INSTALLATION AND OPERATION OF AN ECR ION SOURCE AND ITS PLATFORM IN LEGNARO

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Abstract

The ECR ion source Alice was successfully operated on the new high voltage platform, temporarily held at ground potential. The new installation features a heavy lead box shielding Alice and a long water pipe serpentine to feed cooling water. All technical subsystems of the source proved to behave satisfactorily. First results for ion currents of gas elements are reported, comparing the results with the gas mixing ratio; selectivity of analysis system was found adequate. Some notes are added about the optics of beam extraction from the platform and the design of the accelerating tube (rated 450 kV).

1 INTRODUCTION

This paper describes the reassembling of the Alice ECR [4] ion source on its high voltage platform in the ALPI building in Laboratori Nazionali of Legnaro, and its preliminary performance with noble gases; detail of platform construction and motivation are also given.

An ECR ion source can provide ions of almost element to reasonably high charge state q , which is most needed for efficient and economical beam acceleration; charge state has a broad distribution and usually beams up to

$$q \cong 2\sqrt{A} \tag{1}$$

at a current level of 1 μA can be extracted. Since no stripping is needed in further acceleration up to Coulomb barrier (6 MeV/nucleon) with the full ALPI complex, current delivered to user targets can be larger than current provided by a tandem accelerator. Feasibility of installing an ECR on a HV platform and advantage of this solution for beam quality were already demonstrated by a similar installation in Argonne [1].

2 PLATFORM

Even if the ECR sources are reasonably compact (excluding some large superconducting example), the shielding, the power supplies and the dipole that accompanies it require at least 20 m^2, may weight 10000 kg and use about 100 kW of electrical power, in our case. Note that only 30 kW are actually dissipated into the coil of the source, while most heat is produced into the linearly regulated power supply (switching technology would have been more efficient); heat is removed by water.

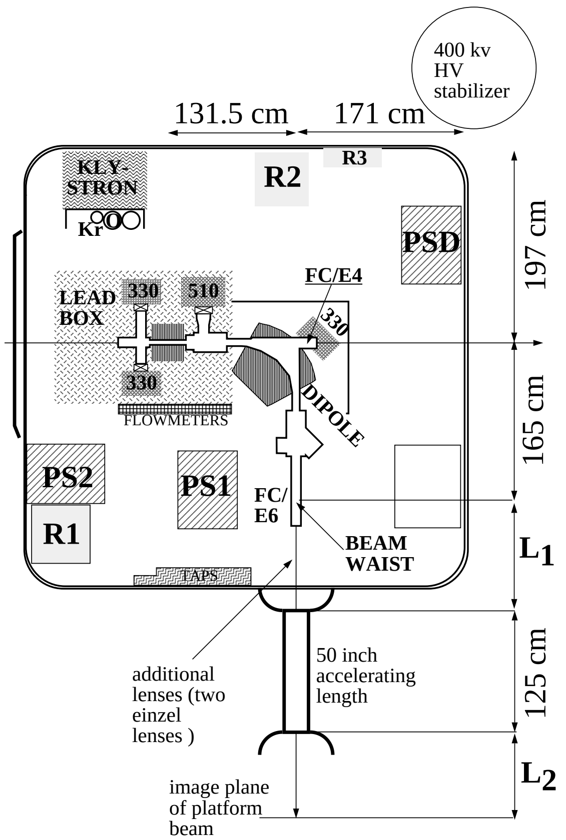

Figure 1: Equipment on the platform and nearby services: the length L_1 L_2 are preliminarily determined to 115 cm and 90 cm, respectively. PS1 PS2 are the ion source coil power supplies.

The platform is 4.5 m side square, made from welded iron beam, and is sustained by five 1.7 m high columns (one central and four near the corners) sharing an uniform load almost equally; this structure has a full square symmetry. The position of the platform is determined by preexisting walls, so that distance to walls is 1.7-1.8 m and beam will leave the platform at a level of 2.95 m above ground; a tilted line was proposed to reach the ALPI level (2.25 m below ground level).

Some care was put in alignment of platform structure, in perspective of the long and complex path of beamlines; corner level was within 2-3 mm. The floor level was in part made flat with calibrated shims (within 1 mm with no load). The ion source Alice had only vertical movements for adjustment, but horizontal movement were provided. At present, Alice axis is aligned by ± 1 mrad with its Faraday cup (at 90 degree deflection); but this can be improved when needed.

All major water and power connection run into the floor of the platform, while auxiliary signal travel over heads. It was found convenient to restrict path to some octagonal steel frame over the platform. The water is feed to the platform by two serpentine (length $L = 63$ m) of tube with large diameter $D =$ 42 mm, since resistance at given pressure drop δP and flow F increase rapidly with D ; we have $R \propto L/D^2$, but $\delta P \propto v^2 f_A L/D \propto LF^{1.75}/D^{4.75}$ (using Blasius approximation for friction coefficient $f_A = 0.316$ Re $^{-1/4}$ with Re the Reynolds number) so that $R \propto D^{2.75}$. With a reasonably purified water (resistivity 20 kΩ m), we get a total resistance $R = 500$ MΩ and $\delta P \cong 0.6$ atm. Water branches into 6 separate lines, each requiring about 15 l/min, with other branches if necessary; one spare line for an heat exchanger cooling klystron exhaust was provided. At full load, we now maintain a 5-6 atm input, 1-2 atm output, which meets specifications of almost any components.

3 ECR SOURCE IMPROVEMENTS

The ion source Alice is a 14.4 Ghz ECR ion source[3], whose cooling and power requirement were carefully optimized [4]. The design required possibility of changing and separately optimize several parts, like the einzel lens or the microwave termination or even the whole ECR chamber (we called it Removable Plasma Chamber, RPC in brief) which can carry iron shimming rings, ovens for metal vapor production and rf meshes; that both offer the practical advantage of correcting errors and the possibility of verifying numerical or analytical models. Actual optimization of the named subparts was indeed actively studied since source construction, but it is far from complete.

All major vacuum sealing are in metal (copper gasket or indium wire), while viton O-ring are presently used for small and auxiliary KF flanges; in original design, viton was a temporary replacement for final aluminium rings; our practical experience with Al ring was anyway less than encouraging (due to difficulty in mounting, aligning and tightening) .

The source central body, constituted by two solenoids and an hexapole, is clearly separated from the head part, where microwave, gases, and metal feeds are located, and the extraction part. Still mounting and dismounting the source proved a difficult task, partly due the complicated and small mechanic part used, and partly to learning periods with continuously changing parts.

A large lead box was built around Alice to shield the emitted X-rays, and that proved helpful also in confining high voltage parts of source. That box of course complicate maintenance of the source.

4 EXPERIMENTAL RESULTS

Also to verify resolution of our selection dipole, we mainly operate with heavy gases like krypton and xenon, with oxygen as mixing gas. An effective, even if simple and completely manual, acquisition system for spectra of ions, was finally put in operation. The field is measured by an high accuracy Hall probe, but instead of using the 4 and half digit serial output, which requires a 0.5 s time at least for sampling and conversion, we use the uncalibrated analog output (accuracy 5 %, 1mV/G with 3 kG full scale), which well follows changing fields. This signal filtered with a 2.2 μF capacitance (roll off frequency 150 Hz) is displayed on a digital scope, together with the signal of the Faraday cup (sensitivity 1 MV/A, clamped at ± 15 V by zener diodes). Voltage was fixed to $V_s = 9073 - 9075$ V in all experiment to now. A typical overall scan from 0 to 3000 G can take 200 s, that means for example, that peak of O^{7+} at 416 G and of N^{6+} at 421 G are separated by 0.4 s in real time. Field rise must be determined by operator, for temporary problem with hardware. The same system allows to sit on a peak , and check ion current at any desired frequency; stability was excellent when magnetic field was exactly tuned, while current decreased slightly and a 50 Hz ripple appeared when B_{dip} was changed by ± 1 part over 500 ; that gave an indication of centering a peak much better than the current value itself and of course much better than during a scan. We conclude that our beam has a fluctuating dispersion, due probably to fluctuation of V_s; that is, when the beam is centered in the middle of the Faraday cup slit (12 mm wide, 24 mm high), small dispersion do not exit from the slit; on the contrary, when the beam is on the edge, small movements change the fraction of beam entering into the faraday cup. This effect allow to indirectly measure ripple on the high voltage V_s (see later).

Faraday cup rejection of secondary electron (giving negative halos of large positive beam) is excellent (less than 5 nA for a 10 μ A beam), when the suppressor voltage $V_r = -250$V is on.

4.1 Experiments with Krypton

Comparison of krypton yield with and without mixing gas gave the usual high charge shift for gas mixing [2]. A relatively large klystron power was used (200 W) . Charge state until 19+ was clearly seen, each charge clearly resolved into 3 peaks corresponding to isotopes $A = 82$, 84 and 86 (respectively with current of 57 nA, 74 nA and $57nA$); track of ^{84} Kr^{22+}, ^{84} $Kr^{23+}$and ^{86} Kr^{24+}can be seen as shoulders or little peaks in the domain of larger peaks, and therefore uncertainty of current is very large. Even not directly optimised for oxygen, current up 0.3 μA of O^{7+} and up 4.5 μA of O^{6+} were observable. Data from a typical oxygen-krypton plasma yield are given in Table 1 and 2.

q	O^{q+}	^{82} Kr^{q+}	^{84} Kr^{q+}	^{86} Kr^{q+}
1	> 15			
2	> 15			
3	6.97			
4	4.85			
5	2.52			
6	1.16	0.033	n.v.	
7	0.18	0.024	n.v.	
8		0.025	0.100	0.034
9		0.052	0.189	0.059
10		n.v.	0.338	0.108
11		0.121	0.510	0.269
12		0.161	n.v.	0.305
13		0.170	0.729	0.240
14		0.143	n.v.	0.253
15		n.v.	0.428	0.187
16		0.054	0.25	n.v.
17		n.v.	0.093	n.v.
19			0.035	
20		tr.	tr.	tr.

Table 1: Spectra of a typical oxygen-krypton plasma, giving the ion current (in μA) resolved for isotopes; measuring error 1 % typically ; pressure 0.00033 Pa, klystron power 230 W ; n.v. means not visible because near bigger peaks of other elements; tr. means small quantities near or less than 10 nA

q	N^{q+}	C^{q+}
1	> 1	> 1
2	1.877	1.05
3	0.514	n.v.
4	0.343	0.145
5	0.2	

Table 2: Spectra of impurities ion current (in μA) for several isotopes ; same plasma condition of table 1

Experiment with krypton alone show an average charge state even lower than expected (5+, with 168 nA of ^{84} Kr^{9+}).

4.2 Experiments with Xenon

Only pure xenon plasma was tried. As for krypton, charge state where low; only up 11+ were detected. The peak of isotopes 129, 132, 134 and 136 can be separated, at a lower scan speed $\dot{B}_{dip} = 4G/s$.

5 BEAM OPTICS

The normalized emittance ϵ_x^N, in part due to the magnetic field B_z on axis of the source and in part to the ion temperature T (equalized among ion species by collisions) is comparable or better than in electrostatic machines

$$\epsilon_x^N = \frac{\pi e B_z r_h^2}{4 m_p c}\frac{q}{A} + 5.6 r_h \sqrt{\frac{T}{A m_p c^2}} \propto \frac{1}{\sqrt{A}} \qquad (4)$$

where the last step comes from bound (1); T is usually estimated $7 - 10$ eV. Source provides acceleration with a small voltage V_s (in our case, 9 kV) so that actual beam emittance is rather large on the platform, and requires large gap d in the analyzing magnet ($d = 80$ mm compared with bending radius $R = 500$ mm). Platform is designed for a typical used voltage V_p of 314 kV for heavy ions (^{238} U^{28+}) and its subcomponents are specified for 400 kV, so that beam handling after platform acceleration will be simpler (platform voltage is not yet active due to delays in approving a proper insulation transformer to transfer power to platform).

Design of the accelerating tube critically depends on $Q = (V_p + V_s)/V_s$ which being rather large implies a strongly focusing lens at entrance with focal lens f :

$$f = -4pL/(Q-1) \qquad (3)$$

which we try to balance increasing the acceleration length L as much as practical ($L = 1250$ mm). Still a rather strong matching lens is required. Here p is a factor, slightly greater than one, describing fringe field effects.

Energy spread is practically given by $\Delta E = eq(\Delta V_s + \Delta V_p)$; from observed beam dispersion on Faraday cup edge, we measured $\Delta V_s = 12$Vpp with a power supplies under load, with a dominant frequency of 50 Hz. Another power supply gave $\Delta V_s = 8$ Vpp, with a clean 50 Hz frequency as a ripple.

Some indication of major point and solution of beam optics problem is worthwhile. Note that since Q depend from V_p changing from heavy (say ^{238} U^{28+}) to lighter ion (say Ar^{14+}), according to the RFQ requirement of constant input velocity (=0.009 c), focal length (3) change dramatically; for that reason we plan two matching lens before accelerating tube.

Linear matrix beam optics calculation of a first version of beam line, with einzel lens as well as the accelerating tube, including fringe field effects, were developed and will be reported elsewhere.

Accelerating tube is also strongly magnetically suppressed.

6 ACKNOWLEDGEMENTS

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