DESIGN AND INITIAL TESTS OF A GAS SCATTERING ENERGY* MONITOR IN THE PEFP RFQ AND DTL

S.H. Han#, Y.S. Cho, PEFP, KAERI, Daejon, 305-600, Korea

Abstract

We have developed a gas scattering energy monitor to measure the energy spectrum of the proton beam from 3 MeV to 20 MeV at the four-vane PEFP (Proton Engineering Frontier Project) RFQ and the DTL tank exit as a function of RF drive power. The energy monitor is comprised of a Xe scattering chamber, two collimators to reduce the beam intensity, and a surface barrier detector for measuring the proton energy. In order to measure the beam current simultaneously, a faraday cup is incorporated into the energy monitor. The calculated flux attenuation through the 0.2 mm diameter collimator is 2.7 x 10^{-3} and the energy loss is 72 keV. We report on design details and multiple gas scattering of proton beams in Xe gas by using a SRIM code.

INTRODUCTION

The PEFP is aiming to produce 20-mA peak beam current at the 100-MeV energy (Table 1). At present a 20 MeV drift tube linac (DTL) is being constructed and will be tested at KAERI in Korea. One of the most important measurements for the beam commissioning is the proton beam energy and its distribution. For most of the linac, the main method for beam energy measurement is to be a time of flight (TOF) measuring the beam velocity. The BPPM (Beam Position and Phase Monitor) is already fabricated for the PEFP beam commissioning. The typical energy measurement accuracy of the TOF is around 1 %, depending on the delay phase measurement accuracy. In order to improve the energy measurement accuracy and measure the energy distribution, a new energy monitor using gas scattering has been designed. This energy monitor can operate even in the case that the beam current is so low that the BPPM could not work. In this paper we describe the gas scattering calculation and preliminary test results of the gas scattering energy monitor.

Table 1: PEFP DTL parameters

Parameters	Values
Operating frequency	350 MHz
Particles	Proton
Beam Energy	100 MeV
Max. Peak beam current	20 mA
Repetition Rate	15 Hz
Max. Beam Duty	24 %

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shhan@kaeri.re.kr

DESIGN AND EXPERIMENTAL CONFIGURATION

The Si surface barrier detector (Ortec, CL-035-025-5, 5-mm-thick active depth) for beam energy measurement only works well with very small particle fluxes such that the probability of two particles arriving within the resolution time of the detector is low (see Fig. 1). The actual time resolution doesn't depend on detector (charge collection time of less than 1µs for up to ~ mm depletion depth), but on the associated electronics such as amplifier, multi-channel analyzer (MCA). The reasonable time resolution is expected to be around 10 µs and so, the proton rate is needed to reduce to ~10^4 per second. In the case of 10 µA beam, the beam current must be attenuated to less than 10^{-9} of its original flux.

The operating principle of the gas scattering energy monitor is to use gas scattering and collimator. The energy monitor is comprised of gas scattering chamber, collimator, and surface barrier detector (see Fig. 2). Beam going through the first collimator is spread out by multiple Coulomb scattering with scatter gas and is attenuated through the second collimator [1,2]. The reduced beam flux allows the silicon surface barrier detector to be utilized. A gas of high atomic number such as Xe is to be used to increase the scattering angle.

Because the accelerated beam from DTL blows up, the flux of particle in the beam will be reduced through the front collimator and gas scattering system even with no gas. The attenuation factor should be estimated by simulating the drift effect and is assumed to be ~10^{-5} in our calculation. The gas scattering energy monitor is therefore required to give an additional attenuation of ~10^{-3}.

Figure 1: Photograph of the surface barrier detector installed in the gas scattering chamber.

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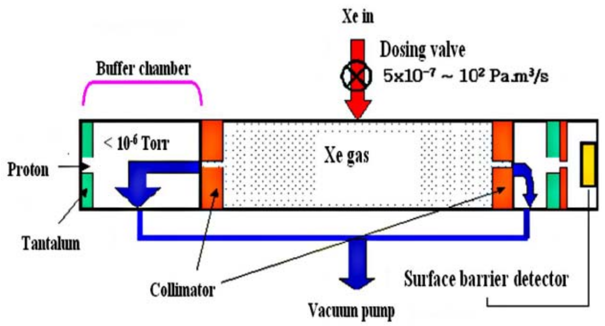

Figure 2: Structure of gas scattering monitor with a detector, two collimators, and a Xe gas chamber.

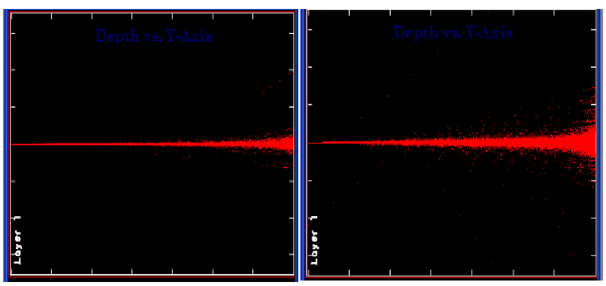

Figure 3: Gas scattering calculation by SRIM code: left for 10 Torr Xe, and right for100 Torr Xe.

A SRIM code was used to evaluate the multiple scattering distributions of 20 MeV proton beams in 0.7 m thick, 10 and 100 Torr Xe gas (see Fig. 3). Since the rms multiple scattering varies approximately as $Z^{1/2}$, a gas of high atomic number such as Xe should be chosen. The calculated flux attenuation through the 0.2 mm dia. collimator is 2.7 x 10^{-3} and the energy loss is 72 keV for 10 Torr Xe. The calculated rms energy distribution at 20 MeV DTL is ±37.5 keV, which is comparable to the energy resolution of the Si detector (30 keV).

Fig. 4 shows a constructed gas scattering energy monitor. The gas scatter is a Xe gas chamber in the form of a 0.7 m long beam pipe closed off at both ends by diaphragm (or collimator) with a 0.2 mm dia. aperture at its center. In order to measure the beam current simultaneously, a faraday cup is installed in front of the Xe gas chamber. The faraday cup has a 0.6 mm dia. aperture at its center for beam transmission into the Xe gas chamber.

The calculated conductance of the collimator with a 0.2 mm dia. and 2 mm thickness is 2.01 x 10^{-7} m^3/s and the throughput of the gas cell is 5.32 x 10^{-5} Pa • m^3/s, being within a range of the dosing valve (Leybold EV016 DOS AB). With the pumping speed of 0.4 m^3/s in the buffer cell, we assure that the buffer cell can maintain the pressure of below 10^{-6} Torr.

PRELIMINARY TESTS

Signals from the detector pass through an EG&G Ortec 142AH preamplifier and then into a Ortec 572 spectroscopy amplifier with 2 μs shaping time as shown

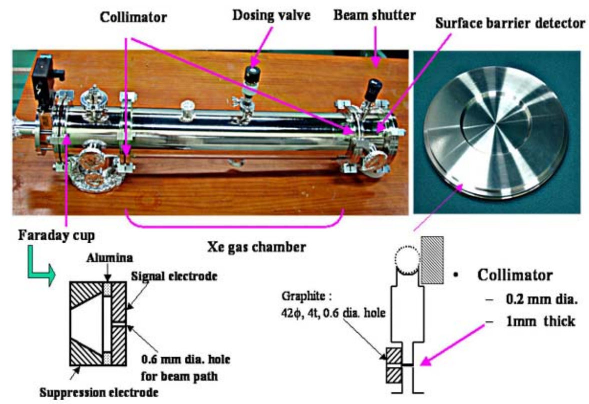

Figure 4: Photograph of gas scattering energy monitor with a faraday cup.

in Fig. 5 and 6). The bipolar signal from the amplifier is passed into Ortec Trump-PCI MCA card to analyze the energy spectra. In order to perform the energy calibration for the surface detector, a linear calibration method using two points was used. The channel calibration of the signal processing electronics was performed by injecting a pulse of known amplitude into the pre-amplifier via a 10 μF capacitor (or electrical charge Q = C x V) and by calibrating the multi-channel analyzer (linear fitting of the electrical charge to channel).

The next step for energy calibration is to find the known energy peak of a charged particle from the pulse height spectrum using the surface barrier detector. Fig. 7 shows a pulse height spectrum for the 5.486 MeV ^{241}Am α source recorded through a tantalum collimator (2 mm dia., 4 mm thick) at a bias voltage of 1000 V with the chamber pressure of 4 x 10^{-3} Torr. The energy resolution of the surface barrier detector is better than 0.5 %, which is reasonably good compared to that for the typical TOF. The average energy necessary to create an electron-hole pair in the Si surface barrier detector is 3.62 eV at room temperature and is independent of the type and the energy of the ionizing radiation. The total charge produced by a 5.486 MeV ^{241}Am α particle in the detector is : ((5.486 x 10^6 eV) / 3.62 eV) x (1.60 x 10^{-19} C) = 2.425 x 10^{-13} C. The channel corresponding to the 5.486 MeV ^{241}Am α particle in the former linear fitting and the latter pulse height spectrum was 432 and 429, respectively.

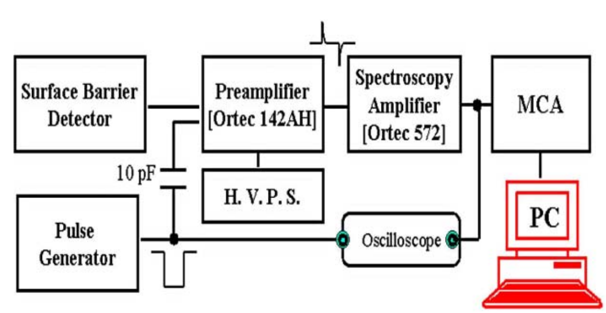

Figure 5: Schematic diagram of signal processing for energy measurement and energy calibration.

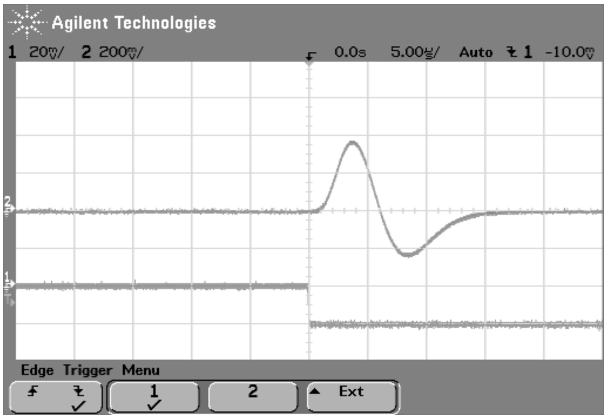

Figure 6: Input pulse and output signals from the pulse generator and the spectroscopy amplifier.

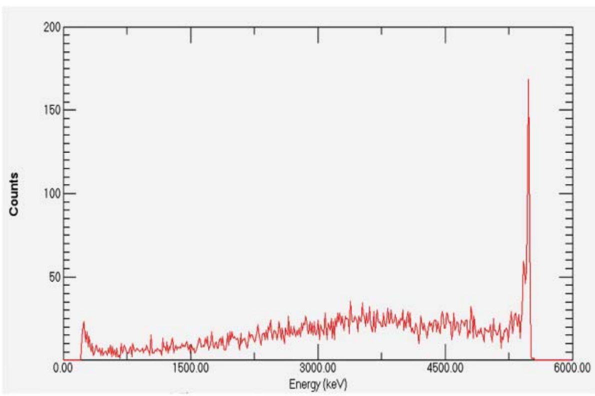

Figure 7: Energy spectrum of ^{241}Am α particle using a 5-mm-thick Si surface barrier detector. A typical detected flux corresponds to 2.23 mm^{-2}s^{-1} and the 5.486 MeV main peak is visible.

The energy corresponding to the zero channel in the corrected linear fitting curve was 94 keV. The final step for the energy calibration was completed by marking the two channels (0 CH and 429 CH) and supplying the energies (94 keV and 5486 keV) for these channels.

CONCLUSIONS

The gas scattering energy monitor has been designed and tested to measure the proton energy at the exit of the PEFP DTL. The flux attenuation of 20 MeV proton beam through the 0.2 mm dia. collimator is estimated to be 2.7 x 10^{-3} and the energy loss is 72 keV with 10 Torr Xe. We have performed the energy calibration of the Si surface barrier detector and measure the energy spectrum of ^{241}Am α particle. The measured energy resolution of the surface barrier detector is better than 0.5 %, which shows the possibility that the gas scattering energy monitor is to be used to measure the energy distribution of the DTL beam for different RF power settings.

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[3] EG&G Ortec®; now part of the Ametek® Group: http://www.ortec-online.com/

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