COMMISSIONING OF THE ION SOURCE FOR SIEMENS NOVEL ELECTROSTATIC ACCELERATOR

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Abstract

Siemens is developing a novel compact DC electrostatic tandem accelerator and currently building a prototype. A dedicated H- ion source for this accelerator has been designed and built. This paper reports on some of the design features as well as results of the commissioning phase of this filament driven DC multicusp volume H- ion source. Stable H- currents of more than 300 μA at 10 keV have been extracted. This satisfies the beam current requirement of the novel accelerator.

INTRODUCTION

The supply of suitable radioisotope tracers is an important precondition for modern medical imaging techniques as Positron Emission Tomography (PET) and Single Photon Emission Computed Tomography (SPECT). Historically SPECT radioisotopes have been mainly supplied by nuclear reactors [2]. Problems with these reactors have repeatedly lead to severe shortages. Therefore efforts have been made to facilitate the expansion of the PET technique, which uses different isotopes. These can be produced with medium energy accelerators, usually cyclotrons with 10-50 MeV extraction energy. With half-lives between 2 minutes (^{15}O) and 2 hours (^{18}F) long-distance transportation is complicated and potentially inefficient as a high proportion of the initially produced isotopes might have decayed when they reach their destination. This has limited the access to PET to large hospitals which could either afford installing, maintaining and running the rather complicated cyclotrons or afford an elaborate supply process from a distant location. The proposed novel electrostatic accelerator [1] aims to provide a simple and robust solution for the production of PET isotopes. It relies on a modified Cockcroft-Walton cascade voltage multiplier and promises to be smaller, cheaper and much easier to operate than a cyclotron. These advantages may make PET accessible to many more medical institutions than it is today. The novel accelerator consists of two sets of concentric hemispherical metallic shells with the highest potential being in its centre. The accelerator will therefore be operated in tandem mode with a carbon stripper foil in its centre and a H^- negative ion source as injector. Given the requirements of app. 100 μA proton current for radioisotope production the ion source should be able to provide a somewhat higher current than this in order to account for the transmission of the accelerator.

THE H^- ION SOURCE

To provide a suitable ion beam for the prototype a very compact volume cusp ion source has been designed. It has been designed as to fit to the beamline of the shells and avoids the necessity of a Low Energy Beam Transport (LEBT) section, therefore hugely contributing to the compactness of the whole system. The ion source produces H^- ions in a hydrogen plasma, which is contained in a magnetic field. The plasma is ignited, maintained and heated by a discharge current between a heated tungsten filament cathode and the walls of the source volume itself. It is fueled by a constant inflow of hydrogen from a pipe and pumped by a vacuum system on the extraction side of the source.

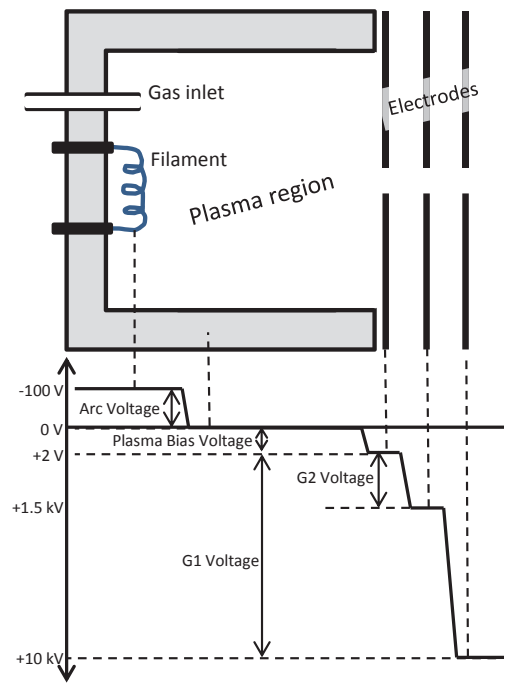

Figure 1: The upper image shows a 2D-cut through the ion source. The lower part of the figure shows the electric potentials (only schematical) of the different parts and how they are referred to in the text. For the sake of simplicity the magnetic fields are not displayed.

In order to provide an ideal environment for the formation of H^-, the plasma chamber is divided into two major regions by a magnetic filter field. The magnetic filter field can only be passed by rather low energy electrons or

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heavier particles, not however by hot electrons, as their gyroradius is small compared to the field region. The first region, on the cathode side of the source, serves as a heating area. The gas/plasma in this area is heated by the discharge current and higher energy electrons are present. H^- formed in this area is prone to destruction by the present electrons. The second area towards the extraction side of the source serves for the formation of H^- where the H^- ions are safer from destruction. Ro-vibrationally excited H_2 molecules from the heating area can drift to this area and then form H^- ions via dissociative attachment of a slow electron ($H_2 + e^- \rightarrow H + H^-$). The DC extraction of H^- ions from the plasma is done with a set of three subsequent extraction electrodes. The first one, the plasma electrode, can be biased in order to overcome the plasma sheath. The second one works as the actual extraction electrode. The third electrode does the final acceleration to the desired energy and at the same time acts as a focusing element together with the second electrode (see also Figure 1) and therefore shapes the extracted beam. Another magnetic filter field around the extraction apertures prevents the extraction of electrons, diverting them either onto the first or the second extraction electrode. Other important parameters for the source operation are the hydrogen flow and the plasma discharge current. Typical values for all parameters are listed in Table 1.

Table 1: Typical Operation Parameters

Parameter	typical value
G1 Voltage	10 kV
G2 Voltage	1.5 kV
Plasma Bias Voltage	2 V
Arc Voltage	100 V
Arc Current	1 A
Gas Flow	3 sccm

COMMISSIONING RESULTS

A number of experiments on the ion source in order to analyse its behaviour and to find the optimum working conditions. For this purpose a Faraday Cup with a 20 mm aperture has been placed at a distance of 6 cm and later at a distance of 20 cm from the ion source. The Faraday Cup contains a magnetic suppression of electrons, so no electrons can enter it and it also has an electrostatic suppressor electrode inside to suppress secondary electrons which might falsify measurements otherwise.

The first analysed parameter is the hydrogen gas flow (see Figure 2). The extracted current has a maximum at a gas flow of 3.5 sccm. This corresponds to the fact that for every volume ion source there is an optimum pressure at which the H^- density has a maximum. According to [7] this pressure increases with the discharge current and voltage. However, in our test setup it was determined only for one current value due to limitations of the pumping system.

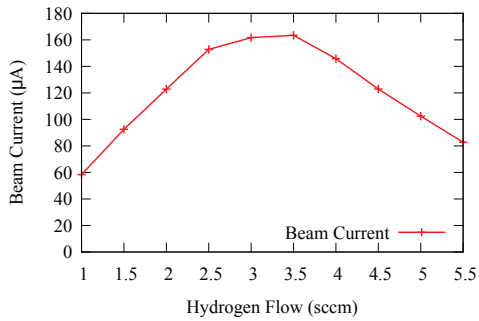

Figure 2: Dependency of the beam current on the hydrogen gas flow (standard cubic centimeters per minute) at a plasma discharge current of 1.23 A

Of course this flow value is only valid in combination with the particular pumping conditions as these effect the actual pressure inside the plasma chamber. Constant and reproducible pumping conditions are therefore a precondition for stable source operation as the source has no mechanism to directly measure the pressure inside the plasma chamber. This also makes comparison to optimal pressures at other sources impossible and the obtained value will only serve as a calibration for this particular source together with its pumping system.

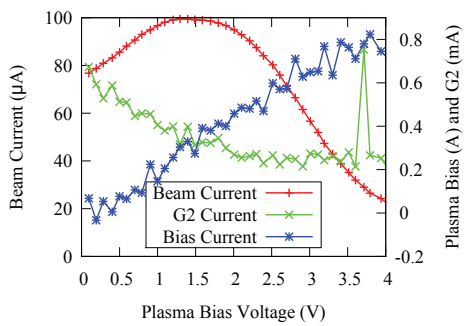

Figure 3: Dependency of beam current, plasma bias supply current and G2 current on the plasma bias voltage.

Another interesting parameter is the bias voltage of the first electrode on the extraction side. This bias has various effects on transport processes in the extraction region and has to be considered together with the magnetic filter field at the extraction. According to [4], both the extraction filter field and the plasma bias voltage can be optimised to enhance H^- transport and extraction. However this also effects the transport processes of the electrons. Often a positive plasma bias voltage has been used to reduce electron extraction, but this did not always have a positive impact on the extracted H^- current (e.g. [5]). For our source it was found that the beam current has its maximum at 1.5 V plasma bias voltage. At the same time the G2 current (equivalent to extracted electrons) goes down by app. 50% and the bias supply current increases rapidly (see Figure 3). The plasma bias voltage reducing the extracted elec-

trons and optimising H^- extraction at the same time is a very beneficial feature that has been observed at other ion sources before (e.g. the ECR driven volume source in [6]).

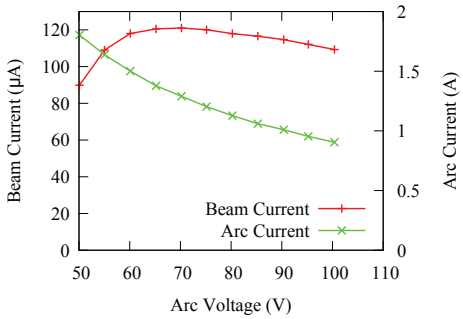

Figure 4: Dependency of the beam current of the arc voltage. The power of the arc discharge has been kept constant at 90 W throughout the measurement.

The next parameter to look at is the voltage between the filament and the walls of the plasma containment. The aim is that electrons from this current excite the H_2 molecules to vibrational states which will then acquire an electron and yield H^-. However, increasing this voltage increases the discharge current. Therefore, to determine the optimal arc voltage, the filament current was reduced whilst increasing the arc voltage in a way that the discharge power was kept constant at 90 W. It has been found that the optimum Arc voltage at 90 W discharge is 70 V (see Figure 4).

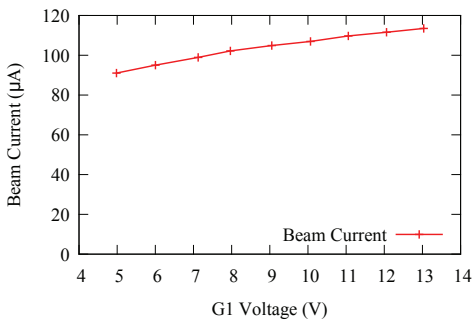

Figure 5: Dependency of beam current on G1. For each G1 value G2 was adapted to the optimum value of G1/7.

The next parameter is the G1 voltage. The higher G1, the higher the electric field which pulls ions out of the source. It has been found that the beam current increases monotonically with G1 (see Figure 5). This behaviour can not be explained by the space charge limits of the Child-Langmuir law, as 250 V would be sufficient to overcome the space charge limitation for the extracted current densities of app. 0.002 mA/mm^2 with the given distance of about 1 cm. However, the H^- production processes in the source should not depend on the extraction voltage and similar behaviour is usually not observed in high power H^- sources or results in bad optics ([4]). Further tests on this have shown however that increasing the extraction voltage does not affect the beam quality and therefore the effect appears different to the one described by Marthe Bacal in [4]. A possible but speculative explanation for the effect would be an enhanced drift of H^- in the plasma by the fields near the extraction aperture.

At higher gas flows we extracted beams of 300 μA at a plasma power of about 300 W. Given the 8 mm extraction electrode and the inner surface of the source body one can calculate the ion source efficiency ψ, which is defined by:

$$\psi = j_- \cdot \frac{A}{P} \quad (1)$$

j_-: extracted H^- current density
P: arc power
A: chamber surface area

Which in our case is about 2mA/W. Within experimental errors this is roughly the same value as for the commercially available d-PACE ion source developed at TRIUMF (see [3]), and therefore a satisfying result.

ONGOING WORK

Current work on the ion source includes some improvements on the pumping system, the addition of a water cooling system and further beam analysis with a wire grid. The wire grid contains 21 wires vertically and horizontally each with 0.2 mm diameter at 1 mm spacing and is mounted inside the Faraday Cup, thus benefiting from the electron filter and suppression system of the cup. All wires can be measured parallelly with a 64-channel high precision electrometer. As the distance between the cup and the source can be varied, the wire grid will be used not only to measure the beam diameter but also the divergence.

CONCLUSION

A thorough understanding of the ion source has been accomplished, featuring satisfying beam currents which meet the requirements of the accelerator as well as an efficiency comparable to other ion sources. It delivers sufficiently narrow beams to avoid the need for an LEBT. Ongoing work with a wire grid will give insights into the beam profile and divergence. This is important for the beam dynamics in the actual accelerator and experimental results will be used as input parameters for simulations to determine the optimal ion source settings for beam acceleration experiments.

REFERENCES

[1] P. Beasley et al.: *A new life for high voltage electrostatic accelerators*, Proceedings of IPAC'10, Kyoto, Japan, 2010
[2] Thomas Ruth, Nature 457, 536-537 (29 January 2009)
[3] http://www.d-pace.com/products_hion5.html 07.01.2013
[4] M. Bacal, Nucl. Fusion 46 (2006) S250−S259
[5] A. Holmes, Rev. Sci. Instrum. 65, 1153 (1994)
[6] R. Gobin et al, Nucl. Fusion 46 (2006) S281S286
[7] M. Bacal et al, Rev. Sci. Instrum. 66, 2533 (1995)

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