A multicharge ion source (Supernanogan) for the OLIS facility at ISAC/TRIUMFa)

Article *in* The Review of scientific instruments · March 2010

DOI: 10.1063/1.3303819 · Source: IEEE Xplore

A multicharge ion source (Supernanogan) for the OLIS facility at ISAC/TRIUMF[a)]

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(Presented 21 September 2009; received 21 September 2009; accepted 9 January 2010; published online 24 February 2010)

The Off-Line Ion Source (OLIS) [K. Jayamanna, D. Yuan, T. Kuo, M. MacDonald, P. Schmor, and G. Dutto, Rev. Sci. Instrum. **67**, 1061 (1996); K. Jayamanna, Rev. Sci. Instrum. **79**, 02711 (2008)] facility consists of a high voltage terminal containing a microwave cusp ion source, either a surface ion source or a hybrid surface-arc discharge ion source [K. Jayamanna and C. Vockenhuber, Rev. Sci. Instrum. **79**, 02C712 (2008)], and an electrostatic switch that allows the selection of any one of the sources without mechanical intervention. These sources provide a variety of +1 beams up to mass 30 for Isotope Separator and ACcelerator (ISAC) [R. E. Laxdal, Nucl. Instrum. Methods Phys. Res. B **204**, 400 (2003)] experiments, commissioning the accelerators, setting up the radioactive experiments, and for tuning the beam lines. The radio frequency quadrupole (RFQ) [M. Marchetto, Z. T. Ang, K. Jayamanna, R. E. Laxdal, A. Mitra, and V. Zvyagintsev, Eur. Phys. J. Spec. Top. **150**, 241 (2005)] injector accelerator is a constant velocity machine designed to accept only 2 keV/u and the source extraction energy is limited to 60 kV. Further stripping is then needed downstream of the RFQ to inject the beam into the drift tube linac [M. Marchetto, Z. T. Ang, K. Jayamanna, R. E. Laxdal, A. Mitra, and V. Zvyagintsev, Eur. Phys. J. Spec. Top. **150**, 241 (2005)] accelerator that requires A/q up to 6. Base on this constraints a multicharge ion source capable to deliver beams above mass 30 with A/q up to 6 was needed in order to reach full capability of the ISAC facility. A Supernanogan [C. Bieth *et al.*, Nucleonika **48**, S93 (2003)] multicharge ion source was then purchased from Pantechnik and was installed in the OLIS terminal. Commissioning and performance of the Supernanogan with some results such as emittance dependence of the charge states as well as charge state efficiencies are presented.
[doi:10.1063/1.3303819]

I. INTRODUCTION

Isotope Separator and ACcelerator (ISAC) is an online-based facility, which has been designed to provide beams up to 6.5 MeV, primarily for astrophysical studies. The ISAC facility also provides beams for nuclear structure physics, spectroscopy studies of exotic nuclei with resonance reactions, studies of shell structures near the limit of stability, nuclear reaction-mechanism studies with neutron-rich projectiles leading to the production of heavy elements, and for many other experiments.

ISAC is a single user machine but has two separate high energy and low energy areas. The online ion source terminal and the Off-Line Ion Source (OLIS) terminal are connected to ISAC through a cross in order to provide beams simultaneously to high and low energy beam lines. While providing radioactive beams from the online terminal to a low energy area, the stable beams from the offline terminal can be diverted to the high energy area and vice versa. This new addition of the multicharge ion source to the OLIS terminal will increase the stable beam availability beyond mass 30 up to mass 150 or higher. Furthermore, since the source can deliver A/q less or equal than 6, a stripping foil after the radio frequency quadrupole (RFQ) is not needed while delivering with the Supernanogan increasing the beam intensity on average of a factor of 3.

II. EXPERIMENTAL SETUP

A. Cart assembly

The design objective of the Supernanogan addition to the OLIS ion source terminal is to provide multicharged ion beams from the Supernanogan ion source while minimizing the impact on the microwave and surface ion source operation. The concept adopted for this functionality is a mobile, virtually self-contained ion source station. This station consists of two main sections, one at ground potential and the other at a high voltage (HV) bias of up to 30 kV. The ground section contains a high voltage isolation transformer, two turbo pumps and controllers, an ion gauge controller, a vacuum box for optics and services, and power distribution and computer control and monitoring. The HV section con-

[a)]Contributed paper, published as part of the Proceedings of the 13th International Conference on Ion Sources, Gatlinburg, Tennessee, September 2009.
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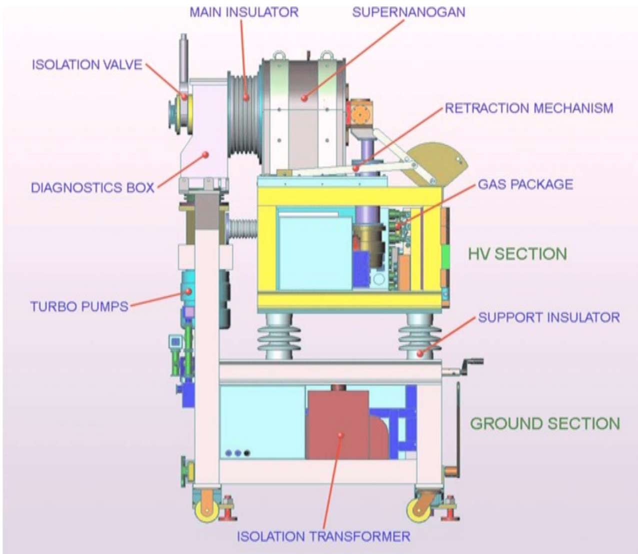

FIG. 1. (Color online) The mobile station, referred to as the "cart," is a self-contained ion source system that has all the necessary power supplies, vacuum components, diagnostic devices, and control systems.

tains the Supernanogan ion source and shielding, dry scroll vacuum pump, gas supply system, dc power supplies for Supernanogan operation, power distribution, and computer control and monitoring. The HV section communicates with the ground section controls via an optical link, then the ground section controls connects to the OLIS controls system (Fig. 1).

The cart rolls into the OLIS HV enclosure and obtains a vacuum tight connection to the OLIS electrostatic switch box at the central port. The cart is then connected to services such as power, rf, water, air, gas, vacuum roughing system, and controls. The operation of the Supernanogan is then much like the other OLIS ion sources, and utilizes the same interlock and safety systems already in use. When the Supernanogan is in need of servicing, it can be disconnected from the OLIS system and be removed without affecting the integrity of either the OLIS or Supernanogan vacuum. When outside the HV enclosure, the Supernanogan vacuum system can continue to operate, and the long conditioning times required for high charge states can be realized. The Supernanogan vacuum conditioning and maintenance time spent outside of the OLIS facility has no impact on the operation of the other ion sources. When the Supernanogan is required to provide beam to ISAC, disruption of OLIS beam operation by introducing the cart into the facility is minimal. The mobile nature and substantial weight of the cart require careful arresting of the cart's motion, precise aligning of the cart with the OLIS vacuum chamber, and securing a viable vacuum connection between the two. These concerns are addressed by a guide system consisting of horizontal guide plates fastened to the OLIS floor that the cart engages by means of a pair of cam followers. The motion is arrested by two shock absorbers fixed to substantial brackets anchored into the concrete floor. Docking utilizes a manually operated lead screw assembly to gently engage mating components and seals. At the same time, four cam followers on the bottom of the cart ride up onto corresponding support blocks that ensure repeatable alignment with respect to the OLIS facility.

The vacuum connection is made by an O-ring seal that is captive in the flange of a compressible bellows attached to the cart vacuum chamber. As the cart approaches its docking position, the face of the bellows flange with its captured O-ring seats against the corresponding face of the mating flange. The compressibility of the bellows allows for a positive sealing pressure on the O-ring. This bellows connection is situated between two gate valves, allowing for the intervalve volume to be evacuated or vented without affecting the vacuum in either the cart or OLIS electrostatic switch box. Figure 2 shows a cross section of the source with the extraction system and the radiation shielding.

B. Gas system

The Supernanogan multicharge ion source requires a variety of different gases to fulfill the ISAC beam schedule. To facilitate the utilization of these gases in the Supernanogan requires that the gas handling system be at the same HV potential as the ion source to avoid the possibility of arcing over through the gas volume.

The gas system employs six lecture size gas bottles with regulators, a dry scroll roughing pump, two gas flow controllers, three calibrated leaks (10^{-4} to 10^{-6} atm cc/s) and the necessary valves, manifolds, and plumbing to provide for a wide variety of background and target gas mixtures (Fig. 3). A programmable logic controller (PLC) controls and monitors the gas system via an optical link. The gas supply system is mounted to a hinged panel located at the rear of the HV section. The gas bottles with regulators and gauges are mounted to the outside of the panel and are clearly visible from outside the HV enclosure, allowing for monitoring of pressures and consumptions rates. An individual bottle with its shutoff valve and regulator can be swapped out as a unit without affecting the previously established gas supply configuration. By swinging out the panel, the flow controllers, leaks, and valving can be easily accessed for inspection or servicing.

C. Magnetic stabilization system

A magnetic field stability system was designed and implemented this year for the mass separator magnet at OLIS. The magnet is connected to a main power supply capable of providing up to 500 A. This power supply has a resolution of about 50 mA. The lack of resolution of the main power supply, along with temperature effects to the magnet material and power supply, and various other factors, affects the magnetic field produced. This creates an unstable beam over short and long periods of time. Through the use of a proportional-integral-derivative (PID) controller, a small power supply with a better resolution is used to correct for changes in the magnetic field over time. A Kepco ABC 25–4DM power supply was connected in parallel with the main power supply to provide a current resolution in the magnet of about 1 mA. The magnetic field was measured with a Group 3 MPT-141 Hall probe with a Group 3 DTM-151 digital teslameter. The 4A Kepco power supply is capable of correcting for as much as 40 G in changes to the magnetic field

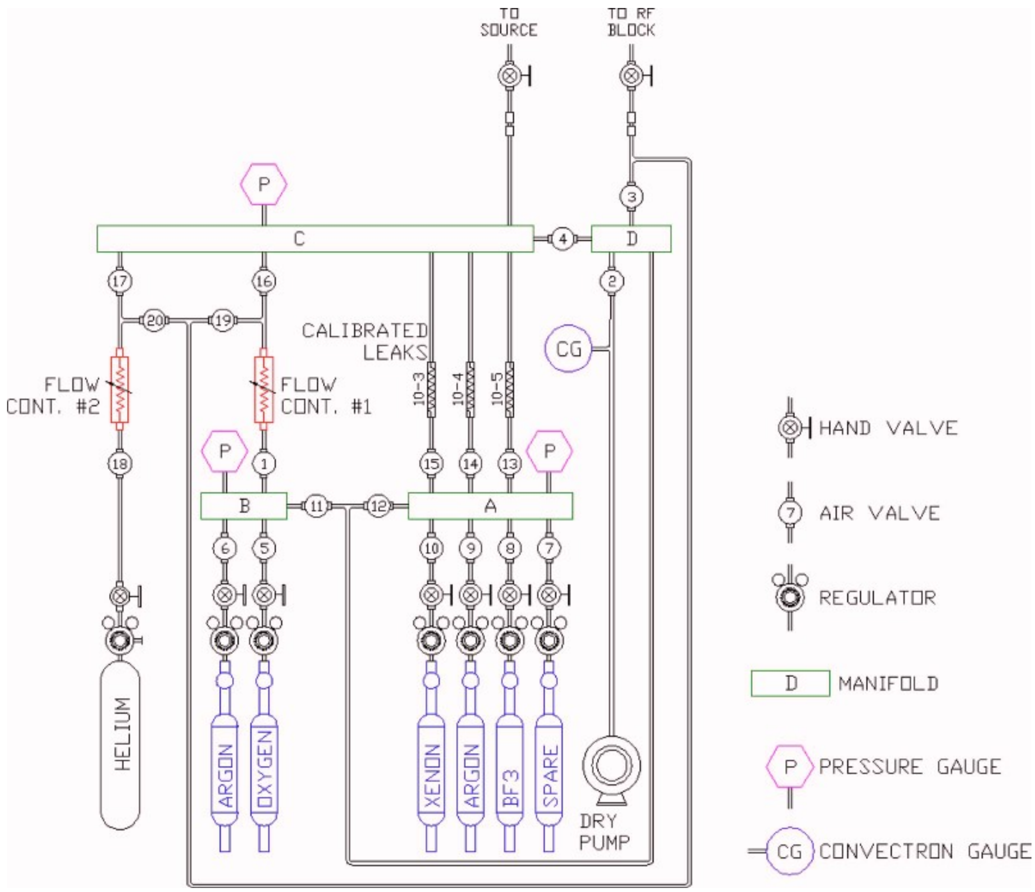

FIG. 2. (Color online) This cutaway illustration of the ion source shows the extraction region with optics elements, HV insulator, and x-ray shielding. Local shielding of the Supernanogan is achieved by a lead shroud with end and bottom plates. Shielding the extraction region with tungsten required the close proximity of shielding elements at high potential difference. The utilization of quartz liners to insulate these components from each other allows for a relatively small configuration of manageable weight.

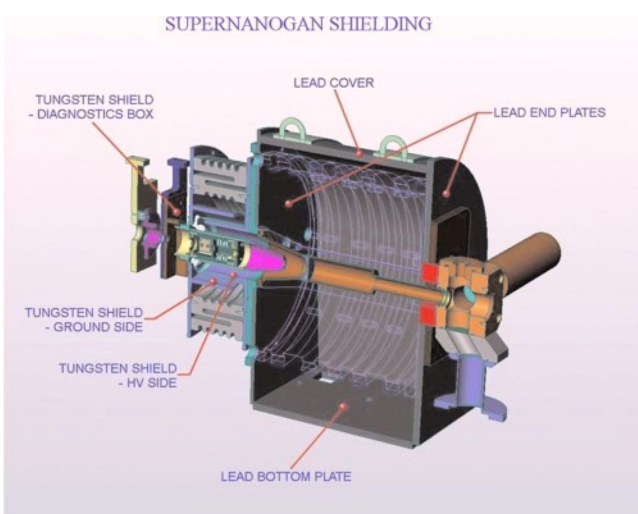

FIG. 3. (Color online) The gas supply system for the Supernanogan is mounted to a hinged panel at the rear of the cart affording easy access to lecture bottles of various gases, flow controllers (0.05–0.5 scc/min), standard leaks ($\times 10^{-3}$, $\times 10^{-4}$, and $\times 10^{-5}$ atm cc/s), manifolds, pressure transducers, and valving. The above graphic shows a schematic of the gas supply routing. This arrangement allows for a wide variety of background and target gas mixtures and leak rates to be configured by computer control. During ideal running conditions a gas flow of 10^{-9} to 10^{-2} atm cc/s can be delivered to the source.

with a minimum of 0.01 G with 1 mA resolution in this particular setup. The PID controller is run continuously to correct for changes in the magnetic field as read by the magnetic field probe. It was found that, over a period of a week of operation, the magnetic field was kept steady to within +/−0.2 G using the PID controller to stabilize the magnetic field.

III. RESULTS AND DISCUSSION

A. Efficiency studies

Multicharge ionization can be achieved by either step-by-step ionization or by Auger transition. Electron cyclotron resonance (ECR) plasma at higher frequencies is able to deliver enough energetic electrons (T_e) and electron densities (n_e) high enough to produce highly charged ions. Most importantly, the Golovanivsky's boundary condition[1] ($n_0/n_e \leq 7\times 10^3 \xi T_e^{-3/2} A^{1/2}/Z$) must be fulfilled in order to increase the population of the given charge state, where Z=desired charge state, A=atom mass number, and ξ=total number of electrons in the outer shell. Since ISAC needs $A/q \sim 6$, the background neutral density must reach a 10^7 cm^{-3} or below which equivalent to vacuum range of 3.5×10^{-8} Torr, if the electron density is to be in the range of 10^{11} cm^{-3}.

Efficiency of the source was measured using calibrated leaks from oxygen and neon isotopes. In order to achieve

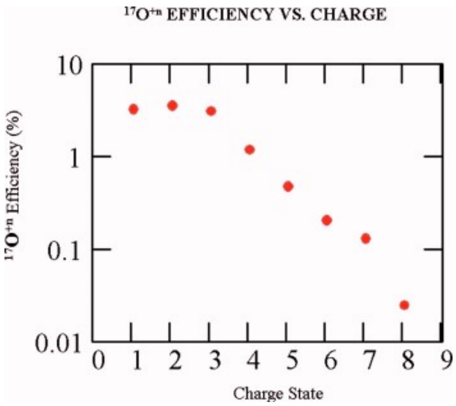

FIG. 4. (Color online) ^{17}O efficiency vs charge state was measured at 18 kV extraction with 2 mm diameter plasma aperture. For this measurement, the source was tuned for minimum emittance of charge state +3. The source pressure with the ^{17}O flow and when the high voltage is on and off are 4×10^{-8} Torr and 5.5×10^{-8} Torr, respectively. Beam current is significant enough to affect the pressure.

maximum efficiency, the gases were sent directly into the source chamber through the hollow coaxial antenna of the source. The efficiency of each charge versus mass is shown in Fig. 4. In order to match the acceptance of the ISAC RFQ, the plasma aperture was reduced to a 2 mm diameter.

B. Emittance versus charge studies

For emittance measurements, an improved version of the electric sweep scanner, originally proposed by Allison,[2] was used. The emittance figure for $^{17}O^{+7}$ is shown in Fig. 5. It was found that emittance of the extracted multicharge ions varies with different charge states of the same element. Since the variation was very little, a new and more accurate data processing method had to be developed in order to minimize

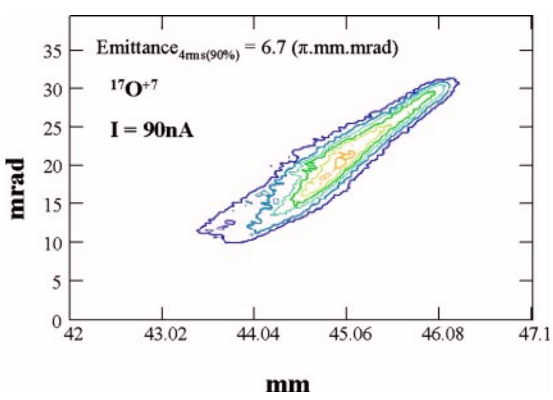

FIG. 5. (Color online) Emittance of the $^{17}O^{+7}$ beam measured with a 2 mm diameter plasma aperture.

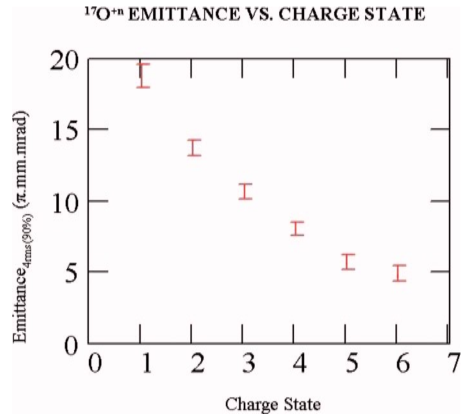

FIG. 6. (Color online) ^{17}O emittance vs charge state was measured at 18 kV extraction. The concentration of higher charge states near the center of the plasma may explain the observed lower emittance of higher charge states.

the noise reduction and emittance calculation error to $\leq 1\%$. Figure 6 shows the variation of the emittance values for different charges of ^{17}O isotope. Detailed analysis of the data is beyond the scope of this paper and will be published elsewhere.

IV. SUMMARY

The ability to vary the frequency with very fine intervals has led to a significant enhancement of source performance. A few watts of rf power can be sufficient to provide the necessary multicharge beams to ISAC. The emittance of multicharge ions was measured. Observed lower emittance for higher charges can be explained by the fact that the concentration of higher charges to the center of the plasma. With the installation of the Supernanogan a stripping foil is no longer necessary and the ISAC beam current capability has increased by more than ten times. A few major experiments were performed in ISAC using rare isotopes such as ^{17}O and ^{18}O, and many more astrophysics experiments such as $^{33}S^{+6}$ are lining up to take advantage of the exotic beams from the Supernanogan at ISAC.

ACKNOWLEDGMENTS

TRIUMF/ISAC receives federal funding via a contribution agreement through the National Research Council of Canada. The authors would like to express their sincere gratitude to the ISAC Controls group for their unwavering support during commissioning and operation.

[1] K. S. Golovanivsky, Instrum. Exp. Tech. **28**, 989 (1986).
[2] P. W. Allison, IEEE Trans. Nucl. Sci. **30**, 2204 (1983).