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Beam energy measurement by the time-of-flight technique

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Abstract

The absolute energy of ion beams accelerated by the JAERI AVF cyclotron has been measured by the time-of-flight technique. We have developed a movable TOF counter system for precise energy measurement, which can be achieved by two TOF measurements for different flight path length.

1 Introduction

Beam energy is an important parameter for experiments of research of irradiation effects. The nominal beam energies of the cyclotron are based on the ones from which initial parameters of the cyclotron tuning are calculated. Actual beam energies are not exactly the same as the nominal ones since the parameters usually have to be changed for optimum tuning of the cyclotron. The energy of the beam extracted from the cyclotron can be estimated with an analyzing magnet while the precision of the energy measurement is not so high for uncertainties of the beam path and the magnetic field in the magnet. A crossover technique[1,2] is a good method to measure an absolute energy for protons with energy below 50MeV. However, it is useful neither for above 50MeV protons due to very small elastic scattering angles nor for heavy ions due to difficulty of finding appropriated targets. A time-of-flight method (TOF)[3] is easier way to determine the absolute energy for the variety of ion species with high precision better than the other energy measurement method such as the crossover technique and analyzing magnet.

The kinetic energy of an ion can be obtained from the equation:

$$E = m_0c^2\left(\frac{1}{\sqrt{1-\beta^2}}-1\right), \quad \beta = \frac{v}{c}$$

where m_0 is the rest mass, c the speed of light, and v the speed of an ion. The speed v can be obtained from measurement of the flight time and the flight path length. The uncertainty in the kinetic energy can be evaluated from the uncertainties in the flight time and the path length, since the contributions of the rest mass and the speed of light are negligible. Because of the short flight time, 10 – 40 ns/m, the flight time should be determined with accuracy of the order of 10 ps to obtain dE/E with an accuracy less than 10^{-3}. It is difficult to measure the absolute flight time, which needs a common time origin for ion detection at two different points, with such a good precision. Therefore, we have developed a movable TOF counter system in which we don't need to know the time origin, as shown in Fig.1.

2 Beam Energy Measurement System

2.1 Start and stop counter

The TOF system has two ion detectors: one is a start counter for production of a start signal and the other, a stop counter, for production of a stop signal.

A beam phase monitor[4], which has been developed to monitor timing characteristics of the beam without beam degradation, is used as the start counter. The beam phase monitor is a fast timing detector with a micro-channel plate which is multiplying secondary electrons coming from a

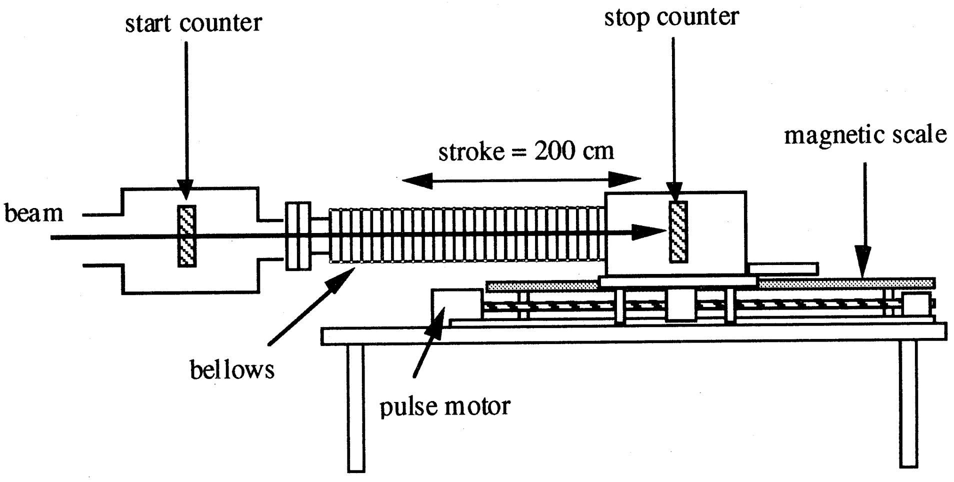

Fig. 1 Layout of the movable TOF counter system.

thin target foil, a 3 micron thick aluminum-strip, when ions pass through it. The foil is mounted at a distance of 50 mm from the MCP. The best time resolutions are 190 ps FWHM for 225 MeV $^{16}O^{7+}$ and 230 ps FWHM for 220 MeV $^{12}C^{5+}$.

A MCP was used as the stop counter, which can directly detect ions and produce a fast timing signal.

2.2 TOF system

The velocity of the ions can be evaluated from the length between the detectors and the time difference of the start and stop signals. Using mass references, the energy of the ion can be calculated from the velocity. The precision of the energy measurement mainly depends on the uncertainties of the measurements of the length and the time difference. Since the maximum velocity of the ion accelerated by the cyclotron, which is obtained in the case of proton, is 0.41 of the light velocity, precise measurement of the length and the time difference is needed for precise energy measurement using the time-of-flight technique.

Errors in absolute measurement of the length and the time difference mainly depend on inaccuracy of decision of the criteria, such as time zero for the measurement of the time difference. In an actual measurement system, the signals from the start and the stop counters have different time delay caused by the difference of cable length and timing properties of the counters.

To achieve precise measurement of the beam energy, we adopted relative measurement of the length and the time difference, which eliminates inaccuracy of decision of the criteria. In this measurement, the length and the time difference have to be measured twice by moving the stop counter.

The counters are installed in different vacuum chambers connected with bellows. The chamber for the stop counter can be moved at the maximum distance of 2 m. The relative change of the length can be measured with a magnetic scale with a precision less than 0.1 mm. The relative change of the time difference is obtained as a shift of the time spectrum peak measured with a time-to-amplitude converter using the relative timing signals from the start and stop counters.

3 Measurements and Results

We measured the beam energies of a 10MeV (nominal) H^+, a 220MeV (nominal) $^{12}C^{5+}$, and a Cocktail beams[5] (mass/charge=5), as shown in Table 1. Since the energy loss in the foil of the start counter is large for heavy ion beams, a 10 μ g/cm^2 thick carbon foil was used for the 220MeV (nominal) $^{12}C^{5+}$, and the Cocktail beam. In the case of the cocktail beam, a semiconductor detector or a plastic scintillation counter, which is not superior to the MCP in timing characteristics, was used as the stop counter to identify ion species from the energy spectra.

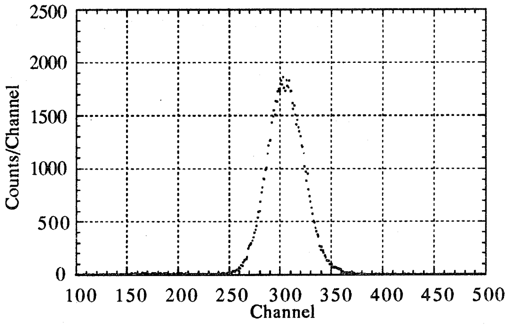

Fig.2 A time-of-flight spectrum for Ar ions of the cocktail beam.

Figure 2 shows a time-of-flight spectrum for Ar ions of the cocktail beam with a FWHM width of 2.3 ns at the minimum flight length. The flight time can be evaluated from difference of the peak positions at different flight path length. The accuracy of the energy measurements, which was around 0.5 % in theses measurements, can be improved by more accurate time calibration.

References

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Table 1 Result of beam energy measurement.

Ion	Nominal energy (MeV)	Measured energy (MeV)
H^+	10	10.17±0.02
$^{12}C^{5+}$	220	225.2±0.6
Cocktail(M/Q=5)		
$^{15}N^{3+}$	56	57.2±0.1
$^{20}Ne^{4+}$	75	76.4±0.2
$^{40}Ar^{8+}$	150	153.2±0.3
$^{84}Kr^{17+}$	315	328.6±0.7