EBIS CHARGE BREEDER FOR RAON FACILITY*

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Abstract

New large scale accelerator facility called RAON is under design in the Institute for Basic Science (IBS), Daejeon, Korea. Both technics of rare isotope production Isotope Separation On-Line (ISOL) and In-Flight Fragmentation (IF) will be combined within one facility for the first time to provide wide variety of rare isotope ion beams for nuclear physics experiments and applied research [1]. Electron Beam Ion Source (EBIS) charge breeder will be utilized to prepare rare isotope ion beams produced by ISOL method for efficient acceleration. Beams of different rare isotopes with masses in the range of 6 – 180 a.m.u. will be charge-bred by an EBIS charge breeder to a charge-to-mass ratio $(q/A) \geq 1/4$ and accelerated by linear accelerator to energies of 18.5 MeV/u. RAON EBIS charge breeder will provide the next step in the development of breeder technology by implementation of electron beam with current up to 3 A and utilization of wide (8") warm bore of 6 T superconducting solenoid. The design of RAON EBIS charge breeder is presented and discussed.

INTRODUCTION

EBIS charge breeder (EBIS CB) is a key element for efficient and cost effective acceleration of rare isotope beams produced by ISOL method. It serves as an interface between ISOL ion source and linear accelerator to convert a singly-charged ion beam into the highly-charged ion beam with required charge-to-mass ratio. Over the last decade EBIS CB has been established as a mature concept with demonstrated superior parameters - high breeding efficiency, short breeding times and low background of stable contaminants in charge-bred rare isotope beams. By this reason EBIS CB is now preferable choice for the most of rare isotope facilities either already operational or being under construction, including RAON. After successful demonstration of effective charge breeding and many years of reliable on-line operation of REX EBIS CB at CERN ISOLDE [2], next generation EBIT CB for MSU ReA3 [3] and EBIS CB for ANL CARIBU [4] both with higher electron beam current and electron beam current density in the ion trap have been developed and commissioned recently.

At present, the CARIBU EBIS CB is the most advanced system with up to 2 A electron beam current and 28% breeding efficiency demonstrated off-line with injected stable $^{133}Cs^{+}$ ion beam [5, 6]. The RAON EBIS CB will provide the next step in the development of the breeder technology further enhancing electron beam current up to 3 A and improving overall system design and performance by implementation of the superconducting solenoid with larger (8") diameter of the warm bore.

Parameters of the RAON EBIS CB are described elsewhere [7] and its general design is presented in [8]. The RAON EBIS CB will be operated in so-called "pulsed' injection mode which provide higher breeding efficiency in comparison with "continuous" injection mode [2]. An RFQ cooler-buncher will be placed downstream of the EBIS CB to convert dc beam of selected rare isotope extracted from ISOL ion source into pulsed ion beam required for "pulsed" injection into the EBIS CB. The RFQ cooler-buncher will deliver to the EBIS CB high quality ion beams with emittance of about 3 π mm∘mrad, energy spread below 10 eV and pulse duration of about 10 μs. Such RFQ cooler-buncher capable to handle high intensity ion beams (up to 10^9 ions/s) has been recently designed [9] and its manufacturing is now in progress.

DESIGN OF RAON EBIS CB

3D model of RAON EBIS CB is presented in Fig. 1. RAON EBIS CB utilize semi-immersed (into magnetic field) type e-gun with pure magnetic compression. Such electron gun has been designed and built by Budker Institute of Nuclear Physics (BINP, Novosibirsk, Russia). The e-gun is semi-immersed (into magnetic field) type e-gun with pure magnetic compression. Thermionic IrCe cathode with diameter of 5.6 mm is used to generate high quality electron beam with up to 3 A current. An electron collector is capable to dissipate up to 20 kW power of DC electron beam. The unshielded 6 T superconducting solenoid with 8" diameter of warm bore has been ordered from Tesla Engineering Ltd. with expected delivery in March of 2017.

Two diagnostics stations consisting pneumatically driven large aperture Faraday cups (FC) and pepper pot emittance probes have been designed and manufactured. The design of pepper pot emittance probe is similar to one described in [7]. A single microchannel plate (MCP) with wide dynamic range coupled to a fast P47 phosphor screen has been chosen as an imaging system for both emittance probes. Its sensitivity is high enough to measure emittance of both injected and extracted beams into/from EBIS CB with wide range of intensities.

Dumping of high power pulsed and DC 3 A electron beam into electron collector is planned as a first step of EBIS CB sub-systems commissioning prior to delivery of the 6 T superconducting solenoid.

Drift Tube Section

Detailed description of drift tube (DT) section design of RAON EBIS CB can be found in [8]. Further modifications were made to address the issue of mechanical stress

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created during in-situ baking of DT section because of inhomogeneity of temperature distribution. Few ceramic standoffs supporting DTs have been found broken at CARIBU EBIS CB [10] most likely because of the effect mentioned above. Two modifications were implemented in DT section design of RAON EBIS CB to prevent damage of standoffs. Diameters of all standoffs were increased from 4 mm to 10 mm. Also each DT is now supported on both sides by two rings attached to ceramic standoffs as shown in Fig. 2. In this case each DT can slightly slide inside supporting rings in longitudinal direction if thermal expansion of supporting scaffold and DT during in-situ baking will be significantly different. This should reduce mechanical stress on DT's ceramic standoffs and prevent their damage.

Potentials of different elements of RAON EBIS CB for injection, breeding and extraction cycles are summarized in Table 1.

The design of DT section was finalized after complete 3D model of 6 T superconducting solenoid became available from Tesla Engineering Ltd.

Additional vacuum ports are allocated on both sides of ion trap for RF pick-ups. These RF pick-ups will allow to detect electrons which may oscillate on both sides of ion trap being reflected from magnetic mirror [11].

Table 1: Potentials of different elements of RAON EBIS CB for injection, breeding and extraction cycles (C and A – e-gun cathode and anode, DT1 – DT11 – drift tubes from 1-st to 11-th, EC – electron collector, PI, PB and PE – potentials for injection, breeding and extraction cycles, DT3 and DT8 - axial barrier drift tubes, DT4 – DT7 – trap drift tubes).

Element	C	A	DT1	DT2	DT3	DT4	DT5	DT6	DT7	DT8	DT9	DT10	DT11	EC
PI, kV	-4	16	14	12	10	8	8	8	8	7	6	4	1	0
PB, kV	-4	16	14	12	10	8	8	8	8	10	6	4	1	0
PE, kV	-4	16	14	12	10	8	8	8	8	7	6	4	1	0

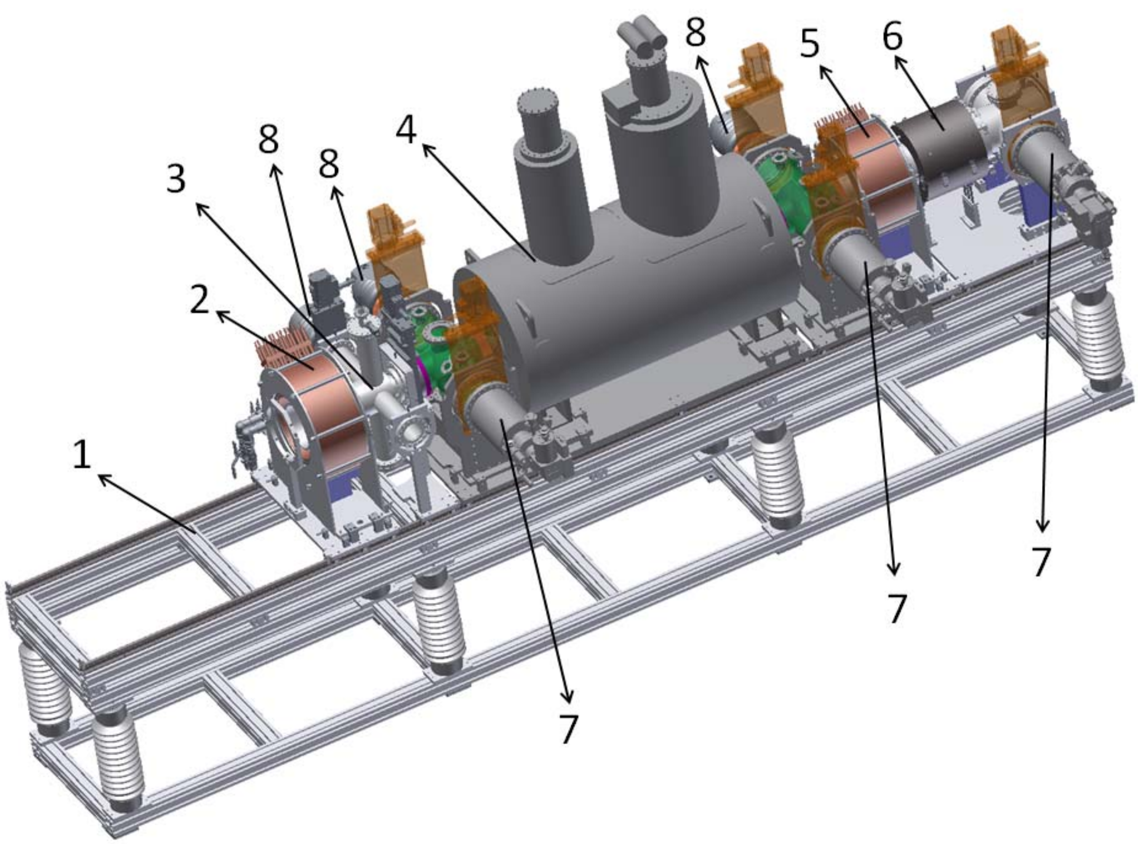

Figure 1: 3D model of RAON EBIS CB: 1 – 60 kV HV platform, 2 – e-gun room temperature coil, 3 – e-gun chamber, 4 – 6 T superconducting solenoid with 8" warm bore, 5 – electron collector room temperature coil, 6 – electron collector with magnetic shield, 7 – cryopump, 8 – turbo pump.

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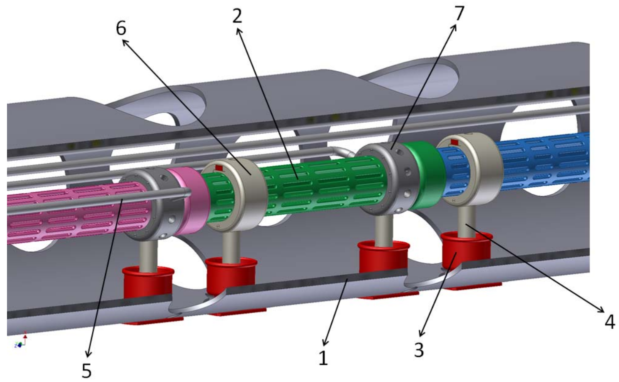

Figure 2: 3D model of RAON EBIS CB DT section: 1 – scaffold, 2 – drift tube, 3 – supporting cup, 4 – ceramic standoff, 5 – potential lead, 6 – first supporting ring, 7 – second supporting ring.

Vacuum System

Vacuum system of the RAON EBIS CB will utilize two cryopumps and two turbo pumps attached to cross chambers on both sides of ion trap. One more turbo pump together with NEG cartridge pump are attached to e-gun chamber. Both cryopumps are Genesis Vacuum Technologies ICP 200 cryopumps with 2200 l/s pumping speed for hydrogen. All three turbo pumps are Edwards's magnetically-levitated oil free STP-451 pumps with 480 l/s pumping speed for nitrogen. All three turbo pumps will be backed by another STP-451 turbo pump (cascade connection) which in turn will be backed by scroll pump. Such cascade connection of turbo pumps allows to overcome limited compression ratio of turbo pumps for hydrogen (typically of the order of 10^5) and significantly improve achievable ultimate pressure. Vacuum simulations have confirmed that at least 10 times lower ultimate pressure can be achieved in the ion trap of EBIS when cascade connection of turbo pumps is used.

Ten SAES Getters double-sided St 707 non-evaporable getter (NEG) strips with width of 30 mm and length of about 1.5 m are placed outside of the scaffold to pump the ion trap. Being properly activated these strips will provide sorption (pumping) speed of the order of several hundred litters per second for hydrogen and nitrogen inside ion trap. Heating and activation of NEG by external current flowing through the strips is not foreseen in the RAON EBIS CB design because of lack of space available inside vacuum chamber to secure electrical isolation of NEG strips from grounded elements during strips heating and thermal expansion. Instead of that, NEG will be activated in the process of in-situ baking of the trap chamber after strip temperature will exceed 200 °C for several hours. Previous experience and estimations have shown that the total amount of gas released during in-situ baking of the DT section significantly exceed NEG sorption (pumping) capacity. The only way to reduce gas load on NEG during in-situ baking is slow ramping up of baking heating to keep pressure rise relatively low especially after temperature will exceed 200 °C. It will be useful to keep baking temperature around 180 °C for relatively long period of time (24 – 48 hours) to allow pumping of significant amount of released gas before sorption of NEG will be activated. Second baking cycle with lower temperature and shorter heating time seems to be useful to re-activate NEG under already much better vacuum conditions.

It should also be pointed out that oil poisoning of RAON EBIS CB vacuum chambers is completely excluded under any circumstances as far as whole vacuum system is based on oil-free pumps and elements.

SUMMARY

Utilization of 3 A electron beam and 6 T superconducting solenoid with wide (8") warm bore diameter for the RAON EBIS CB will allow high efficient and fast breeding of the rare isotope beams with exceptional degree of purity. Design of RAON EBIS CB from e-gun to collector has been finalized. Special attention has been paid to improve performance of vacuum system and to address mechanical stresses created during in-situ baking of DT section. This should improve performance and reliability of whole system.

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