MICROWAVE ION SOURCE AND BEAM INJECTION FOR AN ACCELERATOR-DRIVEN NEUTRON SOURCE *

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Abstract

An over-dense microwave driven ion source capable of producing deuterium (or hydrogen) beams at 100-200 mA/cm² and with atomic fraction > 90% was designed and tested with an electrostatic low energy beam transport section (LEBT). This ion source was incorporated into the design of an Accelerator Driven Neutron Source (ADNS). The other key components in the ADNS include a 6 MeV RFQ accelerator, a beam bending and scanning system, and a deuterium gas target. In this design a 40 mA D⁺ beam is produced from a 6 mm diameter aperture using a 60 kV extraction voltage. The LEBT section consists of 5 electrodes arranged to form 2 Einzel lenses that focus the beam into the RFQ entrance. To create the ECR condition, 2 induction coils are used to create ~ 875 Gauss on axis inside the source chamber. To prevent HV breakdown in the LEBT a magnetic field clamp is necessary to minimize the field in this region. Matching of the microwave power from the waveguide to the plasma is done by an autotuner. We observed significant improvement of the beam quality after installing a boron nitride liner inside the ion source. The measured emittance data are compared with PBGUNS simulations.

INTRODUCTION

An accelerator-driven neutron source (ADNS) for scanning cargo containers to detect shielded nuclear material [1] was designed at Lawrence Berkeley National Laboratory (LBNL). The key components of the ADNS include a high current D⁺ ion source, a low energy beam transport (LEBT) section, a RFQ accelerator, beam bending and scanning magnets, and a deuterium gas target. The system can produce neutrons with energy up to 8.5 MeV in a forward directed flux of up to 2.0E7 n/cm²/s at 2.5 m distance from the target. [2] A schematic diagram of the ADNS is shown in Fig.1. Topic of this paper is the ion source and LEBT section shown in Fig.2. [3-4]. Our design goal is to have a time-averaged beam current of 1.5 mA, at ~ 5 % duty factor. Taking beam loss into consideration, the required peak current from the ion source is ~ 40 mA D⁺ ions with a pulse length of ~ 0.3 ms and 180 Hz repetition rate.

For this application, we have chosen to use the 2.45 GHz microwave ion source because of its capability

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Figure 2: Schematic of the ion source and the test extraction. Diagnostic can be Faraday cup to measure the current, Wien filter to measure the ion species or Pepperpot to measure emittance.

**Ion source design**

There is a magnetic field clamps on front flange of the source to prevent the B-field to penetrate to the extraction area. It has been shown [6] that best D⁺ or H⁺ species and currents are achieved if the magnetic fields are uniform through out the source. We noticed that when the field clamp is used the deformation of the magnetic fields affects the coupling of RF power to plasma reducing the source performance. Figures 3 and 4 show the effect of magnetic clamps to the magnetic fields in the source and the LEBT and the ion current yield. About a factor of two more power is required to gain the same extracted beam current densities with field clamp than with out.

Figure 3: Magnetic fields on the central axis of the source. Measurements are done using 106 A induction current.

Figure 4: Ion current as function of RF power for setup with and without field clamp. In both cases, extraction voltage was 60kV, gas flow 1.5 sccm and magnetic induction currents between 105 A and 106 A.

For the ion species, a drop from ~90 % to ~50% on the H⁺ fraction was detected when the field clamp was added. We suspect that the stronger field caused by the clamp near the BN lining was shielding the BN from the plasma and thus reduced the effect of BN in producing H⁺ ions.

**LEBT**

Preliminary design of the LEBT was done using PBGUNS simulation codes [9]. In our design, the LEBT consists of an extraction gap and two Einzel lens, in total 6 electrodes, as shown in Fig. 5. The two Einzel lenses give good control over the wrists parameters at the entrance of the RFQ. The designed LEBT can deliver the required 40 mA of D⁺ current to the entrance of the RFQ with an emittance of
Error in the definition of any of these variables on the simulation might cause the minor disparity of the beam spot size and divergence seen in Fig. 6. Space charge and charging of the kapton foil in the drift region behind the slit screen were not taken into account when determining the measured emittance. Within the measurement tolerances it seems that the measured and simulated emittance are in good agreement with each other.

**CONCLUSION**

We have produced the required current and species for the ADNS application when in absence of a magnetic field clamp [1]. We observed considerable reduction on the extracted ion currents and $^2\text{H}^+$ species when the field clamp was placed on the plasma electrode. This problem can be overcome by either optimizing the position of the field clamp (e.g. at the back of the extraction electrode) or by using permanent magnets (PM) to generate the required magnetic fields. PM sources have been shown to work well [10] and stray fields from permanent magnets are not as far reaching as fields caused by the field coils.

The measured emittance agrees with the simulated emittance thus confirming the validity of the PBGUNS calculation and its usage in designing the LEBT.

**REFERENCES**