A NEW BETSI TEST BENCH AT CEA/SACLAY

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Abstract

By the 90s, CEA has undertaken to develop the production of high intensity light ion beams from plasma generated by electron cyclotron resonance (ECR). Important results were obtained with the SILHI source in pulsed or continuous mode. Presently, CEA/Saclay is now involved in the construction of different injectors dedicated to large infrastructures like IFMIF or SPIRAL2. Other installations are also interested by high intensity ion sources like ESS or FAIR.

To improve and test new sources, a new test bench named BETSI (Banc d'Etudes et de Tests des Sources d'Ions) is now operating for several years. Low energy beam line diagnostics consist of a Faraday cup, cameras and a species analyzer. The SILHI emittance scanner can also be installed on the beam line. On this test bench, different permanent magnet source configurations are tested.

INTRODUCTION

In the middle of the 90s, CEA/Saclay developed the SILHI source, operating at 2.45 GHz and based on the Chalk River (Canada) principle. More than 100 mA proton or deuteron beams are routinely produced in pulsed or continuous mode. To answer new machine requests, specific source designs have already been performed. For example, a permanent magnet source has been developed to fit in with the 5 mA deuteron expected beam for Spiral 2. Then, to answer the IFMIF (International Fusion Material Irradiation Facility) high intensity deuteron beam request (125 mA), a copy of the SILHI source with a 4 electrode extraction system has been proposed.

Since the IPHI project will enter in a new phase of development, the availability of the SILHI platform will be reduced for source developments. Therefore, the construction of the new test bench named BETSI (described in the following section) has been decided [1]. Up to now, a new accelerator column designed for the Spiral2 ion source has been installed and tested on this test bench. Several simulations have been realized to find an optimization of magnetic configuration.

THE BETSI TEST BENCH

The Low Energy Beam Transport

The BETSI test bench is dedicated to study the influence of the source parameters on the beam characteristics. It operates up to 50 kV and ignites continuous or pulsed hydrogen plasma with a 2.45 GHz magnetron. The LEBT is composed of a pair of solenoids that has to reduce beam divergence and focus it into a classical mass analyzer magnet (Fig. 1).

Between the pair of solenoids and the analyzer magnet, a pumping and diagnostic box is installed. The analyzing part is composed of a vertical and horizontal viewport for CCD camera diagnostics and a vertical movable Faraday cup. Pumping of LEBT is realized by a turbo molecular pump of 1000 l/s, it allows easily obtaining vacuum of 10^{-4} Pascal. A beam stop with magnetic electron reppeler is installed after the mass analyzer for ion beam intensity measurement.

Currently, the two old solenoids have been installed close to each other to obtain a magnetic field as high as possible to focalize the extracted beam. But the field strength is not high enough to focalize H_2^+ or H_3^+. New solenoid, including vertical and horizontal steerers has been designed and built to replace them. It length is 310 mm (including the magnetic shielding) with a maximum magnetic field of .85 T. It will be installed during the next months.

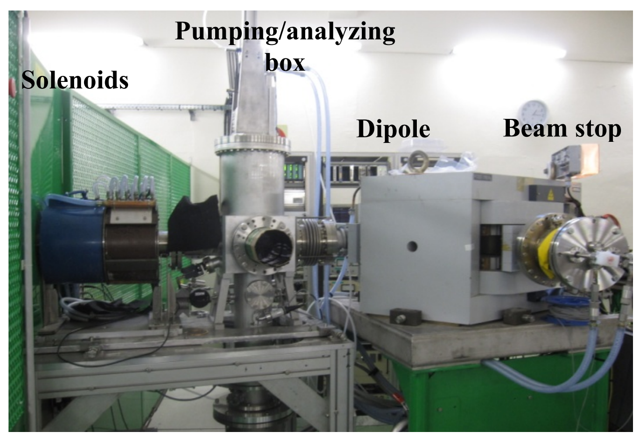

Figure 1: The LEBT of BETSI test bench

The analyzer magnet is a 104° dipole with a radius of 400 mm and double focusing corners. The magnetic field homogeneity within 110 mm from the axis is better than 10^{-3}, for a maximum transverse field of 230 mT. The dipole chamber height is 80 mm. The analyzer dipole is monitored by a Labview program and allows to realize spectra in order to dissociate the three H^+, H_2^+ and H_3^+ species in the beam. A species analysis with transport optimization of both H^+ and H_2^+ is presented in Fig. 2. This optimization is obtained by varying pair of solenoids focalization field. These measurements have been done by successively optimizing H^+ and H_2^+ transport in order to really determine the effective species fractions.

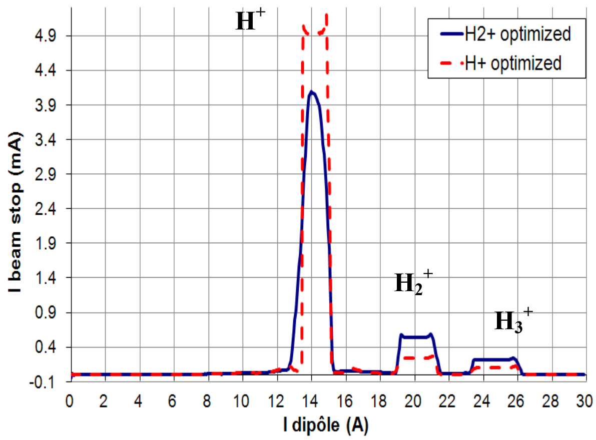

Figure 2: Spectra obtained by analyzer dipole

Easy source system assembly

Ion sources are positioned on a movable table on the test bench that allows quick and easy connection to the beam line. Plasma chamber and RF window are water cooled and the gas injection system is located on high voltage platform close to the source insulated table (Fig. 3). The radio frequency wave injection is produced by a magnetron located at ground potential and fed to the plasma chamber via rectangular waveguides and a DC break. For small extraction hole on the plasma electrode (due to low expected current) an additional pumping is installed on the high voltage table (between the bend and the ridged transition). Such additional pumping allows minimizing the impurity production.

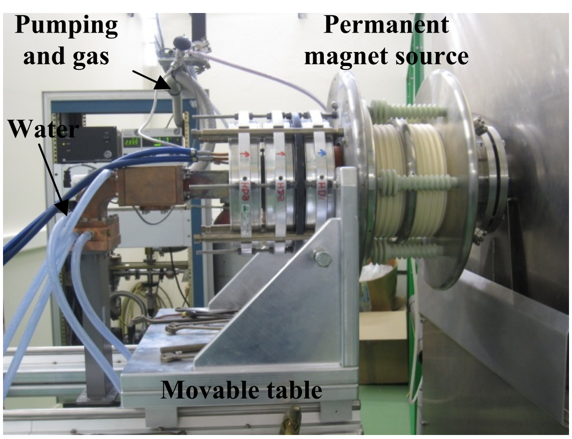

Figure 3: Source on movable table

PERMANENT MAGNET SOURCES

SILHI test bench experiments

First tests with permanent magnets sources were realized on SILHI test bench. The magnetic field is provided by several ring-shaped permanent magnets (with axial orientation) instead of 2 solenoidal coils.

A source with 3 magnets and appropriate shieldings has been installed. Electromagnetic simulations have been carried out to reproduce at best the SILHI source magnetic field profile on the axis. Even if the ECR resonance has been easily adjusted, first experiments showed Penning discharges occurred in the extraction system with the SILHI extraction system [2]. It came from the particular permanent magnet configuration built without shielding. To reduce the magnetic field in that accelerator column, an iron shielding was introduced as close as possible to the extraction hole (Fig. 4).

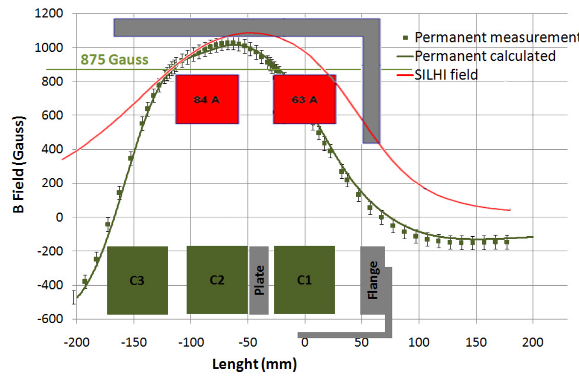

Figure 4: Simulation of iron tube effect on magnetic field with permanent magnet

On the BETSI test bench, the accelerating column (Fig. 5) diameter is reduced from 400 to 200 mm [3] that implies changing the electrode shape and size, which has as consequences to modify electric field distribution in the far axis region. Thus with this new accelerating column, no Penning discharge is occurred for mainly magnetic configurations.

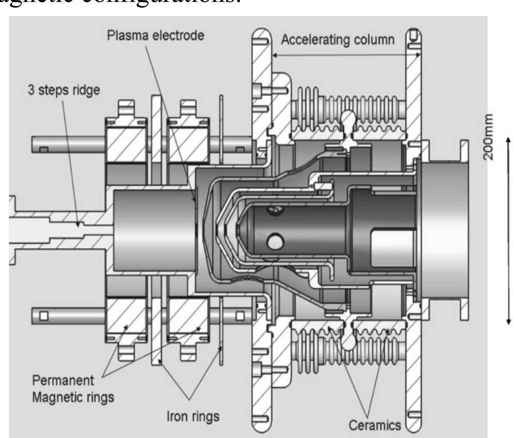

Figure 5: SPIRAL2 permanent magnets source

Magnetic optimization on BETSI

The developments realized on BETSI test bench are focused on magnetic optimization of permanent magnet sources. In order to simplify the shielding, several magnetic simulations were realized with 2 or 3 permanent magnets rings (Fig. 6). Field map shows the role of iron plates or flange for increasing magnetic field on axis at the ring position or reduce fringe field in the accelerating column. White zones correspond to field higher than 0.2 T.

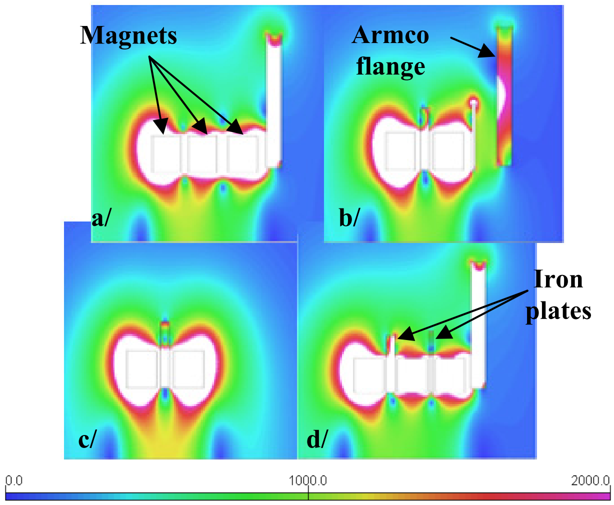

Figure 6: B field map for different permanent magnetic configurations (a/ 3 magnets, 1 flange; b/ 2 magnets, 1 flange, 2 plates; c/ 2 magnets, 1 plate; d/ 3 magnets, 1 flange, 2 plates)

The best results were obtained with 2 permanent magnets and 2 plates (one of 15 mm thick located between the 2 magnets, and the second one of 5 mm on the extraction electrodes side) shown in Fig. 7. The two resonant zones of 87.5 mT were respectively located near radio frequency input and near plasma extraction electrode. A 5.7 mA total beam was extracted with 86 % of H^+ (Tab. 1).

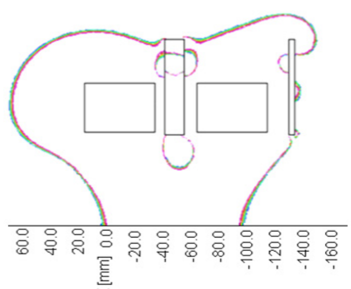

Figure 7: Optimized magnetic configuration and 87.5 mT ECR location

Table 1: Source and beam characteristics

SOURCE CHARACTERISTICS			BEAM CHARACTERISTICS		
Electrode Φ3mm					
Gas flow	0.95	sccm	**Total current**	5.75	mA
Pressure	$5.1.10^{-6}$	Torrs	**H^+ max current**	4.97	mA
e^- Filter	-1.5	kV	**H_2^+ max current**	0.54	mA
HTEI	20	kV	**H_3^+ max current**	0.24	mA
HT	40	kV	**H^+/total**	86.41	%
PHF	550	W	**H_2^+/total**	9.45	%
Pulsed time	50	ms	**H_3^+/total**	4.14	%

The SILHI emittance scanner has been installed on the diagnostic box after the solenoids. A normalized emittance of 0.012 π.mm.mrad has been measured with a 2 mA proton beam extracted at 20 keV through a 3 mm diameter hole (Fig. 8). To produce such beam, the RF injected power reached 800 W.

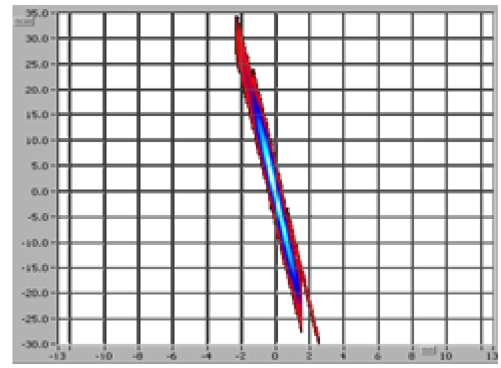

Figure 8: 2 mA H^+ beam emittance after the solenoids

CONCLUSIONS AND PERSPECTIVES

The new test bench named BETSI is now operating at CEA/Saclay, it allows developing and testing new ions sources and beam diagnostics. Several permanent magnets sources have already been tested. A configuration with 2 magnets and appropriate shieldings allowed extracting 5 mA of H^+ at 40 keV with a 3 mm electrode diameter.

Moreover a new ion source and two other diagnostics are under installation in order to better understand the role of plasma chamber size and shape on the plasma-wave interaction. A plasma light emission diagnostic using spectroscopy is also under development for ECR plasma electronic temperature measurements. A second diagnostic will allow measuring the absorbed power by the plasma using wide-band reflectometry technique.

ACKNOWLEDGEMENTS

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REFERENCES

[1] O. Tuske, "BETSI, a new test bench for ion source optimization at CEA SACLAY", Proc. of ICIS, Jeju, Korea, 2007.
[2] R. Gobin, "Development of a Permanent Magnet Light Ion Source at CEA/Saclay", Rev. Sci. Instrum. 77, 03B502 (2006).
[3] R. Gobin, "Development of a permanent magnet ECR source to produce 5 mA deuteron beam at CEA/SACLAY", Proc. Of LINAC04, Lübeck, Germany, 2004.