COMMISSIONING OF THE HIGH INTENSITY PROTON INJECTOR OF THE FACILITY FOR ANTI PROTONAND ION RESEARCH AT CEA-SACLAY

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Abstract

The Facility for Antiproton and Ion Research (FAIR) located at GSI (Darmstadt) in Germany addresses several fields of physics research within a single installation. These include the physics of exotic nuclei, hadron physics using proton-antiproton collisions, relativistic heavy ion reactions at a few tens of GeV per nucleon, plasma physics, and atomic physics. The FAIR accelerator complex will deliver stable and rare isotope beams covering a huge range of intensities and beam energies. A significant part of the experimental program at FAIR is dedicated to antiproton physics that requires an ultimate number 7.10^{10} cooled pbar/h. The high-intensity proton beam that is necessary for antiproton production will be delivered by a dedicated 75 mA/ 70 MeV proton linac. One of the contributions of Irfu/SACM at CEA-Saclay to the FAIR linear proton accelerator concerns the development and construction of the ion source and the low energy line.

The 2.45 GHz microwave ion source will deliver a 100 mA H^+ beam pulsed at 4 Hz with an energy of 95 keV. A low energy beam transport (LEBT) line based on a dual solenoids focusing scheme allows the injection of the proton beam into the radio frequency quadrupole (RFQ) within an acceptance of 0.3π mm.mrad (norm. rms). An electrostatic chopper system located between the second solenoid and the RFQ is used to cut the beam macro pulse from the source to inject 36 μs long beam pulses into the RFQ.

At the end of 2015, a first plasma of 80 Watt at 4 Hz has been produced by the FAIR proton linac ion source.

Then the commissioning of the injector has started beginning by the characterization of the ion beam just after the accelerating column.

This article reports the finalization of the installation of the injector with the details of dedicated diagnostics, the first beam measurements, and gives a planning of the different commissioning phases

INTRODUCTION

The beam commissioning at CEA/Saclay will be divided in three main phases.

- During the phase one, already started, the beam intensity, emittance and species proportion extracted from the source are measured at the source exit, just behind the accelerating column, using a dedicated diagnostic chamber (DIAG2).
- For the phase 2, the LEBT is assembled without the chopper. The same diagnostics are installed first in the FAIR injector diagnostic chamber (DIAG1) between the 2 solenoids, and in a second time the beam is analyzed in the chamber DIAG2 connected at the exit of the second solenoid.
- During the phase 3, the nominal source and LEBT apparatus is assembled. All the diagnostics of the diagnostic chamber DIAG1 are available. The chopper is tested. The beam intensity and emittance are measured after the injection cone. The FAIR p-linac source and LEBT are validated.

INJECTOR LAYOUT

The injector section of the FAIR p-linac [1-2] is composed by an ECR source, delivering a pulsed 100 mA H^+ beam (4 Hz) at 95 keV and a low energy beam transport line required to match the beam for the RFQ injection (Fig. 1). The LEBT is based on a dual solenoids focusing scheme. A dedicated chamber DIAG1 containing several diagnostics (Alisson scanner, Wien filter, SEM grid, Iris, Faraday Cup) will be located between the two solenoids. At the end of the LEBT, an electrostatic chopper system is foreseen to inject 36 μs beam pulses into the RFQ.

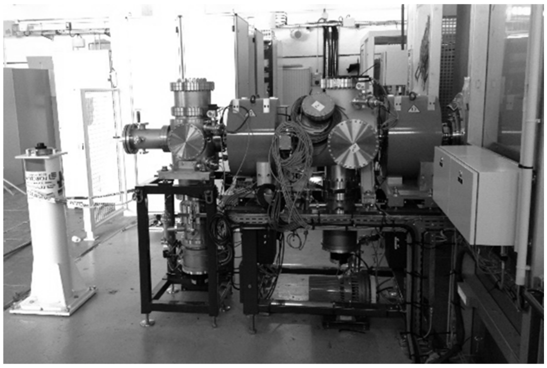

Figure 1: FAIR p-linac injector at Saclay.

ION SOURCE & LEBT REQUIREMENTS

The FAIR p-linac source & LEBT is aimed to produce a 100 mA/95 keV proton beam and to transport and match it for its injection into the RFQ. The main beam parameters that are required are summarized in Table 1.

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Table 1: FAIR p-linac Ion Source & LEBT Requirements

Parameters	Values
Specie	Proton
Energy	95 keV
Intensity	100mA
Time structure	Pulsed at 4 Hz
Energy spread	< 60 eV
Final emittance	$\leq 0.33\ \pi$ mm.mrad
α Twiss parameter	$0.27 \leq \alpha \leq 0.59$
β Twiss parameters	$0.037 \leq \beta \leq 0.046$ mm/π.mrad

Before the commissioning, the ion source accelerator column has been assembled with great care: the system is composed of 5 electrodes non-water cooled. Two plasma electrodes have been designed with aperture of diameter 6 and 9 mm. The 6 mm electrode has been installed for the beginning of the bias test and first plasma. The second electrode called “puller electrode” is biased negatively compared to the HT plate-form up to -50kV. The third electrode is a ground electrode followed by the reppeler electrode negatively biased. This electrode produces an electrostatic field to avoid LEBT free electrons to get accelerated by the positive electric field of the accelerating column and thus produce Bremsstrahlung radiation when they get stopped in the matter. The last electrode is also at ground potential.

BEAM DIAGNOSTICS

Beam Intensity Measurements

The LEBT will be equipped by several diagnostics in order to qualify the beam during the commissioning period but also for daily operation.

In order to measure the beam intensity (Fig. 2), two Alternative-Current Current Transformers (ACCT) have been installed. The first one is located after the source extraction and the second one, after the second solenoid before the chopper. These ACCTs have been designed by Bergoz Company in close collaboration with CEA, taking in account magnetic perturbation aspects. Because of the very short LEBT length (2.4m), ACCTs have been placed close to the solenoids and magnetically shielded to be operated in the solenoids fringe field environment. Bergoz Company did the manufacturing and ACCTs have been in the fringe field of IPHI LEBT second solenoid in order to verify the efficiency of the magnetic shielding and validate the ACCTs design before mounting on FAIR LEBT [3].

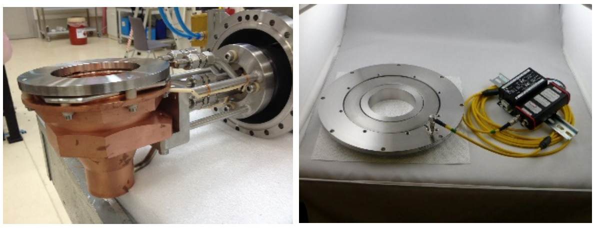

Figure 2: Faraday cup and Bergoz ACCT.

Emittance Measurements

An Allison scanner has been developed by IPHC Strasbourg to measure the beam emittance. The principle is to deviate a beamlet selected by a slit with the electric field produced by 2 bias plates and collect it on a faraday cup equipped with an electron repeller after passing through a second slit. A voltage ramp is applied to collect all the ions with their different initial divergence. All the beam is scanned by moving the system with a step by step motor. The Allison scanner could be placed either in vertical or horizontal position. Several modifications are undergoing to modify the command-control (in Labview FPGA) and also to increasing the shielding of the measurement head against free electrons perturbation.

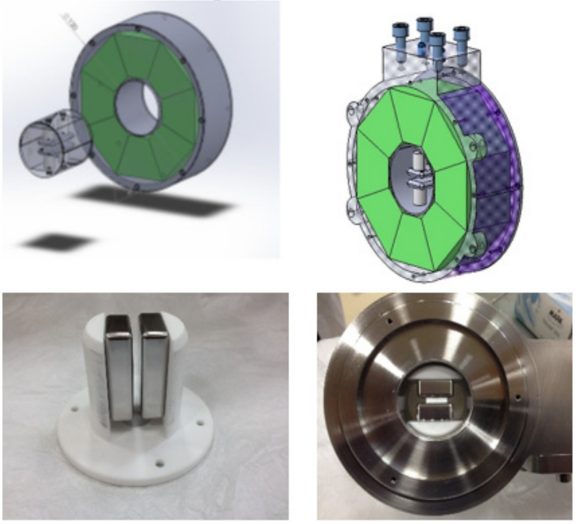

Figure 3: Wien filter, electrodes and Halbach permanent magnet dipole.

Beam Species Measurements Resolved in Time

A Wien filter (Fig. 3) to measure the proportion of the different ion species (H^+, H_2^+, and H_3^+) extracted from the ion source has been design at Saclay. It is a small device with a Halbach permanent magnet structure producing a dipole: configuration with 6 blocks encapsulated in a stainless steel shell. Two small plates for electric deviation with 6 mm space in between installed in the dipole magnetic field. The Wien filter is magnetically shielded by two 3 mm ARMCO plates at both extremities and protected by a tungsten thermal shield at the entrance, which has been assembled on a copper support with HIP technic (Hot Isostatic Pressure – 1200 °C, 1500 bars) by LITEN in Grenoble. The maximum magnetic field is 0.5 T and the field integral reaches 16.90 T.mm. In these conditions 6445 V between the 2 plates are necessary for H^+ selection. A sample hole of ∅0.25 mm trough the thermal shield defines the beam fraction to be analyzed. The selected specie exit the Wien filter through a ∅0.5 mm hole and collected on a plate. A negative polarized electrode before collection is used to eliminate secondary electrons emission. This device is aimed to be used on beam axis. All collected pulses are timed resolved and thus can reconstruct the beam species fraction at any moment during the pulse.

FIRST COMMISSIONING PHASE

The source and LEBT in its final configuration up to the second solenoid has been mounted, aligned and vacuum tested. The first plasma of hydrogen has been produced the 5th of November 2015, with 80 W power of the magnetron at 4 Hz. Then, the high voltage tests have been performed up to 100 kV with gas injection in the plasma chamber without any failure. From that time, the LEBT has been dismounted to allow mounting the DIAG2 chamber in order to fully characterize the beam extracted at the source exit.

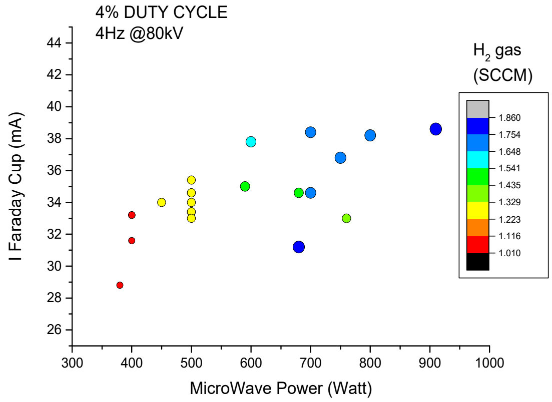

Figure 4: Measured current on the Faraday cup versus Injected Microwave Power in Watt.

A dedicated command-control has been written under Labview in order to remote control equipment on the high voltage platform, leading us to realize several commissioning tests before installing the GSI specific command control system. Several magnetic configurations where tested at 80kV extraction voltage in pulse mode, optimizing:

- the stability of the tuning over time,
- the extracted current pulse shape or the beam noise in CW mode,
- the maximal extracted current value.

In order to increase extracted current of the source, the injected microwave power and the injected gas flux must also be increased as well (Fig. 4). But what was not expected is that the magnetic coil tuning also has a quasi-linar behavior with the gas injection (Fig. 5). The magnetic calculations showed up that for all coils configurations, the resonant zone at 87,5mT is always positioned at the microwave injection point in the plasma chamber.

Maximal current extracted with the 6 mm aperture hole in the plasma electrode was 60 mA measured on the faraday-cup but this specific configuration is not reported on the figure because the tuning point was not stable enough. This extracted current lead to a density current equivalent to the SILHI source.

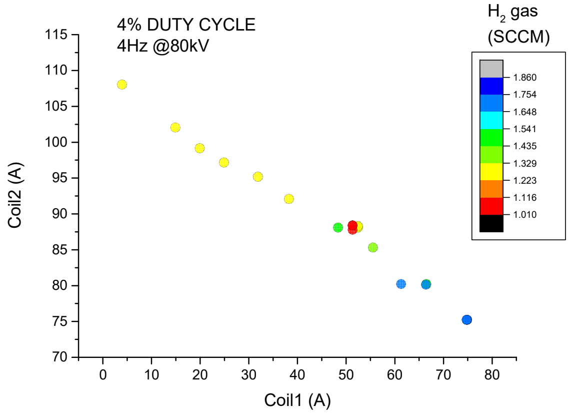

Figure 5: Source Coil Tuning for maximal Extraction recorded on the Faraday cup.

CONCLUSION AND PLANNING OF THE FUTURE WORK

The FAIR proton source has been installed in CEA Saclay with the whole LEBT. The first plasma and first beam where produced this year and preliminary measurements were carried out with only a current transformer and a faraday cup. As the other diagnostics are not completely fully operational at this moment, the next step will be to install the 9 mm aperture hole plasma electrode to achieve the expected beam current in pulsed mode. The source will be fully characterized before the end of the year 2016.

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