OPERATION OF THE LNL ECR ION SOURCE

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Abstract

The completion of a 350 kV high voltage platform intended to preaccelerate the beam from an Electron Cyclotron Resonance Ion Source for injection into the novel superconductive accelerator PIAVE is reviewed. A few test beams were produced; in particular $^{129}Xe^{18+}$ was very convenient for realistic test of the following beam lines; an optimised multipole corrector (successfully used) is described. Ovens are being tested for bismuth beam production. Some comparison between plasma chamber of different diameter is given. Plasma noise, FFT (Fast Fourier Transform) spectra of ion beam and scans of ion species are briefly discussed.

1 INTRODUCTION

The ECR (Electron Cyclotron Resonance [1]) ion source Alice and its platform are intended to supply a broad range of preaccelerated ion beams to the following LNL superconductive accelerators [2]. Test operation of LNL high voltage platform was previously demonstrated and is described elsewhere [3]; this year several ion beams were requested for the commissioning of the following beamlines. Details about beam emittance and its measure are given in a companion paper [2], while the last operating experience of the ion source and platform are here described, after some review of the installation (section 2). Some specific hardware needed for beam adjustment is described (multipole corrector). The new plasma chamber with the waveguide assembly finally restored made Xe^{20+} beams possible (see fig 1 and section 3). Some oven loaded with bismuth was also fitted in the space available.

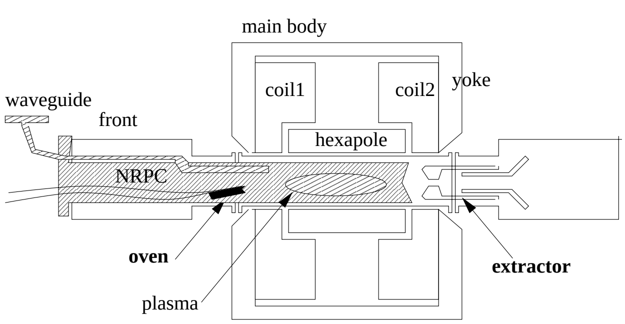

Figure 1: Scheme of ion source Alice (not to scale): note the space constraints, in particular on the waveguide path.

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2 GENERAL LAYOUT

The high voltage platform is a 4.5 m side square sustained by five 1.7 m high columns (see fig 2); similar or larger air gaps separate it from wall and crane. A fence encloses the platform access area and protects the outside electronics from risk of major discharges. Layout of platform equipment was largely dictated by the 3.3 m long connection between the power supply and the ion source and by beam optics consideration. The ion source (with potential V_s respect to the platform) is inside a lead box, to shield X-rays; this box of course contains the oven power supply and the ion gauge controller that stays at source potential. Power supplies of the ion source coils (640 A/29V), the klystron amplifier (14.4 GHz) and other electronics stay around the source box.

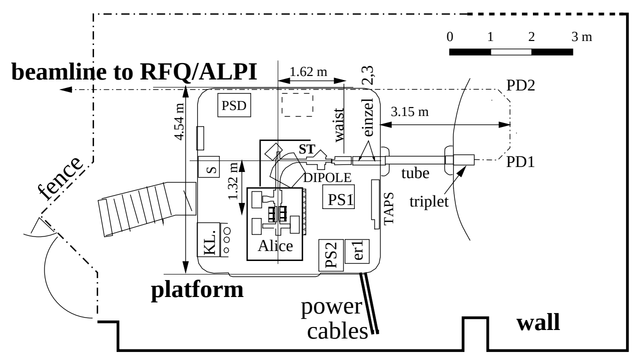

Figure 2: Overall platform layout: note the magnet power supplies PS1,PS2 and PSD, the klystron KL and the corrector ST

A scheme of the source is shown in Fig. 1. The main body (two solenoids and the hexapole) can be disconnected from the front part vacuum chamber and from the vacuum chamber on the extractor side. Alice still uses the concept of a two stage ECR, with metal septa allowing to separate first stage gas flow from the second stage flow. All these septa, waveguides and the plasma chamber liner are assembled in a unit (called Removable Plasma Chamber, RPC) which can be plugged in from the front. Therefore different first stage or equipment (electron gun, Mevva, oven, etc) can be inserted if necessary. Oven maintenance can be simplified and contamination between subsequent runs with different metals can be reduced when several chamber will be available. Moreover plasma chamber contains the focus electrode which guarantees the possibility of decreasing beam emittance by reducing beam extraction hole radius r_h, now 3 mm (note that ECR emittance may be better than theoric estimate, see pg. 310 in Ref [1]).

Over the platform there are the following elements to control the beam: the extractor (with a puller electrode); a collimator; the first einzel E1; a manual beam shutter; a dipole to select the charge of emitted ions; a multipole corrector ST; a steerer ST2; a fixed collimator (with a 12 mm slit) where unwanted ion are stopped; a removable Faraday cup FC/E6; two einzel lenses. In the platform area there are: the accelerator tube; two collimators, the inner one with 32 mm diameter hole; an auxiliary electrostatic triplet, followed by some beam diagnostic PM1 (previously we used a fixed Faraday cup). The first part of the beamline up to FC/E6 selects the ion species and reduce divergence of beam by a factor 2; the einzel lens E2 and E3 match the strong input focal lens of the accelerator tube, so that a nearly parallel beam can be formed, with a faraway waist about PM1; beam size is kept about 12 mm, so that acceleration give a further divergence reduction. Let z the (horizontal projection of the) beam direction and x be horizontal.

2.1 Steeers and quadrupoles

The multipolar corrector ST installed at the end of the dipole and originally intended as a sextupole corrector proved out to be useful as a vertical steerer (after the beamline was risen from the horizontal plane to a 4 mrad inclination), even if larger (5.5 A) than design currents (3.5 A) were necessary. Indeed to improve effectiveness, a steerer must be obviously placed away from planes where an image of the source is formed by the beam optics (these planes roughly coincides with intermediate beam waist) and should be placed near the mechanical bending of the beamline ; this is the position of the multipolar corrector. The additional xy steerer ST2 was indeed placed 0.6 m after, but is not strongly used. The ST magnetic yoke is formed by a soft iron ring (ID 160 mm, OD 190 mm, length 50 mm) from which twelve 40 mm long poles protrude inwards; onto each pole two independent coils were winded. Outer coil has one or two more turns than inner has (N=20), to compensate for smaller coupling to the yoke, as experimentally determined by requesting that both the coils produce equal field at a given test point (10 mm over the pole). To reduce power supplies number, it is convenient to produce only the multipoles expected to be relevant: a vertical y-steerer (horizontal x being provided by the dipole) with amplitude V; a normal quadrupole Q (to introduce some astigmatism between x and y); a skewed hexapole H (to compensate dipole effective field boundary curvature without moving the existing field clamps), so that magnetic field $\mathbf{B} = -\text{grad}\phi_m$ is given by the potential

$$\phi_m \cong V(z)x + Q(z)(x^2 - y^2) + H(z)(y^3 - 3x^2y)$$

Optimal synthesis of these multipoles requests current profiles as $\cos(\theta)$, $\cos(2\theta)$ and $\sin(3\theta)$ respectively, with $\theta = \text{arctg}(y/x)$. The connection used (see fig 3) satisfactorily approximates the requested profiles with levels of 0, 50 % or 100 % of the maximum ampere-turns per pole; moreover only two coils per pole are necessary. Note that

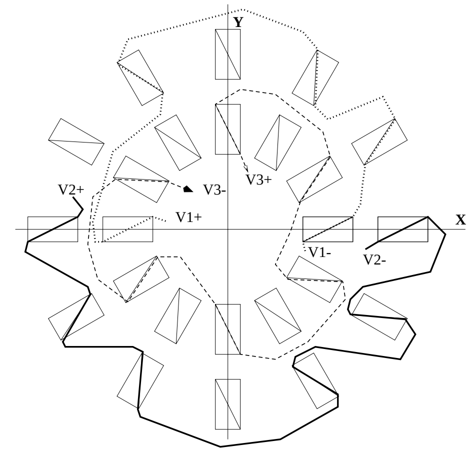

Figure 3: Optimised connection of multipole steerer coils

since we have $V \propto I_1 + I_2$, $Q \propto I_1 - I_2$ and $H \propto I_3$, control of currents is coupled (that is, to get a pure quadrupole $I_1 = -I_2$ is necessary). Before beamline inclination , best beam currents were obtained for $I_1 = -2.5$ and $I_2 = 1.5$ A; after $I_1 = 1$ A and $I_2 = 5.2$ A.

2.2 Ladder and insulation

Thanks to a carefully rounded envelope, voltage up to 400 kV can be sustained by platform alone with negligible dispersed current. Power connection implies four 7 m long cables and a transformer, so that dispersed current rises by some amount (120 ± 20 μA at 350 kV). Other current loss are : the accelerating tube voltage divider, 4.1 $G\Omega$ nominally ; the generator, estimated to 1 GΩ; the water cooling pipes, giving $R_w = 3.8$ GΩ at water best conditions (operation with $R_w = 260$ MΩ was demonstrated possible for a few weeks).

Platform voltage is obviously interlocked: the platform door and the the fence door need to be closed to rise V_p. To avoid frequent removal of the access ladder during tests and adjustments a wood ladder was installed (fibreglass ladder had inconvenient sizes); ladder insulation was supplemented with PVC parts. Tests up to 300 ± 10 kV show no increase (within ± 20 μA) of dispersed current due to ladder presence.

3 SOURCE OPERATION

As said, the modular design of Alice ion source allows to replace the plasma chamber, keeping the vacuum chamber and the magnet system of the source unchanged. Up to 1997 we used stainless steel RPCs with $d = 60$ mm inner diameter [see curve a) in fig 4]. Operation with a new NRPC (NRPC1), with a 63 mm inner diameter Al liner was described elsewhere and it was not completely satisfactory for only for lack of proper waveguides, even if argon beams adequate for injection into PIAVE were easily produced (fig 5 and Ref. [3]). To produce xenon beams, waveguides and a new copper liner were adapted to NRPC1; result for

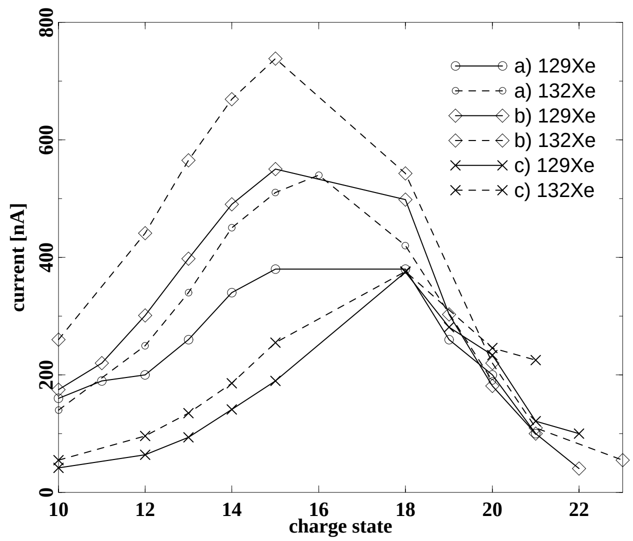

Figure 4: Typical ion current output of ^{129}Xe (solid lines) and ^{132}Xe (dashed lines) in three cases: a) aluminium chamber, inner diameter $d = 60$ mm, total microwave power $P_k = 230$ W; b) copper, $d = 63$ mm, P_k =76 W ; c) copper, $d = 63$ mm, $P_k = 91$ W. The markers indicate the charge states actually measured.

Xenon are shown in curves b) and c) of fig. 4; substantial improvements [over the best previous result a)] if not yet in the charge state, at least in the efficiency of microwave power use, are evident.

Measured data for Xe^{17+} was not included in fig. 4 because affected (decreased) by the negative current background generated by O^{2+} impinging on the collimator or suppressor electrode, as apparent from fig 6; yet a 400 nA $^{129}Xe^{17+}$ was also experimentally available. On the contrary there is some small contribution from $A = 136$ isotope to the $A = 129$ current for charge $z > 17$. To further improve the dynamic range of fig. 6 a proper signal compander seem convenient. Up to now, we take two scans of ion currents versus rising magnetic field, one with current amplifier set at the gain $G_a = 10^7$ V/A and the other with $G_a = 10^5$ V/A.

To fully characterise the plasma behaviour some observations of extracted current fluctuation were performed with NRPC. In quiescent conditions, peaks at 300 Hz (klystron microwave power main fluctuation) and 50, 100 Hz are expected and always present. Some spectra show interesting large peaks at for example 846 Hz and 1712 Hz (see Fig 5) and at 8275 and 20875 Hz, which are not clearly identified, and change with time; they may be related to turbopumps (working at 820 Hz), or to excessive ripple from some power supplies (for example the V_s power supply rectifies a 20 kHz square wave).

3.1 Ovens

To produce bismuth beams, two simplified and miniaturised ovens were placed inside the NRPC1; in view of the

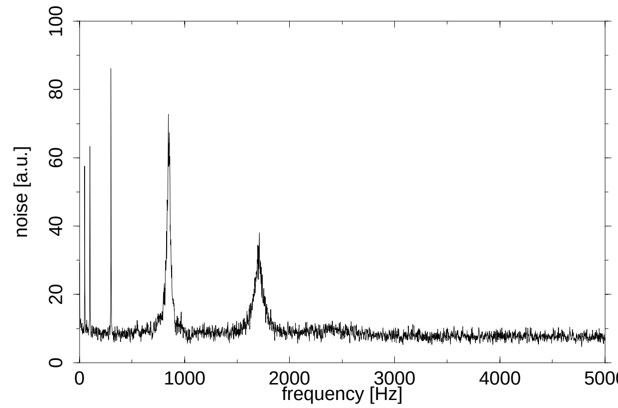

Figure 5: Low frequency spectra: spectral power (a.u.) of relative fluctuation in Ar^{6+} current I_6 (a.u.) vs frequency Hz. Average current 967 nA, rms noise 23 nA, microwave power 90 W. Integration time 5 s, bin size 2 Hz (20 periodograms averaged), higher peaks at 50, 100, 300, 846, 1712 Hz. Last two peaks were much smaller in other runs

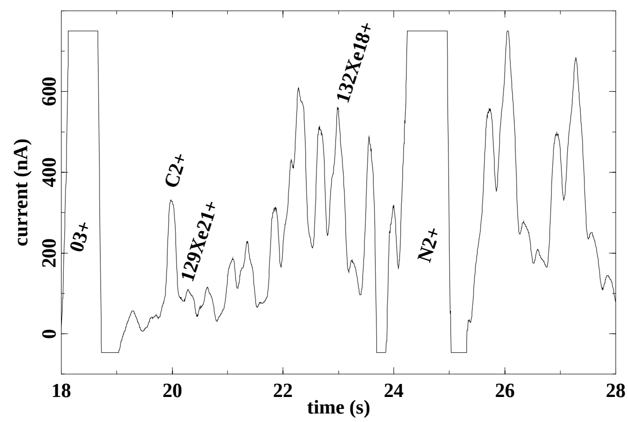

Figure 6: Part of a scan of ion species: magnetic field rises by about 25 G/s; ion source as in case b) of fig 4 ; current is cut between -50 and 750 nA by a current amplifier (gain 10^7 V/A and filter 3 ms) and digitising oscilloscope.

relatively low operating temperature (600^0 C) thermal isolation is minimal. Design emphasised simplicity of manufacturing and large tolerance for tungsten thermal dilation. By measuring current and voltage applied to oven, tungsten temperature may be inferred and controlled. Long degasing times were observed; also even with negligible power applied, the oven reaches the 120^0 C temperature due heating from ECR plasma. Further experiments are necessary.

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