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Original Article

Design Study for Pulsed Proton Beam Generation

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ABSTRACT

Fast neutrons with a broad energy spectrum, with which it is possible to evaluate nuclear data for various research fields such as medical applications and the development of fusion reactors, can be generated by irradiating proton beams on target materials such as beryllium. To generate short-pulse proton beam, we adopted a deflector and slit system. In a simple deflector with slit system, most of the proton beam is blocked by the slit, especially when the beam pulse width is short. Therefore, the available beam current is very low, which results in low neutron flux. In this study, we proposed beam modulation using a buncher cavity to increase the available beam current. The ideal field pattern for the buncher cavity is sawtooth. To make the field pattern similar to a sawtooth waveform, a multiharmonic buncher was adopted. The design process for the multiharmonic buncher includes a beam dynamics calculation and three-dimensional electromagnetic simulation. In addition to the system design for pulsed proton generation, a test bench with a microwave ion source is under preparation to test the performance of the system. The design study results concerning the pulsed proton beam generation and the test bench preparation with some preliminary test results are presented in this paper.

1. Introduction

Recently, the importance of nuclear data related to fast neutrons has been increasing because fast neutrons are essential to evaluate nuclear data in various research fields, such as medical applications and the development of fusion reactors. Fast neutrons with a broad energy spectrum can be generated using proton beams with a target made of

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beryllium. To measure the energy of the neutrons generated through the proton bombardment of a target using a time-of-flight method, the proton beam should be pulsed to have a certain time structure. A short-pulse width is preferred for the proton beam because the neutron energy uncertainty is proportional to the pulse width. In addition, the pulse repetition rate should be low enough to extend the lower limit of the available neutron energy. Therefore, to generate a short-pulse proton beam with a reasonable repetition rate, neutron-based nuclear data acquisition is essential [1].

One method of short-pulse proton beam generation is to use a chopper with a deflector and a slit. In a simple deflector with slit system, most of the proton beam is blocked by the slit, which results in very low available beam current and low neutron flux, especially when the beam pulse width is short. To increase the available proton beam current, we adopted beam current modulation using a buncher cavity, which is operated at radiofrequency.

To maximize the modulation efficiency in the buncher cavity, the electric field pattern along the beam path in the buncher cavity should have a sawtooth waveform [2]. We adopted a multiharmonic buncher with resonance frequencies up to the third harmonic to make the field pattern similar to the sawtooth waveform. The design process of the multiharmonic buncher includes a beam dynamics calculation and three-dimensional electromagnetic simulation.

In this paper, we discuss the design features of the proton beam chopper based on an electrostatic deflector with a slit and a multiharmonic buncher system. The schematics of the chopper system are shown in Fig. 1. In addition to the system design for pulsed proton generation, a test bench with a microwave ion source for the experimental verification of the designed system is described with some preliminary test results including proton beam extraction.

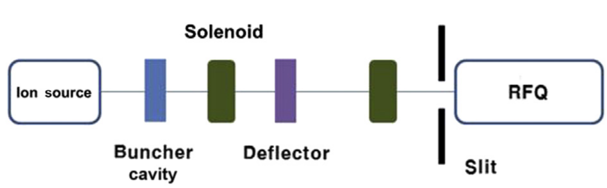

Fig. 1 – Schematic layout of a pulse proton beam generation system. A deflector is located between two solenoids and a slit is located in front of the radiofrequency quadrupole (RFQ). A buncher cavity is placed after the ion source and the distance between the buncher and the slit is determined to maximize modulation of the beam current at the slit position.

2. Design of the pulsed proton beam generator

2.1. *Electrostatic deflector and slit*

The electrostatic deflector is composed of two parallel plates with a high-voltage bias from a pulsed high-voltage system [3]. The beam is deflected by the electric field formed by the biased plates and chopped using a slit. The design parameters of the deflector and slit system depend on various factors such as (1) deflector size, (2) deflector voltage, (3) high-voltage switching speed, (4) proton beam energy, (5) slit width, (6) distance between deflector and slit, and (7) proton beam pulse width.

The beam deflection angle is proportional to the deflector voltage and is reduced at higher proton beam energy. The deflection angle dependency on the deflector voltage is shown in Fig. 2. The important design parameter of the slit is slit width, which can be determined by the required proton beam pulse width and high-voltage pulse rising time. The slit width as a function of the pulse rising time is shown in Fig. 3 at various desired pulse widths. As can be seen in Fig. 3, a wide slit can be used with a fast rising deflector voltage at a given proton pulse width.

The beam dynamics calculation with a deflector and a slit was performed using the PARTICLE STUDIO code and the Phase and radial motion in ion linear accelerators (Parmila) code. The Parmila computer code was developed in the 1960s to study drift tube linac structures and it has been widely used in the accelerator community. This popular code has benefited from years of use and improvements. It has been the basis of many successful linac designs and has been

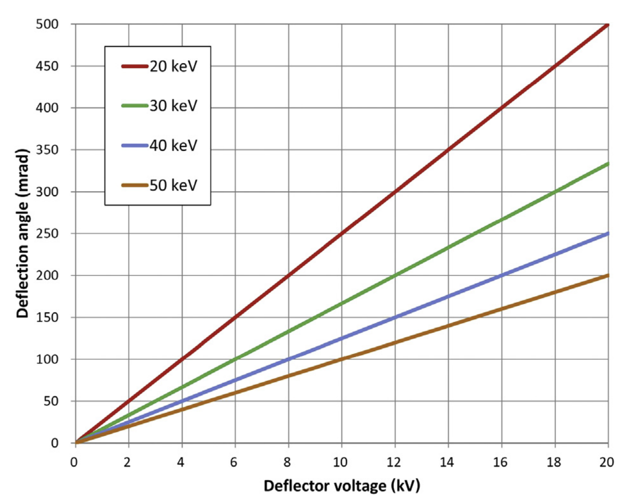

Fig. 2 – Deflection angle dependency on the deflector voltage with various proton beam energies. For a given deflector voltage, the deflection angle is inversely proportional to the proton beam energy.