UPGRADE AND COMMISSIONING OF THE PIAVE-ALPI ECR INJECTOR AT LNL

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Abstract

The positive ion injector for the PIAVE-ALPI complex consists of an ECR ion source placed on a high voltage platform. A 14.4 GHz ECRIS named Alice [1], designed and constructed at LNL in the early '90, reliably delivered gaseous beams to the Superconducting RFQ PIAVE for nuclear physics experiments until 2008 [2]. The requests for heavy ion beams of increased current and energy, needed to perform the experiments planned for the next years with the AGATA demonstrator, prompted us to upgrade our injector with a new ECR source capable of higher output beam currents and higher charge states. This activity started in 2008 and was completed at the beginning of 2009.

A 14.5 GHz, SUPERNANOGAN type ECRIS built by Pantechnik [3], was installed in our refurbished high voltage platform in July 2008. The space available for maintenance in the platform was increased and a new lead shielding for X-rays has been set up. The water cooling circuits have been redesigned to deliver different fluxes and inlet pressures to the equipment mounted on the platform (plasma chamber, extraction electrodes, bending dipole and power supply). A new safety system has been implemented in order to cope with new and more demanding safety rules.

A lot of attention has been paid to the optimisation of the injection line with new diagnostic devices for beam characterisation (movable slits, emittance measurement tools). Commissioning of the new source and injector with beams has started and first results will be reported.

ECR SOURCE AND RELATED EQUIPMENT

The new ECR ion source, named LEGIS (LEGnaro ecrIS) is a full permanent magnet source working at 14.5 GHz. Good performance and low power consumption make it well suited for operation on a high voltage platform.

The source is equipped with a DC Bias tube, which works as a biased disk and coaxial tube for microwave coupling; a 1500° C resistive oven to evaporate solid material like silver or gold; a movable sputtering or direct insertion system to evaporate samples of refractory metals like tantalum.

The maximum microwave power that can be injected into the source is 700W with a water flow for cooling of 200 l/h at an input pressure of 3 bars.

The beam is extracted from the source through a four electrode system: the extraction electrode (V_{max}=30 kV), which gives the beam energy; the puller electrode (V= -5000 ÷ 0 V); the focus electrode (V = -5000÷5000 V) to directly couple the extracted beam to the bending dipole; the ground electrode. The source and its beam line are controlled via National Instruments FieldPoint modules that acquire all parameters and display them through a LabView interface.

All the beam line from the source to the accelerating tube has been redesigned in order to have good flexibility and complete beam characterization: to this scope, two independent movable slits (for beam shaping in both horizontal and vertical plane) and transverse emittance measurements device have been installed (see Fig. 1).

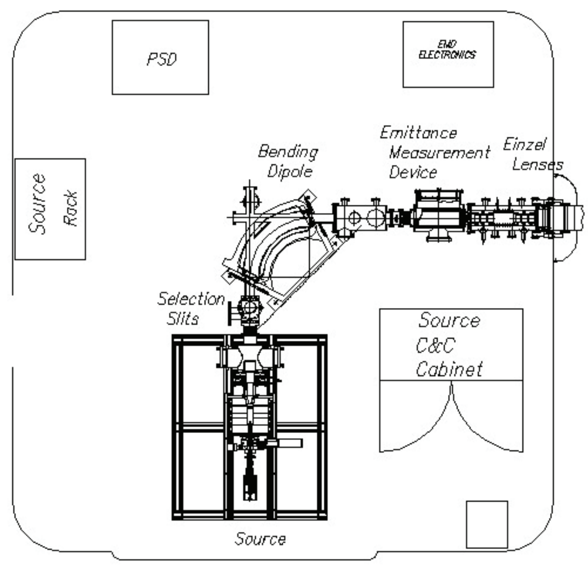

Figure 1: The complete beam line on the high voltage platform and its equipment.

Each slit consists of two water cooled tantalum plates, moved together by a stepper motor. Each plate has a current pickup in order to monitor the beam current lost on it. The plate aperture goes from 37 mm to 2 mm, with steps down to 0.1 mm.

Both slits are software-controlled in a LINUX environment.

The emittance measurement device consists of a slit-grid system (see Fig. 2). A common support holds a 0.12 mm copper slit with a tantalum shield and an 80 wires grid, with 0.5 mm spacing, 280 mm apart. They are centered and moved together by a remotely controlled motor.

The maximum stroke of the system is ± 30 mm while the maximum divergence that can be measured is more than 70 mrad. The resolution of the system (without considering mechanical errors) is 0.36 π mm mrad. The current collected by each wire is preamplified, acquired and processed by a program made in house. The gain of the preamplifiers can be varied in order to characterize beams with different intensities.

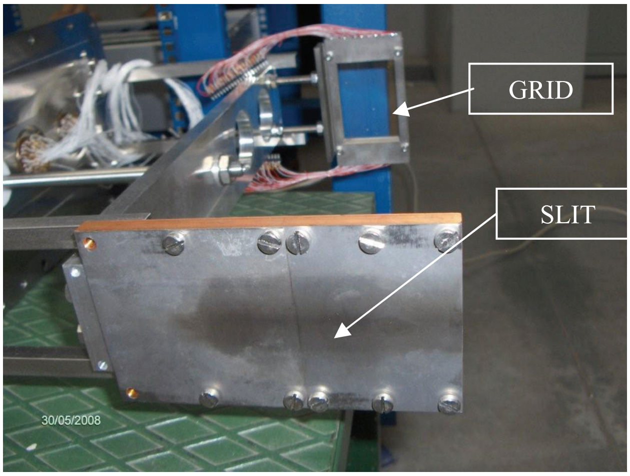

Figure 2: Detail of the slit-grid system for emittance measurement.

Two systems (one for each transverse plane) are mounted on a stainless steel box (Fig. 3) which houses also a Faraday cup and a collimator (an elliptical aperture with vertical axis of 24 mm and horizontal axis of 12 mm) mounted on CF flanges.

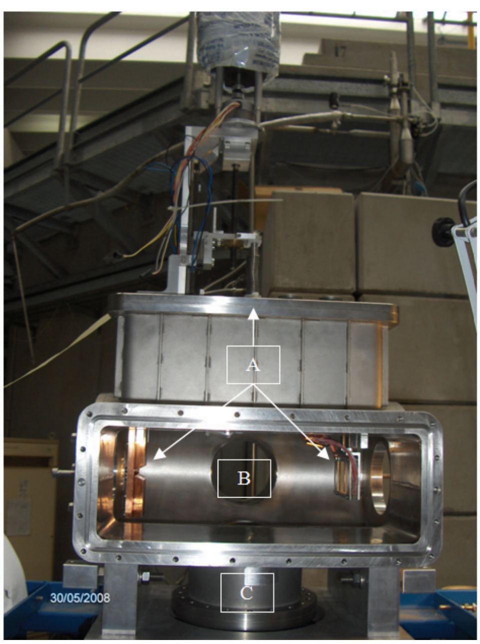

Figure 3: View of the stainless steel box for emittance measurement. A) slit-grid system mounted on a rectangular flange; B) horizontal mounting for Faraday Cup; C) vertical mounting flange for collimator.

In order to protect all the equipment mounted on the platform, a fire-fighting system that uses a mixture of water and nitrogen has been implemented. Sensors and expellers have been positioned close to all the critical points. To start the system, two sensors have to be activated but just one is sufficient to switch off the electrical power on the platform.

The vacuum system is now hardware-protected by means of relays: for each turbo pump, dry contacts coming from the vacuum gauge and the controllers have been put in series with +24 V power supply, in order to automatically close all the valves when the vacuum exceeds the operating threshold.

X-rays coming from the source during operation are stopped by a lead shielding (from the ion source to the bending dipole, see Fig. 4) designed at LNL and built by a local company.

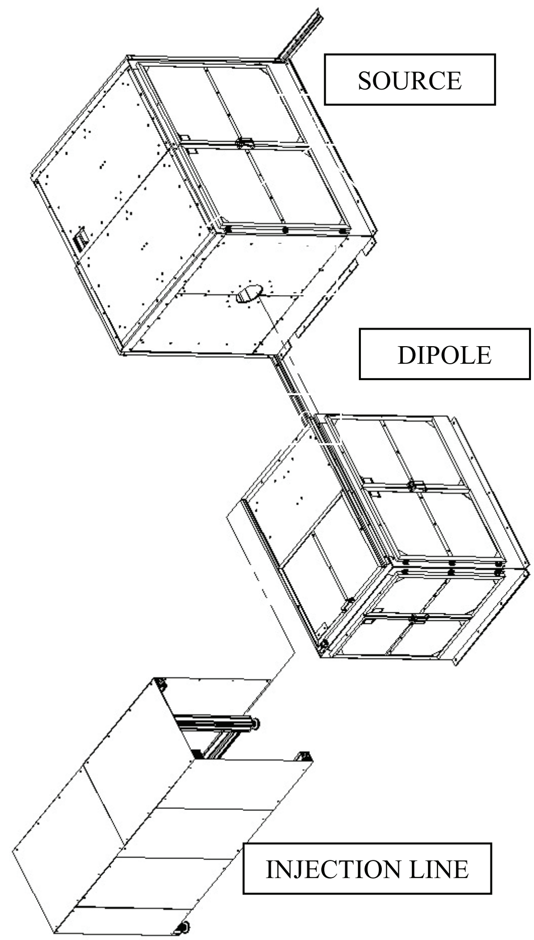

Figure.4: Lead shielding for the source line up to the bending dipole.

The whole beam line has been surrounded by aluminum profiles, creating three boxes. Two of them (one for the source and one for the bending dipole) have been covered with 1 cm thick lead shielding, sandwiched between two steel plates. Each face of the boxes (except for the upper parts) has two extendable shielding plates, forming a sort of window, in order to have easy access to the source for maintenance. The windows have micro switches which allow, when in closed position, high voltage and microwave feeding to the source.

ALIGNMENT [4]

During installation of the new source and its beam line it became necessary to check, and eventually improve, the alignment of the transfer line going from the source to the first dipole (PD1 from now on) which bends the beam towards the injection line of the PIAVE superconducting RFQ.

As a first step, the reference line of PD1 and the two 90° degrees line of the source dipole (LBD from now on) have been defined. Very precise tools (precision ± 0.005 mm) have been machined, controlled on a bench in the LNL workshop, and mounted on the two dipoles.

Two optical levels (model WILD NAK2) have been used: the first one to define the injection axis in LBD, the second one to align the extraction axis from LBD to the reference line of PD1. The tolerance requested by the beam dynamics calculations was ±0.2 mm and 0.4 mrad at the injection in PD1.

For each optical and beam diagnostic element (source electrodes, emittance measurement device, einzel lenses) special aluminum tools have been machined to house very precise (precision better than 0.1 mm) optical marks for the definition of the alignment axis.

When the use of these tools was not possible, due to mechanical restrictions (selection slits, accelerating tube, electrostatic triplet and first diagnostic box out from the platform), crosses with a 80μm tungsten wire have been paced on the flanges.

Independent supports (see Fig. 5) have been mounted at both ends of each beam line component (except for the emittance measurement device and the electrostatic triplet, hold by a single support).

Each support allows a rough regulation in height by means of M10 screws. The beam line component itself is supported by an aluminum plate with a fine regulation in all three directions: three vertical screws for the horizontal plane and 8 more screws for back-forth and left-right regulation. Once centered, the tube is fixed in position by aluminum cover. At the end of the work the precision requested was reached.

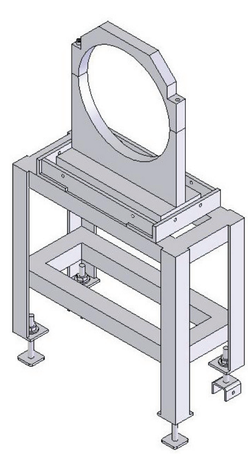

Figure 5: Special support for each part of the beam line.

ACCEPTANCE TESTS

In order to have a proof of good source performances, some requirements for beam intensity and quality have been put in the contract. They regarded the production of two gaseous beams (O^{6+} and Ar^{9+}), three metallic beams from an oven (Ag^{21+}, Au^{26+} and Au^{30+}) and one metallic beam with a sputtering system (Ta^{24+}). Table 1 summarizes the requests for beam intensity.

Table 1: LNL Current Requests

	Ion	Current [□A]
Gaseous beams	O^{6+}	200
	Ar^{9+}	100
Metals with oven	Ag^{21+}	3
	Au^{26+}	10
	Au^{30+}	1
Metals with sputtering	Ta^{24+}	1

For each one of the ions listed in Table 1 a 2 hours test of the beam current stability had to be repeated two times, first at the Pantechnik site and finally at the LNL site after final installation. The current had to stay within ±5% of the reference value for the 98% of testing time. A normalized 4·RMS emittance of less than 0.3 π·mm·mrad for the 90% of the beam was also required for the two gaseous beams.

A brief description of the acceptance tests hold at Pantechnik site will be given in the following. The extraction voltage was fixed at 24 kV for all the beams produced; the test bench used was made by the source directly coupled to a 90° bending dipole and an horizontal emittance measurement device consisting of a slit and a scanning wire.

Gaseous Beams

For both Ar^{9+} and O^{6+} beams the current stability and the emittance test results were satisfactory. Figs. 6 and 7 show spectra acquired during the acceptance test. Even if not so high microwave power was used (about 170 W for both beams) more than 10 μA of O^{7+} and slightly less than 20 μA of Ar^{11+} were recorded. Looking at the emittance measurements (see Fig. 8) we saw that the beam parameters slightly changed during stability tests, showing that the source was still not totally conditioned due to the limited operation time.

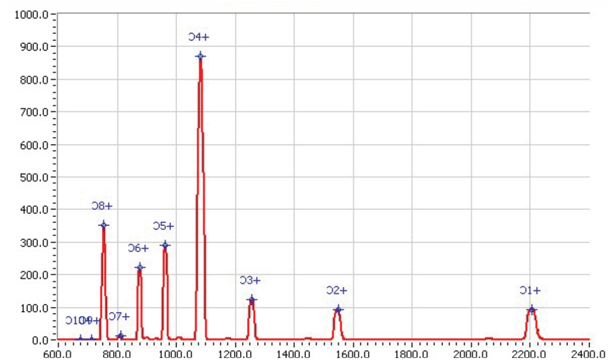

Figure 6: Spectrum acquired at the end of stability test for O^{6+}.

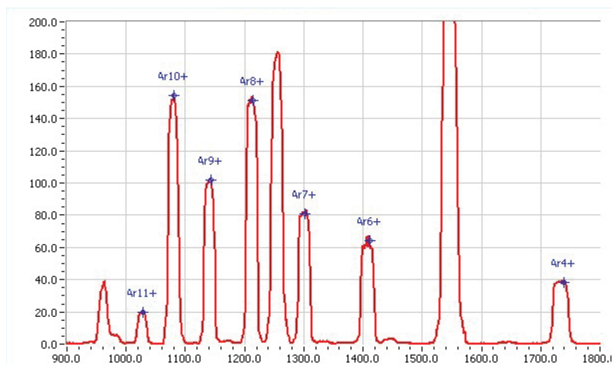

Figure 7: Spectrum acquired at the end of stability test for Ar^{9+}.

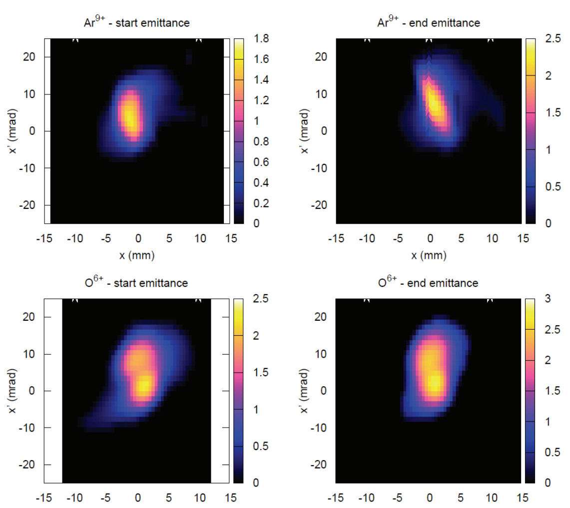

Figure 8: Gaseous beams emittance plots.

Metallic Ion Beams

The new source is equipped with two different systems for production of ion beams from metallic elements:

- A resistive oven, consisting of a tungsten wire heating an alumina crucible containing the sample to be evaporated. Such an oven can produce metallic vapours from elements which reach a vapour pressure of 1 Pa for T< 1500 °C.
- A plasma heating or direct insertion method. It consists of a long movable rod which holds at its extremity the sample to be evaporated in the shape of a cylinder of 1 mm diameter. The sample is carefully placed closer and closer to the plasma until the evaporation starts and metallic ion can be seen in spectra.

The tests with both methods were satisfactory, especially the direct insertion method which proved to be very easy and fast. Fig. 9 shows the spectrum acquired after stability tests for gold: it can be seen that current for both 26+ and 30+ ions are well above the requested ones.

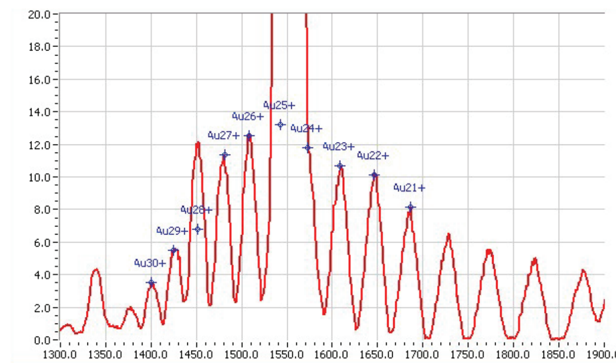

Figure 9: Spectrum acquired after stability tests for gold.

ION SOURCE AND INJECTOR COMMISSIONING [5]

Once the installation was completed, first tests with oxygen beam were performed on the new source. The attention paid on the cleaning of each component put under vacuum played an important role on source conditioning.

Fig. 10 shows an oxygen spectrum acquired in December 2008: it can be seen that more than 270 μA of O^{6+} and 16 μA of O^{7+} have been obtained with 325 W of microwave power. No contaminants are present in the spectra.

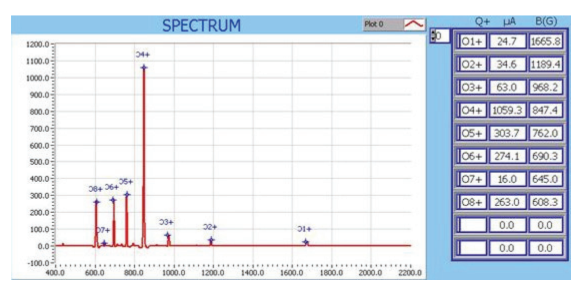

Figure 10: First oxygen beam extracted from the new source mounted on the HV platform.

After source conditioning for some days with oxygen, commissioning of the injector started in March 2009. The chosen beam was Ar^{9+} with a current between 1 and 3 μA; the voltage applied to the platform was about 140 kV to meet the right velocity for injection into the PIAVE RFQ.

Most part of the work was done during the first days: after fixing the voltages on the lenses to couple the beam to the injection line and on the electrostatic quadrupole, the values of the magnetic lenses and of the phases and amplitudes of accelerating cavities have been optimized.

Thanks to the good emittance coming from the source (about 0.05 π·mm·mrad norm. rms in both transverse planes) and to the good job in improving alignment we had an improvement of 10% in transmission at the entrance of the LINAC ALPI.

Moreover, the beam characteristics were reproducible in the following days: in fact putting exactly the same parameters for source tuning and the same values for the magnetic lenses, the beam was transmitted through the injector exactly with the same transmission as on the previous days, except for a slight adjustment of the field of the dipoles.

The injection and complete acceleration in the ALPI LINAC, together with the production of Xe, Sm, Sn and Ca beams, are foreseen for the next moths.

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