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# A Measurement of Proton Beam Energy using Carbon Target for Medical Cyclotron

**Jong-Seo Chai**, M.S., **Jang-Ho Ha**, M.S., **Yu-Seok Kim**, M.S., **Dong-Hun Lee**, M.S.
**Min-Yong Lee**, **Seong-Seok Hong**

*Cyclotron Application Laboratory, KCCH, Korea Atomic Energy Research Institute, Seoul, Korea*

**= 국문 초록 =**

## 탄소 표적물을 사용한 의료용 싸이클로트론의 양성자 에너지 측정

한국원자력연구소 부설원자력병원 싸이클로트론응용연구실

**채종서 · 하장호 · 김유석 · 이동훈 · 이민용 · 홍성석**

한국 원자력 연구소 부설 원자력병원에 설치된 AVF 싸이클로트론을 이용하여 요즈음 핵의학에 널리 사용되는 PET 용 싸이클로트론의 에너지를 검정 할 수 있고 양성자 과잉 핵종인 싸이클로트론 동위원소의 생산 수율에 중요한 변수인 양성자에너지를 탄소에 입사시켜 입사빔의 Range와 에너지를 측정하는 방법을 제시하였다. 본 실험에서 사용된 양성자 빔의 양성자 에너지는 35 MeV와 50 MeV 사이였으며, 탄소 막은 두께 6.3mm, 밀도 1.712 g/cm$^3$를 사용하였다. 탄소 표적물을 0.9° 씩 스텝 모터를 사용하여 회전시킴으로 두께를 변화 시켜 공칭 에너지에 대한 Range를 측정함으로써 입사된 양성자의 에너지를 구하였고 이를 인출반경과 RF주파수를 바탕으로 상대론 적으로 계산된 에너지와 비교하였다.

**Key Words :** Proton beam, Cyclotron, Energy measurement

## INTRODUCTION

Recently spread of PET(positron emission tomography) makes use of short lived radioisotopes become lager than before. Most of PET's are equipped the baby cyclotron for the production of short lived radioisotopes. When the radioisotopes are produced from the cyclotron, yield of radioisotope is depend on value of proton beam energy. Cyclotron beam energy is changed by radio frequency, magnetic field intensity, and beam extraction radius. In the case of baby cyclotron, most of them are fixed energy type which means fixed radio frequency, and fixed size of resonator. Magnetic field intensity can be changed by fluctuation of power supply and temperature of cooling water for the magnet coil. Moreover beam extraction radius can be changed by electrical and mechanical parameters. Most of cyclotrons are needed to get the calibration of beam energy[1, 2].

Cyclotrons have lots of merits compared with other types of accelerators such as the high beam intensity and duty cycle. But the beam energy can not be determined from the cyclotron parameters sufficiently accurate for the above mentioned applications, mainly because of the uncertainty in the determination of the actual extraction radius. The external beams of KCCH AVF cyclotron are obtained using a positionable electrostatic deflector. Positioning is carried out by setting 2 potentiometers, allowing the actual deflection radius 570±10 mm. A calibration of extraction radius as a function of the 2 potentiometer-settings was carried out, allowing a theoretic calculation of the actual beam energy Eb from the formula:

$$E_b = E_0\left(\frac{1}{\sqrt{1-\frac{\Omega^2 R^2}{c^2}}}-1\right) \qquad (1)$$

where R is the extraction radius, $\Omega$ the pulsation of the cyclic particle movement in the accelerator and Eo the restmass of the accelerated particle. .

Many methods have been developed to measure the energy of charged particle beam and are in use in many laboratories[3-6]. They can be divided into two basic types such as calibrating and monitoring methods. For calibration techniques the beam must be transported to special experiment apparatus and it cannot be used for other experiments during this measurement. Beside nuclear resonance and neutron threshold reaction various kinetic methods are usually used for energy calibration of accelerators. The former ones have superior precision (the error value is lower than 10-4), but the calibration is restricted only to some particular energy values. Kinematic methods are free from this limitation and they gain increasing use at low and medium energy cyclotron[4].

The monitoring methods do not have the restriction mentioned above since the beam can be used for the experiment during the energy determination. Analyzing magnets and time-of-flight(TOF) techniques belong here[5]. The first system requires bulky and expensive magnets and NMR-stabilized highpower supply units[6]. It has to be originally planned into the transport system layout, because later the installation is practically impossible. The accuracy of a magnetic system is quite good, but the building site for most low and medium energy cyclotrons do not have enough room for such magnets.

Many applications such as the collection of atomic and nuclear data, the production of fast neutrons or purity tests with activation analysis require a precise information of the energy of the charged particle beam extracted from the accelerator. At the KCCH AVF cyclotron facility a multi-energy, multi-particle ronous sector focused cyclotron is used for neutron irradiation of cancer patients and radioisotopes production[7].

Motivated by results on the linear response of the range with incident ion energy for carbon in present ange we performed energy measurement of proton beams produced on the KCCH AVF cyclotron at Korea Cancer Center Hospital, Korea Atomic Energy Research Institute.

The purpose of the present experiment is twofold: First, the machine, mainly used for neutron irradiation and radioisotope production, is needed the permanent instruments for energy measurement of extracted beams. Second, the development of energy calibration for PET's cyclotron is needed for analysis of cyclotron characteristics.

## MATERIAL AND METHODS

### 1. Material

The experiment was performed using different proton beams from MC 50 cyclotron at KCCH, KAERI. We extracted 4 different nominal energies, 35 MeV, 40 MeV, 45 MeV, and 50 MeV. The target of the 6.3 mm thick carbon plate with

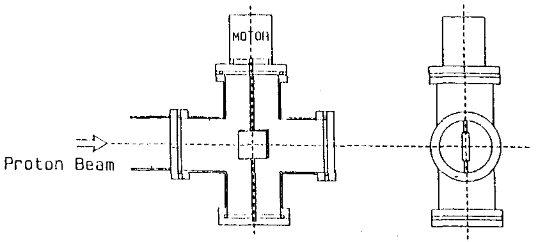

**Fig. 1.** The structure of target chamber.

1.172 g/cm$^3$ was placed in the center of vacuum chamber shown in Fig. 1. Target was turned by stepping motor which was 0.9 degree/step. Stepping motor was driven by pulse generator whose frequency was 40Hz and voltage was 12 V and driving amplifier.

## 2. Methods

### 1) Stopping Power

The linear stopping power S for charged particles in a given absorber is simply defined as the differential energy loss for that particle within the material divided by the corresponding differential path length;

$$S = -\frac{dE}{dx} \qquad (2)$$

The value of -dE/dx along a particle track is also called its specific energy loss or its rate of energy loss.

For particles with given charge state, S increases as the particle velocity is decreased. The specific energy loss is known as the Bethe formula and is written;

$$\frac{dE}{dx} = \left(\frac{e^2}{4\pi\varepsilon_0}\right)^2 \frac{4\pi z^2 N_0 Z\rho}{m_e c^2 \beta^2 A}\left[\ln\left(\frac{2m_e c^2\beta^2}{I}\right) - \ln(1-\beta^2) - \beta^2\right] \qquad (3)$$

where z and Z are the charges of incident ion and target nuclei, A is mass of target nuclei, ρ is the density of target nuclei, No is the Avogadro number and I is the ionization energy.

### 2) Ranges of Charged Particles

The range of a charged particle of incident energy Ei in a material in which its rate of energy loss is dE/dx is given by

$$R(E_i) = \int_0^{E_i} \frac{dE}{\left(\frac{dE}{dx}\right)} \qquad (4)$$

If dE/dx is known for 0 ≤ E ≤ Ei, then the range can easily be calculated. Unfortunately, stopping cross sections have not been measured for very low energies nor can they be calculated with reliability at present. Therefore, computed range-energy relations are subject to considerable uncertainty at low energies. On the other hand, range differences from, say, 1 MeV to Ei can be calculated with confidence. The following curves such range differences are

$$R_{diff}(E_i) = \int_{1\,MeV}^{E_i} \frac{dE}{(dE/dx)} \qquad (5)$$

The total range is given by Rdiff(Ei) + R(1 MeV).

## RESULTS

The incident proton energies of each nominal energies were obtained from measured ranges. We did not know the perpendicular angle for incident beam direction, but the derivatives of measured beam current with rotation angles give the two times of angle corresponding for range.

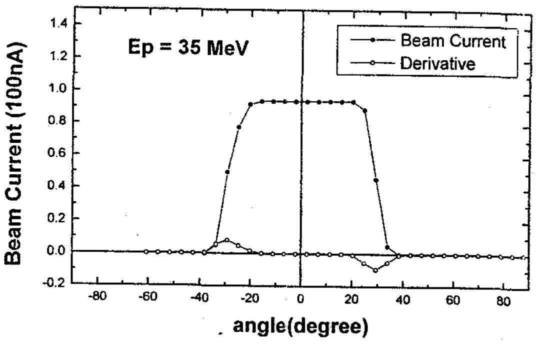

Fig. 2. Excitation curve at Ep=35 MeV.

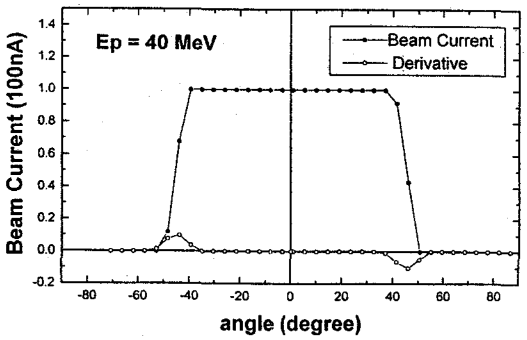

Fig. 3. Excitation curve at Ep=40 MeV.

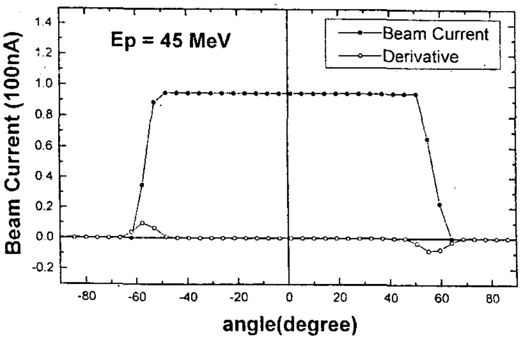

Fig. 4. Excitation curve at Ep=45 MeV.

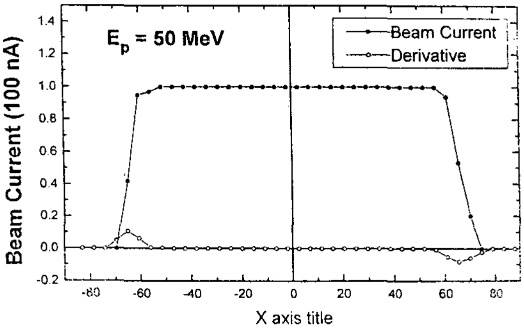

Fig. 5. Excitation curve at Ep=50 MeV.

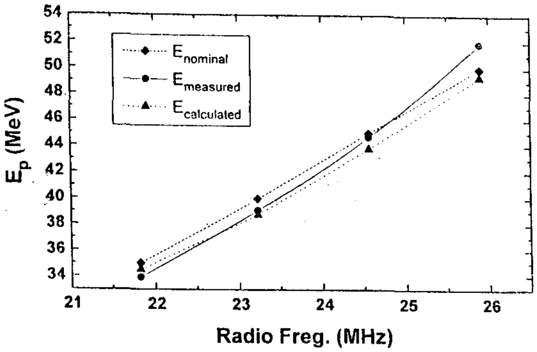

Fig. 6. Comparison of energies of measured, nominal and calculated.

Fig. 2. to Fig. 5. show the measured beam current curves and derivatives with rotation of target at each nominal incident energies.

Table 1. The Calculated Energies for Each Nominal Energies

| Enom(Mev) | Extraction·radius(mm) | Ecal(Mev) |
|---|---|---|
| 35.0 | 577.4 | 34.48 |
| 40.0 | 573.0 | 38.73 |
| 45.0 | 574.0 | 43.78 |
| 50.0 | 575.7 | 79.35 |

Table 2. The Measured Energies for Each Nominal Energies

| Enom(Mev) | Range(mm) | Emeasured(Mev) |
|---|---|---|
| 35.0 | 7.199 | 33.9 |
| 40.0 | 9.248 | 39.1 |
| 45.0 | 11.641 | 44.7 |
| 50.0 | 15.184 | 51.9 |

## DISCUSSION

Such derivatives of beam currents show clearly the critical angles for ranges of the each incident proton energies, and the errors to determined the critical peak position is less than 1%. The measured range is calculated by:

$$Range = \frac{Target\ \ Thickness}{\cos(\theta_{range})} \qquad (6)$$

Using the range, we can determine the incident proton energy with assumption that the the range for incident proton energy is known accurately. In proton energy of 20 MeV to 50 MeV the relation of between the ion incident energy and range is:

$$E_p(MeV) = 12.524 + 3.317R\,(mm) - 0.0477R^2\,(mm) \qquad (7)$$

To obtain the above relation we used the table of C.Willamson and J.Boujot[7], which gives the ranges with errors less than 1% in our energy region.

Table 1. shows the calculated energies by eq.(1) with the extraction radii measured for each nominal energies that informed by manufacturer with radio frequencies. Table 2. shows the energy determined by range measurement of present study.

The energy differences between measured and calculated are taken less than 1 MeV.

Even if we measured just about proton beam energy with this method, other light particles can be applied for energy measurement[8].

## CONCLUSION

We have measured the incident proton beam between 35 MeV to 50 MeV with 5 MeV step. Using the relativistic relation of energy and momentum, eq.(1), the extract proton beam energy calculated with measured extraction radius, and using property that the length of full energy loss of the incidentcharged particles in material is abrupt at the value as defined range, we have determined the incident proton beam energy within 1% error.

The comparison of energies for nominal and calculated by eq.(1) and measured by range shows that the energy determined by range measurement shows consistent within 1 MeV with other methods (Fig. 6).

We also obtained the relation for the incident proton beam energy and the radio frequency of KCCH AVF cyclroton, and when we seek to find new proton beam energy, this result may give the preliminary information about radio frequency for unknown proton beam energy.

From this method baby cyclotrons for PET can be applied for the energy calibration before production of PET's radioisotopes. They can use the cyclotron energy calibration not only proton but also deuteron, alpha, He-3, and other light particles with this method and apparatus.

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