match the RFQ under strong space charge conditions. It is preferable to reduce the space charge using the Space charge compensation effect[1] (SCC).

The SCC effect occurs when the secondary particles created from ionization of the residual gas are trapped by the beam potential and decreases the overall beam potential. Changing the type of gas could affect the dynamics of the SCC. Some experiments have shown that the rms beam emittance of the beam can be improved by using this technique [2].

Measurements were done at the Linac4 Ion Source Test Stand [3], using the first section of the Linac4 LEBT with a solenoid and emittance meter[4]. The pressure inside the LEBT can be varied by the injection of different gases, and compared to beam simulations of the region including the SCC.

EXPERIMENTAL LAYOUT

The Linac4 ion source used in the experiment is a 2MHz RF volume source enhanced with cesium for surface negative ion production, designed and built at CERN[5]. It delivered a 35 mA H- beam at 45 keV with pulses of 600 µs spaced by 1.2 s. The first section of the LEBT (Fig. 1) consists of one solenoid, two steerer magnets for beam trajectory correction, a Faraday cup and a slit-grid emittance meter. The signals from the measurement grid were sampled with an ADC with a resolution of 6 µs. The emittances reported in this paper have been calculated by integrating the signals over a time period of 200 µs, starting 300 µs after the first observed beam from the source.

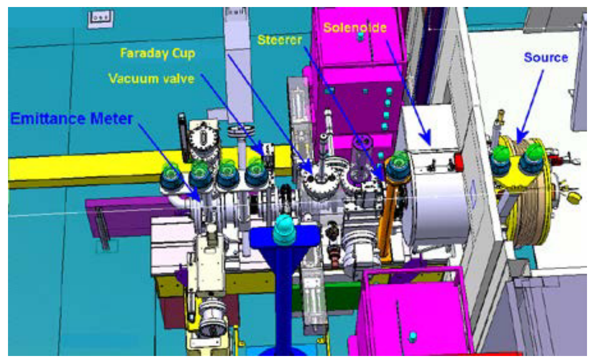

Figure 1: Experimental Setup Distance between the emittance meter and source 1.308 m

From the LEBT entrance, the solenoid start position is 50 mm, the Faraday cup at 876 mm and the emittance meter at 1308 mm. The beam pipe has an aperture radius of 50 mm, the solenoid has a maximum integrated magnetic field of 0.13 Tm. An integrated solenoid field of 0.089 Tm was used during the measurements.

The flux of H_2 gas from the source leads to a minimum pressure 1×10^{-6} mbar of H_2 in the LEBT, from here on referred to as the baseline pressure. A gas injection system was used to control the LEBT gas type and pressure and therefore the degree and speed of SCC.

For the experiments reported here, injection of hydrogen, nitrogen and krypton gases have been used; H_2 is used for H- production and therefore it should not have any detrimental effect on its performance; N_2 is safe and easy to pump; and Kr has been seen in other experiments [1] to be very effective for space charge compensation.

The measurements of the beam phase-space emittance were made as a function of the gas pressures.

SIMULATIONS OF THE EXPERIMENT

The modelling and simulation of the source and beam extraction system [5] has been made with the code IBSimu[6]. First the beam is tracked in the extraction system taking into account the full space charge, as the SCC is supressed by the electric field in the extraction system.

The particle distribution is passed to the input of the LEBT simulations in a region where the boundary conditions can be considered constant. The emittance of the beam is 0.29 mm.mrad (normalised 1sigma) at the LEBT input.

For the baseline pressure (1x10^{-6} mbar) the SCC build-up time[1] is in the same order of the beam pulse and the beam profile changes considerably during the pulse (see Fig. 2), where the beam size can be seen to be varying over at least 200 µs.

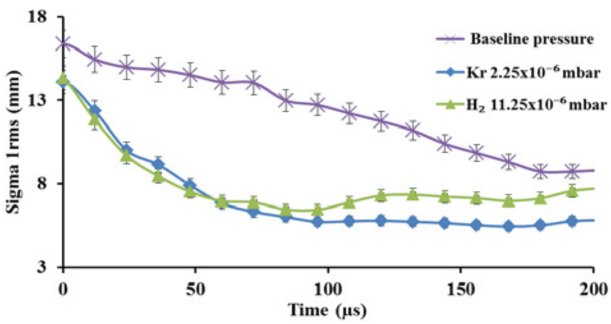

Figure 2: Beam size measured at the emittance meter as a function of time, for the baseline pressure and two different injected gases.

To understand this SCC dependent beam dynamics it is necessary to use a simulation code capable of including the SCC of the secondary ions.

The codes Solmaxp [7,8] and IBSimu [9] can be used for SCC calculations.

The IBSimu and Solmaxp codes perform the following iteration cycle to solve the system:

1) H^- beam is tracked through the LEBT taking into account the magnetic and electric field and the boundary conditions.
2) The potential is calculated including beam space charge.
3) Secondary particles are created from beam gas collisions, taking in to account the cross sections for ionization of each gas type.
4) The secondary particles are tracked and added to the space charge created by the primary beam.

The simulation results in this paper have been obtained with IBSimu. Approximate simulations can also be made in IBSimu with a constant compensation factor, where the beam intensity is reduced by a constant fraction throughout the simulation.

EXPERIMENTAL AND SIMULATION COMPARISON

The agreement between the phase space of the simulation and experiment at the emittance meter position (Fig. 3) can be demonstrated by the unusual features that can be created in the beam.

By increasing the H_2 pressure by 1x10^{-6} mbar from the baseline we can see the rise of a second component of the beam under some circumstances.

Simulation shows that this second component only appears in the H_2 case because of the uneven SCC along the LEBT when the beam waist is before the emittance meter. N_2 and Kr do not show this effect because their larger masses help to create a more constant SCC distribution.

When decreasing the solenoid strength to produce a less focused beam this second component disappears.

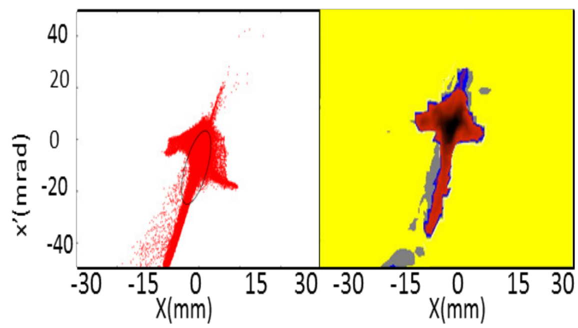

Figure 3: Beam phase space with two components. Simulation (left), measurement (right).

Pressure Dependence

For injected gas partial pressure above 5x10^{-7} mbar there is no increase in the emittance within the measurement error of 10%. But there is a clear rotation of phase space.

At low injected partial pressures, some beam moves from the phase space tails into the beam core, which helps to improve the amount of beam transported within a given acceptance.

Gas Type

Fig 4. shows the emittance as a function of the injected gas pressure where the 0 is the baseline pressure. 10% error bars are shown, these are an estimation from the design specification of the emittance meter. There is no evidence of the emittance value reduction between the injected gas types.

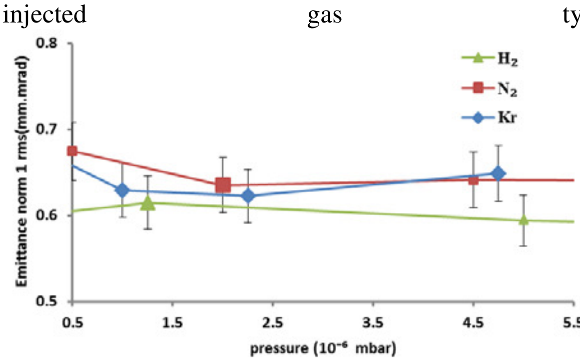

Figure 4 Emittance vs injected partial pressure for H_2, Kr and N_2.

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Another important feature is that the SCC must stabilise quickly with respect to the beam pulse, to limit losses in the beam pulse head. Our desired time of stabilization is 25 us.

The stabilisation time is estimated from the measurements by measuring the beam size at the emittance meter as a function of time during the pulse, this beam size shows an exponential decay to a stable size by the end of the pulse. A comparison of this measured stabilization time is shown in Fig.5, demonstrating that for 25us stabilization time, the pressure for the three gases is $1x10^{-5}$ mbar for H_2, $6x10^{-6}$ mbar for N_2 and $4x10^{-6}$ mbar for Kr

After the SCC becomes stable the final beam size of the beam when we inject Kr and N_2 was 6 mm and for H_2 8 mm. Simulations show that this is because N_2 and Kr can achieve a higher SCC factor than H_2 .

The simulations confirm the absence of a clear dependence of the final emittance on the type of gas observed within the expected precision of the emittance measurement (10%).

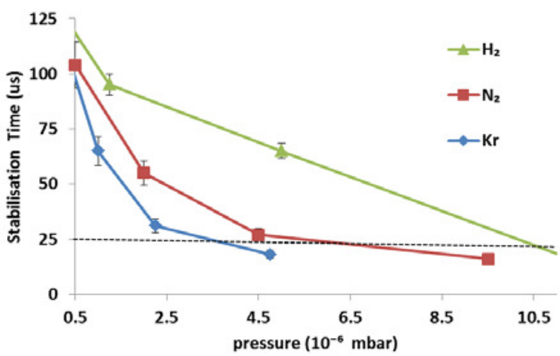

Figure 5: Measured decay time of the beam size of the partial pressure for H_2, Kr and N_2. The dot line shows the required pressure to get a stabilisation in 25 µs.

CONCLUSIONS

Measurements and simulations have been made of the transport of a 45keV 35mA H^- ion beam under space charge compensation conditions, using three different gases as the source of secondary ions.

The simulations show a very good correspondence to the measured phase space, even reproducing fine details which can be attributed to the distribution of compensation ions in the beam.

Measurements confirm that in order to stabilise the beam sufficiently quickly (with a 1/e time of 25us), it is necessary to run at minimum pressures of H_2: $1x10^{-5}$ mbar, N_2: $6x10^{-6}$ mbar, Kr: $2x10^{-6}$ mbar.

The maximum pressure is limited to $1x10^{-5}$ mbar in the LEBT ($5x10^{-5}$ mbar is included in the measurements) in order to avoid high pressure in the RFQ.

For measurements within these pressure ranges there is no significant improvement in the emittance by running at high pressure, and the effect of the gas type is limited to its cross-section for ion production by H^- bombardment.Therefore the choice of gas can be based strongly on the pumping efficiency of the system. In this case N_2 is a good alternative as it will lead to a lower pressure in the RFQ, and increase the pump lifetime. Therefore such a test with N_2 is proposed for Linac4, in conjunction with the RFQ.

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REFERENCES

[1] I. A. Soloshenko Problems of intense negative ion beam transport (invited), Rev. Sci. Instrum. 75, 1694 (2004);

[2] R. Gobin et al, Rev. Sci. Instrum. 70, 2652 (1999)

[3] R. Scrivens et al, Linac4 Low Energy Beam Measurements with Negative Hydrogen Ions, Rev. Sci. Instrum. 85, 02A729(2014).

[4] B. Cheymol et al, Design of the Emittance Meter for the 3 and 12 MeV LINAC4 H- Beam, IPAC2010.

[5] Ø. Midttun et al, Linac4 H- Ion Source Beam Measurements with a Magnetized Einzel Lens Electron Dump, Rev. Sci. Instrum. 85, 02A701(2014).

[6] T. Kalvas et al, IBSIMU: A three-dimensional simulation software for charged particle optics, Rev. Sci. Instrum. 81, 02B703, (2010).

[7] A. Chancé et al, The SolMaxP Code, Proc of IPAC 2012, MOPPC056, New Orleans, USA

[8] N. Chauvin et al, Final Design of the IFMIF-EVEDA low energy beam transport line, Proc. Particle Accelerator Conf. Vancouver Canada, 2009.

[9] Cristhian A. Valerio-Lizarraga et al, Space charge compensation in the Linac4 low energy beam transport line with negative hydrogen ions, Rev. Sci. Instrum.85, 02A505(2014).

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