PERFORMANCE OF BEAM CHOPPING SYSTEM FOR JAERI AVF CYCLOTRON

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ABSTRACT

A beam chopping system was installed for the JAERI AVF cyclotron with external ion sources to supply pulse beams with a wide variety of pulse interval, acceleration energy and ion species. A combination of a pulse voltage chopper in the injection line and a sinusoidal voltage chopper after the exit of the cyclotron was adopted to extract a single beam pulse from the cyclotron beam. Beam deviation by the choppers and time spectrum of chopped beam were measured. This paper presents observed separate and total performance of a couple of choppers in comparison with the designed performance.

1. INTRODUCTION

The JAERI AVF cyclotron provides various ion beam characteristics in order to meet a number of requirements for beam utilization in the research program.[1] Pulsed beam irradiation is one of the important characteristics and is planned mainly for the in-situ analysis of elementary process in irradiated materials and for basic research on radiation chemical reaction process.

The chopping system was designed and made to reduce repetition of naturally bunched beam from the cyclotron (11 MHz - 22 MHz) down to 1 kHz - 1 MHz. A pulse voltage chopper (P-chopper) was installed in the injection line to chop DC beams from the ion sources[2] into pulse beams with intervals of 1 μs - 1 ms and with duration several times as long as the RF period of the cyclotron. A sinusoidal voltage chopper (S-chopper) was installed after the exit of the cyclotron to extract a single beam pulse from a train of plural beam pulses. Both choppers are of the parallel-plate electrode type. The design of the chopping system was reported in last the conference.[3]

Test operation has been carried out since October 1991 to evaluate chopping system performance using H^+ and He^{2+} beam. The time spectrum of chopped beam was measured by two different methods; one is oscilloscopic observation by a Faraday cup, the other is detection of prompt γ-ray induced by nuclear reaction in target materials. Multi-turn extraction was estimated by comparing the duration of beam pulse chopped by the P-chopper with that of a beam pulse train from the cyclotron. Finally we extracted a single beam pulse of 50 MeV He^{2+} beam using a couple of choppers.

Table 1. Design parameters of the chopping system

	P-chopper	S-chopper
elecrode length (cm)	13	120
electrode gap (cm)	8	4
drift length (cm)	60	80
slit gap (cm)	2.4	0.4
maximum voltage (kV)	1.5	40
frequency (MHz)	0.001 - 1.0	1-3
reduction rate 1/m	-	1/4,1/5,1/6

* maximum H^+ energy
for a single pulse extraction : 75 MeV!

2. BRIEF REVIEW OF CHOPPING PROCESS

A geometrical arrangement of the chopping system and the beam chopping process is illustrated in Fig. 1. The DC beams from ion sources are chopped by the P-chopper into beam pulses with 1 μs to 1 ms intervals and total time width T several times as long as the RF period of the cyclotron τ_c. The period of zero volt of P-chopper voltage τ_p is chosen so that the duration at the maximum beam current equals the effective bunching phase time t_b (assumed at 150 degrees of τ_c): τ_p-t_l=t_b, where t_l is the ion transit time through the P-chopper electrodes). The resultant beam pulse is modulated by the buncher into plural bunches, followed by injection into the cyclotron. The bunches are separated into a pulse train by natural bunching during the acceleration. Each pulse is further divided into plural pulses (n pulses) by multi-turn extraction at the deflector. Time length of the extracted beam train is longer than beam pulse width after the P-chopper due to additional pulses from the multi-turn extraction.

The period of the sinusoidal voltage wave is $2m\tau_c$ (1/m: reduction rate), and the length of a beam pulse train must be shorter than the period to extract a single beam pulse from the train. This is realized when T is shorter than $T_{max}=2m\tau_c-(n-1)\tau_c-t_b$, as shown in Fig. 1. The design parameters of the chopping system are listed in Table 1.

3. MEASUREMENT OF BEAM DEVIATION AND TIME SPECTRUM

We measured the beam deviation at the baffle slit, the wave form of chopper voltage, that of a beam pulse after the baffle slit and time spectrum of resultant beam pulses from the cyclotron. The beam deviation was measured by a three-wired beam profile monitor 7 cm upstream from the baffle slit. The wave form of the chopper voltage was observed by an oscilloscope through a capacitive pickup. Chopped beams were detected by a Faraday cup after the baffle slit and the wave form of the beam pulses was observed by an oscilloscope. Though the level of random and non-random noises was high in this measurement, averaging and subtracting functions of background reduced it significantly and signals were observed very clearly.

The pulse beam from the cyclotron bombarded an alumina target. The γ-rays emitted from the target were detected by a plastic scintillation counter and the spectra of time difference between the γ-ray signal and the P-chopper trigger signal were observed without any influence of noise. The time length of the beam pulse train was obtained from the spectra. During the measurement of the P-chopper performance, beams were well focused at the baffle slit with a beam diameter smaller than the designed slit gap (24 mm).

We ensured that beam deviation by the S-chopper was large enough at the baffle slit gap, by observing one of every m beam pulses appeared in the γ-ray time spectra, since we have no beam monitor for the S-chopper.

4. PERFORMANCE OF P-CHOPPER

4.1. Beam Deviation and Wave Form of Beam Pulse

Deviation of 12.5 keV H^+ beam at the baffle slit was measured over the range of the P-chopper voltage V_{pmax} from 500 V to 800 V. The measured deviation is larger than the designed one by about 30% for all the preset value of V_{pmax}. This suggests the difference of the preset and the actual V_{pmax}.

The chopper voltage falls linearly with time from V_{pmax} to zero in 150 ns independently of V_{pmax} and τ_p, and the fall time is shorter than that in the design (200 ns). On the other hand, the voltage rises slowly like a logarithmic function and it takes 350 ns from 10% to

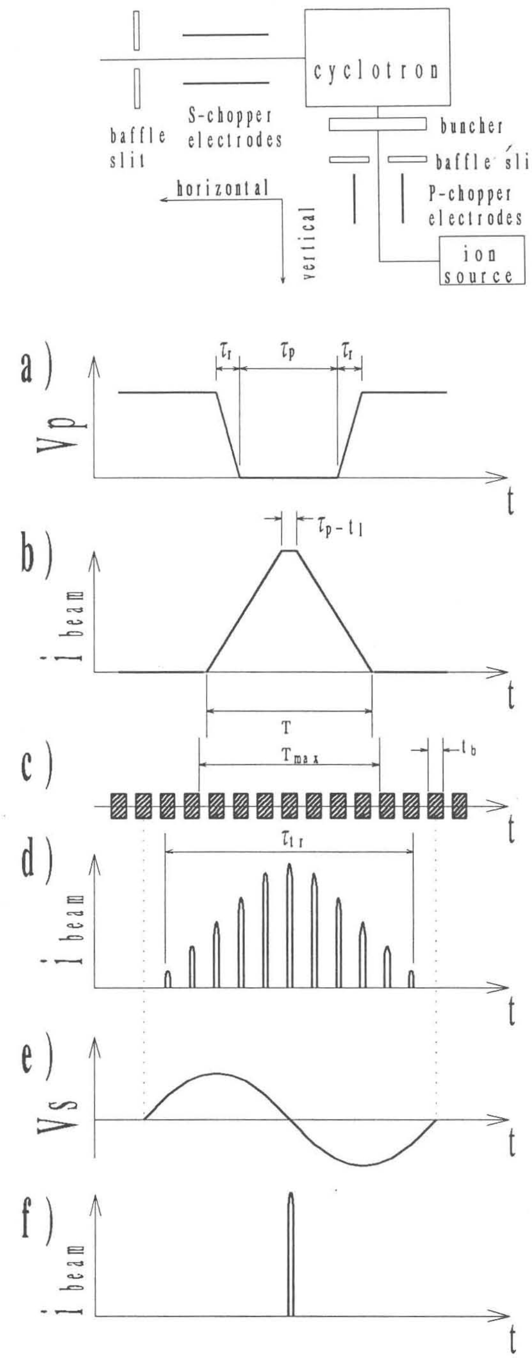

Fig. 1 Geometrical arrangement of the chopping system and diagram of beam chopping process.
t_l:ion transit time through P-chopper electrodes.
τ_r:rise and fall time of P-chopper voltage.
t_b:effective buncher phase.
a) P-chopper voltage.
b) Beam pulse after passing through P-chopper.
c) Acceleration phase.
d) A train of plural beam pulses from cyclotron.
e) S-chopper voltage.
f) Beam pulse after S-chopper.

90% for V_{pmax}. The sum of the fall and the rise times is 100 ns longer than that designed (400 ns).

Signal-to-noise ratio is good in the wave form measurement on pulsed beam by the P-chopper, however, there is a reflection 1 μs after the signal, and this makes it difficult to extract total pulse width from the wave form. Therefore, we adopted full width at twentieth maximum $\tau_{1/20}$ as total width. The observed full width at half maximum and $\tau_{1/20}$ are plotted in Fig. 2 in comparison with those designed. The figure also shows the result of calculation on the wave form of beam pulse using the observed chopper voltages. For full width at half maximum, the observed and calculated widths are roughly close to those in the design. While the full widths from the calculation τ_{cl} are close to those in the design, the values of $\tau_{1/20}$ are different. In the observed wave form, the steep fall of the beam pulse suddenly becomes moderate below half maximum, and it does not agree with the result of the calculation. This may be a reason of the difference between $\tau_{1/20}$ and τ_{cl}. As a result, the total width T is not defined clearly from the obtained data, and is uncertain between $\tau_{1/20}$ and τ_{cl}.

4.2. Estimation of Multi-turn Extraction

The time spectra of the pulse train were measured for 50 MeV He^{2+} with the P-chopper voltage on and the S-chopper voltage off. The structure of the spectrum changed drastically by tuning the base magnetic field of the cyclotron. This indicates the importance of cyclotron tuning to minimize multi-turn extraction. Clear correlation was not observed between the time spectrum and beam extraction efficiency at the deflector.

The number of multi-turn extraction n is deduced from the difference between the total pulsed beam width after the P-chopper and the duration of a pulse train from the cyclotron τ_{tr}. The observed τ_{tr}, under well tuned cyclotron condition, is compared with $\tau_{1/20}$ and τ_{cl} as function of τ_p in Fig. 3. They increase linearly with the τ_p and the differences are almost constant over a wide range of τ_p. This suggests that we can clearly define the number of multi-turn extraction n from the data. The difference of τ_{tr} from $\tau_{1/20}$ and from τ_{cl} are about $2.5\tau_c$ and $5\tau_c$, respectively, and n is estimated to be 4 to 6. As a result, it turned out that the assumption of n=5 in the design was reasonable.

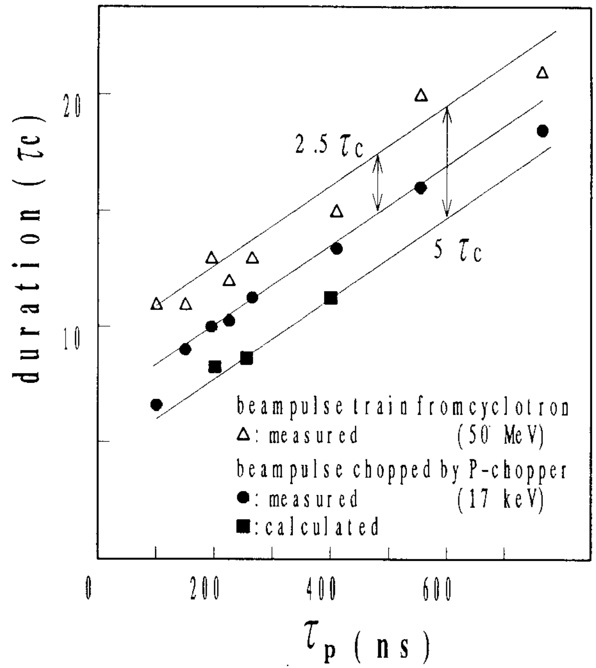

Fig. 3 Estimation of multi-turn extraction from difference between He^{2+} beam pulse width after the P-chopper and pulse train duration from the cyclotron.

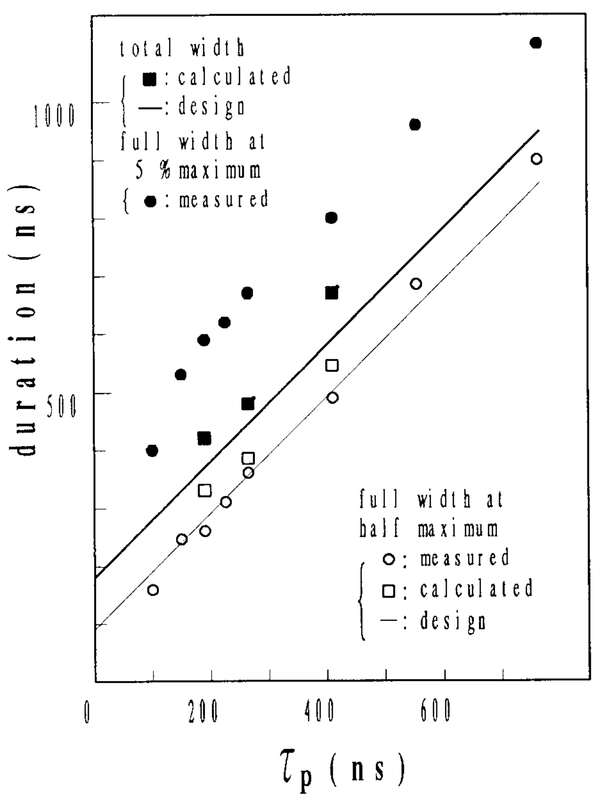

Fig. 2 Duration of 17 keV He^{2+} beam pulse after the P-chopper.

5. TOTAL PERFORMANCE

5.1. Performance of S-chopper

At the baffle slit for the S-chopper, it is important that the accelerated beam is well focused and its diameter is smaller than the slit gap. The slit gap of the S-chopper baffle was set at 4 mm according to the design. The minimum beam diameter was slightly larger

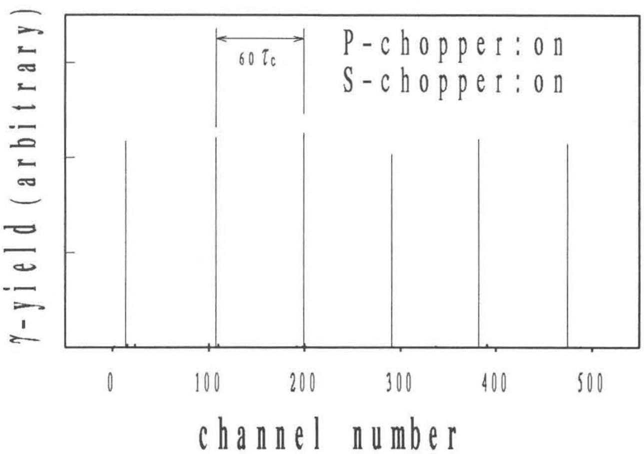

Fig. 4 Beam pulses with a long interval of 3.5 μs obtained by using the P- and the S-chopper.

than the slit gap because about 10% of the total beam current hit the slit edge. We measured the minimum chopper voltage which allowed complete 1/m reduction of beam pulses for m=4,5,6 without the P-chopper voltage. It turned out from the result that the observed voltages satisfied the designed performance.

5.2. Total Performance

The result of beam deviation for each chopper showed the performance as designed or better. The only problem is that the beam pulse width after the P-chopper is uncertain between $\tau_{1/20}$ and τ_{cl} in our measurement. If $\tau_{1/20}$ is the actual total width ($T=\tau_{1/20}$), T is longer than T_{max} and a single pulse cannot be extracted from a beam pulse train using designed reduction rate of the S-chopper. However, T can be reduced if we remove the condition $\tau_p=t_l+t_b$ for maximizing the intensity of the single beam pulse and/or we use higher V_{pmax}. Moreover, the observed τ_{tr} is close to that in the design. Therefore, it is considered that observed performance satisfies the most critical requirement for the total chopping system: $T<T_{max}$.

The single pulse extraction was made for 50 MeV He^{2+} using a couple of choppers, with the P-chopper voltage interval of $60\tau_c$ (3.5 μs) and 1/6 reduction rate of the S-chopper. In Fig. 4, beam pulses with $60\tau_c$ interval are shown under high signal-to-noise ratio and the γ-yields of neighboring peaks are less than a hundredth of those for the extracted beam pulse.

As a result, if the actual T is longer than that in the design within the uncertainty, it is not a serious problem, and the single pulse extraction from a pulse train is considered possible over a wide energy range and a variety of ion species in the design.

6. CONCLUSION

The chopping system was designed and made to reduce repetition of naturally bunched beam from the cyclotron down to 1 kHz - 1 MHz, which consists of a pulse voltage chopper installed in the injection line and a sinusoidal voltage chopper after the exit of the cyclotron. The choppers were tested separately and as the overall performance.

The observed beam deviation is close to that in the design for both choppers. The observed duration of the beam chopped by the P-chopper is also in good areement with that in the design in full width at half maximum. On the other hand, for the total width, there is uncertainty of two and a half times the period of the cyclotron RF. Even if the width is longer than that in the design within the uncertainty, it is not serious for overall performance of the chopping system, because shorter width can be obtained by using higher voltage and/or shorter zero-voltage duration of the P-chopper, and also the observed duration of a pulse train after the cyclotron is close to that in the design.

The number of multi-turn extraction strongly depended on tuning of the cyclotron. We could minimize it by tuning base magnetic field, and the number of multi-turn extraction was estimated at 4 to 6 under well tuned cyclotron conditions, from comparing beam pulse duration after the P-chopper with the duration of a beam pulse train after the cyclotron. We assumed it at 5 in the design and this turned out to be reasonable.

Realization of pulsed beams of 50 MeV He^{2+} with 3.5 μs interval was observed under high signal-to-noise ratio. The single pulse extraction is considered possible over a wide range of energy and a wide variety of ion species in the design.

7. REFERENCES

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