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Commissioning results of single bunch selection system for the RAON heavy-ion accelerator facility

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ABSTRACT

To enable neutron time-of-flight experiments at the RAON heavy-ion accelerator facility, we tested a single bunch beam selection method by combining an RF chopper and a double gap buncher in the low-energy beam transport section. The RF chopper converts a CW beam into a hundreds-nanosecond pulsed beam. Then, the double gap buncher performs bunching to shorten the pulse length to less than one radio frequency quadrupole (RFQ) cycle. Ideally, a single isolated bunch can be achieved after the RFQ. In this study, we discuss the design concept of the single bunch selection system and present initial beam commissioning results.

1. Introduction

For accelerator-based neutron sources, the repetition rate of neutron production directly depends on that of the driver accelerator system. Usually, the continuous wave (CW) proton or deuteron linear accelerators have hundreds of MHz operation frequency, so the repetition rate of the neutron is also hundreds of MHz, yielding tens of nanoseconds in time scale. However, this time scale is often too short for neutron time of flight (TOF) experiments. The neutron energy spectrum can overlap with such a time structure, and if that is the case, one cannot precisely measure the neutron energy spectrum. To overcome this problem, several single bunch selection methods have been suggested. The Soreq Applied Research Accelerator Facility (SARAF) proposed and tested the fast chopper method [1,2]. The Grand Accélérateur National d'Ions Lourds (GANIL) tested a single bunch selection technique at the medium-energy beam transport (MEBT) region based on compensation between the magnetic and electric forces [3,4]. The Tokai Radioactive Ion Accelerator Complex (TRIAC) used a multi-layer chopper to make a short pulsed beam and then applied bunching using a double gap buncher (DGB) in the low-energy beam transport (LEBT) region [5].

2. Design concept

The basic concept of RAON's single bunch selection is generating a short pulsed beam and then performing bunching to make the bunch length of the pulsed beam shorter than one radio frequency quadrupole (RFQ) cycle (see Fig. 1). The RFQ accelerates the beam from 10 keV/u to 0.5 MeV/u with 81.25 MHz operating frequency, which is 12.3 ns in

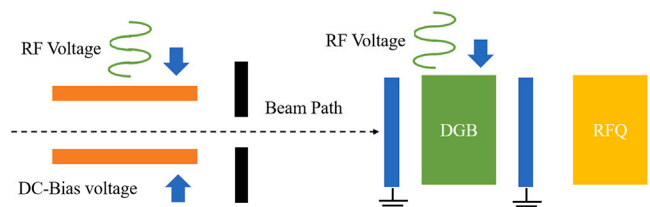

Fig. 1. Conceptual diagram of single bunch selection method for RAON.

time scale. Therefore, our goal is to make the bunch length of the pulsed beam shorter than 12.3 ns. At the beginning of the commissioning, a scheme combining the SARAF-type fast chopper and TRIAC's DGB was tried, thus most of the beam dynamics studies were done under such a configuration. The fast chopper system was designed with a fast high-voltage (HV) switch. It turned out, however, that the long-term durability of the HV switch had a technical issue. Afterward, we replaced the fast chopper with an RF chopper system. Both the fast chopper and RF chopper convert a CW beam into a hundreds-nanosecond pulsed beam. Hence, as long as the pulse length of the beam is similar at the DGB, the beam dynamics through the RFQ would not change significantly regardless of the type of chopper. Table 1 summarizes the simulated beam parameters at the entrance of RFQ obtained with both the SARAF-type HV fast chopper and RF chopper. In terms of bunch length, the RF chopper shows better results than the HV fast chopper.

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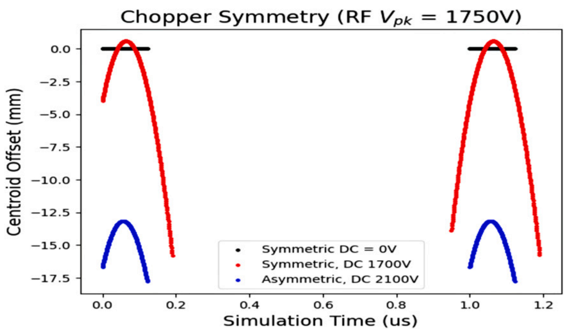

Fig. 2. Centroid shift after the chopper.

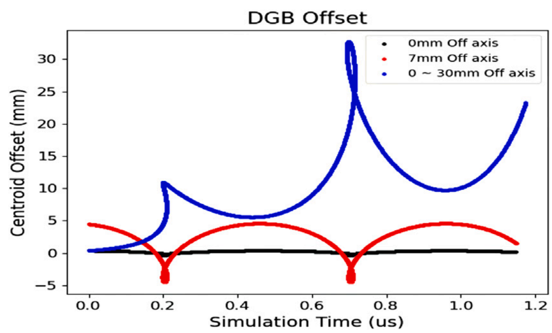

Fig. 3. Centroid shift after the DGB.

Table 1
Beam parameters at the RFQ entrance.

	Proton (A/q = 1)	Deuteron (A/q = 2)	Argon (A/q = 4.44)
Bunch charge (HV switch)	2.14 pC	3.38 pC	9.50 pC
Pulse length (HV switch)	11.3 ns	9.23 ns	10.89 ns
Bunch charge (RF)	0.83 pC	1.67 pC	4.60 pC
Pulse length (RF)	9.27 ns	7.01 ns	10.87 ns

There are two electrodes at the chopper. One electrode is usually used to apply high voltage, and the other electrode is for ground. The HV fast chopper passes a DC beam downstream when the high voltage is turned off. Similarly, the RF chopper passes the beam when the sinusoidal RF crosses zero voltages. When only the sinusoidal RF voltage is applied without any DC bias, however, we cannot operate the bunching system in a pulsed mode. We may try a pulsed operation of the RF system. But, in this case, the DC beam goes downstream when the RF voltage is off, which is not desirable. To overcome this problem, we applied a DC bias voltage to the ground electrode while operating the RF system in a pulsed mode. When the sinusoidal RF voltage is off, the DC bias voltage will dump the beam. When the RF voltage reaches the voltage level which can compensate for the electric kick from the DC bias voltage, then the beam will be transported downstream.

Our RF chopper system uses the existing electrodes which are asymmetric in geometry. Hence, the beam can experience a centroid shift at the chopper when a DC bias voltage is applied. To verify that concern, we performed simulations with the SIMION code. The SIMION simulations show that the centroid of the beam can be significantly affected by the geometry of the chopper. In Fig. 2, the red dots represent the results when the chopper geometry is symmetric, and the blue dots represent the case with asymmetric geometry. When the geometry of the chopper is symmetric, the average of the centroid can be made around zero offset point, whereas the beam gets a centroid kick and exhibits a considerable offset if the chopper is not symmetric. Note that when the chopper is symmetric and no bias is applied (black dots), then there would be no centroid shift as expected. Fig. 3 shows the SIMION simulation results of the final centroid shift when the beam enters the DGB off-axis. The red dots indicate the results when the beam has a 7 mm initial offset. The blue dots are the results when the beam has an entrance angle that yields initial offset distribution from 0 to 30 mm. When the beam has a uniform offset, the centroid of the beam changes but it is in a controllable range. However, if the beam enters the DGB with an angle, the beam centroid is significantly affected. Therefore, we need a steerer to cancel the kick or change the chopper geometry to become symmetric. Fig. 4 is the TRACK simulation result for such an ideal case. If we find an optimal steerer setting that can cancel out centroid shift or modify the chopper to be symmetric, the transmission rate of RFQ will be 97.8% with 7.74% neighboring bunch contamination.

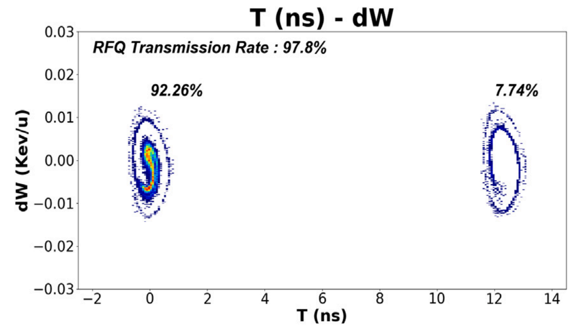

Fig. 4. Longitudinal phase space after the RFQ for an optimal operation of Ar^{+9} beam.

3. Experimental results

We acquired data from BPM electrodes installed after the RFQ with a fast oscilloscope. Figs. 5, 6, and 7 are the experimental results. Since the RF chopper operates with 1.09797 MHz, there is only one bunch train within 1 μs (see Fig. 5). The RF chopper makes a short pulsed beam around 110 ns so that it is divided into around 8∼9 micro-bunches after the RFQ. Fig. 6 is the result when the DGB gives an optimum RF voltage. There appear one main bunch (with the sharpest peaks) and two neighboring bunches. However, in this case, there is a continuous bunch train beside the neighboring bunches. This is why we use an RF chopper to make a short pulsed beam first. Fig. 7 is the main result of the experiment. The BPM signal is taken when both the chopper and DGB are turned on. The RF chopper works with 1.09797 MHz and the DGB works with 2.19594 MHz. The RF chopper makes a short pulsed beam in every 1 μs, so there are no other bunch trains except the main bunch train. The DGB performs bunching to the main bunch train, and beam particles are concentrated at the center of bunch train. Therefore, the signal amplitude of the main peak becomes larger than in Fig. 5, and the number of micro-bunches in the main bunch train reduces.

Ideally, we must obtain a single isolated bunch in Fig. 7. However, there are around 4 ∼ 5 micro-bunches. It is because we could not give enough RF voltage to the DGB during the commissioning. The DGB and RF electronics themselves have the capability to provide higher voltages. However, as we discussed in Fig. 2, the centroid of the beam shifts too much at the chopper. When the centroid-shifted beam goes into the DGB, this shift would increase further. Therefore, if we raise the DGB RF voltage to the optimum level found in Fig. 6, the beam gets too much electric kick and cannot pass the RFQ. Solving this issue will be the main task in the next stage of commissioning.

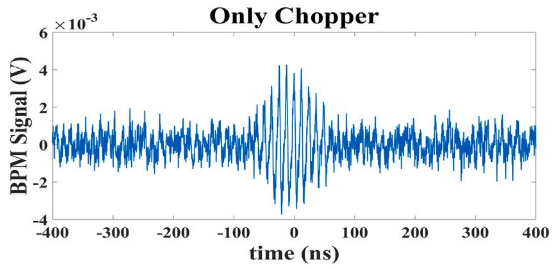

Fig. 5. BPM signal with chopper only.

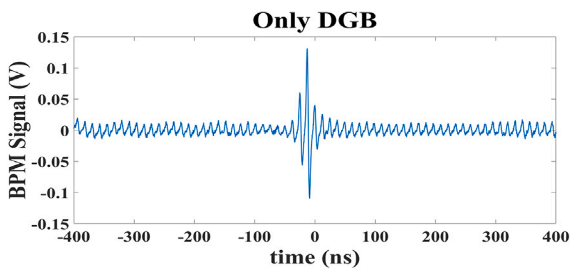

Fig. 6. BPM signal with DGB only. Here, the peak voltage of DGB RF is 2600 V.

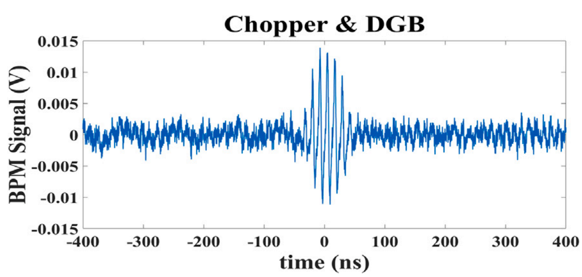

Fig. 7. BPM signal with both chopper and DGB. Here, the peak voltage of DGB RF is 1000 V.

4. Summary

In summary, we validate that the RF chopper and DGB hardware work properly for the RAON heavy-ion accelerator facility. It was found, however, that the RF chopper applies an electric kick to the beam, causing its centroid to shift. As a result, we could not increase the sinusoidal RF voltage of the DGB to an optimum value. To resolve this issue and obtain better single bunch characteristics after the RFQ, modification of the chopper electrode geometry is ongoing. Experimental results with the improved setup will be reported elsewhere.

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.

Acknowledgments

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