CEA/SACLAY LIGHT ION SOURCES STATUS AND DEVELOPMENTS

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Abstract

After several years of high intensity light ion beam production with the SILHI source, CEA Saclay is now involved in the construction of different injectors dedicated to large infrastructures like IFMIF or Spiral 2. Other installations are also interested by high intensity ion sources. Such machines plan to produce and accelerate proton or deuteron beams in pulsed or continuous mode. The SILHI source, based on ECR plasma generation, already demonstrated its performance in both modes.

As a consequence, at present time the construction of 2 new injectors for Spiral 2 and IFMIF (source and low energy beam lines) is in progress at CEA/Saclay. This article will report on the status of both installations. It will also point out on ongoing developments. Such developments are mainly done with the new BETSI test bench operating for several months.

INTRODUCTION

In the beginning of the 90s, Chalk River (Canada) laboratory group demonstrated the production of intense single charge light ion beams with ECR sources operating at low frequency (i.e. 2.45 GHz). At CEA/Saclay, the SILHI source developments started in the middle of the 90,s. Since 1997 more than 100 mA proton or deuteron beams are routinely produced in pulsed or continuous mode with this source [1]. To optimize the beam transport in the low energy beam line, the extraction system was carefully designed and space charge compensation studies were undertaken. Moreover, to comply with new infrastructure requests, specific source designs have been performed.

As a consequence, permanent magnet sources have been developed to fit in with the 5 mA deuteron beam expected production in continuous mode for Spiral 2 [2]. Then, to answer the IFMIF (International Fusion Material Irradiation Facility) high intensity deuteron beam request (125 mA) [3], a copy of the SILHI source with a 4 electrode extraction system has been proposed. Table 1 summarizes the Spiral 2 and IFMIF requested characteristics at the injector and RFQ interface.

Such proposals were accepted and now both injectors for Spiral 2 and IFMIF are presently under construction at CEA/Saclay, as reported in the following sections. In parallel, the SILHI installation is used for optical diagnostic improvements or tests dedicated to the mentioned projects.

As reported in the last section, new developments have been undertaken towards beam profile reconstruction using tomography technique. It is also planned to install a new solenoid on the BETSI ion source test bench, in order to allow molecular ion focusing in front of the analyzing dipole.

All this work is performed within the PROFIIL (Plateforme de Recherche et d'Optimisation des Faisceaux Intenses d'Ions Légers) platform.

Table 1: Spiral 2 and IFMIF requests at the RFQ entrance.

Requests	Unit	Spiral 2	IFMIF
Particle type		(H^+), D^+	D^+ , (H_2^+)
Intensity	mA	0.15 to 5	140
Energy	keV	(20), 40	100
Emittance	π.mm.mrad	0.1	0.2
D^+ fraction		99	99
Mode		CW and pulsed	CW and pulsed

SPIRAL 2 INJECTOR CONSTRUCTION

Several years ago, permanent magnet source has been developed to produce several mA of H^+ or D^+ beams [4]. So, the Spiral2 ion source, presently installed at CEA/Saclay (Fig. 1) is also based on the ECR heating plasma, with a permanent magnet induced magnetic field. Magnet rings are composed of several individuals magnets glued together in an aluminum shell. Magnetic orientation follows the source axis. Shielding plates are positioned in order to concentrate the magnetic flux on source axis and to reduce fringe field which avoids Penning discharges inside the accelerating column. The resonant zone (of 87,5 mT) for plasma heating is located near the ridged transition-plasma chamber interface.

Extraction column is composed of 5 electrodes and is not water-cooled. The gaps are optimized for the lowest extraction RMS emitance: calculations were made for 10 mA of proton beam at 20 keV and also 10 mA of deuteron beam at 40 keV.

At end of 2009 the ion source has been tested with hydrogen gas injection in the plasma chamber, in pulsed and CW mode. The extracted ion beam was collected just at the end of the accelerating column in a Faraday cup equipped with an electron repeller electrode. A total beam of 12 mA has been extracted from the ion source without any characterization. Figure 2 presents repetitive 8 mA

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pulsed beam extracted (pulse width 200 ms at 1 Hz) with 700 W fed to the plasma chamber.

Fig. 1: Spiral 2 ion source on its HV table

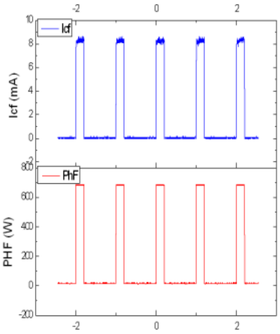

Fig. 2: H$^+$ beam produced with Spiral 2 source

The total LEBT (Low Energy Beam Transport) length from the source to the RFQ entrance, presently under construction (Fig. 3), will be assembled and characterized at Saclay.

Fig. 3: Spiral 2 LEBT under construction at Saclay

IFMIF INJECTOR CONSTRUCTION

In parallel, during the IFMIF-EVEDA (Engineering Validation and Engineering Design Activities) phase, CEA is in charge to build and characterize the injector (source + LEBT) at Saclay, before its transfer on the Rokkasho site in Japan.

The 100 keV beam energy request imposes to install the whole source and its ancillaries on a High Voltage platform. Since the magnetic shielding has been reduced to cover only the 2 coils, the IFMIF source design slightly differs from the SILHI one. Concerning the RF chain, the 2.45 GHz RF power is fed to the plasma chamber via an automatic tuning unit, rectangular waveguides, a 3 step ridged transition and a quartz window. A fast magnetron interruption system, developed by Sairem© is linked to the machine protection system. The water cooled plasma chamber is also equipped with 2 boron nitride disks at both extremities.

In order to minimize the beam divergence at the exit of the accelerator column, one of the most important changes compare to SILHI installation is the extraction system where the electrode number is reduced from 5 to 4 [5]. Such system allows keeping meniscus tuning with a puller to minimize beam looses on the electrodes. Then the puller is followed by the electron repeller and the grounded electrode.

Emittance growth has already been observed in the LEBT. As a consequence, to limit this effect, the length of the line has been reduced as short as possible. Numerous simulations were performed with the SOLMAXP code to better understand the space charge compensation evolution in the transport devices [6]. The use of short solenoids (310 mm long with shielding) allows limiting the total LEBT length at about 2.0 m.

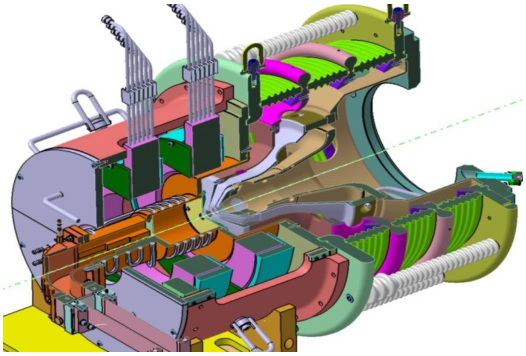

Fig. 4: IFMIF injector source and extraction system

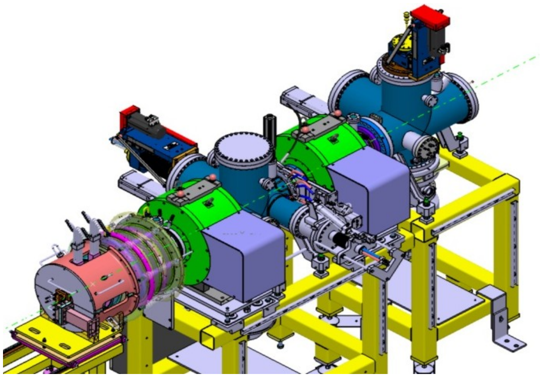

Fig. 5: General injector set up

SILHI AS DIAGNOSTIC TEST BENCH

As previously mentioned, both projects (Spiral 2 and IFMIF) need deuteron beams. Even at low energy, (D,d) reaction occurs when the D$^+$ beam interacts with implanted deuterium in the beam line material surfaces. Therefore beam losses (due to interceptive diagnostics or undesired particles) in the LEBT will lead to important neutron production.

To increase the reliability of the IFMIF injector which is more powerful than the Spiral 2 injector, great care has been done to minimize electronic devices inside the vault and to choose radiation hardened equipments. Following this strategy, the SILHI beam has been used to test CID (Charge Injection Device) cameras and a hardened fiberscope devoted to beam images transport towards a monochromator located outside the accelerator vault.

One CID8726DX6 camera from Thermo CIDTEC has been tested on the SILHI source with a 25 mm objective lens (Fig. 6). FWHM (full width at half maximum) beam profile comparison with CCD camera measurements showed quite good agreement; a difference of only few percent has been observed [7].

Comparative image acquisitions have also been done with and without a hardened fiberscope inserted between the beam line viewport and a CCD camera. The average FWHM difference with and without fiberscope remains in the range of 10 %.

As a consequence, several CID cameras and a 20 m long fiberscope with the characteristics summarized in Table 2 will be installed on the IFMIF injector.

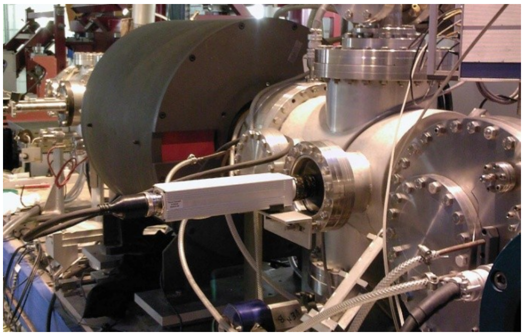

Fig. 6: CID camera tested on the SILHI source LEBT

Table 2: Fujikura fiberscope characteristics

Fiber Part No	FIGR-10
Number of picture elements	10000 +/- 1000
Image circle diameter (µm)	1100 +/- 100
Field of view	20 deg
Working distance	370 +/- 70 mm
Camera end	C-Mount camera lens

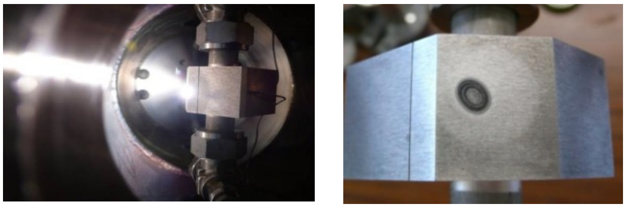

Fig. 7: Thermal screen models during and after test

High intensity beam power does not allow using the 3 gradient method (with optical profile) for emittance measurement. As a consequence, a classical Allison scanner, able to bear 15 kW cw beam, is presently under study. The thermal screen will be made of 2 water cooled copper block covered with tungsten wiles (assembled by brazing). The entrance slit will be defined by these 2 blocks. Two models, equipped with 2 thermocouples, have been tested with the SILHI beam (Fig. 7) to crosscheck the thermal simulations.

Beam density higher than 3 kW/cm^2 led to W tile deformation. In order to keep the slit width constant the beam power will have to be limited (roughly 1 kW/cm^2).

DEVELOPMENTS AND PERSPECTIVES

High intensity beam transport at low energy is a great challenge. In order to really well match the beam at the RFQ entrance, the beam characteristics such as position, profile, emittance, have to be perfectly known. Moreover, the beam power density can reach several 10 kW/cm^2. As a consequence, optical diagnostic development is ongoing for several years at CEA/Saclay. Presently, beam shape reconstruction using tomography technique is in progress within the DITANET Marie Curie European network [8].

To improve and test new sources, a new test bench named BETSI (Banc d'Etudes et de Tests des Sources d'Ions) is now fully operating for several months. It already allows source magnetic structure analysis as well as extraction system developments [9]. It also permits plasma emitted light analysis with a monochromator. In addition, BETSI is going to be renewed to be able to analyze each ion species produced by different tested ion sources. In particular, the molecular ions H_2^+ and H_3^+ are not sufficiently focalized before the analysis dipole. A new solenoid which is a copy of IFMIF solenoids able to focalize 175 mA beam in a strong focusing mode, has been built. It will be installed soon.

Since emittance investigation has been performed in pulsed mode with the SILHI source [10], FAIR project responsible decided to install such source with a 2 solenoid LEBT (built by CEA) to feed the future proton linac with up to 70 mA H^+ short pulsed beam at 4 Hz.

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