EXTRACTION AND LOW ENERGY TRANSPORT OF NEGATIVE IONS*

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Abstract

High perveance negative ion beams with low emittance are essential for several next generation particle accelerators (i. g. spallation sources like ESS [1] and SNS [2]). The extraction and transport of these beams have intrinsic difficulties different from positive ion beams. Limitation of beam current and emittance growth have to be avoided. To fulfill the requirements of those projects a detailed knowledge of the physics of beam formation the interaction of the H^- with the residual gas and transport is substantial. A compact cesium free H^- volume source delivering a low energy high perveance beam (6.5 keV, 2.3 mA, perveance K= 0.0034) has been built to study the fundamental physics of beam transport and will be integrated into the existing LEBT section in the near future. First measurements of the interaction between the ion beam and the residual gas will be presented together with the experimental set up and preliminary results.

1 INTRODUCTION

The production and transport of high current negative ion beams is a key issue for future high current accelerators. For ESS, as an example, an H^- beam with 70 mA at 55 keV (K=0.0035) and $\varepsilon_n = 0.1$ πmmmrad is required using non Liouvillian stacking schemes for the accumulation rings. An ion source has been developed in Frankfurt, which is now able to deliver an H^- current even higher than necessary [3]. To reduce particle losses at high beam energy (above the coulomb barrier) and to maximise the available current the beam has to be treated carefully between the plasmaelectrode and the first RFQ. External and internal fields can induce emittance growth, space charge forces and interactions of the beam with the residual gas can limit the transportable current.

Different extraction and ion beam transporting schemes are under discussion [4,5], each have various positive and negative aspects. To improve the H^- to e^- ratio magnetic filterfields (i. g. dipoles) are used. In our case these filterfields are in conjunction with dipole fields for electron dumping. The quality of beam extraction simulations suffers from these additional magnetic fields in the low energy part of the extractor. The destruction of the rotational symmetry together with the space charge forces causes emittance growth and particle losses within the extraction system. High residual gas pressure near the extractor together with the high cross section for stripping will influence the transmission as well as space charge compensation.

LEBT of high perveance ion beams suffers from high space charge forces. Generally two systems are used:

electrostatic or magnetic lenses. The use of electrostatic lens systems has to deal with the full space charge and therefore has limited current transport capabilities. They suffer from high space charge forces causing in conjunction with field aberrations serious emittance growth. Magnetic lens systems can use space charge compensation to reduce the necessary focusing force and the radius of the beam in the lenses. Hence the emittance growth due to lens aberrations and self fields is reduced. In Frankfurt an experiment is under construction to investigate the influence of various parameters on beam formation and transport under space charge compensated and decompensated conditions. On behalf a H^- source has already been built. After the essential operation conditions for the source are studied the source will be incorporated into the existing **L**ow **E**nergy **B**eam **T**ransport (LEBT) line.

The details of the beamline layout are shown in Fig. 1.

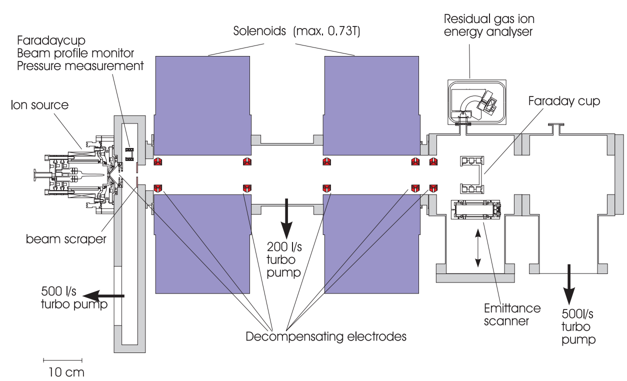

Figure 1: Schematic drawing of the experimental set up of the Frankfurt LEBT line.

An existing double solenoid (max. field 0.73 T) LEBT capable with the ESS scenario will be used for our investigations of high-current beam transport of negative ions. Therefore different beam diagnostic elements have been installed. Emittance measurement device and residual gas ion energy spectrometer and Faradaycups are available along the beampath. The degree of

* Work supported by BMBF under contract No. 06 OF 841

compensation can be regulated by decompensating ring electrodes as well as by varying the residual gas pressure in the LEBT. The measured beam properties, e. g. transverse emittance, degree of space charge compensation support the design of the future LEBT for negative ions.

2 ION SOURCE

An schematic drawing of the ion source for our experiment is shown in Fig. 2.

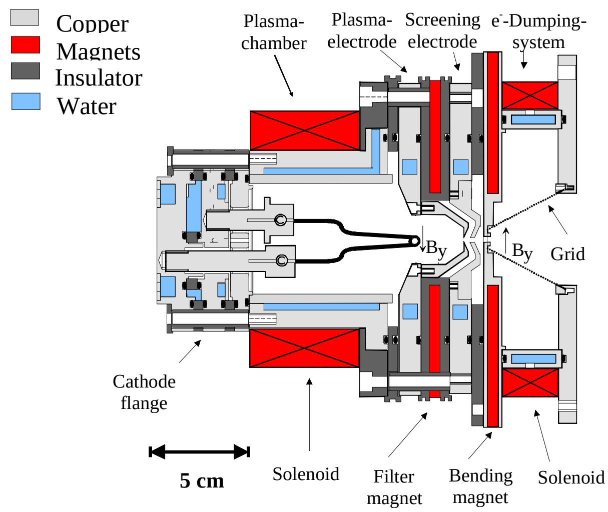

Figure 2: schematic drawing of the ion source.

The ion source [6], is of the volume type using a gas discharge driven by a hot cathode to atomize the H_2 molecules. The electrons are radially enclosed by a solenoidal field. A magnetic dipole filter field (electrical exited) near the extraction area is used to separate slow and fast electrons and therefore enhance the H^- production [7]. To inhibit influence on the diagnostic devices the source will be operated cesium free. This will limit the plasma density and therefore the ion current. The design value for the current density delivered by the plasma was chosen to be 20 mA/cm^2 a commonly reached value for cesium free H^- sources [8]. The H^- to e ratio has to be above 0.02 due to current restrictions by the high voltage power supply.

For the ion beam formation a single aperture accel - decel system is used. Various numerical simulations of the beam extraction using the IGUN [9] code have been performed for different extraction geometries. The goal was to build a compact triode extraction system insensitive to plasma density variations delivering a high perveance ion beam with minimised emittance.

The simulations have been performed for different ion current densities (0-50 mA/cm^2), different extraction voltages (4,5 and 6 kV) and aspect ratios between 0.2 and 1.2. The simulations showed that the boundary conditions are fulfilled for an aspect ratio of S = 0.375 and an extraction of 3 mm diameter. For the matched case a beam emittance of $\varepsilon_{n,RMS}$ = 0.001 πmmmrad (4kV) is calculated. For a current density of app. 25 mA/cm^2 delivered by the plasma generator a 4 keV H^- beam with 1.77 mA beam current is delivered. This will correspond to a beam perveance of K=0.0045 which is app. 30 % higher than proposed for the ESS project [6].

3 EXPERIMENTAL SET UP

To study the fundamental behavior of the ion source for different parameters of the plasma generator a test bench was installed. The details of the test bench layout are shown in Fig. 3.

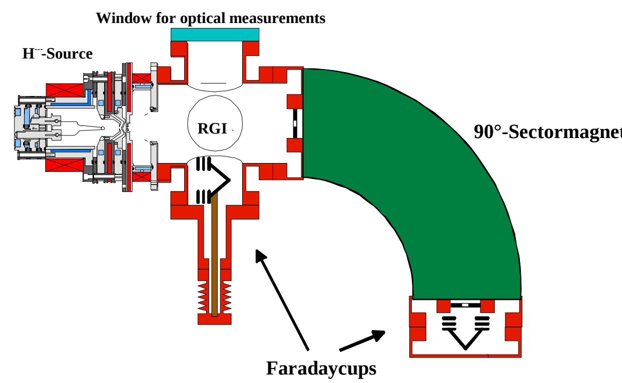

Figure 3: : Schematic drawing of the experimental set up of the test bench for the H^--source.

Multiple beam diagnostic elements like a magnetic spectrometer, a residual gas ion (RGI) energy spectrometer and Faradaycups have been installed. A window gives the opportunity to analyse the radial density profile of the extracted beam by using the incident light emitted by collisions of the beam ions with the residual gas atoms. Additionally the residual gas pressure can be varied in the test bench.

4 MEASUREMENTS

After the design parameters of our H^--source have been reached, the mass spectra of the emerging particle beams have been investigated by the use of the 90° sectormagnet, to prove that H^- has been measured in the Faraday cup.

Fig. 4 shows two spectra measured using a H^--beam of appr. 2 mA at a beam energy of 6.5 kV. The gas pressure inside the ion source has been 0.133 hPa and 5*10^{-6} hPa in the diagnostics chamber (mostly H_2 due to the gasflow from the source). The lower curve (for the negative charged particles) show peaks according to the extracted electrons and H^--ions (due to the electron dumping the spectrum does not indicate the extracted H^-/e^- ratio).

By changing the polarity of the magnetic dipole field we observed also positive ions. The mass of the ions have been calculated under assumption of an ion energy of 6.5kV as well.

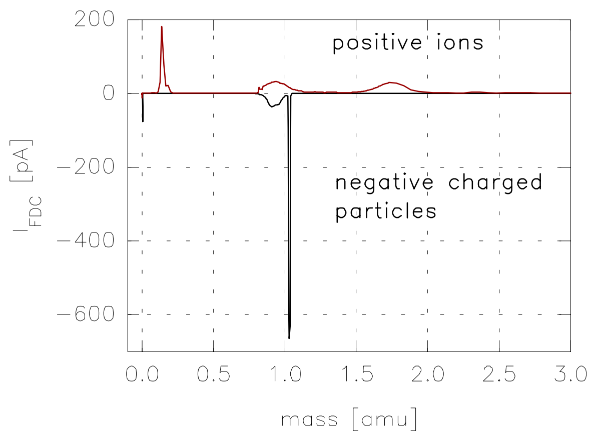

Figure 4: mass spectra of an extracted beam.

The ion energy of the positive ions which possibly are produced by interaction of H^- and electrons with residual gas atoms in the extraction area (at highest gas pressure) cannot be determined without additional investigations due to the fact that neither the ion mass (possible candidates are H^+, H_2^+, H_3^+, N^+, N_2^+, H_20^+) nor the energy is known. To exclude most of the possibilities two additional experiments already have been performed.

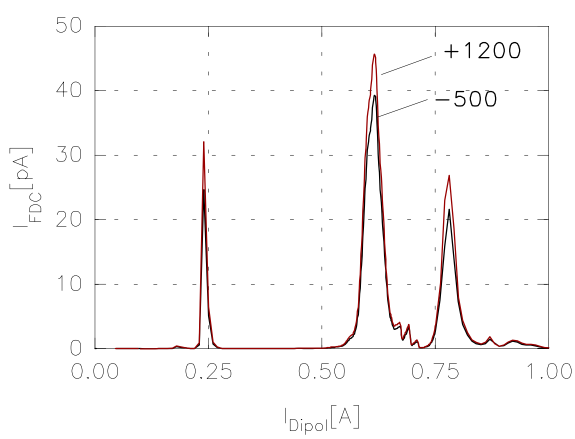

Figure 5: mass spectrum with decelerate potential of 1.2 kV and reference spectrum.

Fig. 5 shows the results of an experiment were the polarity of the secondary electron suppression electrode in front of the Faradaycup of the sector magnet has been changed from negative to positive (compared to ground potential). The electrode was biased up to +1200V (limited by constructional reasons). It is supposed that all positive ions with a kinetic energy below 1200 eV will be suppressed and therefore not detected. As shown in Fig. 4 the detected current is higher (due to the secondary electrons) than for the reference spectra and therefore it is likely that most of the positive ions have energies above 1200 eV. This indicates that their origin is not from inelastic collisions of H^- and e^- with heavy atoms (like N_2,H_20). Fig. 6 shows spectra measured at different extraction voltages (4.5-6.5 kV). We expected a change of the energy of the positive ions

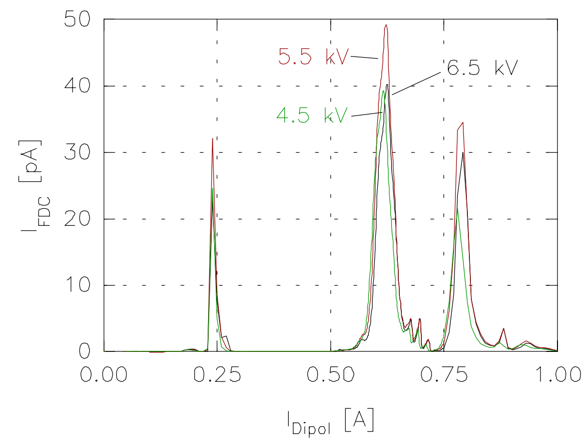

Figure 6: spectra gained for different extraction voltages.

if their energy is determined by the momentum exchange at interaction, but only minor changes of the measured positive spectra can be observed**.** Therefore an additional process determining the energy of the positive ions have to be assumed. Further work to understand these results in more detail are planed.

5 OUTLOOK

After the source tests on the separate test bench the source will be incorporated into the existing LEBT. The experiments will start with a DC beam to study the influence of the external parameters (filter fields, solenoids, residual gas pressure, voltage on decompensation electrodes, source noise) on emittance and transmission. For a next step the set up is already prepared for pulsed mode operation.

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