COMMISSIONING OF THE SPIRAL2 DEUTERON INJECTOR

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Abstract

The SPIRAL-2 superconducting linac driver [1], which aims at delivering 5 mA, 40 MeV deuterons and up to 1 mA, 14.5 A.MeV q/A=1/3 heavy ions, has now entered its construction phase in GANIL (Caen, France). The linac is composed of two injectors feeding one single RFQ, followed by a superconducting section based on 88 MHz independently-phased quarter-wave cavities with room temperature focusing elements. The protons/deuteron injector have been fully built and commissioned at CEA Saclay in 2012, before moving to its final installation at GANIL in 2013. Beam emittances have been measured at different positions of the LEBT and especially at the RFQ injection point. The space-charge beam compensation has been also carefully studied. This paper describes all the results obtained during this commissioning.

INTRODUCTION

The injector was originally fully installed in Saclay, (see Fig. 1), in order to demonstrate its ability to produce 5 mA proton and deuteron beams at 20 keV and 40 keV respectively, both in CW and pulse mode with an emittance of about 0.2 π.mm.mrad norm rms. Due to its very complex and original design, it has been built in a number of stages over a period of two years in order to be able to measure the beam characteristics t at various points along the line. This work was completed at the end of July 2012 with a range of diagnostic tests were carried out at the exact position to be occupied by the future RFQ within the injector. The obtained beam measurements were then used in a simulation model in order to estimate the beam characteristics at the RFQ exit. This is almost certainly the first time that a high intensity beam has been measured at the exact point of injection into an RFQ and then tracked through it using a simulation. The obtained results have confirmed the efficiency of the design and validated the program of tests carried out on the SPIRAL2 injector at Irfu. Meanwhile, space-charge compensation transient time has been carefully measured using the electrostatic chopper [2] installed in the line.

THE DEUTREON INJECTOR DESIGN

The 2.45 GHz ECR source for deuterons and protons, presently installed at CEA Saclay, is based on a permanent magnet design [3]. The associated deuteron LEBT line is based on the use of a double solenoid refocusing the source beam, followed by an achromatic double deviation that ensures an efficient separation of the deuteron beam from the molecular pollutants. The injection line is then composed by an electrostatic chopper followed by four quadrupoles allowing to control the beam sizes in both transverse planes and inject it in a 3*2 slits system, so as to reduce the beam emittances or the beam current if necessary. Finally, a double solenoid adapts the beam into the RFQ.

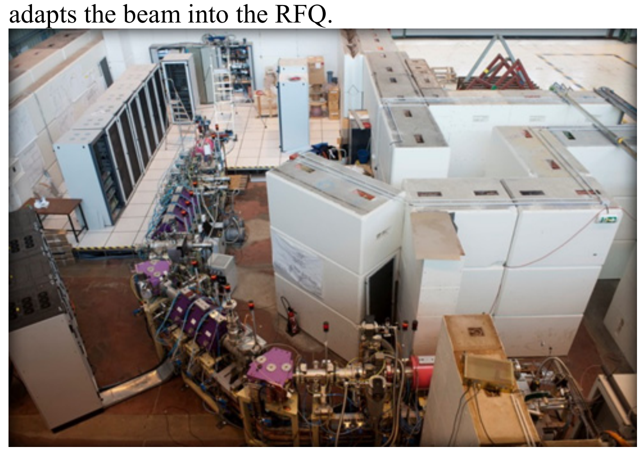

Figure 1: Picture of the full proton/deuteron injector installed in the Irfu bunker.

The detailed layout of the end of the LEBT is shown in Fig. 2. The emittancemeter has been located before and after the last solenoid in order to measure the beam just after the slits system and at the exact future RFQ injection point. Besides the 7 turbo pumps, an extra gas injection valve has been installed close to the last solenoid to ensure a better control of the vacuum in the last part of the line.

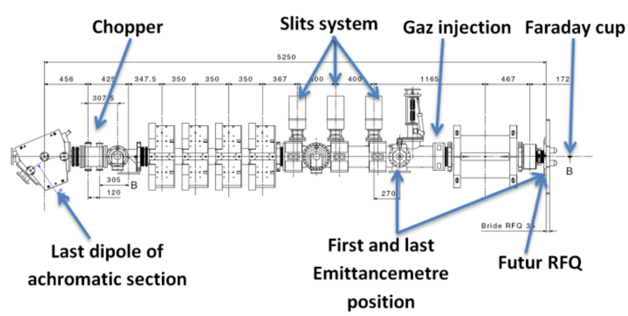

Figure 2: Scheme of the LEBT end.

SPACE-CHARGE COMPENSATION

The commissioning of the SPIRAL2 accelerator superconducting section will require very short beam pulses as clean as possible to avoid beam losses along the linac structures. Our capability to produce a pulsed beam as short as possible with reduced transients is essential for the commissioning phase, the first tuning stages, and the reliable routine operation of the accelerator. Pulsed beam is performed by pulsing the ECR source (rise time: a few ms) and is cleaned with the chopper device (rise time: 20 ns). To estimate the space-charge compensation transient time, a slit is closed enough to reduce by a few tens percent the beam current incoming to the final Faraday

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cup. As the beam shape keeps changing during the space charge compensation transient time, the signal observed on the Faraday cup therefore allows to get an indirect measurement of the space-charge transient time. This measurement has been done for 5 mA proton and deuteron beams with different gas pressures (See Tab. 1 and Tab. 2). The average pressure has been estimated by averaging the three measurement points along the line and it has been adjusted by progressively stopping the 7 turbo pumping devices available.

Table 1: Space-Charge Transient Time for Deuteron Beam

Pressure	SCC rise time
2.7 10^{-7} mbar	750 µs
1.5 10^{-6} mbar	500 µs
1.0 10^{-5} mbar	75 µs
1.7 10^{-5} mbar	40 µs

Table 2: Space-Charge Transient Time for Proton Beam

Pressure	SCC rise time
3.5 10^{-7} mbar	300 µs
7.5 10^{-7} mbar	150 µs
5.5 10^{-6} mbar	30 µs
1.2 10^{-5} mbar	15 µs

Even with 7 pumps regularly distributed, it's not possible to really well control the pressure, especially in the last line section. As soon as the pressure gets high, unacceptable beam losses occur along the rest of the line due to charge exchange, despite a 10 mA current reserve of the source to compensate it. Thus this method doesn't allow to decrease pressure below 1.0 10^{-5} mbar. Finally, the emittance measurements clearly show us that reaching a higher pressure, especially into the last solenoid, could be more comfortable for operation and could be implemented in the final Ganil installation, if needed, to improve the beam quality.

BEAM EMITTANCES

Even if the beam current is relatively low, 5 mA, at 20 keV, the space-charge is very strong in Spiral2 LEBT experiments. The space-charge compensation issue is very complex and experiments showed beam emittances strongly depending on pressure especially in the last solenoid: Figure 3 shows the 5 mA proton beam distribution obtained before the last solenoid and Figure 4 shows the same beam at the solenoid output, for various gas pressures in the last part of the line. Also, several gases have been tested. Finally, the emittance variation (See Fig. 5) at the RFQ entrance according to the partial pressure in the last solenoid roughly shows that whatever the gas type, the pressure seems to be the key point here to improve the beam quality injected in the RFQ.

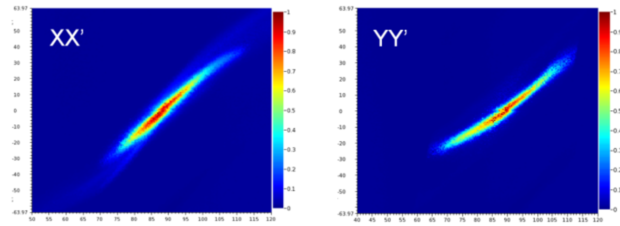

Figure 3: Both transverse planes of the proton beam at the last solenoid entrance at 1.5 10^{-5} mbar. $\varepsilon = 0.2\pi$.mm.mrad.

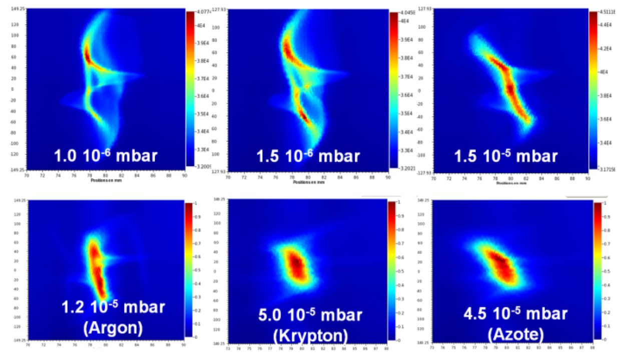

Figure 4: Some examples of the XX' plane of the proton beam at the solenoid output depending on the gas pressure including extra gas injection.

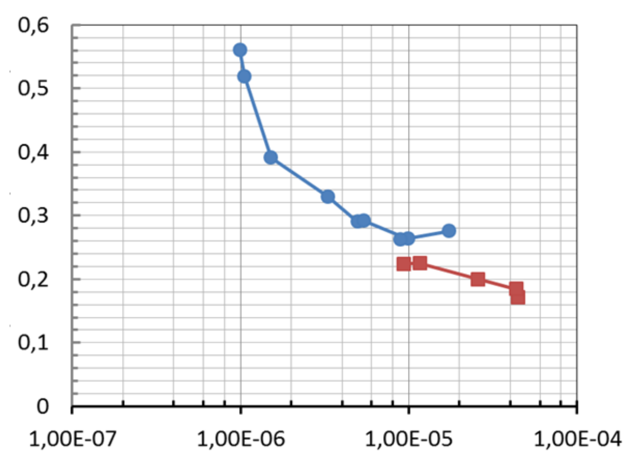

Figure 5: Proton emittance (π.mm.mrad) as a function of the line pressure (mbar). Red dots correspond to a pressure obtained by extra gas injection.

NOMINAL INJECTOR TUNING

In the last phase of the commissioning the full LEBT injector has been completely tuned in order to get the required input beam parameters at the RFQ entrance with proton and deuteron beams. The automatic tuning procedures defined by simulation using the CEA code TraceWin [4] have been validated (See Fig. 6). Finally, the nominal beam characteristics have been measured for both beams, for both planes in CW and pulse mode (See Fig. 7) and injected by simulation in the Spiral2 RFQ using the Toutatis [4] code. The measured deuteron and proton emittances were respectively, 0.2 π.mm.mrad and 0.23 π.mm.mrad.

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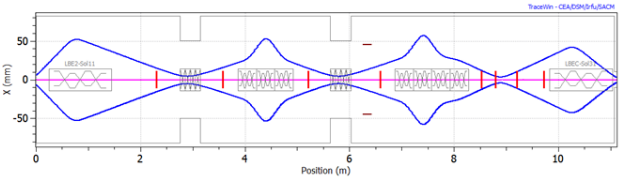

Figure 6: Simulation of the deuteron beam tuned envelope from source to RFQ.

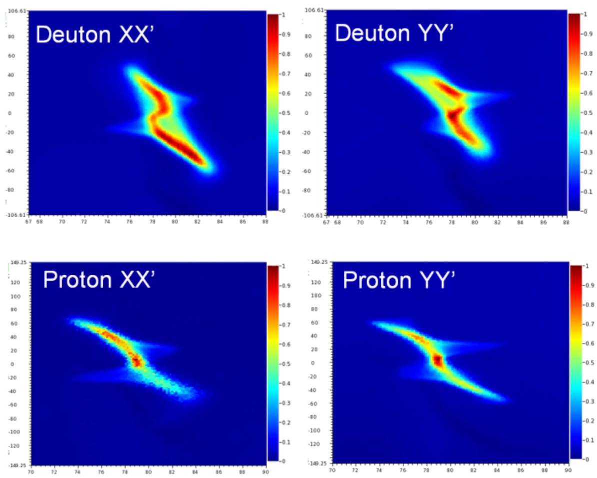

Figure 7: Deuteron and proton emittances at the exact RFQ entrance position at 5 mA in CW mode.

A 100,000 macro-particles distribution input beam has been created from the measured beam densities and injected in the Spiral2 RFQ (see Fig. 8). No loss and no emittance growth were observed.

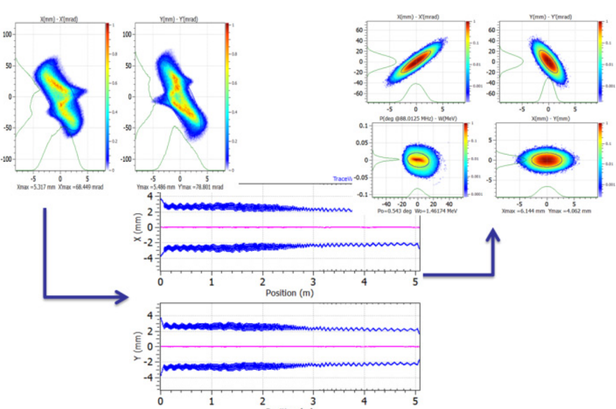

Figure 8: Envelopes of the Spiral2 RFQ simulation.

RELIABILITY AND STABILITY

A very important objective of the commissioning completed at Saclay was to assess the reliability of the whole injector. A test campaign was conducted during a whole week without any beam strip observed, while controlling and stabilizing the output current from the source better than one per cent. All in all, this very good reliability performance has been a very long-term work (2 years) for all the implied teams from Ganil, CEA/Irfu and LPHC Strasbourg.

CONCLUSION

The Spiral2 proton/deuteron LEBT injector has been fully commissioned at Saclay/Irfu. All the initial objectives have been achieved.

- **Reliability:** has been demonstrated with a final long beam test.
- **Reproducibility:** even after a long shutdown, nominal settings can be directly set back to ensure a beam transport in good conditions up to the point of injection of the RFQ.
- **Beam emittance characterization:** the full characterization of the output beams have been performed in pulsed and CW mode, with nominal current, 5mA, and very low current. Results are totally on line with the Spiral2 project requirements.
- **Space-charge compensation management**: the space-charge compensation has been studied and its transient time has been measured.
- **Tuning procedures**: they were all defined by simulations and validated with beam with almost no change.

  Pencil beam: a very stable pencil beam of a few 50 µA that could be used for the very first machine tunings, has been produced using the slits system, See Fig. 9.

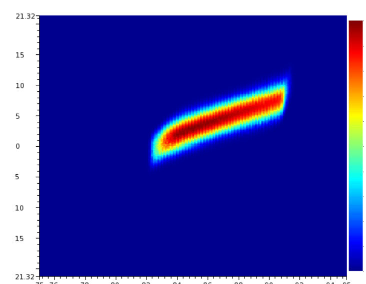
Figure 9: Pencil beam, 50 µA, ε=0.2 π.mm.mrad.

Today, LEBT has been moved at GANIL and, as soon as the building of the linac will be ready (in 2014), will be restarted to inject this time the beam inside the real RFQ cavity.

ACKNOWLEDGMENT

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