DESIGN OF RISP RFQ COOLER BUNCHER

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Abstract

Under RISP project, wide variety of intense rare isotope ion beams will be provided. An EBIS charge breeder has been designed to charge breed these beams. Its optimum operation requires injection of bunched beam with small emittance and energy spread. An RFQCB is designed to meet these requirements. In this respect, the RFQCB should efficiently accept high intensity continuous beams and deliver to EBIS bunched beams with emittance around 3 π.mm.mrad, energy spread < 10 eV and short bunch width (~10 μs). A new design concept to be implemented in this RFQCB have been developed, including a novel injection/extraction electrodes geometry with improved differential pumping system. Simulations have shown high efficiency of transmission more than 93 % of incoming ions for beam intensities up to 1 μA with improved beam quality. A set of beam diagnostics tools including Faraday cups, pepper-pot emittance-meter with MCP based detector are designed to characterize the ionbeams.

RISP PROJECT

A heavy ion accelerator facility called RAON [1] is being designed to produce various rare isotopes under the Rare Isotope Science Project (RISP) [2]. Using the ISOLand IFbeam production methods [3], as well as a combination of these methods RAON will provide wide variety of intense rare isotope ion beams [4] for nuclear physics experiments and applied science.

An efficient and cost effective acceleration of rare isotope beams requires utilization of charge breeder as an interface between ion source and linear accelerator to convert a singly-charged ion beam into the highly-charged ion beam. An Electron Beam Ion Source (EBIS) charge breeder (CB) has been designed [5] and is being built to charge breed rare isotope ion beams for further acceleration. EBIS CB is preferable choice for the most ongoing projects, including RISP, because of its high breeding efficiency, short breeding time, and in particular, high purity of charge bred ion beams. The optimum operation of EBIS CB requires injection of bunched beam with small emittance and low energy spread. An RFQ Cooler/Buncher (RISP-RFQCB) is designed to meet these requirements.

RFQ COOLER-BUNCHER

At present, RFQCB is operational at multiple rare isotope facilities like CARIBU, ISCOOL, NSCL and others [6]. In order to meet requirements of modern ISOL facilities, it is necessary to increase the beam intensity limit of such device from typically several tens of pico-amperes (~10^6 pps) to several tens of nano-amperes (~10^9 pps) and to accumulate the ions during time determined by the required EBIS charge breeding time (~10-1000ms). As the existing devices are not able neither to handle high beam current nor to accumulate ions for long period of time, a new RISP-RFQCB device is being developed. In order to meet the EBIS beam requirements, the RISP-RFQCB should efficiently accept high intensity continuous beams from ISOL ion source and deliver to the EBIS charge breeder bunched ion beams with small emittance (~3 π.mm.mrad), low energy spread (<10 eV) and short bunch width (~10 μs).

The RISP-RFQCB is designed to handle intense ion beams with large emittances and wide range of ion masses (6-180 a.m.u), and to deliver bunches with high rep-rate (1-100 Hz). A new design concept to be implemented in the RISP RFQCB have been developed, including a novel injection/extraction electrodes geometry. An overview of the RISP RFQCB design concept will be presented. Simulated performance of the device and design of different sub-systems will be presented and discussed as well.

Optics Design

The RFQCB must accept up to few tens nAmps continuous beam with energy <=60keV and transverse emittance going up to 40 π.mm.mrad over a mass range between 6 and 180 uma. It must also deliver bunched beams in agreement with EBIS injection beam requirements. To conform a conceptual design capable of satisfying these requirements, several ion optical simulations were performed using SIMION 8.1 to model ion optics, including RF/DC fields, buffer gas and space charge effects.

As for all RFQCB devices, ion optical system of the present device can be divided into three sections [7]: injection section, cooling section and extraction section. These sections have to ensure an efficient transmission of the input beams. To efficiently cool RISP beams, the injection energy that will bring the ions to the cooling section should be of ~20-100 eV. Therefore, the relatively high energy of beam should be decreased using a DC electric field. The deceleration can be done by the injection plate electrode setting at high voltage (HV) platform and grounded input electrode, Figure 1. Other injection electrodes provide a fine-tuning of beam transmission. The cooling section consists of the main RFQCB chamber placed at HV platform. This chamber is filled with helium buffer gas and it accommodate the radiofrequency quadrupole (RFQ). It is devoted to trap efficiently the injected beam and to cool it progressively with the buffer gas. To guide the ions along the RFQ up to the extraction section, the RFQ electrodes are segmented and a DC potentials are applied to these segments. The structure is 800 mm in length and is separated into 27 segments of various length. Several electrodes are placed at RFQCB exit to extract and accelerate cooled and bunched ion beam back to the same energy as that of the

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injected beam. Extraction section structure and geometry are similar to structure and geometry of the injection section, Figure 1. Numerical simulations, done by SIMION [8], were carried out to design this system. The beam is extracted from the cooling section through the extraction aperture. Once it passes through this aperture, it is strongly accelerated by the DC electric field created between the extraction aperture and the ground electrode. Two conical electrodes are used to prevent ion losses. Multiple simulations were undertaken to confirm the design of the RISP-RFQCB. The simulations were done for a uniform circular distribution of one thousands of 133Cs+ ions in helium buffer gas. The ions initial conditions were determined for ion beam with 60 keV energy, 40 π.mm.mrad transverse emittance, 10 mm diameter and 10 eV energy spread.

Once the ions are successfully injected into the RFQ, they progressively undergo the cooling process and then released in short bunches [9]. The cooling will occur over 750 mm through the RFQ and the bunching will be done using the 26th segment. Simulations of the bunching and extraction section were carried out to understand operating parameters to be used in experiments. Several parameters that may involve the cooling effects are evaluated in SIMION including the gas pressure, input beam energy, ion mass, ion charge, guiding DC voltages and RF voltage. Simulations were performed with various operating parameters and only the optimal results will be presented.

The described device is designed to be used either as a cooler (DC mode) or as a cooler buncher. In DC mode the ions are guided via DC potential distribution up to the RFQ output where they are extracted and accelerated to their initial beam energy before entering RFQCB. Simulation results showed more than 95 % of incoming ions can be transmitted through the extraction section with an energy spread ~ 2 eV and a beam emittance ~2.9 π.mm.mrad for 10 nA beam current. With higher beam currents the space charge effect becomes considerable on the beam features. This was well depicted in the progressive beam growth reaching ~ 3.4 eVenergy spread and ~4 π.mm.mrad emittance (Figure 2)for 1 µA input beam current. The transmission remains above 95 % in spite of the significant contribution of the space charge effect.

In our case, the RFQCB will be operated in bunched mode, collecting ions of interest for some amount of time, bunching, and ejecting them in a tight packet. Simulations of emittance, ion pulse duration and energy spread for 10 nA beam current and 10 ms cooling time were performed with the same parameters as for DC mode described above. The extracted beam has the following parameters in this case: an emittance of 3.1 π.mm.mrad, an ion bunch duration of 1.9 µs and an energy spread of 2.2 eV (Figure 3).

RFQ CB Beamline

The entire RFQ CB beamline consists of five sections (Figure 4): Pre-injection section (1), Injection section (2), RFQ cavity (3), Extraction section (4), Post-extraction section (5). These sections are connected via CF-160 flanges and consists of stainless steel vacuum chambers. All sections are pumped by Turbo-molecular pumps (TMP). Buffer gas is injected into the RFQ section and diffuse to other sections as well. All vacuum components are chosen to be standard commercial when it is possible. Stainless steel is used for manufacture of all electrodes and ceramic-for most of insulators. The gap between various electrodes were chosen to avoid breakdowns.

RFQ chamber is filled with 0.5-3 mbar of helium. There are several differential pumping stages between RFQCB chamber and other sections of the RFQCB.

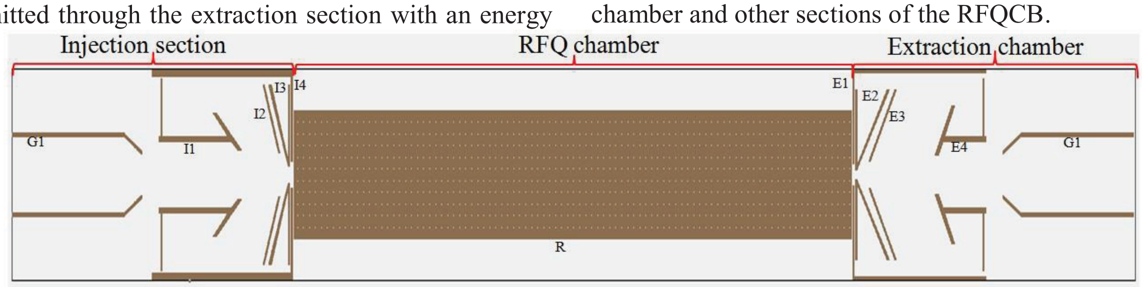

Figure 1: Optics design of the RFQ CB and overview of the three sections forming its optics system: Ground electrode(G1), 1st injection electrode(I1), 2nd injection electrode (I2), 3rd injection electrode(I3), injection plate(I4), RFQ section(R), extraction plate(E1), 1st extraction electrode(E2), 2nd extraction electrode(E3), 3rd extraction electrode(E4).

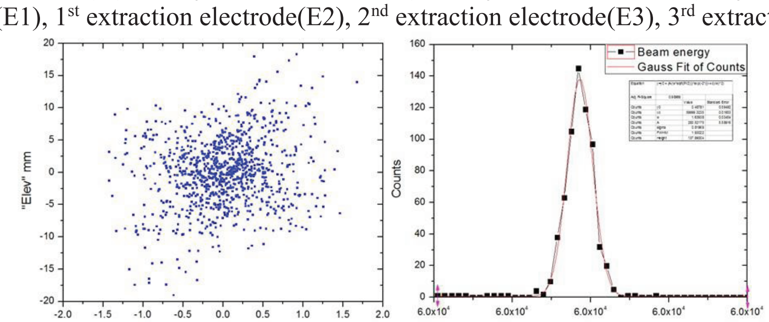

Figure 2: Extracted DC beam parameter (simulations are performed with buffer gas pressure of 2.6 Pa, RF voltage amplitude and frequency of 5 kV and 5MHz, a guiding field of 0.14 V/mm): beam emittance (left) and beam energy spread (right).

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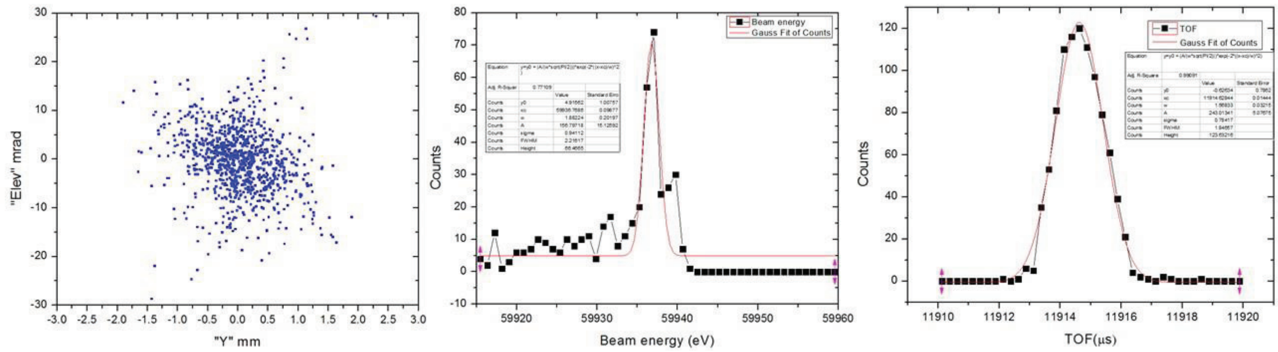

Figure 3: Simulated parameters of extracted beam in bunching mode: beam emittance (left), energy spread (middle) and bunch width (right).

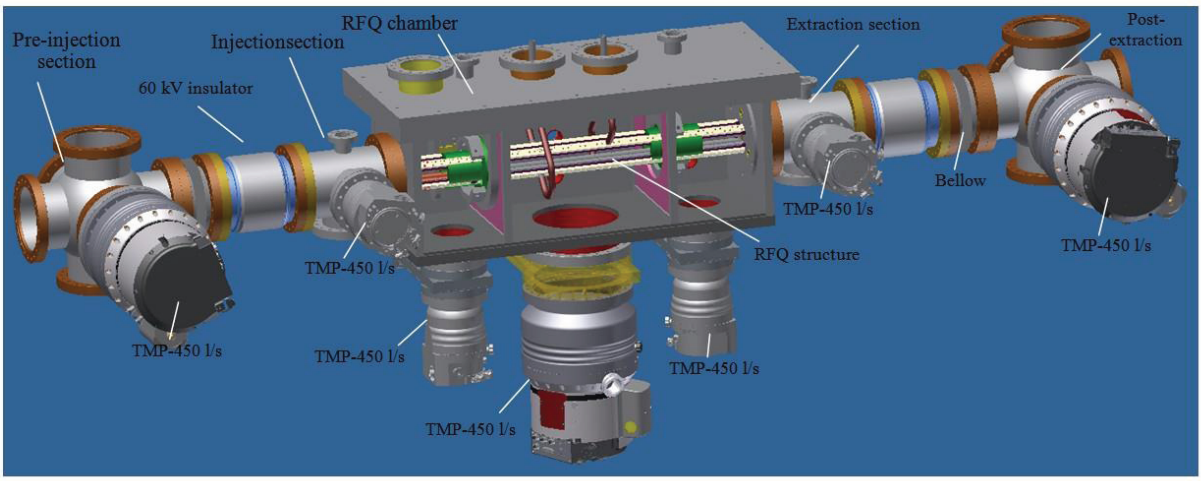

Figure 4: Engineering model of the RISP RFQ Cooler-Buncher.

BEAM DIAGNOSTIC

Efficiency RFQCB, output beam emittance, energy spread and bunch width will be measured and optimized during off-line commissioning.

The transmission is the ratio of the beam current extracted from RFQCB and injected into RFQCB. These currents will be measured by two identical Faraday cups placed at the input and output of RFQCB. Emittance of output beam will be measured by pepper-pot emittance meter. Measurement of beam energy spread is very important for understanding the cooling process of intense beam. The measurements of the transmission as a function of the DC retarding potential, applied to the last segment of the RFQ, will be used to determine the longitudinal energy spread using the width (FWHM) of its derivative. The bunch width will be measured using fast MCP detector. Some details of these beam diagnostic tools are described below.

Faraday Cup

The 3D model of Faraday cup is presented in Figure 5. Faraday cup is with 47 mm input aperture is driven by air stroke. It stops all beam particles and the resulting signal is measured to obtain information on the beam intensity. The accuracy of the method depends on the noise level present in the system and the charge collection efficiency. Low-energy beams can be easily stopped in a metal plate, but backscattered and secondary particles can carry the charge away. For ions, it is resolved with additional suppression by means of an electric field.

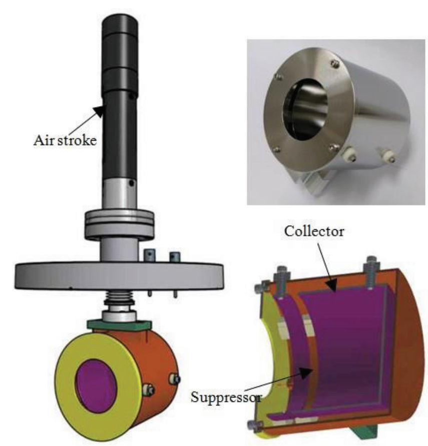

Figure 5: Faraday cup system. (Left) Faraday cup attached to air stroke, (right) sketch of its collector and suppressor.

Emittance Meter

The pepper-pot method is a common way to determine the transverse beam emittance. The pepper-pot mask consists of an even plate with a 2D array of holes in it. Ion beam which passes the pepper-pot mask through its holes

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gets separated into several beamlets which hit a scintillating screen (MCP-chevron type) located further downstream. Design of pepper-pot meter is based on one described in [10]. It has the following parameters: an MCP active area of 40 mm, a mask aperture of 40 mm, mask holes separation/size 1mm/20 um. The distance between the MCP and the mask is adjustable from 5 to 50 mm, to provide optimization for non-overlapping beamlet images with maximum diameter. The rms transverse beam emittance can be calculated from the position, size, and shape of these images. The geometric transverse emittance can then be deduced from the rms emittance where it is defined at 90% of the action volume.

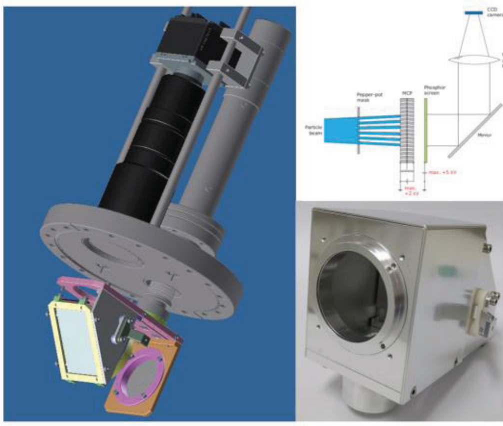

Figure 6: Emittance meter system. (Left) 3D model Schematic of the pepper-pot emittance meter. (Right) scheme of the ion beam imaging system [11].

MCP Detector

The MCP (Micro Channel Plate) detector consists of a MCP screenbacked by a P46 phosphor screen spaced by few millimeters gap. The MCP screen is a matrix of thousands of miniature electron multipliers oriented parallel to one another and fabricated on a lead glass. The length to diameter ratio of each channel is typically around 60, and the channel axis is normally biased at a small angle to the MCP input surface. Thus the incident particle can strike out a large number of secondary electrons when a typical voltage of 1 kV is applied between the two sides of the MCP. With a typical gain of several 10^4 it provides the capability to detect single ion. Since this detector is fast, it is also used for obtaining the time-of-flight information on ions. An assembly of two MCPs is often used to enhance the signal multiplication. An Einzel lens and an attenuator can be mounted in front of the MCP screen for high-sensitivity detection.

As each ion reaches the MCP detector plane, its arrival time is binned appropriately, creating a time of flight histogram for each extracted ensemble that simulates the experimental ion signal recorded by the MCP detector. These signals imitate the temporal distribution of extracted cooled beam and possible contaminants.

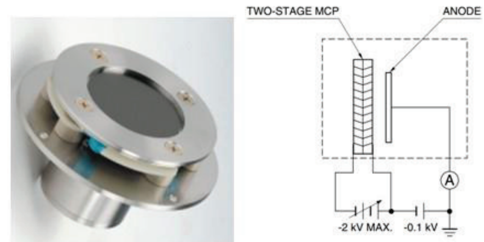

Figure 7: MCP detector system. (Left) schematic of the MCP, (right) MCP bias diagram of MCP when detecting positive ions [12].

CONCLUSION

RFQCB capable to handle high intensity rare isotope DC ion beams has been designed for future RAON facility. Based on the RFQ CB design presented in this paper, the manufacturing of the various subsystems (electric system, vacuum system, control system, (DAQ) has been started. Described ion beam diagnostic tools will be used for RFQCB off-line commissioning.

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