SACLAY HIGH INTENSITY LIGHT ION SOURCE STATUS

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Abstract

SILHI (High Intensity Light Ion Source) is an ECR ion source developed to produce high intensity proton and deuteron beams for the IPHI project (Injector of Protons for High Intensity). It will soon be moved to the demonstrator site. The IPHI prototype is developed by a CEA/DSM – CNRS/IN2P3 collaboration for several applications based on the use of High Power Proton Accelerators. The aim of the source is to produce up to 100 mA cw beams at 95 keV at the RFQ matching point. SILHI has been producing intense beams since 1996 and different beam line diagnostics allow beam characterization. A new extraction system and new control system led to large improvements in term of intensity, beam line transmission, stability. More than 130 mA are now routinely produced at 95 keV. This article will report a summary of the proton beam analysis, in cw and pulsed modes, pointing out parameters such as reliability, emittance, beam noise, stability. Deuteron pulsed beams (135 mA-95 kV) were also produced in the framework of the CEA participation to the IFMIF project. The deuteron beam performance will also be presented.

1 INTRODUCTION

For several years, in France, CEA and CNRS have undertaken an important R&D program on very high beam power accelerators. CEA is also implied in projects such as ESS (European Spallation Source) and IFMIF (International Fusion Material Irradiation Facility).

SILHI is developed to be the source of the IPHI prototype [1]. The SILHI main objective is to produce 100 mA proton or 140 mA deuteron CW beam currents at 95 keV with rms normalized emittances lower than 0.2 π mm.mrad. An electron cyclotron resonance (ECR) source has been chosen to reach these performances with a high reliability – availability. Experiments with SILHI are also devoted to the production of deuterons for IFMIF and a new test bunch is under study for H- ion production.

Since 1996, SILHI has been regularly producing proton beams, in cw or pulsed mode, with performance close to the request [2]. A new extraction system has been designed to minimize beam losses on the electrodes by reducing the initial divergence. Beam of more than 130 mA total current are now currently extracted (section 2). New reliability tests were performed to analyze EMI-hardened device improvements as well as automatic procedures. The first deuteron pulsed beam measurements are briefly reported in section 3. The source is presently disassembled to be installed at its final location in the IPHI site building.

2 PROTON SOURCE PERFORMANCE

2.1 General Layout

The ECR source operates at 2.45 GHz and the 875 Gauss ECR axial magnetic field is provided by 2 coils. The RF power is fed to the source through rectangular waveguides and a specific ridged transition. The source and its ancillaries are located on a 100 kV platform behind a protective cage. The source is running at 95 kV. A 5 electrode extraction system allow easy meniscus tuning to minimise beam losses and backstreamed electron limitation.

Different classical diagnostics (Faraday cup, insulated screens, cameras, current transformers, emittance measurement unit) allow beam characterisation in the 2 solenoid low energy beam transport (LEBT) line. As high beam density precludes from using interceptive diagnostics, specific optical diagnostic development are in progress to analyse the beam at the RFQ matching point [3].

2 turbomolecular pumps (1000 l/s each) are used to provide source and LEBT vacuum. The working pressure (with a 5 sccm hydrogen flow) turns out to be higher than 0.1 Pa in the plasma chamber and varies from 2 to 1 mPa in the LEBT.

2.2 Beam intensity and noise

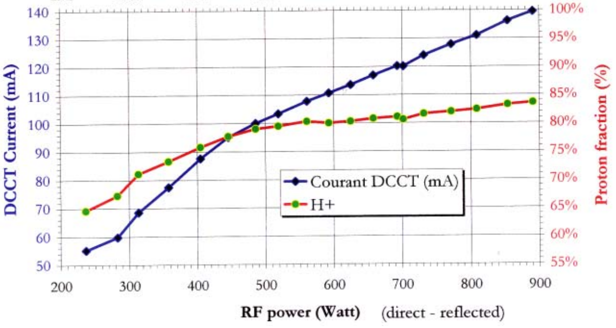

Fig.1: Extracted beam and proton fraction vs RF power

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The extracted beam intensity is checked by using DC or AC toroids as well as Faraday cup. The DCCT is located at the exit of the source and plots the total extracted current. A maximum of 157 mA has been observed and current as high as 130 mA are routinely extracted. Figure 1 shows the total extracted beam and the proton fraction plotted versus the effective RF power transferred to the plasma.

The 6 MHz bandwidth ACCT installed between the 2 solenoids allows beam noise analysis and/or pulsed beam monitoring. 19 kHz oscillations are transferred to the plasma from the magnetron RF switched power supply (see the recorded spectrum obtained with a 120 mA total beam Fig. 2). A 50 Hz ripple due to alternative magnetron filament heating is also observed. Nevertheless, rms beam noise lower than 1 % is currently achieved and fits in with the RFQ request.

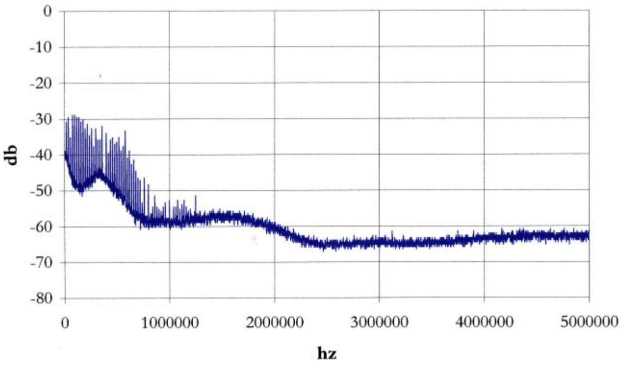

Fig.2: Beam noise spectrum for 120 mA extracted beam

Classical CCD cameras are used for beam position monitoring. Beam interacts with the residual gas in the LEBT and produces excited and ionised gas atoms. In the visible region, emitted light (mainly the Balmer lines of the atomic hydrogen spectrum) gives information on the beam position and current [4].

2.3 Emittance measurements

The emittance measurement unit could be placed in two different places either at the exit of the source (0.53 m from extraction) or 3.9 m further behind the 2 LEBT solenoids. First, the emittance has been analyzed as a function of the intermediate electrode voltage which modifies the extraction electric field configuration (Fig.3). This experiment has been done with a 97 mA proton beam (120 mA total). Extraction simulations indicated a minimum emittance value for a 40 kV first gap extraction voltage which has been confirm by the measurement. The r-r' rms normalized emittance value varies from 0.175 to 0.15 π mm.mrad while the intermediate electrode voltage is going from 27 to 49 kV. The minimum value has been obtained for 43 kV.

Then the EMU was moved to the second location. Emittance measurements were performed by tuning the intensity, the LEBT magnetic configuration and the intermediate electrode voltage. The beam emittance at the end of the LEBT depends dramatically on the LEBT solenoids values and looks quite stable by varying the extraction electric field configuration. A minimum value of 0.23 π mm.mrad has been observed downstream a cross over located at the future RFQ entrance for 70 mA transported proton beam.

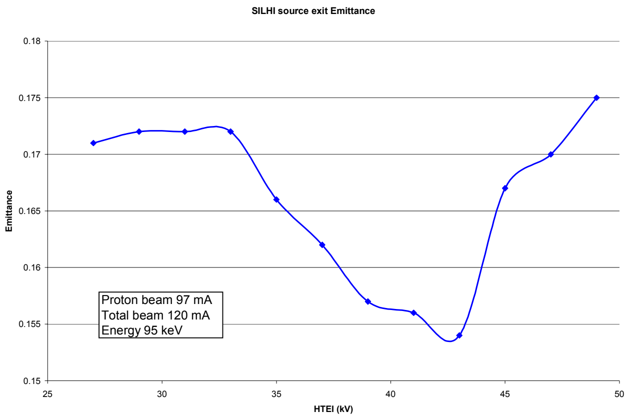

Fig.3: Source emittance vs intermediate electrode voltage

Previous work [5] also indicated the emittance is strongly dependent on the space charge compensation in the beam line. Heavy gas injection (Ar or Kr) in the LEBT creates a large amount of free electrons which allow space charge compensation and emittance improvements.

2.4 Reliability tests

Since SILHI delivered its first beam in 1996, several specific tests have been performed to analyze the source reliability-availability. To minimize possible breakdown and to optimize the reliability, different developments and technical choices were progressively adopted.

The following list presents several items developed in this framework:

- Quartz window protected behind a water cooled bend
- Electrode shape optimization to minimize the electric field and the spark rate
- Large safety margins on all Power Supplies (HV and others)
- Optimization of Power Supplies air or water cooling
- Separate cable path and shielding for signals and power
- Galvanic insulation of analog and digital signals
- Use of EMI hardened devices especially for all sensitive electronics and PLC
- Development of beam current feedback
- Development of EPICS automatic start/restart procedures

Table 1 summarises the 5 reliability runs. This table shows the reliability-availability can reach higher than 99.5 % with a very low number of beam off within a whole week. Since the source remote control is completely updated with the EPICS system, automatic procedures and home internet network connections allow us to leave the source working without any operator locally. In March 2001, an oil LEBT contamination led to a very high spark rate. To minimize new contamination risk, dry pump will be nearly installed.

Table 1: Reliability tests

Parameters	**Déc. 97**	**Mai 99**	**Oct. 99**	**March 01**	**June 01**
Energy (keV)	80	95	95	95	95
Intensity (mA)	100	75	75	118	114
Duration (h)	103	106	104	336	162
Beam off number	**53**	**24**	**1**	**53**	**7**
MTBF (h)	**1.75**	**4**	**n. appl.**	**≈ 6**	**23.1**
MTTR (mn)	**6**	**5.3**	**2.5**	**≈ 18**	**2.5**
Uninterrupted beam (h)	**17**	**27.5**	**103**	**25**	**36**
Availability (%)	**94.5**	**97.9**	**99.96**	**95.2**	**99.8**

Up to now, more than 800 hours continuous operation gave lots of information to optimize the source behavior. Several weak point have been solved. No spark occurs without beam after specific accelerator column conditioning. The use of EMI hardened devices enhanced dramatically the source performance. Sparks now do not lead to power supplies failures or PLC reboots. Moreover, as the source is also dedicated to other experiments like diagnostic developments or EPICS control improvement, short experiments indicated a lower spark rate with a lower beam intensity as well as with pulsed beam. These results will have to be confirmed by specific runs.

3 DEUTERON SOURCE PRODUCTION

For the IFMIF project, CEA analysed the characteristics of the deuteron beam produced by such an ECR source (with the 120 mA proton extraction system). To minimise structure activation, the deuteron beam has been produced in pulsed mode (2ms / s) by modulating the 2.45 GHz magnetron power. A 135 mA-100 kV beam has been easily produced and guided through the beam line with a 75 % transparency (Fig. 4). The deuteron fraction reached more than 96 % and D_2^+ was lower than 4 %. No D_3^+ or heavy masses were observed.

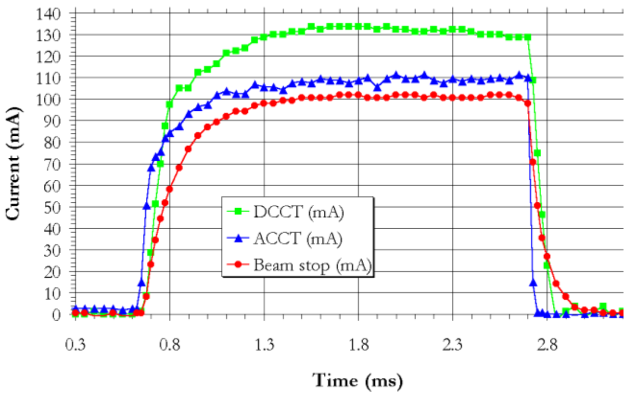

Fig. 4: LEBT transparency for 135 mA total deuteron beam

Coherent measurements (intensity, beam noise, species fraction) were checked for a 135 mA total extracted beam. Results are developed in a companion paper [6]. As a result, the SILHI source looks as well adapted for deuteron production as for protons. As the (d,D) reaction at the surface of the copper target produces 2.45 MeV neutrons, leading to a progressive activation level increase, the experiment has been done within only 2 days. Appropriate shielding will be necessary for further experiments.

4 CONCLUSION

The SILHI source, based on ECR plasma generation was built in 1996 and is, since then, regularly producing high intensity light ion beams. Table 2 summarises the beam characteristics either in Proton or Deuteron.

Table 2: SILHI beam characteristics

Particles	**PROTON**		**DEUTERON**	
Parameters	Requests	Status	Request	Status
Energy [keV]	95	95	95	100
Intermediate Electrode [kV]	55	56	?	50
Proton , Deuteron Current [mA]	100	108	140	129
Total Current [mA] **(I max)**	110	130 **(157)**	155	135 **(166)**
Proton, Deuteron Fraction [%]	> 90	83	> 90	96
Plasma electrode diameter [mm]	-	9	-	9
Current Density [mA/cm²]	140	204	243	212
Availability [%]	AHAP	> 99	AHAP	-
RF Forward Power [W]	< 1200	850	< 1200	900
Duty Factor [%]	100	100	100	0.2 *
H_2 , D_2 Gas Flow [sccm]	< 10	5	< 10	1
Beam Noise rms [%]	2	1.2	2	1.2
Source exit rms normalized emittance [π.mm.mrad]	0.2	0.15 @120 mA	0.2	-

*** Limited by neutron production**

SILHI has been recently stopped to be moved in the future IPHI site building. A previous move showed a minimum of 6 months will be necessary before to restart the source and recover the present results.

5 REFERENCES

[1] P-Y. Beauvais: "Status Report on the construction of the French High Intensity Proton Injector (IPHI)", this conference, THPLE028.

[2] R. Gobin et al.: RSI, Vol.73, n°2, February 2002 (922)

[3] P. Ausset et al.: Optical Transverse Beam Profile Measurements for High Intensity Proton Beam, this conference, THPRI066.

[4] B. Pottin et al.: "Optical beam profiler for high current beams, EPAC 2000, Vienna, Austria

[5] P-Y. Beauvais et al.: RSI, Vol.71, n°3, June 2000, (1413)

[6] R. Ferdinand et al.: "Deuteron Beam Tests for IFMIF", this conference, THPLE060.