NEW PERFORMANCES OF THE CW HIGH-INTENSITY LIGHT ION SOURCE (SILHI)

R. Gobin, P-Y. Beauvais, D. Bogard, G. Charruau, A. France,
R. Ferdinand, F. Harrault, J-L. Jannin, J-M. Lagniel, P-A. Leroy
Commissariat à l'Energie Atomique, CEA/Saclay, DSM - DAPNIA - SEA,
F 91 191 Gif sur Yvette, France

Abstract

The ECR source SILHI (High Intensity Light Ion Source) is being studied at CEA-Saclay to produce 100 mA proton or 140 mA deuteron beam. An output energy of 95 keV and an rms normalized emittance lower than 0.2 π mm. mrad were the target parameters. This source will be dedicated to the injector of the CW IPHI demonstration project. Extensive measurements have been performed with hydrogen as the injected gas. In April 1997, 108 mA of beam was extracted through an 8 mm diameter aperture plasma-electrode. The measured rms normalized emittance for an 80 mA of beam at 80 keV was 0.17 π mm. mrad. A new molybdenum plasma electrode with a 10 mm diameter-aperture allowed us to produce even higher i.e. 122 mA of total beam at 92 keV. We will compare the beam characteristics for both the extraction configurations. As a first attempt to measure the long term reliability of the ion source, 96% availability was recorded during 103 hours of continuous operation with a 100 mA of total beam at 78 keV. Complete results for this test-run will be presented. Initial results of operating the source in a pulsed mode will also be reported.

1. INTRODUCTION

This work is a part of a wide range of activities presently undergoing at the CEA in the field of high power proton or deuteron linear accelerators. We are studying the CW IPHI demonstration project [1]. This accelerator will consist of a high intensity light ion source (SILHI), an RFQ [2] and a DTL up to 10 or 11 MeV. The main applications of this kind of accelerators are the high flux neutron beam production for spallation reactions, the international IFMIF program and nuclear waste treatment.

The SILHI requirements are: 100 mA proton or 140 mA deuteron in more than 90% of the total extracted beam, at 95 keV and 0.2 π.mm.mrad rms normalized emittance. The ECR ion source operates at 2.45 GHz with an approximate 875 G axial magnetic field. The first proton beam was produced in July 1996.

Section II summarizes the ion source design and presents its performances with two different diameter plasma electrodes. This section also reports the long term reliability of the ECR ion source working in a continuous mode during more than one hundred hours. Section III describes the RF chain in pulsed mode and compares the first measurements achieved with plasma and pulsed beam.

2. SOURCE AND LEBT DESCRIPTION

The source is installed on a 100 kV high voltage platform. Both ends of the cylindrical plasma chamber are lined with 2 mm thick boron nitride discs. The plasma electrode is designed with a simple diameter aperture. Two different diameters (8 and 10 mm) have been tested.

The RF power is produced by a 1.2 kW magnetron source at 2.45 GHz. The RF is fed to the source through the quartz RF window via standard rectangular wave-guides with a four stub automatic tuning unit. A three-section ridged wave-guide transition is placed at the plasma chamber entrance to enhance the axial RF field. The magnetic field is produced by two or four coils tuned and positioned independently. Coils and plasma chamber are located inside an iron magnetic shield. All the source ancillaries are located on the platform.

The five electrodes extraction system has been computed with the multi-particles Axcel code [3]. An adjustable intermediate electrode is located in the acceleration gap to minimize the distortions in the phase-space distribution [4],[5] and to allow beam focusing. A slightly negative (about - 2 kV) electrode is inserted between two water cooled grounded electrodes to prevent electrons from residual gas ionization to transport to the extraction area.

The LEBT has been designed to characterize the extracted beam and to compare the results with computations. A 2200 Gauss, 500 mm long solenoid focuses the proton beam in the diagnostic box. Different classical diagnostics are used along the LEBT (CCD cameras, DCCT, ACCT, beam stops, thermocouples) [6].

The emittance measurement unit (EMU) is composed of a water cooled copper beam stop, with a 0.2 mm diameter aperture tantalum sampler and a 64 wire profile monitor. A Wien filter with a +/- 5 mrad total horizontal acceptance, allows the measurement of the only proton beam emittance.

All the beam analysis which have been done with a 8 mm diameter aperture plasma electrode, have been published at the last ICIS conference [7]. The main results are summarized in the third column of Table 1. New results with a 10 mm aperture are also shown in the last column of Table 1. The total extracted current is now about 122 mA, with a slightly lower proton fraction

TABLE I : SILHI source requirements and status.

Parameters	Request	8 mm aperture	10 mm aperture
Energy [keV]	95	95	92
Intermediate electrode potential [kV]	65	48	43
Proton extracted beam [mA]	100	91	98
Total extracted beam [mA]	110	108	122.5
Proton fraction [%]	> 90	84	80
Extracted beam density [mA/cm²]	140	215	156
Forward RF power [W]	1200	1100	1200
Duty cycle [%]	100	100	100
Hydrogen mass flow [sccm]	< 10	~2.0	~3.2
Beam noise [%]	± 1	± 2	to be done
LEBT rms normalized emittance [π.mm.mrad]	0.2	0.17 @ 80 mA	0.21 @ 97 mA

(80%), leading to 98 mA of protons, very close to the requirements. The rms normalized emittance of the 78 keV proton beam alone is measured at 0.21 π.mm.mrad with a 97 mA total current (77 mA proton current), which is in agreement with the RFQ requirements. Long term reliability testing has been performed with these beam conditions. The source has been continuously operated for 5-day (103 hours). The average reliability on this period is 94.9% (Fig.1). The operation has been interrupted basically by HV sparkdowns between electrodes. Most events occurred during the first 24 hours, and the rate of sparkdowns was pretty much lower on the rest of the period. The 35 breakdowns observed during the first 24 hours seem to be du to the conditioning.

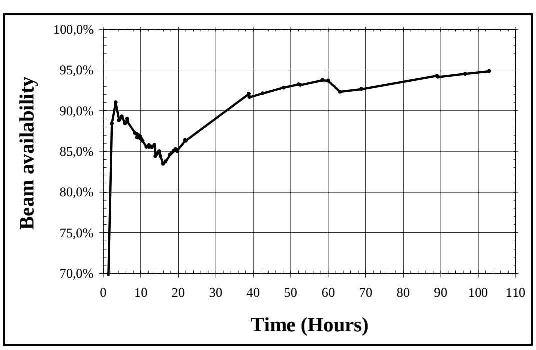


Fig.1: SILHI reliability vs elapsed run time

Two interruptions were also due to failures in the compressed air ancillaries. The mean time between failures (MTBF) for the last 80 hours of the run turns out to be 5.5 hours, and the mean duration of 85% of these failures is lower than 6 minutes.

3. PULSED MODE

In order to condition the high power, high current RFQ, it is desirable in a first step to use a pulsed beam, having nominal characteristics within the pulse, and a low duty cycle. This pulsed mode allows to prevent beam losses from damaging the structure. The present experiment shows that rather short rise and fall times are achievable by pulsing the RF power fed to the source. The bloc-diagram of the RF set-up is shown at Fig. 2. The # 1 circulator is used for magnetron locking, as already explained [7]: this eliminates the well-known drawbacks (load-pulling, frequency drift vs. power and poor spectral purity) of the magnetron. The # 2 circulator protects the RF transmitter against power reflected by the source. The spectrum analyzer is used to monitor the envelopes of the transmitted and reflected pulses. Their duration is 10 ms, with a 500 ms repetition interval, a 5 µs typical rise-time, and a 800 W forward power in the pulse. Fig. 3a shows the plasma pulse observed on the intermediate electrode polarized at -300 V. The rise-time (Fig. 3b) is about 10 µs, with a 40 µs fall-time (Fig. 3c). The beam pulse observed on the Faraday Cup (Fig. 3d) has a much longer rise-time of about 2 ms, with a fall-time lower than 100 µs. Several hypotheses have been tested to explain this phenomena, but none was really satisfactory. The large difference between rise and fall times seems due to beam losses on the extraction system which only induce HV intermediate electrode and electron repeller potential variation [8].

4. REMARKS

Despite promising results, a few improvements are still needed. The beam diameter is at present too large, and a new solenoid to be placed close to the HV column is under study. A magnetic deflector will be also added under vacuum to help align the beam axis on the RFQ axis. The long rise-time of beam pulses may be a problem for the RFQ injection. Additional measurements on the plasma will help understanding.

The long term reliability test shows that the duration of most of the failures is due to EMC (electromagnetic compatibility) problems, the high transitory currents generated by the sparkdowns inducing failures in electronic circuits or errors in digital lines. An on-going EMC effort already gave promising results.

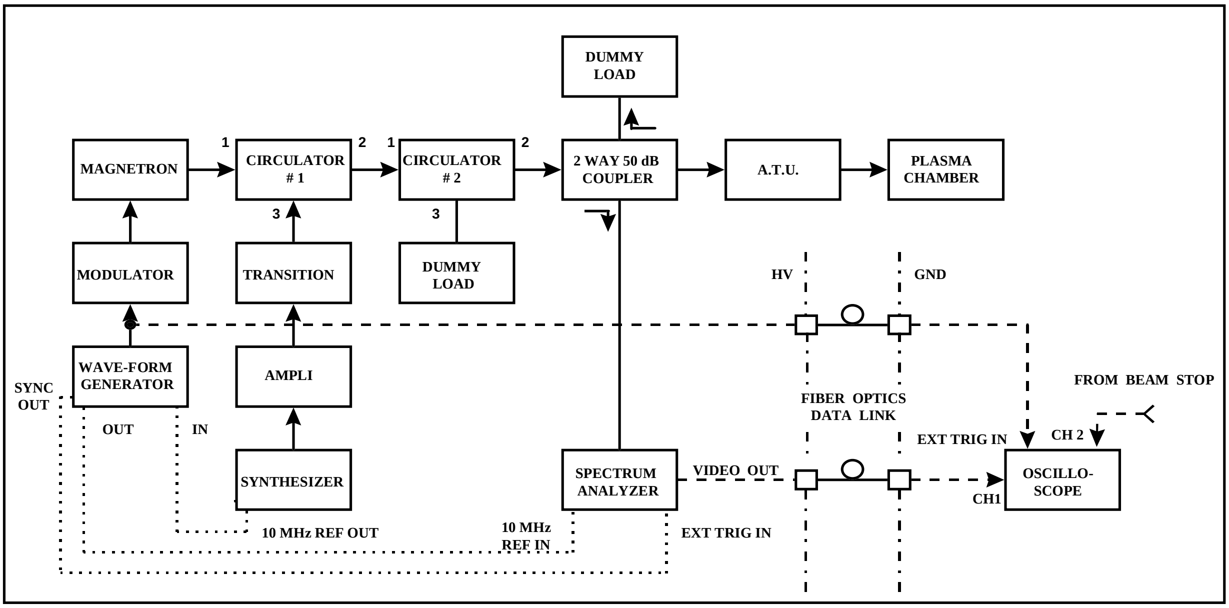
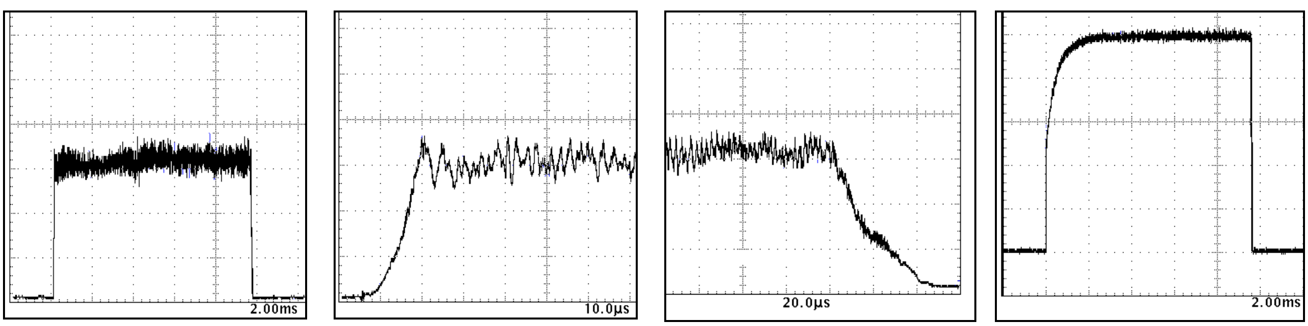


Fig. 2. RF system in pulsed mode, with injection-locking.



a b c d

Fig. 3: (a) 10 ms plasma pulse, (b) plasma rise-time, zoomed, (c) plasma fall-time, zoomed, (d) 10 ms beam pulse

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REFERENCES

[1] J-M. Lagniel et al., "IPHI, the Saclay High-Intensity Proton Injector project.", PAC Conference 1997 Vancouver Canada

[2] R. Ferdinand et al. "Parameter Optimization in RFQ Design",(this conference)

[3] P. Spädtke, "Axcel-V 3.42", INP, D-65205 Wiesbaden, Germany.

[4] A. France et al., "High-current proton and deuteron ECR source developments at CEA", EPAC 1996, Barcelona, Spain.

[5] P-Y Beauvais et al., "First Beam of the CEA-Saclay CW High-Intensity Microwave Source", PAC Conference 1997, Vancouver, Canada.

[6] P-Y Beauvais et al., "The Saclay high-current proton and deuteron ECR source", LINAC Conference 1996, Geneva, Switzerland.

[7] R. Gobin et al. "Last results of the continuous-wave high-intensity light ion source at CEA-Saclay", Rev. Sci. Instrum.. **69**, 1009, (1998).

[8] J. Sherman, private communication.

[9] J. Sherman et al. "Status report on a dc 130 mA, 75 keV proton injector, Rev. Sci. Instrum. **69**, 1003, (1998).