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Development of a Single-Bunch Selector for the Riken Ring Cyclotron

N. Inabe, M. Kase, I. Yokoyama, A. Goto, and Y. Yano

The insitute of Pysical and Chemical Reaearch (RIKEN)
Wako-shi, Saitama 351-01, Japan

Abstract

We have developed a single-bunch selector with fast repetition rate (1 MHz) for the RIKEN Ring Cyclotron. The system is compact due to use of a beam chopper for the beam with low velocity. Moreover by operating the buncher for injection in the AVF cyclotron with a sub-harmonic mode, a purity of the single-bunched beam was raised up. The obtained purity of the beam is more than 99.7 %.

1. Introduction

A single-bunched beam is often demanded to measure a time spectrum in very short range (< 1 ms). To fulfill the demand a single-bunch selector has been developed. In the first step a beam chopper was installed at the injection line of the AVF cyclotron (AVF). We could get the almost single-bunched beam. A purity, that is a ratio of the current of the desired bunch to total one including undesired bunches, is about 90 %. However the purity is not enough for the experiment to measure the time spectrum with a low background. In the next step we tried to raise up the purity by operating the buncher with sub-harmonic frequency of the AVF.

In similar cyclotron, the single-bunched beam is normally produced at downstream of the cyclotron where the beam energy is relativity so high. For the case the purity is independent of extraction of the beam but the system is very large and needs a high power. On the other hand, for the present method a single-turn extraction is needed. As the beam can be extracted from the AVF and the RIKEN Ring Cyclotron (RRC) 1), the present method can be applied in our facility. Since single-bunched beam can be produced at low energy the whole system can be small and of low cost

2. Principle

Figure 1 shows the method for production of the single-bunched beam. The single-bunched beam can be produced by sweeping undesired bunches.

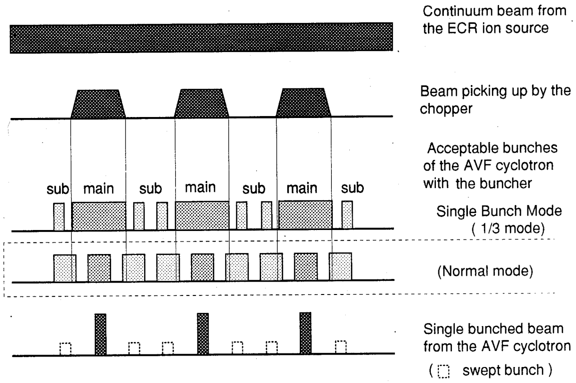

Fig. 1. Production scheme of the single-bunched beam in the method.

One way is to sweep the beam transversally using the chopper with parallel-plate electrodes. In the present method sweeping is done for the continuum beam with a low energy from the ion source (extraction voltage < 10 kV). A base of the single-bunched beam is formed by the remaining part which is not swept. It has tails inevitably as shown in Fig. 1. Origins of the tail are a traveling time that the beam is passing through the electrodes with low velocity as well as a rise and fall time of the voltage supplied to it. In order to produce the pure single-bunched beam the tails should not overlap with the acceptance of the next bunch to the desired one. However, as it is difficult to shorten the tails for technical problems there is a limitation to produce the pure single-bunched beam in this way.

Another way is to sweep the beam longitudinally by operating the buncher with the sub-harmonic mode. In this way, a phase acceptance becomes wide for a bunch synchronized to the AVF and narrow for the other bunches. As the result, the intensity of the synchronized bunch is much stronger than that of the others. By use of the synchronized beam as the desired one the intense single-bunched beam can be produced although the purity is not so high.

By combination of the two ways, clearly, overlap between the tail and the acceptance of the undesired bunch becomes small. There might be no limitation for production of the pure single bunched beam in the combined way. In principle, if the acceptance of the desired bunch can becomes wide enough to include the tail, the single-bunched beam with the purity of 100 % can be produced.

3. Devices

The electrodes of the beam chopper connect with a DC power supply via a switching module. The repetition rate of the switching module is 1MHz that is demanded from a typical experiment.

A schematic drawing of the circuit of the switching module is shown in Fig. 2.

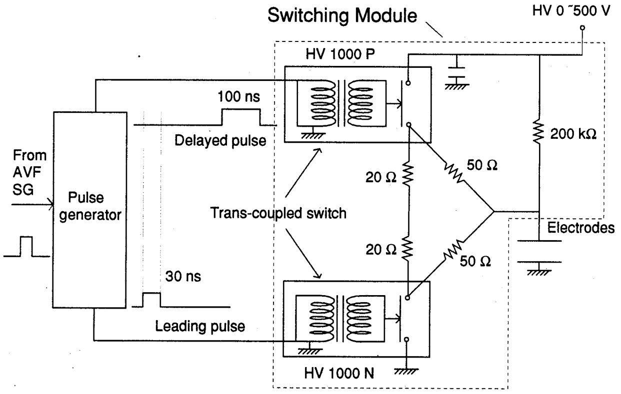

Fig. 2 Schematic drawing for the circuit of the switching module

The switching module has two trans-coupled switches with repetition rate of 1 MHz (HV 1000 P, N), which are bought from DEI inc in USA. One is for the charge-up of the electrode and the other for the discharge. To avoid an electrical oscillation between two switches and the electrode, we inserted several resisters there. Two pulses for the switches are made by a pulse generator located at upstream of the switching module. One is a leading pulse which is sent to the switch for discharge and the other is a delayed pulse which is sent to the one for charge. The difference of time when each pulse arrives at each switch corresponds to the duration for the base of the single-bunched beam. Characteristics of the pulse made by the switching module are summarized in Table 1. The choppers are installed on the two injection line. One is from the ECR ion source (ECRIS) and the other is from the polarized ion source (PIS).

Table 1. Characteristics of the pulse made by the switching module.

Voltage	0 ~ 500 V
Repetition rate	< 1 MHz
Rise time	15 ns
Duration time	100~250 ns

We used the buncher that has been already installed.[2)] In order to operate the sub-harmonic mode we must use the buncher with low frequency (4 ~ 8 MHz). For the purpose we made a new frequency divider that an amplifier and a phase is controllable. A wave made by the divider is sent to the buncher via the wide-band amplifier. A shape of the voltage is sin-curve. For the single-bunch operation, the range of phase to be compressed is wider than that for the normal one. In this case, even the sin-shape can compress the phase efficiently because the sin-shape is approximately a straight line for the main region of the phase to be compressed.

4. Performance Study and Result

A performance study of the single-bunch system was carried out for the 7.45 keV H_2^+ beam from the PIS which was accelerated to 7 MeV/nucleon by the AVF with an RF frequency of 16.3 MHz and to 135 MeV/nucleon by the RRC with an RF frequency of 32.6 MHz. The setup is shown in Fig. 3.

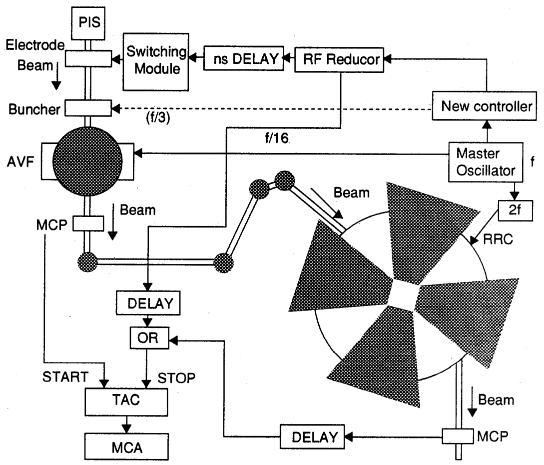

Fig. 3 Setup for a performance test of the single-bunch system.

The duration that the voltage between the electrodes was switched off was 150 ns. Voltage of the electrodes was 470 V. The variable delay connected with the switching module was adjusted so as to get the purest single bunched beam for the RRC. Time structures of the beam after the AVF and RRC were measured by using a time of flight (TOF) between a reduced RF signal and a timing signal of micro channel plates (MCP's) with a target [3)]. In this study we operated the buncher with the normal mode because the frequency divider had not been installed by that time.

Figure 4a shows a typical example of the TOF spectrum of the AVF. The main peak in Fig. 4a is due to a single bunched beam to be extracted.

The peak next to the main one is due to the next bunch of the main one. The existence of the other two peaks means that the same bunch inside the AVF is extracted with two-turns. Production mechanism of those peaks is explained in Fig. 5a. The result of the many peaks in the spectrum might be caused by the adjustment of the variable delay that is suitable to the RRC. In fact, using the system we obtained the single bunched beam as shown in Ref. 1 by adjustment of the variable delay for the AVF and by single-turn extraction from the AVF.

Figure 4b shows a typical example of the TOF spectrum of the RRC. The main peak in Fig. 4b is made by the single bunched beam to be extracted. The peaks next to the main one are due to the next bunches of the main one. The two small peaks correspond to another turn of the RRC (right side) and that of the AVF (left side). The purity of the single bunched beam is ~ 80 %. Production mechanism of those peaks is explained in Fig. 5b. As shown in Fig. 5b, in principle, the other turn of the AVF gives a bad effect to the single bunched beam extracted from the RRC but the peak of the turn is not so strong. This might be due to bad transmission of the RRC for the turn.

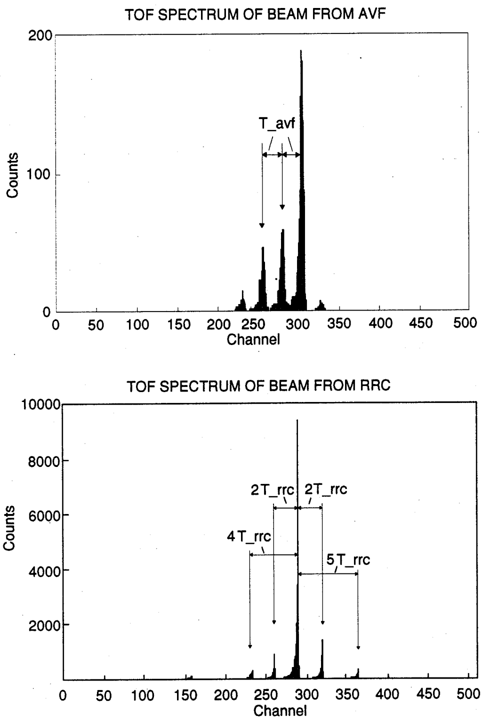

Fig. 4 Examples of time spectra of the single-bunched beam. From the AVF in a) and from the RRC in b) T_avf means the RF period of the AVF and T_rrc, of RRC.

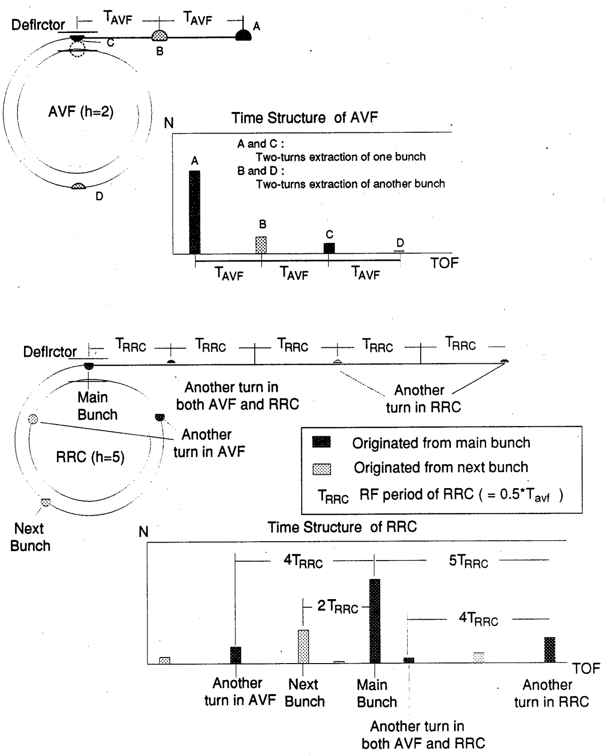

Fig. 5 Time structure of the extracted beams for the two bunches with two-turns extraction from the AVF and the RRC. The case for the AVF is shown in a) and that of RRC in b).

Recently, the whole system including the new controller was used to make a single-bunched beam for the deuteron beam from the ECRIS which was accelerated to 4 MeV/nucleon by the AVF with an RF frequency of 12.3 MHz. For the beam we used the buncher with an frequency 4.1 MHz. The purity of the single-bunched beam is 7 % by using the only buncher with the sub-harmonic mode. Using the whole system we obtained the beam with the purity of 0.3 %. The current of the beam was about 100 enA.

References

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2) K. Ikegami et. al., RIKEN Accel. Prog. Rep., 22, p213 (1988)

3) T. Kawama et. al., RIKEN Accel. Prog. Rep., 27, p135 (1993)