DEVELOPMENT OF A PERMANENT MAGNET ECR SOURCE TO PRODUCE A 5 mA DEUTERON BEAM AT CEA/SACLAY.

R. Gobin*, P-Y Beauvais, G. Charruau, O. Delferrière, D. De Menezes, R. Ferdinand, Y. Gauthier,
F. Harrault, Commissariat à l'Energie Atomique, CEA-Saclay, DSM/DAPNIA,
91191 Gif sur Yvette Cedex, France
N. Comte, Commissariat à l'Energie Atomique, CEA-Saclay, DEN/SAC/DSP/SPR,
91191 Gif sur Yvette Cedex, France
P. Leherissier, J-Y. Paquet, GANIL, Bd Henri Becquerel, 14076 Caen Cedex 5. France

Abstract.

The high intensity light ion source (SILHI) is an ECR ion source operating at 2.45 GHz which produces high intensity (over 100 mA) proton or deuteron beams at 95 keV. This encouraged us to propose a permanent magnet source based on the SILHI design to fit in with the injector of the Spiral 2 project, requesting 5 mA of D^+ beam with an energy of 40 keV and a normalized rms emittance lower than 0.2 π mm.mrad. The new source has been recently assembled and the first beam (proton) extracted. The source design improvements and the preliminary results are reported.

INTRODUCTION

In France, CEA and CNRS have been working on high beam power accelerators for several years. In a first step, the SILHI source has been built to produce high intensity proton beams. Experiments were also devoted to the production of deuterons for irradiation tools. Deuterons are now also needed by the future SPIRAL 2 facility [1] and a “low” intensity (5 mA) deuteron source is presently under study at CEA Saclay.

The goal of SPIRAL 2 at GANIL, consists in extending the possible radioactive beam types. SPIRAL 2 is based on the fission of a Uranium carbide target induced by neutrons. The neutron flow will be produced by interaction of deuteron beam with a Carbon target. SPIRAL 2 requires a maximum of 5 mA - 40 keV CW D^+ beam (at the RFQ entrance) with rms normalized emittances lower than 0.2 π mm.mrad. To answer these requirements, an ECR source has been proposed, extending the SILHI design with permanent magnets.

SOURCE DESIGN

Magnetic structure

The SILHI ECR ion source, operating at 2.45 GHz, is producing more than 100 mA proton beams [2] with a high reliability. Taking into account the deuteron experiments already successfully performed with SILHI (130 mA at 100 keV in pulsed mode) [3], the design of such a source fulfilling the SPIRAL 2 requirements has been undertaken. The reproducible performance led us to propose a permanent magnet 2.45 GHz ECR source: the magnetic field is provided by 3 ring shaped permanent magnets instead of 2 solenoidal coils on SILHI. Electromagnetic simulations have been carried out to reproduce at best the SILHI magnetic field profile on the axis [4]. The plasma chamber and the RF power chaine keep the SILHI design. In order to increase the plasma density, 2 Boron Nitride discs are also located at both ends of the plasma chamber.

No problem occurred when assembling the source but a 6 % deviation has been observed between the magnetic measurements and the simulations. Even if the ECR resonances have been easily placed, we discovered experimentally a major problem. It came from the particular permanent magnet configuration built with no shielding. Consequently, in the extraction region, the magnetic field was 40 times higher than in the SILHI case with coils and magnetic shielding, reaching a value of about 0.2 T. This high magnetic field contributed to initiate a discharge between the electrodes when the high voltage increases. The extraction system is designed for electric fields as high as 60 kV/cm and only few kV/cm between electrodes led to important currents in glow discharge and to a vacuum increase.

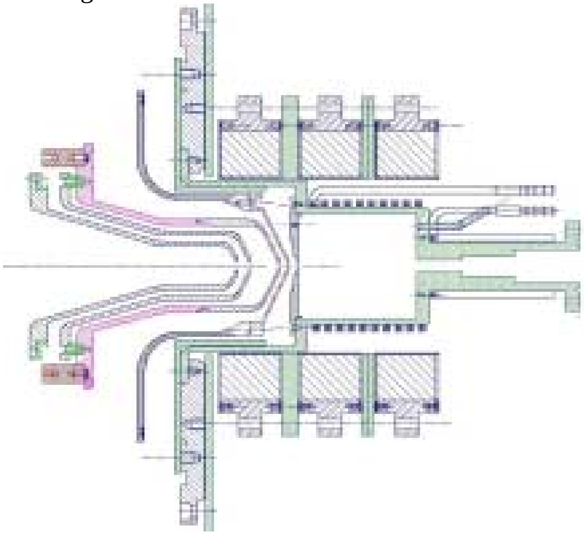

Fig.1: Permanent magnet ECR source with magnetic shielding and discs.

So, new magnetic configurations have been tested to lower the magnetic field between electrodes. But magnetic shielding leads to a decrease of the magnetic field in the plasma chamber. A compromise has finally been found by inserting two iron discs of 13.5 mm and 5 mm width between the permanent magnet rings (Fig. 1) in addition with two 5 mm thick shielding plates in front of the first electrode (Fig. 2). The first one is located under vacuum in the accelerator column and the second one is positioned outside the vacuum between the first ring and the flange. The field is now comparable even lower than for SILHI in the extraction system.

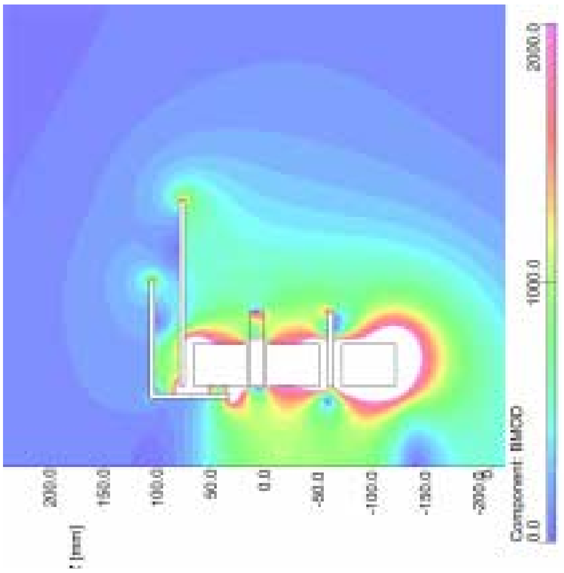

Fig 2: Magnetic simulations with shielding and discs.

Extraction system

The extraction system has been designed to be tuneable continuously at 40 keV, between 0.1 to 5 mA D^+ beam, by using 2 intermediate electrodes to adjust the accelerating gap [4]. The first simulations for a 6.4 mA total beam current have been done using AXCEL, without space charge compensation. The beam divergence and emittance optimisation has led to the first electrode configuration with a 2.5 mm diameter and 64° angle plasma electrode. The two intermediate electrodes have 3 mm and 3.5 mm diameter respectively. The 4th electrode is the – 2 kV electron repeller. The divergence was going from 10 mrad for 0.1 mA to 60 mrad for 5 mA. The rms normalized emittance given by AXCEL was very low, between $6\ 10^{-3}$ and $1.2\ 10^{-2}$ π.mm.mrad.

The extraction hole had to be enlarged to ensure a better pumping of the plasma chamber (see section III). Further simulations with AXCEL have been performed with 3 mm and 4.8 mm (Fig. 3) plasma electrode diameter. Other calculations have been done with PBGUNS in order to compare both codes. The 4.8 mm diameter plasma electrode is designed with an angle of 60°. The other electrodes have been modified with larger diameters and adjustment of their relative distances. The electrode potentials are respectively 40, 30, 10, - 4 and 0 kV from the plasma electrode to the ground. The calculated rms normalized emittance, at 7.6 mm from the hole, is about $2.3\ 10^{-2}$ π.mm.mrad with ion temperature set at 0.2 eV. The divergence is kept under 40 mrad (Fig.4). PBGUNS simulations indicate bigger tails on the emittance plot, compared to AXCEL.

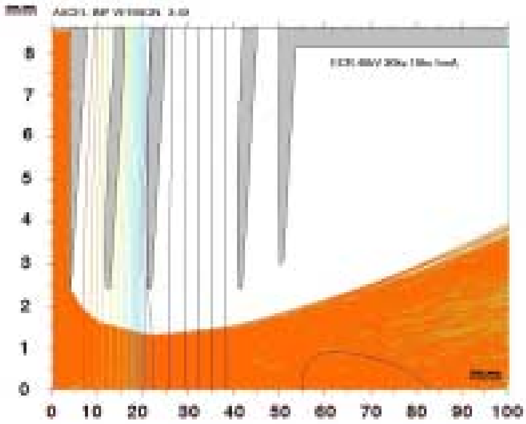

Fig 3: 4.8 mm diameter hole extraction system

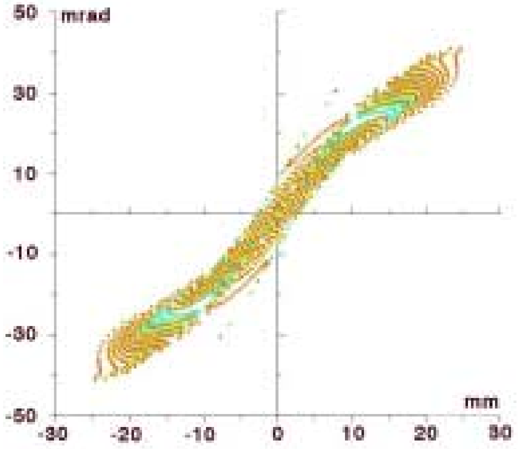

Fig. 4: Emittance at 7.6 mm from extraction hole

PRELIMINARY RESULTS

Even at low energy, deuteron beam leads to 2.45 MeV neutron emission due to the d,D reaction when the D^+ ions hit the deuterium molecules at the surface of the target. So, the new source originally started by producing H^+ beams. To keep a good plasma density, the preliminary simulations led to a 2.5 mm diameter aperture instead of 9 mm for SILHI. As the plasma chamber is only pumped through this hole, the small conductance led to tuning difficulties and finally, no efficient running mode was obtained in this configuration.

Therefore, the extraction aperture diameter has been enlarged to 3 mm and a specific turbomolecular group has been installed to directly pump the plasma chamber. By tuning the magnetic field (ring position and addition of iron plates, see section II), more than 7 mA total beams, with 1 kW RF power, have been extracted with less than 10 % of impurities and 77 % of protons. Emittance measurements have given a normalised rms value of 0.15 π mm.mrad.

Recently, deuterium gas replaced the hydrogen gas, and the total extracted beam reached 6.5 mA with 65 % of deuterons, for 1.1 kW RF power. In these conditions, the first measured D^+ beam emittance indicated a normalised rms value of 0.11 π mm.mrad (Fig. 5), largely higher than the estimated AXCEL's value

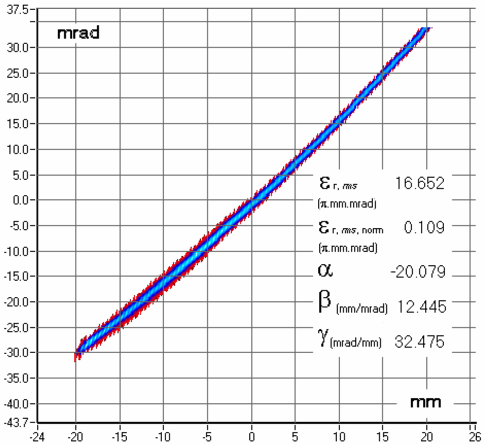

Fig. 5: First beam emittance measurement
(D^+ current = 4.2 mA).

NEUTRON PRODUCTION

Preliminary neutron production measurements were done [5] while the SILHI source was equipped with a small diameter (4.8 mm) extraction system to reduce the intensity. A 5 mA – 40 keV CW deuteron beam was produced. The neutrons were measured online with a LB 6411 probe under permanent control of the security staff. This experiment allowed acquiring data on 2.45 MeV neutron emission from d,D reaction.

After a short period in pulsed mode, the beam was rapidly produced in CW mode. Finally the source produced a deuteron beam for 4 days (6 hours per day). The beam was collected on a water cooled copper plate installed downstream the first solenoid, at about two meters from the extraction aperture. The neutron probe was located 0.40 m from the beam stop, outside the beam line, behind a 25 mm thick flange. A maximum neutron production saturated dose of 420 µSv was observed. The neutron emission appears isotropic around the copper target and follows the $1/r^2$ decay rule. As the beam starts, the neutron emission rise time is rather short and reaches a saturated level which linearly depends on the beam intensity. The neutron emission rise time is about 1 hour with a 5 mA-40 keV deuteron beam on a cleaned target and shorter after a beam restart on a deuterium polluted target. The neutron emission goes immediately down to 0 when the beam stops.

Moreover, the neutron emission decreases rapidly by changing the extracted particles. Just after switching from D^+ beam to H^+ beam, the neutron emission fall time goes down from 415 to 25 µSv/h after 6 min and to 0.5 µSv/h after 30 min. This residual emission is due to gas mixing in the pipes for few minutes.

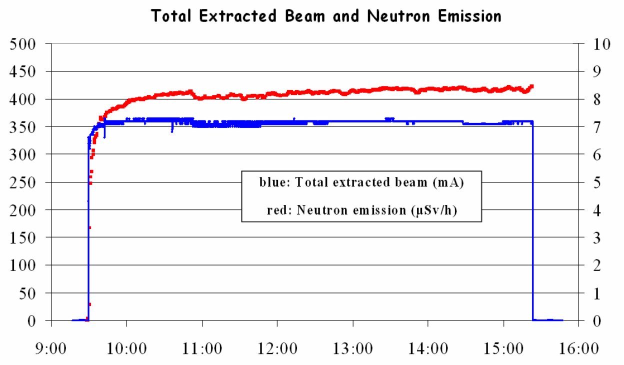

Fig 6: Neutron Emission and Extracted Current vs time

On Figure 6, the red curve presents the neutron emission (plotted each 30 sec.) acquired by the LB 6411 probe with total extracted beam between 7 and 7.3 mA (blue curve). These measurements have been performed over a 6 hour long run with no beam off. New measurements are needed to confirm these results with systematic data record and specific shielding.

CONCLUSION

The permanent magnet technology can not simply replace a coil magnetic configuration. New magnetic simulations were needed to face the important problems leading to glow discharge. The source is now producing its first deuteron beams and the complete beam characterization is expected for the end of September.

ACKNOWLEDGMENTS

The authors would like to thank all the IPHI group members who participate to the SILHI program. In addition, people from the SPIRAL 2 group are also thanked especially M.H. Moscatello and J.M. De Conto. We do not forget L. Ando and L. Celona from INFN Catania who participated in fruitful discussions. The Saclay security staff is also gratefully acknowledged, especially F. Fardeau and H. Guillo who ensured the control for neutron measurements.

REFERENCES

[1] M-H. Moscatello, “SPIRAL2 at GANIL”, This conference

[2] R. Gobin et al, “Status of the light ion source developments at CEA/Saclay”, 2003 ICIS Conference, Dubna, Russia, to be published in RSI (2004)

[3) R. Ferdinand et al.; Proceedings of EPAC conference, Paris, France, June 2002, (p. 894-896)

[4] O. Delferrière and D. De Menezes, “Extraction design and LEBT optimization of space charged dominated multispecies ion beam sources”, 2003 ICIS Conference, Dubna, Russia, to be published in RSI (2004)

[5] N. Comte et al, “Compte rendu d'expérience de mesures neutroniques avec un faisceau intense de deutons (5 mA – 40 keV) sur SILHI”, internal report.