HIGH CURRENT PROTON AND DEUTERON ECR SOURCE DEVELOPMENTS AT CEA

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Abstract

A high current ~ 100 mA proton and deuteron ECR (electron cyclotron resonance) source is under development. Preliminary results have shown that a 75 mA/cm^2 beam current can be extracted at 10 kV through a 3 mm diameter aperture. The proton fraction is higher than 80% with a nitride coating on the plasma electrode. Previous work on the 10 kV source installed in CEA-Grenoble is recalled, and the development on the 100 kV source installed at Saclay is presented.

1. INTRODUCTION

The development of a new ECR source for proton and deuteron beam production is part of a considerably larger activity presently undergoing at CEA in the field of high intensity linear accelerators. One main application of this source is for the international IFMIF program. Other potential applications of high current accelerators include the production of high fluxes neutron beams for spalliation reactions (TRISPAL, ESS), for future reactors, or for nuclear waste retreatment. The 100 mA, CW proton and deuteron beams for these accelerators may reach an energy as high as 1 GeV, and the rms normalized emittance must be lower than 0.2 π mm.mrad.

It has been decided to develop a new source with the following requirements: 100 mA proton, 140 mA deuteron, 100 keV, 0.1 π mm.mrad rms normalized emittance and a 90% proton or deuteron fraction. The ECR source principle has been chosen for simplicity and reliability reasons, demonstrated by the Chalk River National Laboratory and the Los Alamos National Laboratory.

The following sections include the preliminary results obtained at the 10 kV source at CEA-Grenoble, the description of the new 100 kV source at CEA-Saclay, the definition of RF-based plasma diagnostics, and proton beam dynamics computations.

2. THE CEA - GRENOBLE SOURCE

This 10 kV ECR source was originally designed for heavy ions production, and has been recently adapted to high current proton beam generation. The plasma cooled chamber is cylindrical with a 93 mm diameter, and a 200 mm length. The 2.45 GHz radiofrequency is fed to the source with a rectangular waveguide. The electron cyclotron resonance is obtained with a 875 G magnetic induction, following the well-known relationship:

$$\omega_{RF} = e\ B / m_e$$

where e and m_e are respectively the charge and the mass of the electron. The waveguide window is made of 5 mm thick quartz. For life-time requirements, it is placed behind a bent section of a cooled waveguide, in a region of high magnetic induction. The magnetic field is generated by three independently tuned coils. The 10 kV extraction system is calculated following Pierce design, to obtain a 10 mA proton beam through a 3 mm diameter aperture in the plasma electrode.

First results [1] showed the extracted current increases monotonically with forward RF power. The extracted beam maximum density is 75 mA/cm^2 with a 60 mm long flat magnetic induction of 875 G in the vicinity of the extraction aperture. A 85% proton fraction has been achieved with a nitride coating of the plasma electrode.

3. THE CEA - SACLAY SOURCE "SILHI"

The experiences of several authors [1],[2],[3],[4],[5], have been used to design a High Intensity Light Ion Source (SILHI - Fig. 1 & 2). The plasma chamber is cylindrical, with a 90 mm diameter and a 100 mm length. The RF signal is produced by a 1.2 kW magnetron source at 2.45 GHz, and is fed to the source via standard rectangular waveguides. A three section ridged waveguide transition is placed between the plasma chamber and the cooled bend to enhance the axial RF field.

As in Grenoble, the electromagnetic window is placed behind the bent section, in a high magnetic field area. The magnetic field is produced by four coils, independently tuned and positioned. The coils are magnetically shielded to reduce the power dissipation under 8 kW. The inner surfaces of the flat discs at both ends of the plasma chamber are covered with boron nitride discs (2mm thick), to improve the proton fraction. The proton beam is extracted through a 10 mm diameter aperture in the plasma electrode.

The above components, including ancillaries, are all placed on a 100 kV platform. The source is connected to the LEBT (low energy beam transport) via a 300 mm long HV (high voltage) column, having three successive insulating rings made of alumina. The extraction system includes five electrodes. The first one (plasma electrode) is polarized at + 100 kV. The following one may be adjusted between 60 kV and 100 kV. The third electrode is grounded. The fourth one is slightly negative (around - 2 kV) to prevent electrons from drifting back to the source. The last fifth is also grounded. The design of the electrodes has been optimized with the multi-particles code "Axcel"[6], which has the ability to compute the shape of the plasma emissive surface. As a result, the diameter of the aperture is chosen to be 10 mm for the first three electrodes, and 12 mm for the last two. The vacuum in the source, HV column and the LEBT is achieved with two 1 000 l/s turbomolecular pumps.

4. RF PLASMA DIAGNOSTICS

The main spectral characteristics of the RF forward signal, i.e. the center frequency and the bandwidth, are continuously monitored (with a standard microwave spectrum analyzer), as they are directly related to the resonance condition in the chamber. By the same way, the stability of the magnetic induction has to be monitored; the DC current in the magnetic coils is stabilized at 10^{-4}. It is felt the natural instability of the magnetron may be related to the characteristics of the extracted beam. The possibility to observe the second harmonic (at 4.9 GHz) may also give some insight in possible non-linear processes in the plasma.

An automatic tuning unit, associated to a reflectometer, is placed on the feed line, and helps matching the impedance of the plasma. Further developments may include -1) pulsed waveforms measurements, -2) improvement of the frequency stability to the synthesizer grade and -3) feeding the chamber with the RHCP (right hand circular polarization) mode, which is best absorbed in the ECR process.

5. BEAM DYNAMICS

The beam emittance has been computed in a plane situated at 10 cm from the plasma electrode, with the "Axcel" code. In these computations, the beam is supposed to contain protons only, with an intensity of about 100 mA. The plasma electrode potential is constant at 100 kV, and the potential of the second electrode is varied from 50 kV to 70 kV.

The simulation shows that "filamentations" in the phase-space distribution are decreasing as the potential grows from 50 kV to 70 kV. Table 1 shows the variation of the rms normalized emittance as a function of the second electrode potential.

Potential (kV)	rms norm. emitt. (m.rad)
50	$2.05\ \pi\ 10^{-7}$
55	$1.67\ \pi\ 10^{-7}$
60	$1.43\ \pi\ 10^{-7}$
65	$1.34\ \pi\ 10^{-7}$
70	$1.37\ \pi\ 10^{-7}$

Table 1 : Emittance vs the second electrode potential.

An operating voltage of 65 kV has been chosen in accordance with the flat optimum in the emittance shown by this simulation.

Then a multi-particle (77% H^+, 15% H^{2+}, and 8% H^{3+}) simulation has been used to generate input conditions for the computation of beam dynamics in the LEBT. The trajectories of the particles in the LEBT are calculated with the "Bacchus" code [7] which allowed the simulation of the rms emittance step by step, including the true magnetic field computed with coil and shield of the focusing solenoid; the beam has been supposed to be totally neutralized.

6. CONCLUSION

All these preliminary simulations allowed us to design the source on the 100 kV platform, the HV column and the LEBT at Saclay. Other computations are used to define the following diagnostics: beam stopper, emittance meter, Wien filter. The first part of the experimental set-up (source, accelerator column, the first vacuum vessel and the magnetic lens) is assembled and the diagnostic box is under construction. We are now in the process of measuring the first plasma characteristics. We intend to extract the first proton beam from the source at the end of June. These results will be reported at the Linac Conference (Geneva) in August. We will also present at this conference a general description of the different diagnostics.

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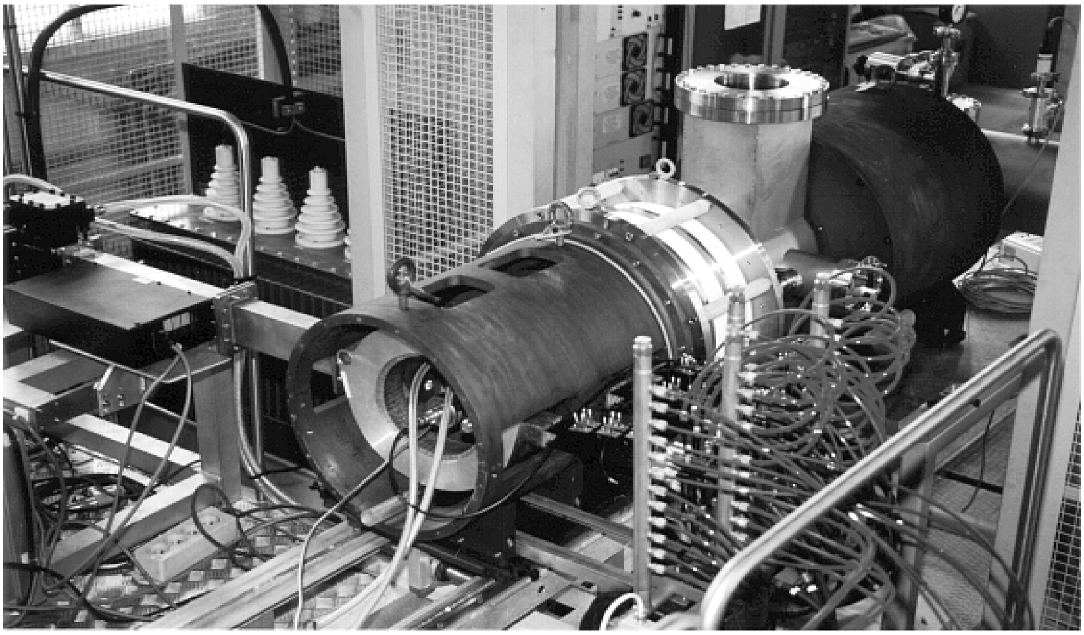

Figure 1 : View of SILHI experimental setup

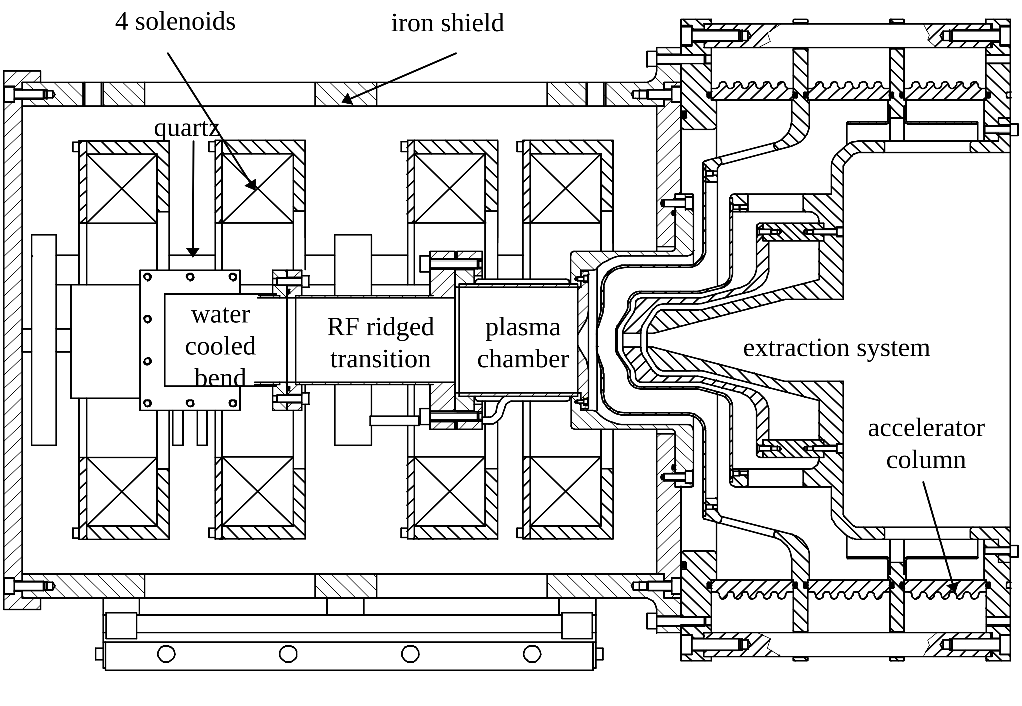

Figure 2 : Sketch of the ECR ion source.