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 NSNS [2]). The production, 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 fulfil the requirements of those projects a detailed knowledge of the physics of beam formation and transport is substantial. An caesium free H^- volume source based on the high current source for ESS has been built and will be integrated into the existing LEBT section in the near future. To investigate the influence of beam extraction, electron dumping, focusing fields of the solenoids and space charge compensation on transmission and beam emittance different beam diagnostics are available. Numerical simulation of beam extraction and beam transport 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 big 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 ε_n = 0.1 πmmmrad is required using non liouvillian stacking schemes for the accumulation rings. 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 beam - residual gas interactions can limit the transportable current.

Different extraction, electron beam dumping and ion beam transporting schemes are under discussion [3,4], each have various positive and negative aspects. To improve the H^- to e^- ratio magnetic filterfields (i. g. dipoles) are used. These filterfields often in conjunction with dipole fields for electron dumping. The quality of beam extraction simulations suffers from these additional 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. Therefore an experiment is under construction in Frankfurt to investigate the influence of various parameters on beam formation and transport under space charge compensated conditions. A H^- source has already been built. It will be tested and incorporated into the existing LEBT line consisting of two solenoids in the near future.

2 ION SOURCE

An schematic drawing of the recently developed ion source is shown in figure 1.

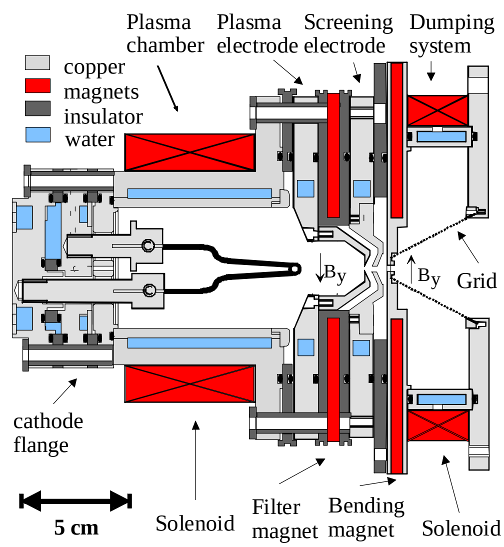

Figure 1: schematic drawing of the ion source.

The ion source, based on the ESS-source [5], is of the volume type using a gas discharge driven by a hot cathode to atomise 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 [6]. To inhibit influence on the diagnostic devices the source will be driven caesium 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 caesium free H^- sources [7]. The H^- to e ratio has to be above 0.02 due to current restrictions by the high voltage power supply.

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3 EXTRACTION SYSTEM SIMULATION

For the ion beam formation a single aperture accel - decel system is used. Various numerical simulations of the beam extraction using the IGUN [8] code have been performed for different extraction geometries. The goal was to build a compact triode extraction system delivering a high perveance ion beam with minimised emittance and insensitive to plasma density variation.

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 for an aspect ratio of S = 0.375 and an extraction of 3 mm diameter the boundary conditions are fulfilled.

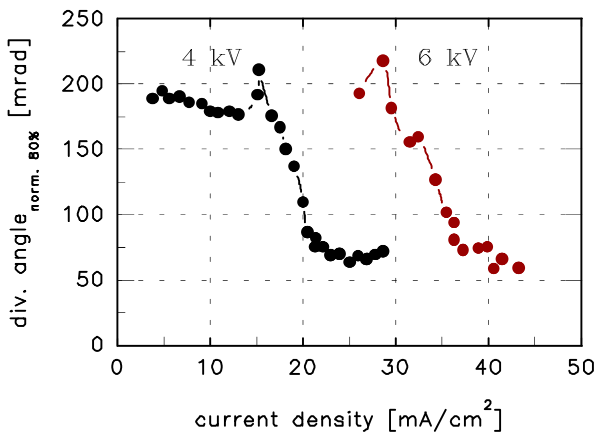

Figure 2: IGUN calculations of the divergence angle as function of the current density.

The figures 2,3,4 show the development of the beam angle, the emittance and the brilliance for the finally chosen extraction geometry. Fig. 2 shows the change of the divergence angle as function of the current density. For low plasma density the focus of the beam is near the outlet aperture. The beam is overfocused 16 mm behind the outlet aperture. With increasing current density the beam divergence declines to a minimum at 60 mrad (focus at observation point), corresponding to the matched case. At higher current density the divergence angle increases which means, that the beam is started divergent at plasmameniskus.

In Fig. 3 the corresponding emittances are shown. For the matched case a normalised beam emittance of 0.0011 πmmmrad (4 kV) and 0.0014 πmmmrad (6 kV) is reached. In Fig. 4 the brilliance as function of the current density is plotted reaching a maximum in the matched case.

The trajectory plot for the chosen geometry delivering a matched beam is shown in figure 5. For a current density of app. 25 mA/cm^2 delivered by the plasma generator (left side of the plot) a 4 keV H beam is

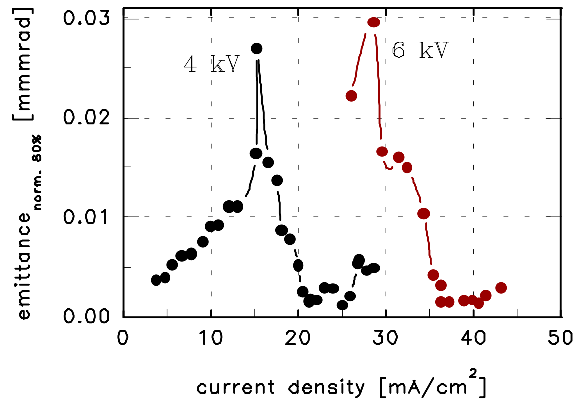

Figure 3: IGUN calculations of the emittance as function of the current density.

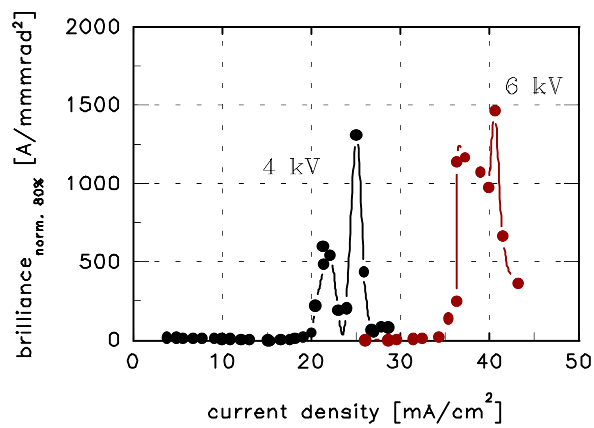

Figure 4: IGUN calculations of the brilliance as function of the current density.

delivered with 1.77 mA beam current. This will lead to a beam perveance of K=0.0045 which is app. 30 % higher than required for the ESS project.

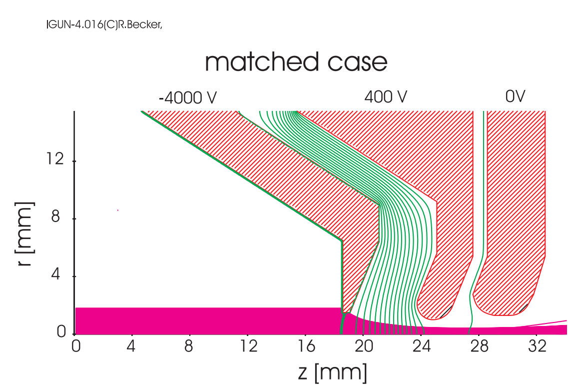

Figure 5: Plot of the beam trajectories for the matched case calculated with IGUN.

4 DUMPING SYSTEM

Negative ion extraction is always accompanied by the extraction of electrons which must be removed from the beam before further acceleration. Depending on the extraction voltage and the electron to H^- ratio the electron beam power to be dumped can be high (max. 300 W for this experiment, 7.5 kW for ESS).

The dumping system consists of a bending dipole magnet (mounted in the screening electrode) and a water-cooled dumping tube. The electron beam will be deflected from the H^- and dumped in the water-cooled tube outside of the beam channel. To minimise the magnetic field strength at the outlet aperture, the filter magnet (max. 0.03 T) and the bending magnet (max. 0.03 T) have opposite polarity and equal distance from the outlet aperture. As the measurement shows, we get a minimised B_y field strength in the plasma sheath region. By this an undesired beam deflection in the accelerator gap is reduced.

5 EXPERIMENTAL SET-UP

The presented ion source will be connected to the existing **L**ow **E**nergy **B**eam **T**ransport (LEBT) line. The details of the beamline layout are shown in Fig 6.

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. Therefrom the emittance growth due to lens aberrations and self fields is reduced.

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 devices and residual gas ion spectrometer and Faradaycups are available along the beampath. The degree of 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. The beamline was designed as a test bench for H^--beam transport measurements.

6 OUTLOOK

High voltages tests as well as the generation of a source plasma have already been performed successfully.

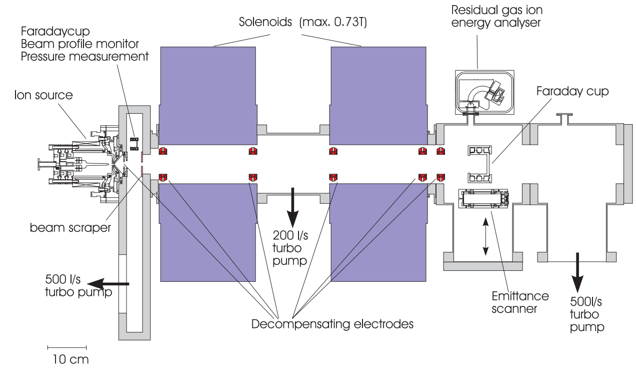

Figure 6: Schematic drawing of the experimental set-up of the Frankfurt LEBT line.

The influence of the dipole magnets on the extracted beam current and the bending of the electrons have been validated. The optimisation of source performance will start in July. After source tests on a 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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