TWO-CHARGE-STATE INJECTOR FOR A HIGH POWER HEAVY-ION LINAC[*]

N.E. Vinogradov[#], Northern Illinois University, De Kalb, IL 60115, USA

V. N. Aseev, P.N. Ostroumov, R. Scott, M. Sengupta, ANL, Argonne, IL 60439, USA

T.V. Kulevoy, ITEP, Moscow, Russia

Abstract

A permanent magnet (PM) ECR ion source and following low energy beam transport (LEBT) system with the capability to deliver two-charge-state heavy-ion beams for high-power linacs is being prototyped at Argonne. The injector consists of the PM ECR ion source, a transport line with beam diagnostics including emittance measurements and a multi-harmonic buncher. Recently the ECR ion source was installed on a high voltage platform to increase the accelerating voltage up to the design value of 100 kV. The unique feature of the multi-q injector layout is that the charge separation is performed out of the platform after acceleration of the multi-component ion beam. Two-charge-state beams are analyzed and recombined using an achromatic bending system. Improvements of the PM ECR performance and beam optics studies based on measurements of various heavy-ion beams will be discussed in this paper.

INTRODUCTION

The proposed design of the Rare Isotope Accelerator (RIA) driver linac is a cw, fully superconducting, 1.4 GV linac capable of accelerating uranium ions up to 400 MeV/u and protons to 1 GeV with 400 kW beam power. Recently, it was recognized that the construction of the RIA facility should be staged due to funding reasons. A possibility for the first stage includes a ~850 MV driver linac to deliver uranium beams at 200 MeV/u and protons at 570 MeV. As envisioned at ANL, the facility, named Advanced Exotic Beam Laboratory (AEBL), would consist of a driver linac, a post-accelerator and experimental areas with upgradeable capabilities to the full-size RIA [1]. Thanks to successful tests of the front end systems both at LBNL [2] and ANL [3], 400 kW beams can be obtained with increased intensities of heavy-ion beams from the ECR and higher rf power in the linac even at the first stage of the facility. The design goal of 400 kW uranium beam from the driver linac can be achieved employing a concept of simultaneous acceleration of several charge states. This concept becomes especially important for AEBL where the required beam power must be provided at lower uranium beam energy of 200 MeV/u.

Currently we are developing a multiple-charge-state injector system (multi-q injector) which is located in the Dynamitron high-bay area of the Physics Division at Argonne National Laboratory.

This paper describes the basic design of the multi-q injector system and initial results of beam measurements.

TWO-CHARGE-STATE INJECTOR

Figure 1 shows a general view of the multi-q injector system. The multi-q injector system for the AEBL driver linac includes a permanent magnet (PM) ECR ion source installed on a high voltage (HV) deck, a LEBT and one-segment of the prototype RFQ. Unlike all other ECR ion sources being operated worldwide where the HV platform voltage is applied after selecting a specified q/m, in the AEBL driver injector all ion species from the ECR source are accelerated by the platform voltage and the analysis and selection of appropriate ion charge states take place in the following magnetic bending system. The HV platform has been constructed using de-commissioned 300 kV, 100 kW isolation transformer and Faraday cage available from previous accelerator projects. At present the injector system allows us to accelerate all ion species up to q×100 keV total kinetic energy, where q is the charge state of an ion. In the current installation, the accelerating tube is followed by a 90° magnet and an emittance measurement station as shown in Fig. 2. The ECR source has been recently upgraded with an additional TWT rf amplifier operating at 12.75 – 14.5 GHz and an oven for production of heavy metal ions.

The design and construction of the LEBT (see Figure 2) is in progress. The LEBT includes an achromatic bending system for charge-to-mass separation, a straight section that includes a grid-less multi-harmonic buncher and
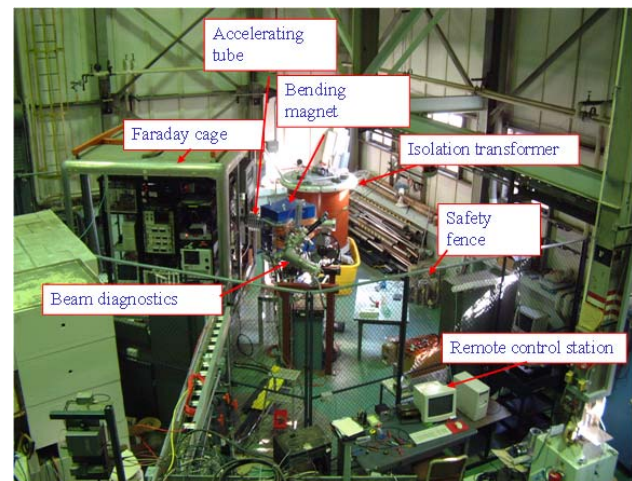

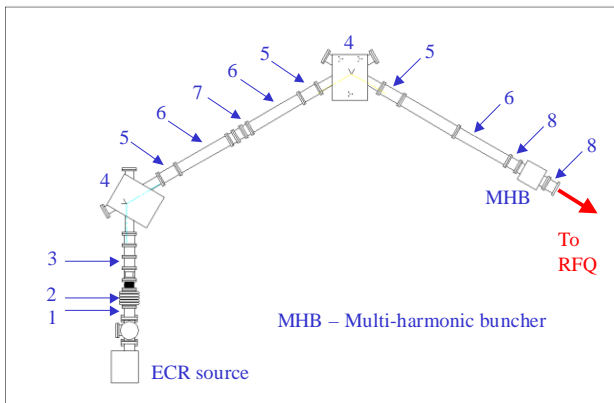Figure 1: General view of the injector.

Figure 2: Layout of the multi-q injector and the LEBT: 1−vacuum valve, water-cooled collimator and water-cooled movable beam stop; 2−accelerating tube; 3−Einzel lens; 4−60° bending magnet; 5−corrector; 6−set of electrostatic quadrupoles; 7−adjustable horizontal slits for charge-state selection; 8− scanning wire.

transverse focusing elements followed by an RFQ accelerator. The achromatic bending system consisting of two 60° bending magnets in combination with a number of focusing elements is used to select the required dual charge-state beam [3]. The first bending magnet creates a high dispersion area in the symmetry plane of the achromatic system. The second bending magnet combines two-charge-state beams in the phase space. The following straight section includes the multi-harmonic buncher and transverse focusing elements to match beam to the following RFQ.

BEAM MEASUREMENTS

Comprehensive ion beam studies delivered by the ECR have been carried out before the ECR was moved on the HV platform. Layout of the ECR and beam-line for initial beam measurements is shown in Fig. 3. For careful studies of the output beam we have designed and built the diagnostic station, which consists of a system of adjustable slits, removable Faraday cup and emittance measurement device (EMD). The emittance scanner is based on conventional combination of narrow slit and wire for each transverse direction. Two EMD slits are cut in the same stainless steel plate, which is inserted into the beamline by a linear actuator orientated at 45° with respect to the vertical line. The slits are perpendicular to each other and cut at 45° with respect to the axis of actuator motion. Therefore, the beam is collimated first by the vertical and then by the horizontal slit during one linear movement. The scanning wires work the same way. The remote control of the EMD equipment, data acquisition and data analysis are provided by a user-friendly software implemented using LabVIEW. The code produces transverse beam profiles, emittances and Twiss parameters online. Another LabVIEW code incorporates remote control of the analyzing magnet power supply, gaussmeter and pico-ampermeter connected to the Faraday cup, and provides users with online mass scan

analysis. Detailed emittance measurements of various ion species produced by the PM ECR have been made. Analysis of the measurements verifies that the ECR source forms a beam in which neighboring charge states have similar phase space distributions. This is an important property required to enable the simultaneous acceleration of two charge states as called for in the AEBL driver design. The typical emittances for each charge state in a 15 eμA lead ion beam are shown in Figure 4. As seen from Table 1, the Twiss parameters of the different charge states generated by the ECR are very close to each other.

Recent upgrade of the multi-q injector allows us to operate the high voltage platform in order to apply 100kV
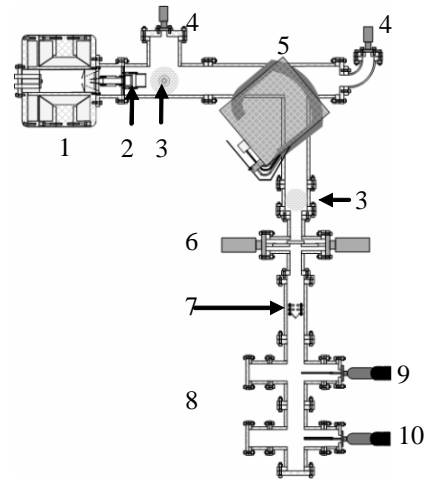

Figure 3: Current layout of the ECR ion source: 1-source body; 2 - Einzel lens; 3 - turbo pump; 4 - vacuum gauge; 5 - analyzing magnet; 6 - slits system; 7 - Faraday cup; 8 - EMD; 9 - EMD slits actuator; 10 - EMD target wires actuator.
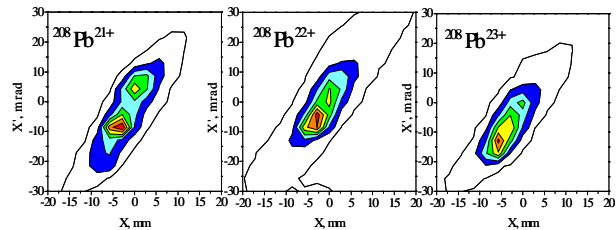

Figure 4: Horizontal emittances of the lead ion beam for three different charge states.

Table 1: Phase space distribution parameters for sample Xenon and Lead beams. Columns: 1-charge state, 2-intensity (eμA), 3-normalised RMS emittance (π·mm·mrad), 4-RMS α, 5-RMS β (mm/mrad).

1	2	3	4	5
Pb^{23+}	15	0.053	-2.6	2.39
Pb^{23+}	14.5	0.05	-2.31	1.55
Pb^{23+}	14	0.049	-2.24	1.65
Xe^{12+}	25	0.056	-4.32	2.73
Xe^{13+}	22	0.051	-4.76	3.00
Xe^{14+}	19	0.055	-4.71	3.03

for beam acceleration. All devices on the HV platform are operated by a PC installed on the deck. This computer is connected remotely through the fiber optics to the control station computer located outside of the safety fence. The control station PC also allows us to operate the EMD, perform mass scan analysis, etc.

When ECR beams are accelerated by an additional 75 kV platform voltage, the ion beam intensities will be increased by a factor of 2 to 4 compared to the low voltage operation. Table 2 shows an example of xenon beam parameters.

Table 2: Horizontal phase space distribution parameters for q×80 keV xenon beam. The units are the same as in Table 1.

1	2	3	4	5
Xe^{13+}	43	0.084	0.6	1.7
Xe^{15+}	35	0.076	0.52	1.8

UPGRADE OF THE LEBT

The following upgrades of the multi-q injector are being pursued a) installation of two 60° bending magnets along with focusing elements and remotely adjustable horizontal slit; b) development of the grid-less multi-harmonic buncher for longitudinal matching of the two-charge-state beams to the following RFQ; c) development of beam instrumentation for measurements of bunched multiple-charge-state beams downstream of the MHB.

All elements of the LEBT are being procured. The grid-less four-harmonic buncher operating at 28.75 MHz fundamental frequency is being designed. The full power one-segment RFQ has been constructed and tested [5].

Numerical studies of beam dynamics in the 2Q-LEBT have been performed using the multi-particle code TRACK [6]. TRACK simulates a multiple-component ion beam dynamics through pre-calculated 3D fields and taking into account space-charge effects. The realistic geometry of the ECR extraction region and beam-line shown in Fig. 2 was set up into the TRACK model. The two-dimensional electrostatic fields in the initial part of the beamline that consists of puller, Einzel lens and grounded electrodes were calculated using the POISSON code. 3D representation of magnetic field including fringe fields was implemented using genuine configuration of the 90° bending magnet. The phase space distribution parameters of the input beam were optimized to fit the measured output beam emittance and are shown in Fig. 5a. Recent beam measurements allowed us to develop a more realistic model of the beam initial conditions for the design of the beam transport and acceleration system. Particularly, in the simulations we have introduced 50% beam neutralization upstream of the accelerating tube in order to match the measured and simulated beam emittances at maximum transmitted current. In the simulations we assume 5 mA total beam current of the multi-component ion beam are extracted form the ECR.

The design goal is to combine two charge states of heavy-ion beam with a minimum emittance growth and

focus it to a ~8 millimeter beam diameter at the location of the MHB. Figure 5 shows beam phase space plots at various locations along the LEBT together with the beam envelopes.
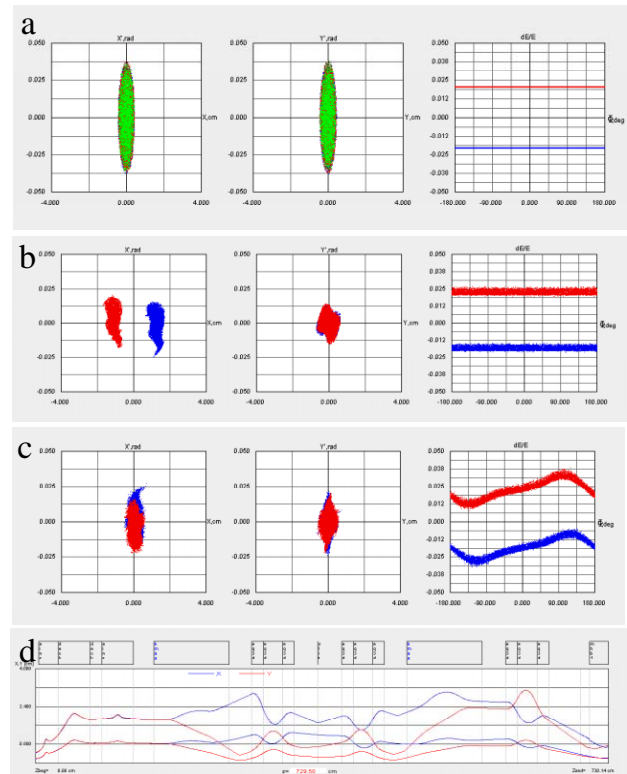

Figure 5: Beam phase space plots and envelopes in the LEBT. a − input beam; b − downstream of the slits; c − downstream of the MHB; d−full and RMS envelopes for Bi^{24+} and Bi^{25+} dual charge-state beam.

CONCLUSION

The obtained results show that the dual charge-state injector is feasible and can be used as a Front End for the RIA, AEBL or any similar high power heavy-ion linac. The extraction, transport and combination of multiple charge state beams is a simple and powerful technique and can be applied to increase the intensity of both conventional ECR sources and rare isotopes obtained from charge breeders. The completion of the multi-q-state injector prototype is expected in FY07 if appropriate funds will be available.

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