BRIC: AN ELECTRON BEAM ION SOURCE AS CHARGE STATE BREEDER FOR RADIOACTIVE ION BEAM FACILITIES

G. Brautti, T. Clauser, A. Rainò, V. Stagno,
Dipartimento di Fisica dell'Università and INFN - Sezione di Bari, Bari, Italy
G. Lamanna and V. Variale, INFN - Sezione di Bari, Bari, Italy
P. Logatchov, BINP, Novosibirsk, Russia

Abstract

This work deals with the "charge state breeder" that will be tested at INFN Laboratory of Bari (Italy). The breeder, based on the Electron Beam Ion Source (EBIS) scheme, is designed for applications in Radioactive Ion Beam (RIB) production facilities based on the Isotope Separation On-Line (ISOL) method. Some improvements with respect to the classical EBIS have been foreseen and numerically simulated. The relevant one is the insertion in the ion chamber of a RF Quadrupole aiming at filtering the unwanted masses. The breeder design and the numerical simulation results are reported.

1 INTRODUCTION

The SPES Project at the LNL-INFN of Legnaro (Padua) aims to the assembling an advanced facility for Radioactive Ion Beam (RIB) production based on the Isotope Separation On-Line (ISOL) method. In the framework of the SPES project, our INFN group in Bari is involved in the development and testing of a charge state breeder of the EBIS (Electron Beam Ion Source) type: BRIC. The accelerated radioactive atoms will have probably a mass lying in the range 80-200 a.m.u. A facility of this type, has two acceleration stages. The secondary stage is intended to accelerate the radioactive ions at the desired energy. The singly charged ion beam is injected into a "charge state breeder" to enhance the ion charge state at high level. This allows to increase the efficiency of the beam transmission and to lower the cost of the secondary accelerator. For efficient acceleration by compact LINACs, charge over mass ratios greater than 1/10 are required. At the present state of art two sources type seems useful for charge state breeding: the Electron Cyclotron Resonance Ion Source (ECRIS) and the Electron Beam Ion Source (EBIS). Comparison between this two ion sources have been reported by several authors (see for example [1,2]).

In a typical scheme of an EBIS source, the ion charge state enhancement is obtained through the interaction with an external electron beam. The electron gun, the ion chamber and the collector are coaxial and the ions are injected and extracted from the same side of the set up. The injected ions are trapped in a longitudinal potential well where they remain until the extraction. Two ion injection mode can be considered [1]:

- fast injection mode:
  where the ions are decelerated before the injection, enter the breeder through the collector and are finally trapped by raising the potential barrier on the collector side. The ions are injected in a pulse whose length has to be shorter than the round trip time in the potential well. In this mode a Penning source is also required.
- slow injection mode:
  where the ions have an energy higher than the potential barrier on the collector side and enter continuously the chamber during the confinement time. They reach the required charge state during one round trip time and then remain trapped in the confinement area. In this case no preliminary pre-bunching trap is required.

The number of ion that can be contained in an EBIS depends on the electron beam current Ie and energy Ue, on the confinement length l and on the reachable fraction of space charge compensation k which is ≈ 50%. This number is given by:

$$N_q^+ \leq k\sqrt{\frac{m_e}{2e^3}}\,\frac{l}{q}\,\frac{I_e}{\sqrt{U_e}} \qquad (1)$$

2 BRIC EXPERIMENT

2.1 Set Up Assembly

The BRIC experimental set up is, at a first step, of the same type as described in the introduction. The general scheme of the breeder is shown in Fig. 1. Different configurations are in order for the future studies. In the new assembling the electron gun and collector axis will have an angle with respect to the ion chamber axis. This configuration, just adopted in the our pioneer experiment TIS (Trapped Ion Source) [3], has the advantage to inject and extract the ions on the opposite sides of the breeder

2.2 Electron Gun and Collector

The BRIC electron gun (upper part of fFig. 1) is a classical Pierce gun supporting a reserve cathode with ∅ = 1 cm providing a current up to 1.5 A. The beam can be focused and modulated by controlling the voltage of the Pierce electrode. The output energy can be raised up to 10 keV. The gun will be placed in the semi-immersed configuration with respect to the solenoid field. The collector (lower part of Fig. 1) allocates a static quadrupole to focus the ion at the exit hole. The solenoid field lines have to be cut to increase the electron beam collection collector (lower part of Fig. 1) allocates a static quadrupole to focus the ion at the exit hole. The solenoid field lines have to be cut to increase the electron beam collection efficiency and to avoid the electrons to come back quadrupole to focus the ion at the exit hole.

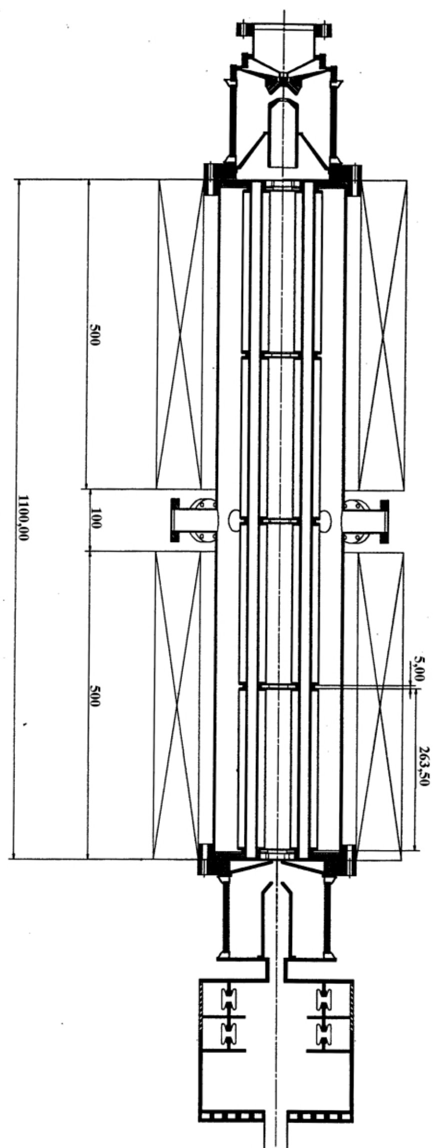

Figure 1: BRIC Set Up Assembly.

2.3 Ion Chamber

The ion chamber (central part of Fig. 1) has been designed to allocate the drift tubes, the barrier electrodes for the longitudinal ion trapping and the RF-Quadrupole. All the feed troughs for DC voltage and RF power supply, diagnostics and so on, have been inserted in the central zone of the chamber. The overall chamber (110 cm length) is immersed in the field of two solenoid (50 cm long, only 10 cm apart). The magnetic field is important to ensure the highest possible electron beam current density J thus reducing the ion-beam containment time τ_c to reach the required charge state.

BRIC Charge Breeding Parameters.
If, following the SPES project requirements, an ion mass of about 100 Amu and a charge state of 10 (charge over mass ratio = 1/10) is considered, from the condition [4]:

$$J \bullet \tau_c \approx 3 \div 4 \ [A \bullet sec/cm^2]$$

the resulting containment time τ_c, for e-beam current density J of tens A/ cm^2 is in the range: 100 ÷ 300 msec.

2.4 The RF- Quadrupole

The figure 2 reports the transverse section of the BRIC ion chamber together with the RF-Quadrupole. The design parameters have been chosen accordingly to the parameter $\eta = r/r_o$ where r is the cylinder radius and r_o is the distance of the cylinder from the axis). Instead of the "magic number" η = 1.145, the best approximation η = 1.1 has been assumed [5]

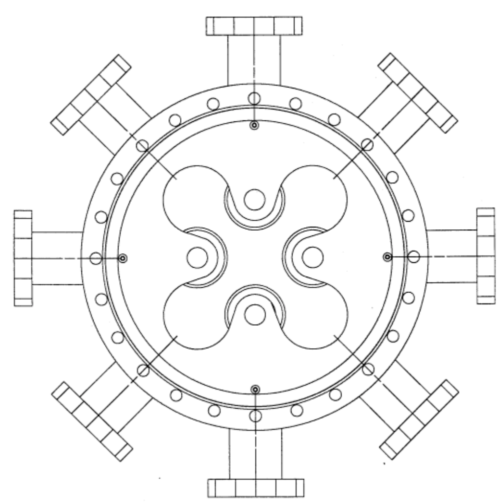

Figure 2: Ion chamber section with the RF-Quadrupole.

The equations of the ion motion, in the transverse (x,y) plane, for a pure RF-quadrupole, are two Mathieu equations, whose coefficients $a_{x,y}$ and $q_{x,y}$ depends on the DC component and the AC component of the quadrupolar field respectively. These coefficients determine also the stability conditions. The interesting first stability region in the plane (q,a), has quasi-triangular form of base $q \approx 0 \div 0.9$ and vertex $a = 0.23$, $q = 0.7$.

When the effects of the solenoid and of the electron beam are taken into account, the stability diagram is modified. Namely the new equations of the ion motion in the plane (x,y) depend also on two other coefficients accounting for the magnetic field and the electron beam space charge. Nevertheless also in this case, new stability regions can be identified. The magnetic field and the electron beam space charge act in opposite way: the first one reshapes and reduce the stability region area, whereas the second increases the stability area, due to the enhancement of the transverse containment of the ions.

3 BRIC NUMERICAL SIMULATIONS

3.1 Electron Beam Simulations

The electron beam propagation from the gun to the collector has been numerically simulated by the EGUN code in several possible experimental conditions. Figure 3 refers to an electron energy of 10 keV and a magnetic field of the solenoids of B=0.18 Tesla. The deep in the central zone of the ion chamber is due to gap (10 cm) between the two solenoids.

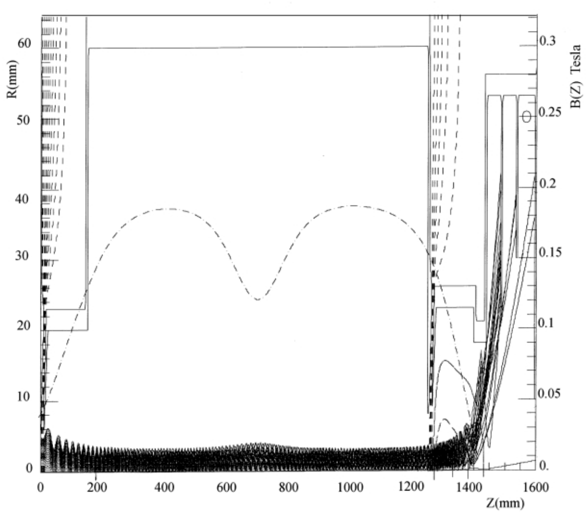

Figure 3: BRIC Electron Beam Simulation.

3.2 BRIC Code-Ion Simulation

The electron and ion propagation in the RF-quadrupole has been simulated by a code properly developed. This code allows to include all the effect of the magnetic field of the external solenoids and of the space charge force due to the electron beam. Several possible configurations of the system have been considered and tested. All the parameters have been varied. From the obtained results the filtering action of the RF-quadrupole resulted evident. By plotting the mass range versus the AC component of the quadrupolar field, for fixed DC component value, stability and instability regions can be enlighten. This shows the possibility to select the mass range of interest with a good resolution by varying the amplitude of the RF DC and AC components. A particularly intersting example for zero DC component, RF frequency of 1 MHz and mass range 80÷200 (as probably will be the case of the SPES project) is reported in Figure 4. Here, the chosen parameter values are: electron beam current : 100mA; electron energy: 5 keV; solenoid magnetic field on the axis: 150 Gauss.

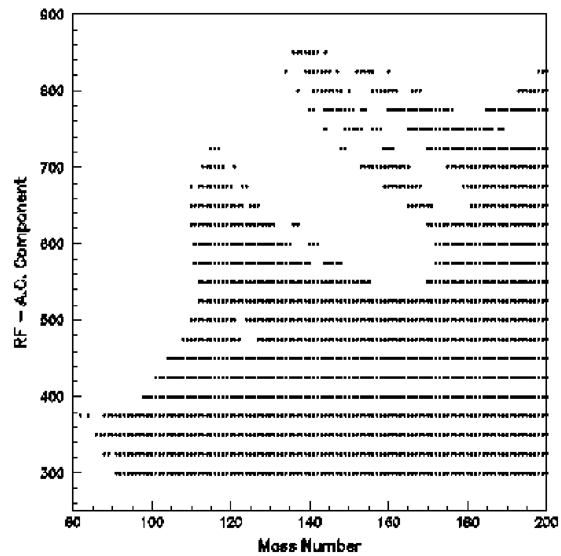

Figure 4: Stability Regions for Ion Masses.

For a RF-AC component of 850 Volt only masses in the range 136÷142 are stable.

5 CONCLUSIONS

The numerical simulation of the charge state breeder BRIC show that it is possible to obtain an increase of the filtering through the insertion of an RF-quadrupole into the ion chamber . Several parameters can be varied to match the best experimental conditions for increase the filtering action, the containment of the desired ion masses with the charge state ionization required. The strong instability of the light masses obtained through the quadrupole can help to increase the chamber vacuum by eliminating the residual gas masses. It has been estimated that the efficiency can be increased by properly adjusting all the breeder parameters.

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