THE FRANKFURT H^- SOURCE FOR THE EUROPEAN SPALLATION SOURCE*

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Abstract

The **E**uropean **S**pallation **S**ource (ESS) requires two ion sources, each delivering a pulsed 70 mA H^- beam with a pulse length of 1.2 ms and a repetition rate of 50 Hz. At the University of Frankfurt, an H^- volume source based on the HIEFS (**Hi**gh **Ef**ficiency **S**ource) has been developed and tested. The source consists of a cesium seeded multicusp plasma generator, in which negative ions are produced via volume and surface processes. Due to improvements of the cesium injection method, the beam current density has been enhanced up to 153 mA/cm^2. Thus, an H^- beam current of 120 mA has been extracted using an aperture radius of 5 mm.

This paper reports about these recent developments of the Frankfurt H^- source. After a description of the experimental setup, measurements of the beam current density, the electron to H^- ratio and the lifetime will be presented followed by a beam emittance estimation.

1 INTRODUCTION

For the ESS, two H^- sources, each delivering a 70 mA H^- beam in 1.2 ms pulses at a repetition rate of 50 Hz (duty cycle = 6 %) are foreseen [1,2]. The normalized rms beam emittance in front of the first RFQ should be 0.1π mm mrad or smaller. These requirements have to be fulfilled with great constancy and reliability. The source must operate over an acceptable period of time.

Within the ESS study, the Institut für Angewandte Physik of the Frankfurt University is concerned with the development of the accelerator part and especially with the development of H^- ion source prototype. As promising candidate for this task, the so-called HIEFS was chosen. It was developed in Frankfurt [3] and belongs to the volume type family. In case of positive ion production (H^+, H_2^+, D^+, He^+, N^+, Ar^+, and Bi^+) this source has proven its capability to produce high current ion beams of a single mass to charge ratio at very low beam emittances (200 mA H^+ [4], 80 mA D^+ [5], 70 mA Bi^+ [6]).

2 EXPERIMENTAL SETUP

A schematic cross-sectional view of the experimental setup is shown in Figure 1. The plasma chamber of the ion source is made of a water-cooled copper cylinder. It is surrounded by 10 CoSm magnets in cusp field arrangement. Near the chamber axis, four tungsten filaments (1.8 mm diameter) are mounted. The front end of the chamber is enclosed by the plasma electrode. It is electrically connected with the anode. An electromagnet is installed in the flange of the plasma electrode. Its transverse magnetic field (B_f) acts as an electron filter.

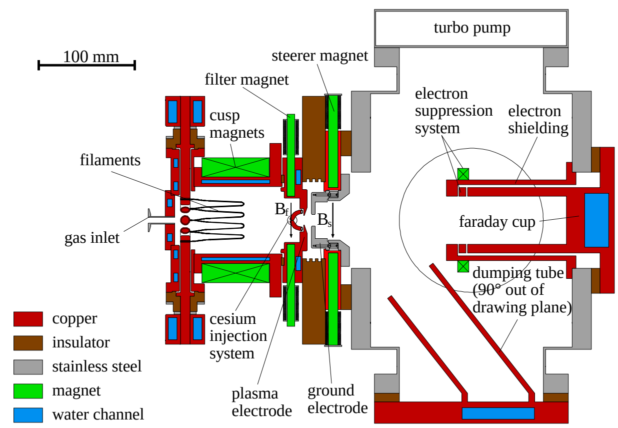

Figure 1: Schematic drawing of the experimental setup.

The arc power is provided by an array of capacitors (C_{tot} = 0.53 F) and gated by a high current switch. The used pulse generator allows arc powers up to 50 kW during 0.15 to 1.2 ms pulses and variable repetition rates from 1 to 400 Hz. Furthermore, for beam currents beyond the current limit of our extraction power supply (65 kV/300 mA), its charge also has to be accumulated in a capacitor (C = 3.5 μF). A wiring diagram of the ion source is presented in Figure 2.

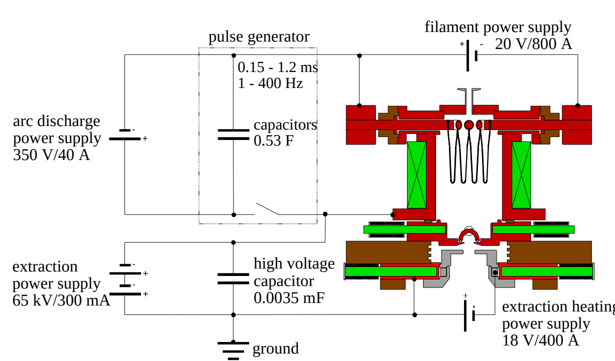

Figure 2: Wiring diagram of the H^- ion source.

An external oven is mounted on the flange of the plasma electrode for introducing cesium. By means of two small pipes, the cesium vapor is deposited close to the outlet aperture. The whole system is temperature controlled.

* Work supported by BMBF under contract number 06OF841I and FZJ GmbH.

In order to extract the H^- ions, a single hole diode extraction system with an aspect ratio of 0.8 is used. A heater is integrated in the ground electrode to run the extractor at temperatures around 250 °C. That way, a cesium deposition on the ground electrode is avoided which would lead to high voltage breakdowns in the extraction gap otherwise.

As the extraction of H^- ions is always accompanied by the extraction of electrons, a device for electron beam removal is necessary. Our concept is to dump the electron beam behind the extractor at full beam energy in a water-cooled cup. Due to the extension of the filter magnet field into the gap of the extractor, the electron beam is deflected out of the beam axis. As the deflection angle of the electron beam depends on the filter field strength and the extraction energy, an additional so-called "steerer magnet" is necessary (B_s) to contrive the electron beam in the dumping tube.

The ion beam diagnostic consists of a water-cooled Faraday cup, encapsulated in a grounded screen. It is equipped with an electrostatic and magnetic electron shielding.

3 EXPERIMENTAL RESULTS

There are two dominant processes for H^- generation in this ion source: volume and surface production. Both processes can be intensified by supplying cesium to the plasma chamber [7]. In operation with cesium, the H^- emission current is up to 4.5 times higher and the e/H^- ratio is about 7 times lower compared to an operation without cesium.

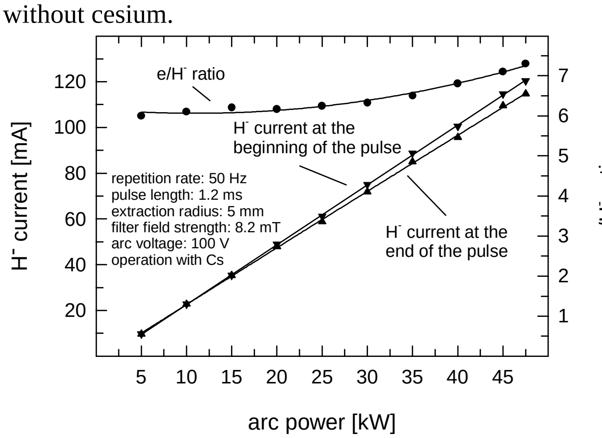

Figure 3: H^- current and e/H^- ratio vs the arc power.

Figure 3 illustrates the H^- current as function of the arc power for a cesiated source operation. The graph is split for higher arc powers: the upper graph shows the H^- current at the beginning of the pulse, the lower graph indicates the H^- current at the end of the pulse. This splitting, or current decrease during the pulse, is due to the "burn in" of the arc discharge. Especially for higher arc powers, it takes more time until the discharge achieves its balance. For an arc power of 47.5 kW, the ion source produces 120 mA H^- at the beginning of the pulse and 115 mA H^- at the end of the pulse. The former value corresponds to an emission current density of 153 mA/cm^2. In this mode of operation, the required extraction voltage for a matched beam is 33 kV (E_{gap} = 5.3 kV/mm). It is remarkable that the H^- current increases linearly as function of the arc power. Hence, a further enhancement of the H^- current is expected for arc powers beyond 50 kW. For short times 140 mA have already been achieved.

Figure 3 also shows the e/H^- ratio as function of the arc power. The plot displays a small growth rate. For full arc power the e/H^- ratio is about 7. This value corresponds to an electron current of 850 mA, equivalent to a mean electron beam power of 1.7 kW. Almost 100 % of the electron beam is captured in the dumping tube where the deposited energy of the electron beam is removed easily.

Figure 4 presents the evolution of the H^- current during a 1.2 ms pulse. After a rise time of 75 µs the curve reaches its maximum, shows a reduction of 4 %, and falls down within 35 µs.

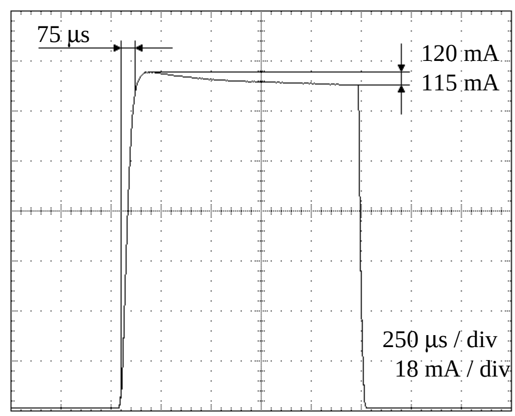

Figure 4: Oscillogram of the H^- beam.

For an arc power of 47.5 kW and a matched beam the noise level is less than 1.5 % (peak to peak). To attain such a low level, both the H^- and the electron beam must not hit any electrodes.

An ion source operation without cesium leads to a considerably faster current decrease during the pulse. Also, the beam noise level is dramatically higher.

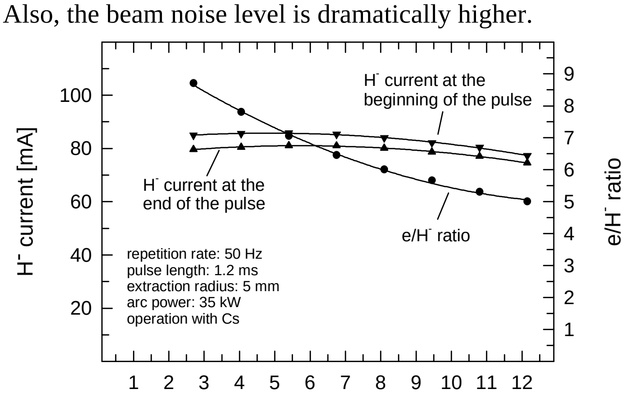

Figure 5: H^- current and e/H^- ratio vs filter field strength.

In a further experiment, the influence of the filter field strength on the H^- current and the e/H^- ratio was investigated. The measurements were made at an arc power of 35 kW. As illustrated in Figure 5, rising the filter field strength reduces the e/H^- ratio while having little influence on the H^- current. Consequently, the ion source is operated with a filter field strength of 8.2 mT.

In the course of the experiments, the dependence of the H^- current and the e/H^- ratio on the plasma electrode temperature was investigated. As depicted in Figure 6, an increase of the temperature yields higher H^- currents. For about 200 °C, the H^- current is about 1.3 times larger compared to its value at room temperature. Over the same temperature range, the e/H^- ratio drops by a factor of 2.

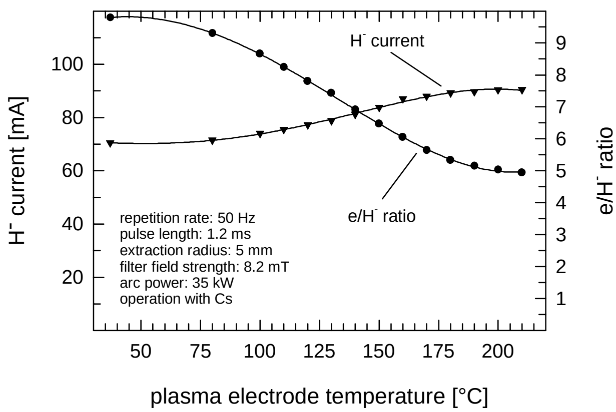

Figure 6: H^- current and e/H^- ratio vs plasma electrode temperature.

Besides a high H^- current, an appropriate ion source lifetime is another important requirement. For a given operational gas, the lifetime is limited by the wear of the filament which is approximately antiproportional to the duty cycle and the arc power. In order to obtain a long ion source lifetime, one should employ several filaments with large cross sections. This of course requires a filament power supply of the proper size. In other words, many thick filaments - which unfortunately have to be operated with a large power supply - are favorable for a long lifetime of the ion source. With the configuration described in this paper, the ion source was operated for 190 h at an arc power of 40 kW. After this time, the experiment was interrupted to check the condition of the filaments. Their diameter was reduced from 1.8 mm at the beginning to 1.5 mm. Since the filament can be used down to a thickness of about 0.9 mm, the ion source lifetime would be about 15 to 20 days.

As cesium is injected on demand only, in the normal mode of operation the injection system is off. That means, there is also a wear of the cesium layer which has to be rebuilt every 10 to 18 h. To achieve a controlled cesium deposition, a specific temperature profile of the plasma generator has to be kept. To account for this fact, the arc power has to be reduced for about 15 min. At the moment, a cesium injection system is developed, which will allow the cesium injection at high arc powers.

So far, the beam emittance has been not measured with our slit-grid emittance measurement device. Nevertheless, the H^- beam was recorded with a video camera to get a rough emittance estimation. After an optical analysis, the beam radius and the divergence angle of the 120 mA - 33 keV H^- beam could be estimated to 3 mm respectively 10 mrad. Hence, a phase space area emittance of 30π mm mrad is covered. For a KV distributed beam, the rms emittance is 7.5π mm mrad, the corresponding normalized rms emittance is 0.063π mm mrad.

4 CONCLUSIONS

In the present article, the status of the Frankfurt high duty cycle H^- ion source is described. The investigations have shown that the ion source is capable of producing a 120 mA H^- beam at an arc power of 47.5 kW (50 Hz, 1.2 ms, duty cycle = 6 %). This corresponds to an emission current density of 153 mA/cm^2. The required extraction voltage for a matched beam is 33 kV. A rough estimation indicates an excellent beam emittance of $\varepsilon_{rms,\ norm} \sim 0.06\pi$ mm mrad only. The achieved current is much lager as required for ESS, but further work has to be done to improve the lifetime of the source. A long-standing milestone is to have an ion source which satisfies simultaneously all the ion source requirements for ESS, a goal that is now within sight.

5 ACKNOWLEDGMENTS

The authors would like to thank Dr. Ka-Ngo Leung (LBNL) for the good cooperation and many fruitful discussions. We are also thank the members of the electronic lab and the mechanical workshop for their technical support as well as the ion source group members for their assistance with this work.

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