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Recent status of pre-bunching and re-bunching systems for low-energy experimental facilities at RAON

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ABSTRACT

Rare isotope Accelerator complex for ON-line experiments (RAON), which is being constructed in Korea, will provide both rare isotope and stable ion beams for various nuclear physics experiments as well as other applications, at a wide energy range up to a few hundreds of MeV/nucleon. The ion beams will be provided to low-energy experimental facilities at RAON such as Korea Broad Acceptance Recoil spectrometer and Apparatus (KoBRA) and Nuclear Data Production System (NDPS). Since the bunch length of some ion beams becomes unsuitably long at the targets of these facilities, a re-bunching system has been designed and developed. Besides, a pre-bunching system based on a fast chopper and a Double Gap Buncher (DGB) has been developed and installed upstream of the Radio-Frequency Quadrupole (RFQ) to lower the repetition rate for the time-of-flight measurements of secondary particles at KoBRA and NDPS. We present the status of the pre-bunching and re-bunching systems for the RAON low-energy experimental facilities.

1. Introduction

Low-energy experimental facilities at the Rare isotope Accelerator complex for ON-line experiments (RAON) comprise Korea Broad Acceptance Recoil spectrometer and Apparatus (KoBRA) [1,2] and Nuclear Data Production System (NDPS) [3,4]. Stable ion beams from Electron Cyclotron Resonance (ECR) ion source or Rare Isotope (RI) beams from Isotope Separation On-Line (ISOL) facility [5] will be provided to low-energy experimental facilities. These ion beams will be accelerated up to a few tens of MeV/nucleon through Radio-Frequency Quadrupole (RFQ) and Super-Conducting Linac 3 (SCL3) [6] of the RAON.

The pre-bunching system has been designed to provide low repetition rate beams for the time-of-flight measurement of the secondary particles at KoBRA and NDPS. It comprises the fast chopper and the Double Gap Buncher (DGB), which is installed at the Low Energy Beam Transport (LEBT) line of RAON. The fast chopper lowers the repetition rate of ion beams and the DGB reduces the beam bunch length as less than 12.3 ns at the RFQ entrance.

The re-bunching system is designed to provide the beam with a bunch length of less than 0.5 ns (in σ) for the KoBRA production target. It is based on a 5-gap Interdigital H-mode Drift Tube Linac (IH-DTL) type Radio Frequency (RF) cavity.

In this work, we present the recent status of pre-bunching and re-bunching systems for the RAON low-energy experimental facilities.

2. Pre-bunching system at LEBT line

The pre-bunching system is composed of the fast chopper and Double Gap Buncher (DGB) as shown in Fig. 1. The frequency of the RAON main RFQ is 81.25 MHz [6], and the repetition rate of the beam at production targets of the low-energy experimental facilities will be the same as the RFQ frequency with Continuous Wave (CW) operation. Such frequent beam decreases mass resolution for particle identification at KoBRA, and induces overlap of the pulsed neutrons in neutron time-of-flight experiments at NDPS. Therefore, a fast chopper has been installed at the LEBT line for adjusting the beam repetition rate to about 2 MHz for KoBRA and less than 200 kHz for NDPS, respectively.

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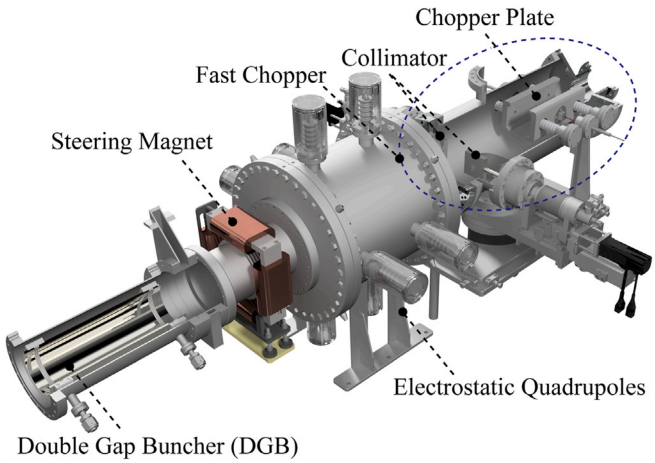

Fig. 1. The pre-bunching system at LEBT line of RAON.

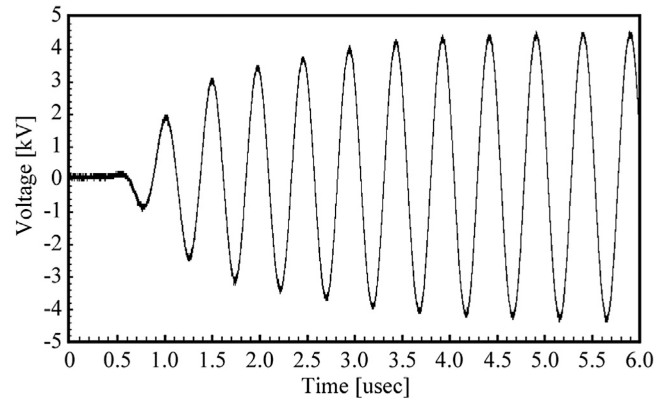

Fig. 3. Single-acting test result of the voltage boosting circuit for DGB.

The fast chopper consists of a capacitive-type electrode and a size-variable slit type beam collimator. Time-varying transverse direction electric field of the capacitive-type electrode shifts the transverse momentum of the CW ion beams. The beam collimator located downstream of the electrode only transmits the part of the beam and makes the bunched beam with a lower repetition rate. The repetition rate of the bunched beam is regulated by adjusting the frequency and shape of the time-varying electric field between the electrodes.

Since the predicted bunch length of the bunched beam chopped by the fast chopper exceeds over 100 ns at the RFQ entrance, which is too long to obtain a single isolated bunch. Therefore, the DGB is installed downstream of the fast chopper for longitudinal bunch compression [7].

The DGB has three cylindrical electrodes arrayed in the longitudinal beam direction. The structure of the DGB is similar to that of the Einzel lens, but the high-voltage RF is applied in the central electrode of the DGB. The RF frequency of the DGB was determined as 2.03125 MHz, which is 1/40 of the main RFQ frequency.

In order to obtain the best efficiency with sinusoidal RF waves in terms of beam energy control, the phase difference between two gaps of electrodes should be 180°, but we designed the length of the RF electrode in DGB as 270 mm corresponding to 140°. It is for applying pseudo sawtooth RF with the highest energy efficiency in future [8,9].

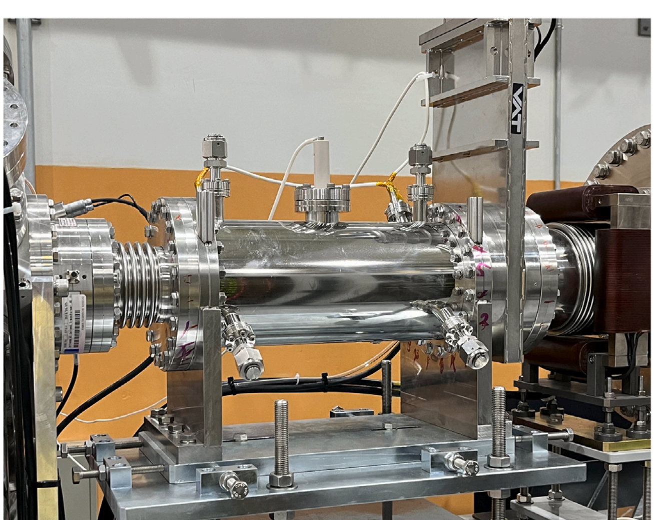

Fig. 2. The Double Gap Buncher (DGB) installed in the LEBT line at RAON.

The DGB has been installed in the LEBT line as shown in Fig. 2, and a 1 kW RF amplifier has also been connected. Since the A/q value of the beam for the low-energy experimental facilities is up to 7, the maximum RF voltage requirement on the RF electrode was calculated as about 4 kV. However, the maximum voltage of the 1 kW RF amplifier to 50 Ω impedance-matched device is 316 V. Therefore, a voltage-boosting circuit has been installed between the RF amplifier and the DGB, in order to supply high RF voltage with limited power. Through the principle of series resonance, the voltage-boosting circuit was designed as shown in Fig. 25 in Ref. [7]. Supplying up to 4.4 kV RF via the voltage-boosting circuit to a capacitor, which has the same capacitance as the DGB, was successful as shown in Fig. 3.

In a single-acting test of the DGB, 2.1959 MHz RF, corresponding to 1/37 of the RAON main RFQ frequency, was applied to the RF electrode of the DGB, because the voltage-boosting circuit operates most stably at this frequency. Furthermore, the maximum effective voltage with 2.1959 MHz is slightly higher than that with 2 MHz since the longitudinal length of the RF electrode is 270 mm. The voltage boosting circuit stably supplied up to about 4 kV RF to the RF electrode of the DGB. The beam test with the pre-bunching system is planned in 2023, in order to verify the bunch compression performance of the DGB.

3. Re-bunching systems for the low-energy experimental facilities

In NDPS, both white and mono-energetic neutrons will be provided to users by employing 49 MeV/nucleon D^+ and 20–83 MeV/nucleon H^+ beams, with thick (graphite) and thin (lithium) targets, respectively.

The Full Width at Half Maximum (FWHM) of D^+ ion beam bunch should be less than 1 ns for neutron TOF measurements. The expected bunch length at the NDPS thick target is calculated as slightly over the requirement, but an existing Half-Wave Resonator (HWR) cavity installed at downstream of the SCL3 linac will be used as a rebuncher for NDPS.

On the other hand, KoBRA needs an additional rebuncher to reduce the longitudinal bunch length for TOF measurement. The rebuncher will be installed in SCL3-KoBRA beamline, because the expected longitudinal bunch length at the target does not satisfy the requirements for KoBRA experiments when beam energy is less than 15 MeV/nucleon. The 5-gap normal conducting IH-DTL type rebuncher was designed and manufactured by BEVATECH for the beam with an energy range between 5 MeV/nucleon and 15 MeV/nucleon.

Fig. 4 shows the structure of the IH-DTL, which is being manufactured since 2022. The longitudinal electric field with 1 J of stored energy and quality factor value of the IH-DTL were calculated via

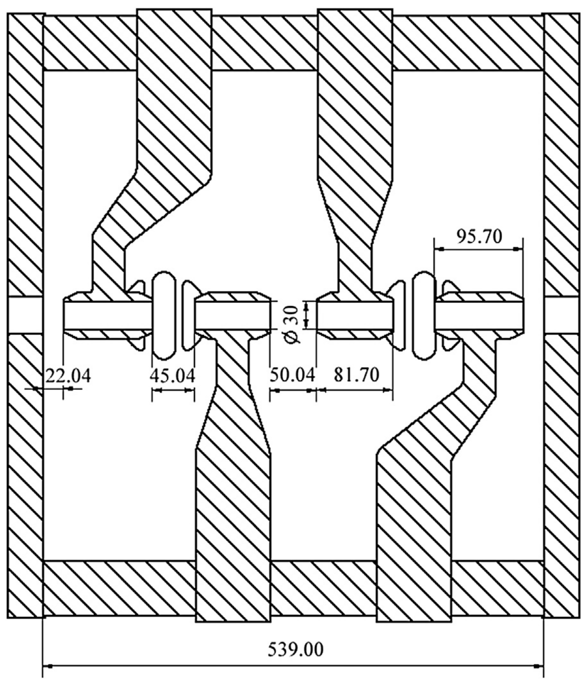

Fig. 4. Layout of 5-gap IH-DTL rebuncher.

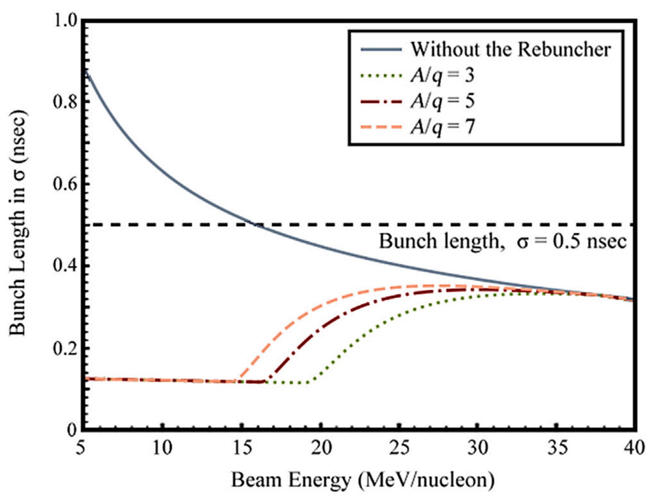

Fig. 5. Calculated bunch length at KoBRA production target according to beam energy and A/q. The experimental requirement (RMS bunch length $\sigma < 0.5$ ns) can be satisfied by applying the rebuncher for the beam energy of 5 MeV/nucleon or higher.

eigenmode solver of CST STUDIO [10], in order to calculate the maximum effective voltage of the IH-DTL according to beam energy. The bunch shape at the KoBRA production target according to beam energy was calculated by changing the effective voltage of IH-DTL to less than its maximum value, and the minimum bunch length at the KoBRA target was calculated as shown in Fig. 5. The detailed calculation method will be presented in the near future. The standard deviation of bunch length at the KoBRA production target will be less than 0.5 ns for the beam energy of 5 MeV/nucleon or higher. The installation and commissioning of the rebuncher are scheduled to be completed by the end of 2023.

4. Summary

In summary, the pre-bunching system, which consists of the fast chopper and the DGB, has been installed at upstream of the RFQ in the LEBT line. We performed the single-acting test of the DGB and succeeded in applying up to about 4 kV to the RF electrode of the DGB. Since the voltage requirement for compressing the beam with $A/q = 7$ is about 4 kV, we expect the DGB will provide enough longitudinal effective voltage for most of the ion beams in future experiments. The IH-DTL type rebuncher, being manufactured since 2022, will be installed in SCL3-KoBRA beamline in 2023. We confirmed that the bunched beams were compressed longitudinally as intended using the IH-DTL rebuncher at KoBRA target. The IH-DTL type rebuncher is planned to be commissioned using the Ar^{9+} ion beam.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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