OPERATION EXPERIENCE OF THE ALICE ION SOURCE

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Abstract

The ion source Alice, a compact 14.4GHz ECRIS, was stably operated over its high voltage platform, capable of reaching 350 kV, to provide several beams for ion transport studies, and for injection of accelerators; prevailing beams were O^{3+} and $^{129}Xe^{18+}$. To further improve reliable operation, two independent microwave power systems were installed; moreover computer serial lines and hardware interlock were improved. Platform voltage ripple results low. Progress in extracted beam diagnostic are described. The flexibility of use of optical elements installed with the accelerator tube is demonstrated. Some upgrading plans and developments, including an enhanced sputter probe and planar filaments, are presented.

1 INTRODUCTION

The complex of the Alice ion source and its high voltage platform[1], previously built, has reliably accelerated several beams around and above the RFQ input speed $\beta_2 c = 0.089c$ and has made several tests of following diagnostic equipment possible. The source voltage $V_s = 11.09$ kV produces ions at speed $\beta_1 c$ depending on $M = A/i$, where A is the mass number and i the charge, while the platform voltage $V_p \leq 350$ kV is regulable to match RFQ input β_2. Prevailing beams were O^{3+}, N^{2+} and $^{129}Xe^{18+}$ (other xenon isotopes are of course available, but object of less extensive tests). Accelerated beam diagnostic equipment includes: beam profile monitors (from PM1 to PM5), an emittance meter and a fast Faraday cup; extensive discussions of measured emittance are given elsewhere[2]. Consequently, the source-platform complex in general and its beam transport in particular, have been the subject of several studies and improvements to maintain a reliable operation and to better understand beam transport, as described in this paper.

In section II operating experience and minor revisions are described. In section III the good stability of acceleration tube focusing is explained; moreover, a newly developed (hardware) compander for Faraday cup currents acquisition is described. In section IV source upgrading (sputter probe, a bigger magnet) and future developments (the planar filament ohmic oven) are presented.

2 OPERATION

Alice is a compact 14.4 GHz Electron Cyclotron Resonance (ECR) ion source (ECRIS) [3], which requires a limited amount of microwave power P_k from the generator (typically $P_k = 100$ W, with a maximum of 360 W in past years). Ions of different $M = A/i$ are separated by a 90^0 bending dipole D with a resolution $M/\Delta M \cong 100$ and their current $I_i(A) = I_{\rm fc}$ is measured on a Faraday cup fc. Current extracted from the source is $I_s \cong 0.5$ mA. As a mi-

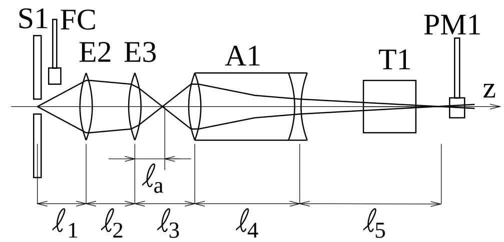

Figure 1: The acceleration line of ECRIS platform

crowave generator we can now use or a Ku-band compact 400 W TWT amplifier or the old klystron amplifier capable of $P_k = 2.4$ kW; this redundancy allows for repair and maintenance on the other generator, but make system more complex. Both generators are wired to the same interlock system, which, among other basic tasks, stops microwave (and ovens) when water cooling of the ECR chamber is off.

All RS232C connections with equipments were gradually rewired from two old DECservers to a new Linux based PC, which is faster and has shown to be more stable. One DECserver is now used to interface HP34970 acquisition system, which controls the electrostatic triplet T1 and monitors the platform high voltage generator V_p via analog signals, which need extensive shielding.

Gradual improvement of ion source performance continues a few weeks after the vacuum was sealed. When base pressure (that is, with gas input valve closed) reached a very low value $p_b \cong 3$ μPa, best performances were obtained: $I_{18}(129) = 750$ nA at $P_k = 126$ W and pressure outside plasma $p_a = 11(0)$ μPa. Typical performance was lower: $I_{18} = 200 \div 400$ nA at $P_k = 89W$. In this condition, I_{18} stability depends from P_k stability.

Platform high voltage V_p is measured through the voltage divider of the accelerator tube, when cup fc is inserted; precisely, the tube is made by a stack of fifty insulating rings and 50 titanium electrodes (plus a ground flange); fifty 82 MΩ resistors connect electrodes; the last end is attached to ground via a 1 MΩ resistor (in parallel with protection elements: two spark gaps an a varistor), where the signal V_t is formed and transported with a 20 m coaxial to the measuring device (when the HP34970 is used, nominal dividing ratio is $R(0) = V_p/V_t = 4510$ and calibrated value is 4402 ± 100; when an oscilloscope is used $R(0) = 8200$). A a 50 Hz 2 mVpp ripple is visible on the scope, with platform at $V_p = 265$ kV; calibration $R(\omega)$ of the divider at this frequency is possible and gives $R_{50} = 7635 \pm 100$ which indicates a platform ripple not larger than $\tilde{V}_p = 15 \pm 5$ Vpp. This show the effectiveness of a three-phase $\Delta - Y$ transformer in reducing the 50 Hz coupling to a platform and of filtering of the 400 kV generator. Analysis of ripple in the mHz range is in progress.

3 ION TRANSPORT

It is very convenient, for a simple analysis and for operation tuning, to divide the platform beamline into two parts: ion source line (extractor, einzel lens E1, bending dipole D, the following multipole corrector/steerers ST, fixed slit S1) and acceleration line (fixed slit S1, einzel lenses E2 and E3 , acceleration tube A1, and electrostatic triplet T1 and a diagnostic box PM1), shown in fig 1. A Faraday cup fc may be inserted immediately after slit S1. The acceleration has many degree of freedom to regulate beam transport as easily seen: assume that an image plane at a distance ℓ_5 after the accelerating tube (for example $\ell_5 = 1.49$ m and $\ell_1 = 0.29$ m, $\ell_2 = 0.36$ m, $\ell_3 = 0.44$ m, $\ell_4 = 1.27$ m) is desired and triplet is kept off; assume the ion source line makes an image plane at the slit (it has to be near anyway). It is convenient to introduce the parameter $R \equiv \beta_2/\beta_1 = [1+(V_p/V_s)]^{1/2}$ (non relativistic formulas); for example $R = 4.90$ for $M = 129/18$, that is $^{129}\mathrm{Xe}^{18+}$, and $R = 4.23$ for O^{3+}. It is well-known that the accelerating tube focusing depends on V_p/V_s or R; let $z_a = z_3 + \ell_a$ the position of the object plane of the accelerating tube; this implies ℓ_a be a function of R; when $\ell_a > 0$ the object is after the lenses E3. When $\ell_a < 0$ the object is before E3; since our einzel lenses can only focus the beam ($q_3 \geq 0$) operation of the other lenses E2 is necessary. In detail, to obtain an image at z_a the settings q_2, q_3 must satisfies

$$\begin{aligned} M_{12} = \quad & \ell_1 + \ell_2 + \ell_a - q_2\ell_1(\ell_2 + \ell_a) \\ & -q_3\ell_a(\ell_1 + \ell_2) + q_2 q_3 \ell_1 \ell_2 \ell_a \quad = 0 \qquad (1) \end{aligned}$$

where M is the transfer matrix from S1 to a. If $l_a = 0$ we have $q_2 = \ell_1^{-1} + \ell_2^{-1}$ and q_3 is arbitrary. If $l_a \neq 0$, one solution (which is positive) is $q_2 = \ell_1^{-1} + q_3$ and

$$q_3 = \left(\ell_2 + 2\ell_a - \sqrt{\ell_2^2 + 4\ell_a^2}\right)/(2\ell_2\ell_a) \qquad (2)$$

For continuity, other positive solutions exists. This proves that the q_2, q_3 system has one degree of freedom.

For example eq (2) gives $q_2 = 5.43$ and $q_3 = 1.98$ for $^{129}\mathrm{Xe}^{18+}$ and $q_2 = 6.65$ and $q_3 = 3.20$ for O^{3+}. From Ref. [4] data, corresponding einzel lens voltage can be easily computed; for $^{129}\mathrm{Xe}^{18+}$ $V_{e2} = 7.8$ kV and $V_{e3} = 5.5$ kV. Note this is a solution, not the only solution; indeed we used $V_{e2} = 6.8 \div 7.7$ kV and $V_{e3} = 6 \div 7$ kV in most experimental runs.

Since dependence of q_3 is smooth at $R = 4.90$, q_2 and q_3 setting may be kept constant while changing ion with approximately same M, for example from $^{129}\mathrm{Xe}^{18+}$to N^{2+} or even O^{3+}, as we verified occasionally.

Remote scans of ion peaks on PM1 were performed successfully, from N^{4+} to $^{132}\mathrm{Xe}^{19+}$ to O^{2+}, keeping the platform voltage $V_p = 265$ kV constant. Since R is constant in this case, the accelerating line tunings are constant. This scan proves the possibility of immediate beam change. Some charge state peaks partially covered secondary electron emission on fc are more visible on PM1; for example $^{132}\mathrm{Xe}^{17+}$.

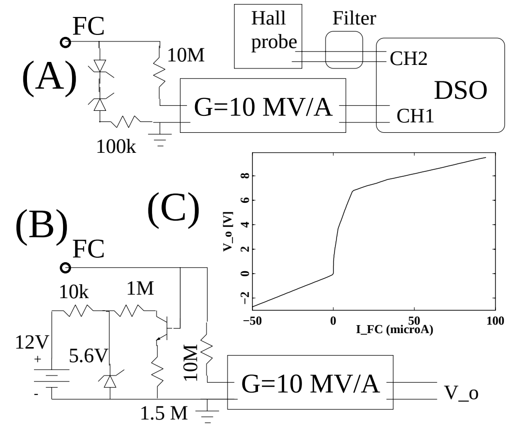

Figure 2: Non linear load compander: A) a simple scheme; B) a principle scheme; C) characteristic $V_o(I_{\mathrm{fc}})$ of an actual device

3.1 *Non-linear-load (NLL) compander*

Scan of the extracted ion current is the best way to document ECRIS status and is obtained by changing linearly the dipole current I_d and measuring the current I_{fc} and the dipole magnet field B_d; during scan (typically taking 50 s), eddy current flow is stationary, so the relative peak position is not affected. Signal I_{fc} is converted to a voltage $V_o = GI_{\mathrm{fc}}$ by a linear current amplifier with gain $G = 10^m$ V/A (with $m = 3, 4, \ldots, 10$); V_o and B_d are recorded by a digital sampling oscilloscope (DSO).

The maximum resolution of most DSO is 8 bit (and is 12 bit for most acquisition boards); on the contrary, it is desirable to record peaks as small of 50 nA (to enhance them with further ECRIS adjustment) and as big as 100 μA (typical value of O^+ in our case) or -2 μA (due to secondary electron emission on the fc). We see that a $10 \div 10^5$ nA dynamical range is necessary. One solution is taking two scans, one with $G = 10^7$ V/A and the other with $G = 10^5$ V/A. This is precise, but time consuming. Moreover, the off-line analysis program has to collate peaks visible in first scan with peaks visible in the second scan and it becomes not reliable in some cases.

Another solution is to compress the dynamics of I_{fc}; most desired transformation is given by $V_o/G + gV_o^3 = I_{\mathrm{fc}}$ with $G = 10^7$ V/A and $g = 10^{-7}$ A/V^3; an approximation with a piecewise linear transformation $V_o(I_{\mathrm{fc}})$ is satisfactory. In principle this is obtained by by a circuit A) in fig. 2, where ideal zener diodes are invocated; when $|I_{\mathrm{fc}}| > 350$ nA, most current is diverted from the amplifier. No zener diode with the required off-state resistance ($\gg 10$ MΩ) were available. Circuit B) works on another switching principle, but it may be built with existing transistors (MM3904, MM3906) . In practice, 3 loads of kind (B) are connected in parallel to get the desired curve (C); battery is replaced by a low voltage stabilised power supply; switches, proper protections and shieldings complete the device. Calibration curves $I_{\rm fc}(V_o)$ were taken; from preliminary simulations of the electrical circuit with SPICE [5], its temperature stability in the range $T_a = 22 - 35\ {}^0$C is acceptable ($\Delta I_{\rm fc}/I_{\rm fc} \le 0.01$). A typical scan is shown and peaks are labelled in fig 3.

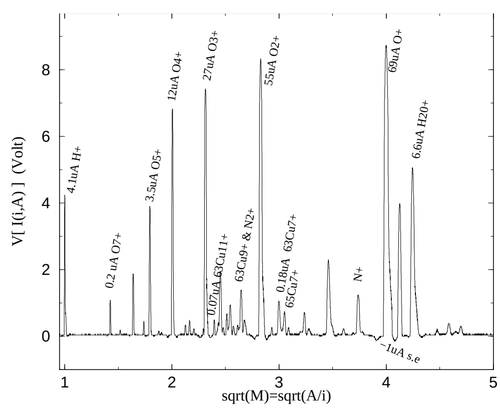

Figure 3: Scan of a reference ion spectra with the NLL compander; μA typed as uA in labels

4 DEVELOPMENTS

Upgrading plans consists in using the newly developed rf oven [6] and the planar coil ohmic oven (in development, see fig 4) for metallic ion production and in implementing a better gas flow regulation system, in the short term. Construction of an improved copy of the hexapole and solenoid set is also being considered (see fig. 5)

Planar filament were originally developed for making electron sources: a WCu metal composites is cut (by electro-erosion) to shape and copper is removed by heating. Elimination of copper from the W matrix proceeds in two phases; at $T_f = 1060 \pm 30$, liquid copper gathers in drops over the filament; at $T_f = 1300 \pm 100$ they rapidly evaporates. A test planar filament was operated up to $V_f = 18$ V and $I_f = 94$ A, reaching an estimated temperature of 2700 ± 200 K; a creep developed then for electromagnetic and thermal stresses.

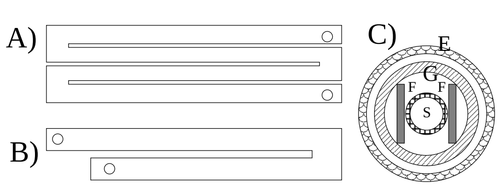

Figure 4: A) a planar filament; B) planar filament for an oven; C) scheme of a planar filament oven: S evaporation sample; F filament; G isolator; E enclosure.

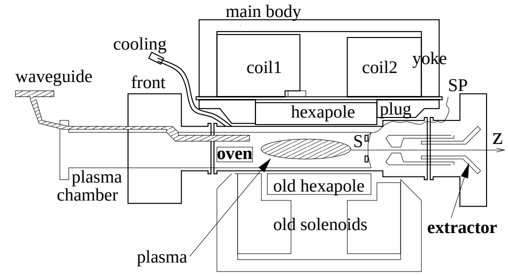

Figure 5: A) Study of a new Alice solenoid set; new parts in thicker lines, while old solenoid left in the lower part of the picture. Note the sputter ring S (near the plasma chamber right end) and its connection SP.

About the improved solenoids, a larger magnetic field is a major point for increasing ion charge states; fig 5 scheme envisions a slightly larger coils, as permitted by space, and iron plugs [7]. An increase of $|B|$ can be obtained from the improvements of permanent magnet material, while geometry keeps the original Alice design using an Halbach configuration. In 1990-1991, Alice proposal envisioned the concept of a negatively charged sputter probe, especially for metals as gold or copper, as an alternative to oven. It is generally assumed that a sputter probe S will stay at a typical oven position. But, considering the lower magnetic confinement on the extraction side, an interesting placement of sputter probe S is that base of the plasma chamber (see fig 5). Moreover superthermal sputtered ions can be reflected by the injection side, so plasma density is used twice. We also note that the Simon short circuit effect[8] can interact with this probe. Probe can be shaped a ring to select the optimal injection radius. There is a technical difficulty of powering the probe, but a minifeedthrough on the extraction side or a tube inside attached to walls of a plasma chamber are possible solutions.

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