DESIGN AND TEST OF 2-4MHz SAWTOOTH-WAVE PRE-BUNCHER FOR 26MHz-RFQ*

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Abstract

The measurement of $^{12}C(\alpha,\gamma)$ reaction is planned at TRIAC(Tokai Radioactive Ion Accelerator Complex). An intense pulsed α beam with the width of less 10ns and the interval between 250ns and 500ns is required for this experiment. Because the Split Coaxial RFQ (SCRFQ), which is one of the TRIAC accelerators, has a radio frequency of 26MHz, the bunch interval becomes 38.5ns. In order to make the bunch interval of 250ns or more, the pre-buncher with a variable frequency of 2-4MHz, is considered to be installed upstream of the SCRFQ. It is designed as the pre-buncher has two gaps with non-π mode. In order to make the bunching beam profile like a pseudo sawtooth-wave, the RF voltage synthesized three harmonic frequencies is applied to these gaps. Consequently, the pre-buncher has a compact size and no leakage electric field outside gaps, and can keep the RF voltage low. The beam test of this pre-buncher with a 2MHz was performed using $^{16}O^{4+}$ and $^{12}C^{3+}$ beams. The clear bunch structure with a interval of 500ns was obtained by the SSD set downstream of the SCRFQ. The results of the beam test are almost consistent with those of the beam simulation code.

INTRODUCTION

The $^{12}C(\alpha,\gamma)^{16}O$ is one of the key reactions in stellar nucleosynthesis. The plan to measure this reaction by using the TRIAC accelerators set up in the JAEA-Tokai tandem site was proposed. The events of this reaction must be well separated from neutron background from the $^{13}C(\alpha,n)^{16}O$ reaction using a time of flight method [1]. The separation interval is required to be that of 250ns or more. On the other hand, the TRIAC has a linac complex comprising a 26-MHz SCRFQ and a 52-MHz interdigital-H (IH) linac. The beam bunch interval by the linacs becomes 38.5ns. In order to make the bunch interval between 250ns and 500ns, the pre-buncher with a variable frequency of 2-4MHz was designed and installed upstream of the SCRFQ. Figure 1 shows the layout of TRIAC with the pre-buncher. The intense α beam with the energy of 2 keV/u is generated by the CB-ECRIS. The beam is bunched with a pulsing interval of 250ns or more by the pre-buncher. The SCRFQ accelerates ions with the energy up to 170 keV/u. The output energy from the IH linac is available in the range of 0.17 to 1.1 MeV/u. The γ ray angular distributions are measured by the three high efficiency NaI spectrometers. In order to deflect the beam particles of out-of-bunch phase efficiently, the beam chopper was installed upstream of the pre-buncher [2].

SAWTOOTH-WAVE PRE-BUNCHER WITH TWO GAPS

The pre-buncher is placed at the 92.6cm upstream of the SCRFQ. Although the effective bunching for the frequency of 2MHz requires far distance from the SCRFQ, this location was decided due to the spacing limitation. For example, in order to make the bunch interval 250ns or more, 7 or 13 micro bunches of the 26MHz-SCRFQ should be collected to the center bunch by the pre-buncher. The collections of 7 and 13 micro bunches

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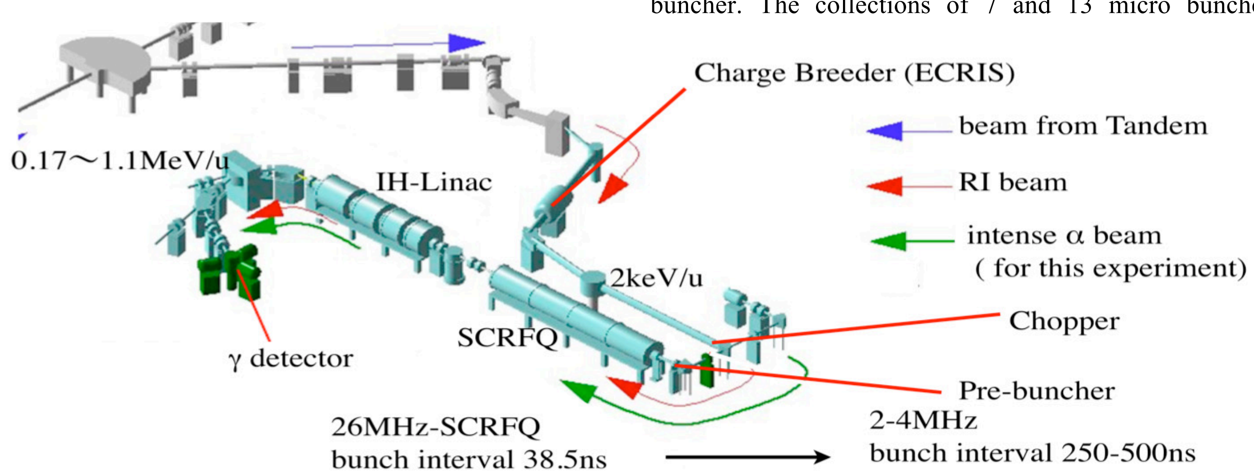

Figure 1: Layout of TRIAC with pre-buncher.

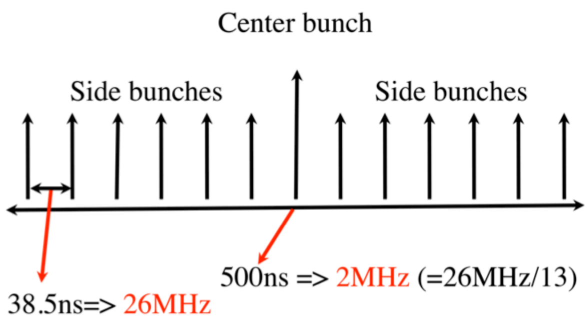

Figure 2: Time structure of micro pulse.

require the frequencies of 3.7 and 2MHz for the pre-buncher, respectively. Figure 2 shows a time structure of the micro pulse in the case of 2MHz pre-buncher. The side bunches are 12 micro bunches without the center bunch. The frequency of 2MHz is corresponding to the period of 500ns.

The required performances for this pre-buncher are as follows; 1) the frequency is variable of 2-4MHz. 2) the efficiency for the bunching at the center (= the bunching efficiency) is high. 3) the number of particles in the side bunches is low. 4) the power consumption is low. In order to make the bunching efficiency high, the applied bunching voltage pattern is like a pseudo sawtooth-wave [3,4,5,6]. This wave was assumed to synthesized three harmonic frequencies, as shown in the following;

$$F = \text{Fundamental frequency } (f\text{=2-4MHz}) + 1/3\times\text{second harmonic} + 1/9\times\text{third harmonic} \quad (1)$$

At first, we considered a single gap to apply the RF voltage like Eq. 1. As $\beta\lambda/2$=15.5cm (for 2MHz) becomes the same size as one of the pre-buncher structure, the influence of the leakage electric field is not negligible. Therefore the efficient bunching is not achieved. Consequently, the two gaps structure was adopted. This has no influence for the leakage electric field and keeps the RF voltage low. In order to make the pre-buncher compact, the multiple buncher system was not adopted. However, in the simple π mode, where the interval of two gaps is equal to $\beta\lambda/2$, the second harmonic wave becomes 2π mode and the sawtooth-wave bunching is not obtained. Despite this, we found the method of obtaining an equal performance to get the sawtooth-wave bunching by setting the interval of two gaps to non-π mode spacing. The gap interval is expressed as $\beta\lambda\theta/2\pi$, here θ is a phase difference between two gaps, and the voltage applied to the first gap is given by the following;

$$V_{1st} = \sum_{i=1}^{3} a_i \sin(i\omega t + \phi_i) \quad (2)$$

Where i indicates the harmonic number. At the second gap, the sign of a_i becomes reverse and the phase ϕ_i becomes one that was advanced by θ. When a_i and ϕ_i in Eq. 2 are chosen as Eq. 3, the sum of the acceleration voltage received by two gaps becomes Eq. 1. As a result, the beam achieves the same effect as the bunching obtained by the pseudo sawtooth-wave after passing through two gaps.

$$\phi_i = -\frac{(\pi + i\theta)}{2}, a_i = \frac{1}{2\cdot 3^{(i-1)} sin(-i\theta/2)} \quad (3)$$
$$(i=1,2,3)$$

In addition, when θ is chosen to be 140 or 220 degrees, the root mean square of the amplitude of Eq. 2 can be minimized. The power consumption in this case becomes about 1/3 compared with one of the single gap pre-buncher. In the case of f=2MHz and θ=140 degrees, the gap interval becomes 12.05cm.

Figure 3 is the photos of the pre-buncher chamber and its drift tubes based on above design principles. The flange of the vacuum vessel, which supports the drift tubes, is movable with the stepping motor. The gap interval is variable from 8 to 16cm. The drift tubes are electrically contacted by the eight skewer sticks, which are inserted in the cylinders of the drift tubes.

BEAM SIMULATIONS

Pre-buncher with two gaps

The effect of the 2MHz sawtooth-wave pre-buncher with two gaps was simulated with the TRACEP code, as shown in Figure 4. TRACEP is the particle tracer code, which can deal with the elements of the acceleration gap with RF [7]. The vertical axis indicates the energy spread

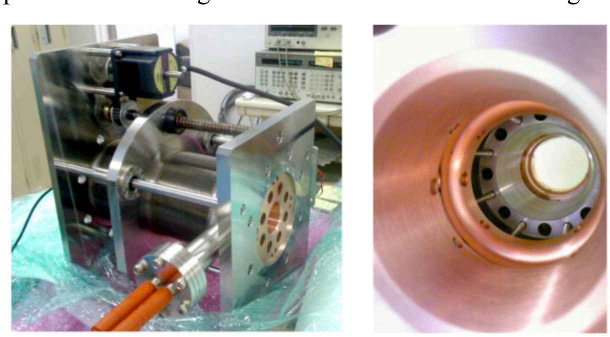

Figure 3: Pre-buncher chamber and its drift tubes.

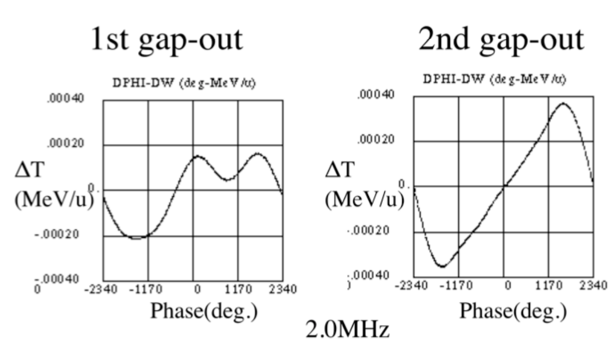

Figure 4: Simulation for the pre-buncher.

(ΔT), and ΔT=0 corresponds to energy 0.002MeV/u. The horizontal axis indicates the phase in 26MHz, and the width for ±2340degrees is corresponding to 500ns interval. At the exit of the second gap, the shape of the longitudinal beam profile is clearly obtained as one of the pseudo sawtooth-wave.

Low Energy Beam Transport Line and SCRFQ

We also simulated ions in the low energy beam transport line (LEBT) including the pre-buncher and the SCRFQ. The ions in the SCRFQ were simulated with the PARMTEQ code. Figure 5 shows the resultant longitudinal beam profiles at the entrance and the exit of the SCRFQ. The incident 1000 particles are generated, and 41% ions are in the center bunch at the exit of the SCRFQ. This value includes 90% of the transmission efficiency in the SCRFQ. About 10% of the incident particles remains in the side bunches.

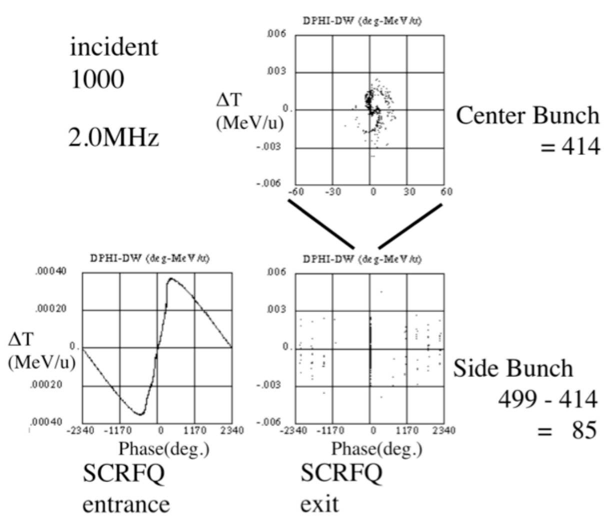

Figure 5: Simulation for the LEBT and the SCRFQ.

BEAM TESTS

To confirm the effect of pre-buncher, the beam tests were performed with $^{12}C^{3+}$ or $^{16}O^{4+}$ ions in October 2009. The SSD was placed on the beam line downstream of the IH linac. The beam was accelerated up to the energy of 0.17MeV/u only with the SCRFQ. To measure ions directly with SSD, the beam intensity was weakened less than 10kHz. The time structure of the beam was measured as the difference between the timing of the SSD and one corresponding to the RF with 2MHz to be fed into the pre-buncher. Figure 6-(a) indicates the case where the pre-buncher is off. The time structure of the 38.5ns (f=26MHz) interval is clearly seen. Figure 6-(b) shows the time structure when the pre-buncher was turned on. It succeeds in the collection of the beam from other bunches to the center bunch. The efficiency of the bunching at the center bunch was achieved to about 40%. This value is consistent with the result of the beam simulation. Moreover, the particles in the side bunches remain about 10% for incident ones and they become to make the background events. This value is also consistent with the result of the beam simulation. However, the S/N ratio must be improved to less than 1/1000 by using the chopper [2] for the $^{12}C(\alpha,\gamma)$ experiments.

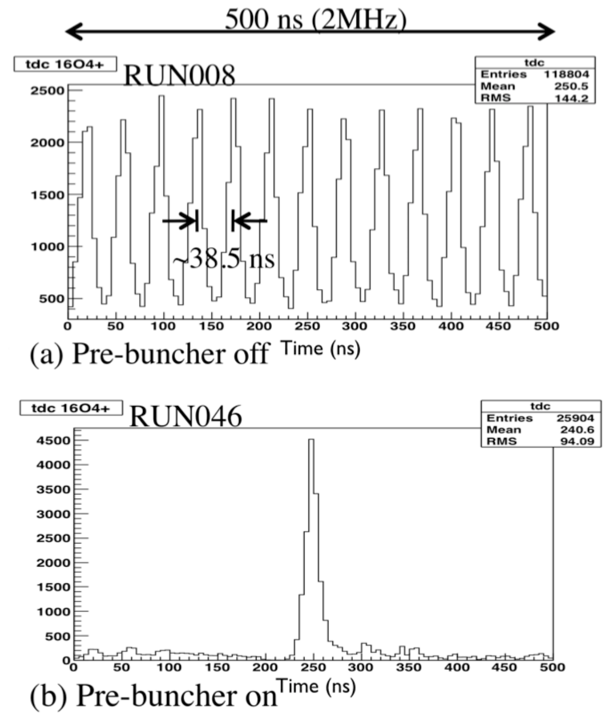

Figure 6: Results of the beam test.

SUMMARY

The compact pre-buncher with two gaps, which was developed for the intense pulsed α beam, has been tested. Because the proper RF voltage synthesized three harmonic frequencies is applied to two gaps with non-π mode, the pseudo sawtooth-wave bunching can be achieved. As the results of the beam test, the obtained time structure is consistent with the results of the beam simulation. About 40% bunching efficiency was achieved. The system will be utilized to the measurements of $^{12}C(\alpha,\gamma)$ reaction cross-sections at the stellar energy, which are important describing element-synthesis in the evolution of massive stars.

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