ADVANCED EBIS CHARGE BREEDER FOR RARE ISOTOPE SCIENCE PROJECT*

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Abstract

The Rare Isotope Science Project (RISP) is under development in Korea to provide wide variety of intense rare isotope beams for nuclear physics experiments and applied science using both Isotope Separation On-Line (ISOL) and In-Flight Fragmentation (IF) techniques [1]. A rare isotope beam facility to be built is called RAON. An Electron Beam Ion Source (EBIS) charge breeder (CB) is a key element of the RAON facility to efficiently accelerate rare isotope ion beams produced by ISOL and IF methods. These beams with rare isotope masses up to 180 a. m. u. will be charge-bred by the EBIS CB to a charge-to-mass ratio (q/A) ≥ ¼ and accelerated by linac post-accelerator to energies of 18.5 MeV/u. Utilization of 3 A electron beam and 6 T superconducting solenoid with wide (8”) warm bore diameter in RAON EBIS CB will allow a high efficient and fast breeding of rare isotope beams with an exceptional degree of purity. The main features of RAON EBIS CB design and current status of the project are described and discussed in this paper.

INTRODUCTION

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. Either EBIS or Electron Cyclotron Resonance (ECR) charge breeders are available choices to accomplish this task. The performance of both systems was significantly improved over the last 15 years. Nowadays, EBIS CB is preferable choice for the most ongoing projects, including RISP, because of its higher breeding efficiency, shorter breeding times and, in particular, much better purity of charge bred ion beams. The latter parameter is crucial for many nuclear physics experiments with rare isotope ion beams making the EBIS charge breeder a primary option for the most facilities. 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 and 20% breeding efficiency demonstrated off-line [5]. The RAON EBIS CB will provide next step in the development of the breeder technology further enhancing electron beam current up to 3 A and improving overall system design by implementation of the superconducting solenoid with larger diameter of the warm bore.

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CURRENT STATUS OF RAON EBIS CB DEVELOPMENT

Parameters of the RAON EBIS CB are described elsewhere [6]. The RAON EBIS CB is currently at design stage.

An 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. The e-gun has been commissioned in BINP and delivered to Institute for Basic Science (IBS) in 2015.

An electron collector capable to dissipate up to 20 kW power of DC electron beam has been designed and currently it is under manufacturing.

The unshielded 6 T superconducting solenoid with 8” diameter of warm bore has been ordered from Tesla Engineering Ltd. with scheduled delivery in March of 2017.

A drift tube (DT) section between e-gun and collector has been designed and it is under manufacturing. The details of DT section design are described below.

RAON EBIS CB injection and diagnostics lines is under development using SIMION and TRAK codes. A special attention is paid to optimization of Cs^+ surface ionization ion source optics to provide aberration-free low emittance ion beam for EBIS CB off-line commissioning.

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. Design of a test bench dedicated to this task is described below as well.

DESIGN OF DRIFT TUBE SECTION

The design of drift tube section is the most delicate and challenging part of the overall EBIS CB design. The challenges are related to the requirement of an ultra-high vacuum inside the ion trap (~10^{-11} mbar), the presence of combination of strong magnetic (several Tesla) and electric (several kV/mm) fields in surrounding space, strict requirements (~ 100 μm) for alignment of long (~ 1 m) structure, and limited space inside the bore of the superconducting solenoid.

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

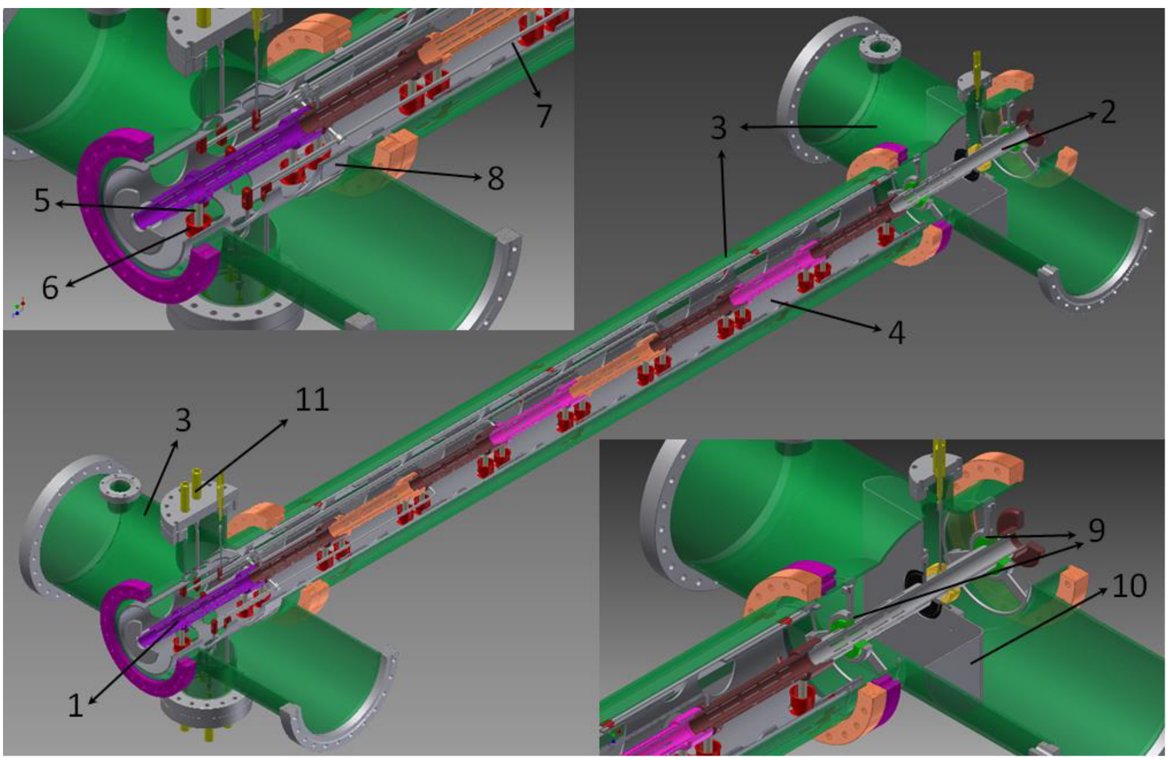

Figure 1: 3D model of RAON EBIS CB DT section (middle), zoomed e-gun side (upper-left), zoomed collector side (lower-right) (1 – DT1, 2 – DT10 (8 DTs are placed between DT1 and DT10), 3 – vacuum chambers, 4 – scaffold, 5 – ceramic standoff, 6 – protection cup, 7 – potential lead, 8 – NEG strip, 9 - DT10 support and alignment fixture, 10 – differential pumping baffle, 11 – HV feedthrough).

The requirement of ultra-high vacuum in the presence of strong magnetic field inside ion trap put restrictions on materials used, their machining, treatment and handling procedures:

- Non-magnetic electro-polished 316 stainless steel should be used for all metallic parts
- 99.8% pure alumina and/or zirconia should be used for all isolators
- Water based cutting fluids should be used for machining everywhere
- All metallic parts should be vacuum fired at 950 °C for 2 hours to move hydrogen out of bulk material
- Assembling of DT section should be done inside clean room
- In-situ baking of DT section at 450 °C for 72 hours is required.

The CARIBU EBIS CB [8] was used as a baseline for design of the RAON EBIS CB DT. At the same time significant modifications were implemented to scale up electron beam current and drift tube potentials required for the RAON EBIS CB. In several aspects the design of

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DT section was also improved taking into account the experience with assembling and commissioning of the CARIBU EBIS CB. As it was already mentioned above there are two main advancements implemented in the RAON EBIS CB in comparison with its predecessor the CARIBU EBIS CB – the higher electron beam current and the lager diameter of the superconducting solenoid warm bore. The former requires the higher DT potentials to avoid formation of a virtual cathode. The latter not only improves electron beam transport in transition areas (e-gun – superconducting solenoid and superconducting solenoid – electron collector), but also enhance pumping speed in the ion trap and allow more space for the design of the DT structure.

The potentials of different elements of the RAON EBIS CB for injection, breeding and extraction cycles are presented in Table 1. These potentials were taken into account for design of the DT section.

An engineering model of the RAON EBIS CB DT section is presented in Fig. 1. The major modifications implemented in the RAON EBIS CB DT section design are listed below:

- Internal diameter of all DTs has been increased to 24 mm
- Diameters of ceramic posts and potential leads have been increased to 5 mm
- Gaps between neighbouring DTs have been increased to hold higher potentials
- Supporting and alignment fixture of DTs # 10 and # 11 has been modified to simplify assembling and improve alignment
- Internal diameter of DT # 11 and collector input apertures has been increased
- Ten non-evaporable getter (NEG) strips are used instead of scaffold NEG coating.

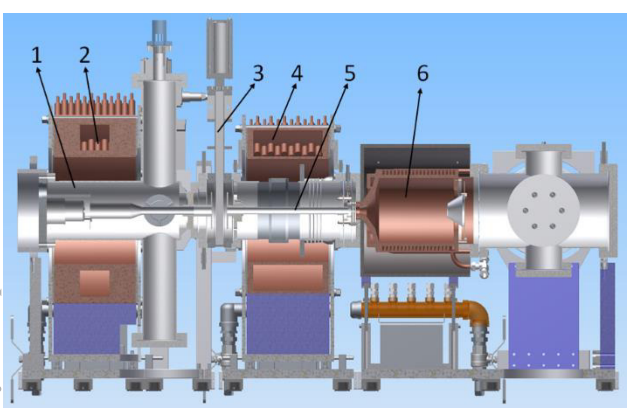

Figure 2: E-gun – collector test bench (1 – e-gun, 2 – e-gun coil, 3 – vacuum valve, 4 – collector coil, 5 – drift tube, 6 – electron collector).

Being properly activated ten SAES Getters double-sided St 707 NEG strips with width of 30 mm and length of 1.5 m will provide sorption (pumping) speed of the order of several hundred litters per second for hydrogen and nitrogen inside ion trap. Utilization of NEG material around the ion trap is absolutely necessary to reach required vacuum level (target goal is 10^{-11} Torr) because pumping speed of turbo and cryo pumps placed on both sides of DT section is in the order of only few l/s in the trap area being limited by conductance of the vacuum chamber. NEG will be activated and will start pumping in the process of in-situ baking as soon as temperature will exceed 200 °C for few hours. Previous experience and estimations show 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 is slow ramping up of baking heating to keep pressure rise relatively low especially after temperature will exceed 200 °C. We have chosen NEG activation during in-situ baking of DT structure without option of NEG heating by external current through NEG strips. Second baking cycle with lower temperature and shorter time may be required to re-activate NEG at better vacuum conditions.

E-GUN – COLLECTOR TEST BENCH

The cross section of e-gun – collector test bench is presented in Fig. 2. The test bench consists of 3 A e-gun, drift tube with internal diameter of 17 mm and 20 kW electron collector. Two electrically isolated tantalum apertures with diameters 13 mm and 14 mm are installed at the entrance of the collector. The smaller aperture will be used to measure and minimize losses of incoming 3 A electron beam. The larger aperture will be used to measure and minimize the backstream flow of secondary electrons from collector into DT section. The test bench was designed taking into account that all elements will be later utilized for off-line RAON EBIS CB commissioning. The elements of the test bench are under manufacturing and experiments will be carried out later this year.

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. The RAON EBIS CB is currently under design stage. The high-perveance e-gun with current up to 3 A has been commissioned and delivered recently. Design and manufacturing of the 6 T superconducting solenoid is in progress with scheduled delivery in the beginning of the next year. Design of e-gun – collector test bench and the drift tube section has been completed. Manufacturing and procurement of all required components are in progress. Tests of high power pulsed and DC electron beam dumping into collector will be carried out later this year.

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REFERENCES

[1] S. Jeong, "Progress of the RAON heavy ion accelerator project in Korea", presented at the 7th Int. Particle Accelerator Conf. (IPAC'16), Busan, Korea, May 2016, paper MOAB01, this conference.

[2] F. Wenander *et al.*, "The REX-ISOLDE charge breeder as an operational machine", *Rev. Sci. Instr.*, vol. 77, 03B104, 2006.

[3] A. Lapierre *et al.*, "First charge breeding of a rare-isotope beam with the electron beam ion trap of the ReA post-accelerator at the National Superconducting Cyclotron Laboratory", *Rev. Sci. Instr.*, vol. 85, 02B701, 2014.

[4] S. Kondrashev *et al.*, "First charge breeding results at CARIBU EBIS", in *Proc. 12th Int. Symposium on Electron Beam Ion Sources and Traps*, East Lansing, MI, USA, May 2014, pp. 54-67.

[5] C. Dickerson *et al.*, "Offline testing of CARIBU EBIS charge breeder", in *Proc. 6th Int. Particle Accelerator Conf. (IPAC'15)*, Richmond, VA, USA, May 2015, paper THPF110, pp. 3973-3975.

[6] J. W. Kim *et al.*, "An EBIS system for Rare Isotope Science Project in Korea", in *Proc. 12th Int. Symposium on Electron Beam Ion Sources and Traps*, East Lansing, MI, USA, May 2014, pp. 38-43.

[7] S. Kondrashev *et al.*, "Emittance measurements for stable and radioactive ion beams", in *Proc. 25th Int. Linear Accelerator Conf. (LINAC2010)*, Tsukuba, Japan, Sept. 2010, paper TUP086, pp. 608-610.

[8] S. Kondrashev *et al.*, "Development of electron beam ion source charge breeder for rare isotopes at Californium Rare Isotope Breeder Upgrade", *Rev. Sci. Instr.*, vol. 83, 02A902, 2012.

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