1. 9. New Fast-neutron Time of Flight Facilities at CYRIC


Cyclotron and Radioisotope Center, Tohoku University
Department of Physics, Graduate School of Science, Tohoku University*

The fast neutron time of flight facilities at CYRIC has been extensively used, together with the old K=50 MeV cyclotron, for detection and momentum analysis of fast neutrons since 1977\(^1\), being upgraded in 1988\(^2\). In the two decades of the last century, the TOF facilities worked as the powerful tool for studying isospin and spin-isospin excitation nuclei by the charge-exchange (p,n) reaction\(^7\), particle transfer (d, n)\(^9\), (\(^3\)He, n)\(^5\) and (\(\alpha\), n)\(^6\) reactions, and neutron scattering\(^7\).

In 1998 and 1999 school years, the cyclotron was replaced to K= 110MeV one\(^8\) along with the beam transport system\(^9\) including beam swinger. Related facilities, for example, neutron detector matrix for TOF experiments have been renewed as well in these year\(^10\).

In this report, a brief description of the new TOF facilities and results of performance test by the (p,n) reaction on \(^6\)Li are given. It is remarkable that the measured time resolution of the micro-burst in beams from the new AVF cyclotron has been in the order of several hundred pico-seconds, which gives a quite nice place for fast-neutron time of flight experiments.

BEAM SWINGER AND BEAM DUMP

Figure 1 illustrates the new beam swinger by which the axis of a beam, having magnetic rigidity of 15.5 kG-m in maximum, is rotated from −5 to 110 degrees in order to make it possible to measure the angular distribution of cross sections for reaction products, setting at rest the neutron detector matrixes at distances of ~40-meter long from the target.

Accelerated beams enter through quadrupole-quartet and switching magnets into the −60 degree-bending dipole-magnet forming a image point, then enter into the second +150 degree-bending dipole-magnet which has the horizontal and vertical magnification of one in their absolute values. The beam after target enter into the beam-dump to be measured it's beam current though a beam-dump dipole magnet with a magnetic rigidity of 10 kG-m when measurement is done at forward angles \(\theta_{ab}<5^\circ\).
SINUSOIDAL BEAM CHOPPER

In order to obtain sufficient dynamic range in the neutron-momentum measured by TOF with a flight-path in a finite length and to detect neutrons with higher efficiency, it is crucial to have a proper pulse interval of the micro-burst of beams from the AVF cyclotron. Acceleration RF-frequency of the CYRIC cyclotron is ranging in 10.5 through 22MHz, natural beam-burst interval being in 45 through 95 nanoseconds. Thus, one of 1/5 ~ 1/10 beam-chopping is needed to get a pulse interval of several hundred nanoseconds, by which it is capable to measure 90-MeV neutrons with a dynamic range of ~90% in the momentum without overlapping of neutrons in the TOF spectrum. In addition, detection efficiency increases more than one order of magnitudes.

Figure 2 illustrates the electric-power part of the chopper. A 300 watt solid state amplifier drives the push-pull circuit with 2 pieces of power-tetrodes EIMAC 4CW10000, then RF-power is transmitted to a pair of copper electrodes, the dimensions of which are 1m-long, 5cm-wide and 5mm in their thickness with a variable gap ranging 30 through 50 mm. The electrodes are mounted in a 1300mm-long and 600Φ-dia. vacuum tank located at a position 1300-mm up-stream of a pair of slits with a 4mm gap, to remove unwanted beam pulses from the beam-line. Setting of experimental conditions of the chopping rate and voltage applied to the electrodes is performed through the programmable logic controllers (PLC)(1). Adjustment are carried out as well by PLC for tuning of the RF-power parts to obtain sufficient RF high-voltage in the order of 40kV, and for the proper phase difference between accelerating RF and that of the chopper to meet with a TOF measurement with a reasonable beam intensity. TIL signal for TOF is used for the stop signal of events.

NEUTRON DETECTOR

The neutron detector is illustrated in Fig. 3. Liquid scintillator Bicron BD50LA is encapsulated in a can, the dimensions of which are 203.2 mm in its diameter and 50 mm thick, thus a detector contains 1.6 liter scintillator. Light events are guided to photo-multiplier EMI 9823KB. A optical fiber is connected for the purpose of monitor for the gain of photo-multiplier. Experimental arrangement of 32 neutron detector matrix are shown in Fig. 4.

Time resolution of the neutron detector has been measured by detecting the energy deposit by cosmic-ray muons passing through two detectors. The typical time resolution of these detectors are ~500 pico seconds. Energy deposit by cosmic-ray muons are utilized for the energy calibration together with those by 4.43-MeV gamma-rays from an Am-Be source, neutrons from which are used for the test of neutron-gamma discrimination power of these detector as well.

Several hundred-hours long run test for light outputs have been carried out by observing Compton edge for 4.43-MeV gamma-rays and lights from LED fed through optical fiber. Results of this measurements are illustrated in Fig. 5 for five detectors labeled as #13, 17, 22, 27 and 28 among 32sets of the present neutron detector.
NEUTRON DETECTION ELECTRONICS

Figure 6 illustrate the electronics diagram of one neutron counter for detecting neutrons and analyzing their flight time, discriminating the light event for them from those for gamma rays. Three dimensional data are stored for one light event. The first one is for the flight-time information (TOF). A timing pulse is generated in a constant fraction discriminator device (CFD) by the signal from photo-multiplier, and is led to a time to digital converter (TDC) to measure the time between neutron arrival and cyclotron RF-signal which corresponds to beam-pulse arrival at the target. For convenience, the logic of “RF-start and neutron-stop” is applied.

The second one is for total light amount generated in the analog to digital converter (ADC) by the analog pulse from the photo-multiplier. This information is used to eliminate the Lapland neutrons which enter into a neutron spectrum due to the limited interval of the cyclotron beam pulses.

The last one is for n-γ discrimination. Deferent mechanism of light yields for neutrons and gamma rays in the liquid scintillator give deferent pulse-shape for these two radiations, thus enabling us to separate the former from latter by delayed integration of their partial light out put. Two dimensional display of two total and partial light out-puts readily provides a spectrum for n-γ discrimination.

DATA ACQUISITION AND ANALYSIS

Figure 7 illustrate the data acquisition system. Digitized event by event data from Analog to Digital Converter (ADC) or Time to Digital Converter (TDC) are received by VME Crate Controller (SBS 617VME bus adapter), controlled by a front-end PC (altair), which is connected to a back-end PC through ethernet for the purposes of on-line and off-line analyses.

A flow chart of the present data analysis software is depicted in Fig. 8. Starting at three-dimensional raw data from 32 pieces of the neutron detector, neutron momentum (TOF) spectrum or excitation energy spectrum is generated with and without two-dimensional n-γ discrimination. Also obtained are summed spectra over the data from each detector, the maximum number being 32. The position of γ -flash peak of each detector is used to adjust the relative time lag in each detector.

PERFORMANCE TEST BY (p,n) REACTION

Figure 9 depicts time spectrum of gamma flush measured for time structure of 70-MeV proton beams from the cyclotron. Gamma rays were detected by 1 inch φ and 1 inch thick plastic scintillator, the intrinsic time resolution of which was less than 200 pico seconds. Typical time resolution was indeed in the order of several-handled pico seconds. The time structure of beam burst is adjusted by a pair of slits located at the first-turn region of the cyclotron to limit the phase interval of accelerating RF-voltage. Of course, narrower beam

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burst yields less intense beam, thus an intense ion source and the efficient beam injection line is crucial for reliable experiments.

Performance test for the TOF facilities has been carried out by 50- and 70-MeV proton beams. Beams from the new cyclotron are transported successfully to the swinger, then beam axis is rotated from 0 to 20 degree in the laboratory frame without adjusting any beam handling parameters. Almost all beams are collected on the Farady cup in the beam dump after the cleaning dipole-magnet.

Result of performance test has been carried out for the sinusoidal beam chopper, by which unwanted micro-bursts of the beam are completely removed from the beam-line as seen in Fig. 10. With a chopping of 1/8, we are able to obtain a time interval of 0.5 nanoseconds giving, a dynamic range 10–70 MeV for detected neutrons after 44 m-long flight.

In Fig. 11, neutron time-spectrum of the $^6\text{Li}(p,n)^7\text{Be}$ reaction taken with $E_p = 70$ MeV at $\theta_{ab} = 0^\circ$ is illustrated. The flight path is as long as 16 meter, and thickness of the $^6\text{Li}$ metal foil is 6mg/cm$^2$. Overall time resolution is 0.9 nano seconds.

In a summary, construction of the new fast neutron time of flight facilities have been carried out. They contain a system with reliable beam swinger, scattering chamber and beam-dump, and large-angle detector matrix involving 32 pieces of disk-type detector, etc. Performance test has been made successfully by studying $(p,n)$ reactions on $^6\text{Li}$. Excellent time-resolution of a beam-burst makes it quite promising to study nuclear spin-isospin excitation by high-resolution measurements.

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References

Fig. 1. New beam swinger and beam dumping system.

Fig. 2. Schematic drawing of sinusoidal beam-chopping system.
Fig. 3. Liquid scintillator neutron detector.

Fig. 4. Experimental arrangement of 32 neutron detector matrix.

Fig. 5. Long run stability for light output corresponding to the Compton edge of 4.43-MeV gamma rays. Horizontal axis denotes running time in hour, while vertical one does deviation from the average.
DETECTION AREA

COUNTING ROOM

Fig. 6. Electronic setup for TOF measurement.

Fig. 7. Schematic Drawing of data acquisition system.
Flow chart of program to make excited energy spectrum from data (beta 0.8)

Fig. 8. Flow chart of data analysis software.
Fig. 9. Time spectrum of $\gamma$-flash detected by a plastic counter located at the exit of cyclotron.

Fig. 10. Result of performance test for the sinusoidal beam chopper, by which unwanted micro-bursts of the beam are removed from the beam-line.

Fig. 11. Time spectrum of neutrons taken for the $^6$Li(p,n)$^7$Be reaction at $E_p=70$ MeV measured at $\theta_{Lab}=0^\circ$. 

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