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Introduction

The neutron time-of-flight (TOF) facility of CYRIC (Cyclotron and Radioisotope Center), Tohoku University\(^1,2\) has made it possible for us to perform high energy-resolution measurement for fast neutrons in large dynamic range by means of both a long flight path up to 44m and a beam chopper system which increases time between each cyclotron beam burst. By using a good time-resolution beam from the K=50 MeV AVF cyclotron in combination with the TOF facility, 35 MeV (p,n) experiments have been performed for an extensive study on nuclear spin-isospin excitation\(^3-5\), while (d,n) reaction at 25 MeV has been studied to obtain ground state properties of target nuclei as well as proton single-particle nature in residual nuclei\(^6,7\).

The beam chopper deflects the cyclotron beam bursts off the beam line axis by electric field of a pair of electrodes located in the beam line, and permits the beam bursts at 0 voltage between the electrodes to be transported to the target. The beam bursts deflected by the chopper are dumped with a subsequent slit.

The beam chopper installed in the TOF beam line at CYRIC is a sinusoidal type where a phase of 0 or 180 degree for the RF signal leads to 0 voltage between the electrostatic plates. Thus, the beam chopper driven at 1/2N (N : integral) of the cyclotron acceleration frequency gives the chopping rate of 1/N for the cyclotron beam bursts.

Recently, the K=50 MeV cyclotron at CYRIC was replaced by a new K=110 MeV AVF cyclotron. The maximum energy for a proton beam provided from the new cyclotron increases up to 90 MeV. The other light ions can be accelerated up to the respective maximum energies corresponding to the cyclotron K-number. The beam transport system at CYRIC was simultaneously improved for more energetic beams from the new cyclotron.
In addition, The neutron time of flight facilities, including the new beam swinger and the detector matrix, etc. have been upgraded\(^8\). The control system for the cyclotron and beam transport system was replaced by new one based on programmable logic controller (PLC) system (Yokogawa FA-M3 controller)\(^9\).

The sinusoidal beam chopper at CYRIC has been improved by developing a new RF system as well as a PLC based control system. In the present paper the new RF system and control system are described together with results of a performance test for the new beam chopper system using a proton beam from the new cyclotron.

**New control system**

The PLC system generally used at automated factories is available to control experimental machines and instruments as well. It consists of the CPU and some modules such as DI/O (digital input / output), AD/DA, motor-control, and LAN modules. The CPU controls other modules on the basis of programs downloaded from a personal computer connected to the PLC system via the ethernet LAN. The DI (DO) and AD (DA) modules are used to monitor (control) machines via the status (control) signals from (to) the machines. Stepping motors can be controlled with motor-control modules connected to their motor-drivers. The PLC modules located in separated rooms can be controlled by the identical CPU using a light fiber cable connected between them. If the CPU is located in an experimental room it should sufficiently be shielded from neutron radiation because the CPU fault due to the radiation damage may be caused.

The new control system for the present beam chopper is illustrated in Figure 1. The CPU of the PLC system for the beam chopper is located in a control room. The PLC modules located in the separated rooms are connected with the optical fiber cables. Furthermore, the CPU for the beam chopper is connected to those for the cyclotron and beam transport system with link cables for interlock of the whole control system. Personal computers are used to control and monitor the system using the LabView visual interface\(^{10}\) as well as to develop PLC programs downloaded to the CPU through the TCP/IP network.

**New RF system**

The RF system for the beam chopper determines chopping rate, magnitude and phase of RF voltage for the electrodes, and their stability. A new low level RF system for the present beam chopper has been installed because the previous system is not available due to change of the control system for the beam transport lines. A diagram of the new RF
system is shown in Figure 1. The basic specification of the improved beam chopper system is listed in Table 1.

**Low level system**

An input RF signal for the low level system from that for the cyclotron has the cyclotron acceleration frequency \( f \). When the beam chopper operates at the chopping rate of \( 1/N \) where \( N-1 \) of \( N \) cyclotron beam bursts are deflected, the input signal is converted so that the output frequency of the beam chopper is \( f/2N \). The frequency ranges of the input and output signals are 10.5 - 22 MHz and 0.5 - 1.6 MHz, respectively. The \( N \) values of 6 - 10 are available. As a result, a time interval between beam bursts ranges from 312.5 nsec to 1 usec. Phase shift for the output signal can be varied more than 360 degree in order to optimize the TOF spectrum. A TTL signal of \( f/2N \) frequency is used for an RF stop for the TOF measurement.

In order to stabilize both electrode voltage and phase, an electrode signal is fed back to the low level system. The phase deviation of the output signal is compensated with an automatic phase controller (APC) on the basis of the phase difference between the input and feedback signals detected by a phase comparator while the amplitude is also kept constant with an automatic gain control unit (AGC) in a similar way. Finally, the RF low level system gives the output signal amplified by a 300 W preamplifier to an RF power amplifier.

The low level system is also controlled with PLC modules. The phase and amplitude of the electrode signal are set with 12 bit data from the DO module to the APC and AGC, respectively. The chopping rate data is also given by the DO module. Progressive and reflected waves of the output are monitored by measuring voltages of their monitor signals from the preamplifier with the AD module. The monitor signals are calibrated so that a range of 0 - 10 V corresponds to 0 - 400 W for the progressive wave, and 0 - 200 W for the reflected wave.

**RF power amplifier and electrode**

The RF power amplifier used for the beam chopper system is a push-pull type consisting of a drive stage with two 4-125A tetrodes and a subsequent final stage with two 4CW10000 tetrodes. The present beam chopper system does not need the drive stage because the new low level system can drive the final stage using the 300 W preamplifier which provides the output with a sufficient amplitude for the final stage. Thus, the output
signal from the preamplifier enters directly into the final stage.

The power of the RF signal is supplied to the tank circuit from the final stage via a coupling coil. The maximum peak-to-peak amplitude of 50 kV between the electrodes is designed. The feedback loop signal to stabilize both phase and voltage of the electrode signal is provided from dividing condensers by which 1/1000 of the electrode voltage can be detected. Because the electrodes has a large capacity, the tank circuit needs to be tuned over the full frequency range by means of change in not only capacities of the variable condensers but also inductance of a tuning coil in the tank circuit by replacing it with the other one having different inductance. When the tuning coil is changed, a coupling strength of the coupling coil between the final stage and the tank circuit needs to be tuned to optimize the plate resistance of the 4CW10000.

The control system for the RF power amplifier was modified for the new PLC based system. Power supplies for the 4CW10000 were equipped with a newly developed interface for PLC based control. The control lines for the power amplifier were connected to the PLC modules through a distributor including some DC power supplies for electric circuits, AC power supplies for reversible AC motors, stepping motor drivers and some relay units. The capacities of the variable condensers, the distance between a pair of the electrodes and a gap of the slit can be changed with stepping motors controlled by the stepping motor module or reversible AC motors controlled by the DO module while the AD modules read the DC voltage from potentiometers indicating each position. Status signals from sensors for the upper / lower limits in each position and cooling water are read with the DI modules. The distributor and PLC modules were located in the same room as the beam chopper. The PLC modules were sufficiently shielded from the radiation damage.

**Performance test of the new beam chopper system**

Since the previous beam chopper system was used for a proton beam up to 40 MeV from the old cyclotron, a 50 MeV proton beam from the new cyclotron was used for a performance test of the improved beam chopper system. Figure 2 shows a measured TOF spectrum for gamma flash from the target with or without the beam chopper driven at 1/8 chopping rate. It is found that beam bursts from the cyclotron have clearly been deflected by the beam chopper. The maximum peak-to-peak voltage between the electrodes has been achieved up to 50 kV with good stability in both voltage and phase of the RF signal. In the course of regular experiments at CYRIC, the performance test was successfully carried out with increasing proton beam energy up to 90 MeV.
Conclusion

The sinusoidal beam chopper for neutron TOF experiments at CYRIC has been improved by developing both the new RF system and the PLC based control system. The output frequency ranging from 0.5 to 1.6 MHz provides a dynamic range of 312.5 - 1000 nsec for TOF measurement. The maximum peak-to-peak amplitude of 50 kV between the electrodes has been obtained with good voltage and phase stability. The beam chopper driven by the new RF system has successfully been used for a more energetic beam from the new cyclotron. The PLC system is useful to develop and improve the control system for experimental instruments.

References

8) Terakawa A. et al., Nucl. and Instru. and Meth. in press.
9) Yokogawa Electric Corporation, Musashino, Tokyo 180-8750, Japan (http://www.yokogawa.co.jp).

Table 1. Specification of the sinusoidal beam chopper system.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Input frequency</td>
<td>10.5 ~ 22 MHz</td>
</tr>
<tr>
<td>Output frequency</td>
<td>0.5 ~ 1.6 MHz</td>
</tr>
<tr>
<td>Chopping rate</td>
<td>1/6, 1/7, 1/8, 1/9, 1/10</td>
</tr>
<tr>
<td>Maximum voltage</td>
<td>50 kV (peak to peak)</td>
</tr>
<tr>
<td>Voltage stability</td>
<td>&lt; 1/100</td>
</tr>
<tr>
<td>Phase shift</td>
<td>−200 ~ 200 deg.</td>
</tr>
<tr>
<td>Phase stability</td>
<td>&lt; 0.2 deg.</td>
</tr>
</tbody>
</table>
Fig. 1. Diagram of the RF and control systems for the CYRIC sinusoidal beam chopper.

Fig. 2. TOF spectra for gamma flash measured using a 50 MeV proton beam with or without the beam chopper operated in 1/8 chopping rate mode.