BETSI, a new test bench for ion sources optimization at CEA SACLAY[a)]

O. Tuske, G. Adroit, O. Delferrière, D. De Menezes, Y. Gauthier,
R. Gobin, and F. Harrault
CEA/Saclay, DSM/DAPNIA, 91191-Gif/Yvette, France

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In the framework of several International HPPA projects (such as IFMIF, IPHI, and Spiral2) the CEA handles the design and the developments of several electron cyclotron resonance (ECR) ion sources. For the IFMIF EVEDA demonstrator, a 140 mA cw extracted deuteron beam will be required for high yield of neutron production. For radioactive ion production in the Spiral2 project, several milliamperes of deuterons will be delivered with a permanent magnet source. The optimization of the beam quality at the entrance of the radio frequency quadropole (RFQ) accelerator system triggered the need of a new test bench for ion source optimization and beam qualification. The BETSI ion source test bench will operate up to 50 kV and ignite cw or pulsed hydrogen plasma with a 2.45 GHz magnetron. Great care has already been taken to design electrostatic optics of the extraction system to minimize the emittance growth. Plasma diagnostics will be inserted in the source chamber and several beam diagnostics (emittance and current measurements, beam species analysis) will also be implemented on the low energy beam line transport (LEBT). These diagnostics allow the simultaneous analysis of the beam quality with the plasma parameters of the source. Regional funding request will also be needed to improve the LEBT for space charge compensation measurements. The design of the present and upgraded test bench will be reported as well as the first extracted beam analysis. © *2008 American Institute of Physics.* [DOI: 10.1063/1.2805625]

I. INTRODUCTION

Development of new accelerators requires also upgrading existing ion sources to fulfil the requirements of theses new machines in terms of beam intensity, brightness, and stability in time. The CEA Saclay is involved into several major projects: IFMIF EVEDA (Engineering Validation and Engineering Design Activities) facility in Rokkasho (Japan) which has for purpose to test the mechanical behavior of several materials under high flux of neutron radiation. IFMIF utilizes the deuteron-lithium (d-Li) neutron producing reaction to simulate the 14 MeV neutron environment in deuterium-tritium (D-T) fusion reactors. The tested materials will be used in the construction of fusion reactors, such as DEMO. Also at GANIL in Caen, France, the Spiral2 project is willing to produce new variety of rare radioactive elements in order to understand more precisely the interactions inside the atomic nucleus. Those two projects are both using a deuteron beam which impacts a target that generates the required neutron flux: 250 mA of D^+ at 40 MeV on a lithium liquid target for the irradiation facility and 5 mA at 40 MeV on a carbon target for the Spiral2 project.

In CEA Saclay, with the SILHI source platform of the IPHI low energy beam demonstrator project (high intensity proton injector), source developments and testing were possible. Several tests and measurements[1] were made with a dedicated accelerator column. Presently some new tests are made for the IFMIF EVEDA ion source.[2] Since the IPHI project will enter in a new phase of development, the availability of the SILHI platform will be reduced. This paper reports the development and the design of a new platform BETSI (ion source test bench) for light ion source testing. Also a new accelerator column has been designed for the Spiral2 ion source and installed on the BETSI test bench and some preliminary measurements were made.

In this low energy part of the transport, the beam dynamics is dominated by nonlinear space charge effects which increase the beam emittance. For a better understanding of these effects and to validate code simulations, an upgrade solution of the BESTI test bench LEBT is also in project and will be summarized in the last part.

II. ION SOURCE AND ACCELERATOR COLUMN

A. Permanent magnet source

The Spiral2 ion source (Fig. 1) was based on an existing electron cyclotron resonance (ECR) source developed for a high intensity proton injector[3] (IPHI) and was largely modified to fulfil the specified requirements: the extraction hole diameter was reduced from 9 to 3 mm; the magnetic field is generated by magnetic rings composed of 24 pieces of permanent magnets instead of regular electromagnetic coils. Magnetic orientation of magnets is only axial and generates a heating zone (the ECR surface is at 87.5 mT for 2.45 GHz rf wave) just at the entrance of the plasma chamber.

The accelerator column has also been redesigned for a lower beam current: the multielectrode structure has been

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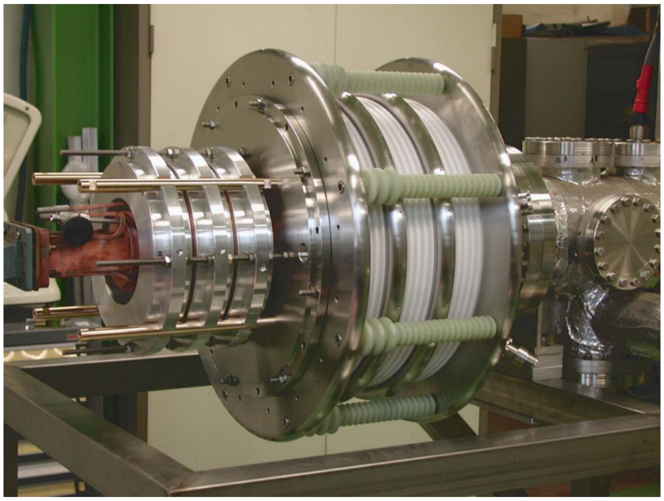

FIG. 1. (Color online) (Color online) Permanent magnet source adapted on the modified SILHI accelerating column.

kept but the position and biased potentials have been adapted to extract the required beam. The performance of the source satisfies the Spiral2 requirements with notably more than 7 mA of D^+ beam (Fig. 2).

Due to the geometry of the accelerator column, the magnetic field produces locally a penning discharge in the outer diameter of the column. To lower the magnetic field in those regions, a magnetic shielding has been used. As the plasma chamber is shortened by 10 mm, two magnetic rings are only necessary for operating.

B. New accelerator column

Another solution was to design an accelerator column with a smaller radial diameter and is also adapted to the new BETSI test bench. The accelerator column is a five electrodes system. Electrode positions and shapes have been inspired by the accelerator column used on the SILHI platform, and new simulations with AXCEL® code have shown the possibility to extract up to 30 mA proton beams with a 4.8 mm diameter extraction hole and beam divergence lower than 60 mrad. As the column radial diameter has been reduced from 400 to 200 mm, it was possible to use two stages

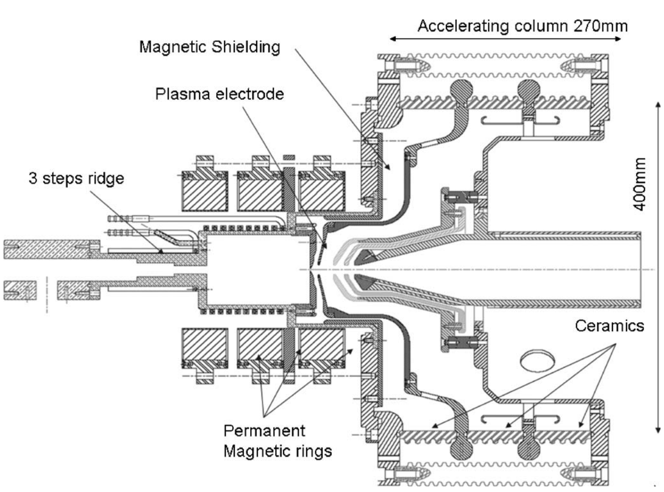

FIG. 2. The five-electrode extraction system.

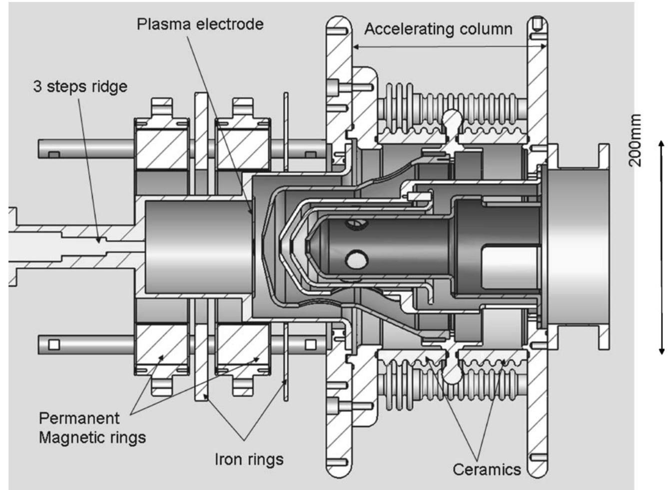

FIG. 3. Compact accelerator column on BETSI.

of ceramic (instead of three) to maintain mechanically the electrodes. The overall length is now 191 mm instead of 270 mm (Fig. 3).

III. HIGH VOLTAGE PLATFORM FOR ION SOURCE TEST

The BETSI test bench is equipped with the new accelerator column mounted on a compact high voltage platform biased up to maximum of 50 kV positively or negatively. Hydrogen gas is injected through a controlled valve at high voltage, while the hydrogen gas tank is at ground potential. The rf power is generated by a magnetron (either 1.2 or 6 kW maximum power) with an automatic four-stub tuning system also at ground potential. The rf chain is isolated from the high voltage platform with a dc break. Several insulators have been tested for the dc break: a 200 μm Kapton® foil lasted only a couple of minute at 50 kV before getting damaged. A 3 mm Mylar® foil seemed to be a good candidate but was too thick and let the rf leak out of the rectangular wave guide. Finally a 1.5 mm Mylar® foil is now regularly used.

The injection inside the plasma chamber is made with a three-step ridged wave guide transition that concentrates the electromagnetic field on the source axis for a better coupling with the plasma electrons. The vacuum is generated with a turbomolecular pump. The operating pressure inside the plasma chamber is about 1.2×10^{-3} Torr with a 4.8 mm extraction diameter hole. The pulse length and pulsed power are controlled through a LABVIEW® virtual instrument, which analogically commands the magnetron. The pulse length can be extended to cw mode.

Presently a small chamber with a Faraday cup equipped with a secondary electron repeller is installed just after the accelerating column. A DCCT measures the power supply drain current and is compared to the extracted beam current collected on the Faraday cup located at 535 mm from the plasma electrode.

A 25 mA beam is extracted from the source with 1.2 kW of rf input (Fig. 4). The pulsed power can reach 6 kW, but above 1.2 kW, the reflected power increases linearly with the

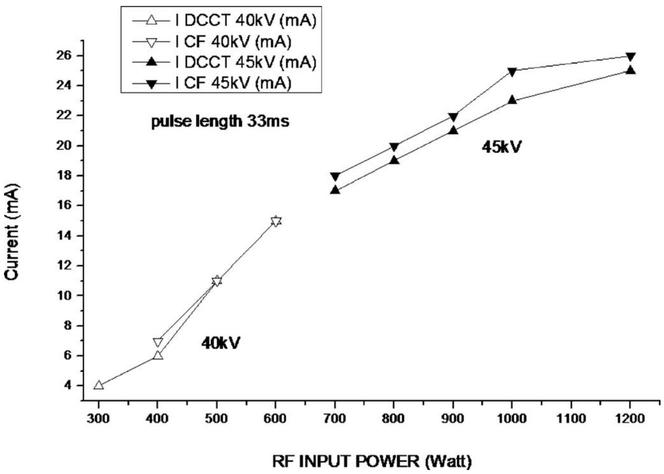

FIG. 4. Extracted and drain current vs rf input power for two high voltage potentials with pulse length of 33 ms.

input power: the extracted current is not enhanced. Since the drain current is equal to the extracted current, we can assume that the Faraday cup diameter is large enough to collect the entire beam. Simulations with AXCEL® code, taking in account the space charge compensation (better than 97%), showed a diameter much smaller than the 10 cm Faraday cup diameter. The simulated beam divergence is about 60 mrad.

The bias voltage of the platform can also been reversed in order to produce and extract negative particles. A multipole magnetic configuration ECR ion source is mechanically adapted to this test bench[4] to produce H^- negative ions.

IV. LOW ENERGY BEAM TRANSPORT (LEBT)

A. First Step

After the extraction the beam dynamics is dominated by nonlinear space charge effects. When the beam ionizes the residual gas, electrons and secondary ions are produced. In transit gaps, where no magnetic or electric field influences the particle trajectories, electrons are naturally trapped in the beam potential and positive ions are repelled toward the walls. As a result a reduction of the space charge is observed. As soon as the beam crosses a magnetic field region, electron trajectories are modified and the space charge compensation is disturbed, leading to an emittance growth.

A two-dimensional code showed a good agreement with experimental measurements on the IPHI LEBT.[5] The adaptation of this code to three-dimensional is actually in progress.[6] The need of experimental data is fundamental to validate this code, that led us to investigate the development of beam diagnostics (beam profiler, emittance meter).

The BETSI test bench is dedicated to study the influence of the source parameters on the beam characteristics. The "First Step" LEBT will be composed of a pair of solenoids that has to reduce beam divergence and focalize it into a classical mass analyzer magnet. This dipole is a 104° dipole with a radius of 400 mm and double focusing corners. The homogeneity within 110 mm from the axis is better than 10^{-3}, the chamber height is 80 mm, and the maximum transverse field is 230 mT. The LEBT ends with a vertical movable slits followed by a Faraday cup.

A pumping/diagnostic box will be implanted between the solenoid and the dipole in order to compare two types of beam profiler: the first is a classical multiwire system that collects electrical charges and reconstruct the transverse beam profile. This system cannot be used in case of very intense beam. The second one uses a nondestructive method: a camera measures the light emitted by the interaction of the beam with the residual gas.

Also the dipole will help us to quantify the proportion of protons versus molecular ions. In the case of negative ion production it will help us to purify the beam before collecting the current in the last Faraday cup.

B. Toward a new transport line

For several projects, beam transport between sources and RFQ uses magnetic devices (generally solenoids) in order to adapt the beam to the cavity entrance. As the space charge compensation is affected in the magnetic region, the First Step LEBT will be modified in order to compare beam transport through solenoid LEBT and one equipped with quadripoles and especially to understand the space charge compensation in each beam line. The upgraded version (or Second Step) of this LEBT is made up of three parts.

A first part composed of two solenoids: a compact design for IFMIF EVEDA has already been realized[2,7] for controlling and reducing as much as possible the emittance growth. Some diagnostics will be necessary for beam measurements, just like the diagnostic box developed for the First Step LEBT.

A symmetric magnetic dipole deflects the beam into one line or the other without any focusing. The primary design has been realized and is compatible with an 80 mm beam diameter. The beam emittance is the same at the two exits of the dipole, finally, the two beam lines, one made up of quadripoles and the other one with solenoids. Faraday cups and emittance meters will be installed at the beginning and at the end of both part of these LEBTs.

This upgraded version has been initiated with the CEA Saclay proposal to get regional funding support from Region Ile de France.

V. CONCLUSION

The evolution of the IPHI test bench availability in Saclay led us to design and built a new test bench for ion source testing. A smaller accelerator column for Spiral2 ion source has been mounted on the new BETSI test bench and delivers 25 mA for proton beam production. A simple LEBT is under construction with a mass analyzer dipole, and also an upgraded version has been designed for a better understanding of the space charge compensation in solenoid or quadripole low energy beam line transport.

[1] R. Gobin *et al.*, Rev. Sci. Instrum. **77**, 03B502 (2006).
[2] O. Delferrière *et al.*, Rev. Sci. Instrum. in these proceedings.
[3] J.-M. Lagniel, Rev. Sci. Instrum. **71**, 830 (2000).
[4] O. Tuske, Rev. Sci. Instrum. **77**, A507 (2006).
[5] A. Ben Ismail, Proceedings of 2005 Particle Accelerator Conference, Knoxville, June 2005 (unpublished), p. 2947.
[6] A. Ben Ismail, Phys. Rev. ST Accel. Beams **10**, 070101 (2007).
[7] R. Gobin, Rev. Sci. Instrum. in these proceedings.