A RIDGE FILTER FOR 36 MEV PROTON BEAM APPLIED TO BT AND ST*

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Abstract

We designed a ridge filter to offer a uniform depth-dose distribution as well as to deliver high linear energy transfer along the depth of a target for 36 MeV proton beam. The designed ridge filter has a continuous cross-sectional line shape of ridges so that the smooth depth-dose distribution can be maintained near the distal falloff for lower proton energy than 36 MeV. The uniform dose distribution in sample-depth is formed from the sample surface to the range of 36 MeV proton in the sample. Aluminium was chosen as the material to reduce the radioactivity induced by proton irradiation. The dose distributions were simulated by a Monte Carlo simulation code, MCNPX with version 2.5.0. The ridge filter was fabricated and its performance was tested on a proton beam delivery system.

INTRODUCTION

In general, fast charged particles, such as proton or ions, slow down gently as they pass through a medium and finally stop after they deliver the remaining kinetic energy to the medium. This property is characterized by a Bragg curve composed of two regimes. One is the linear energy transfer (LET) regime with a gradual variation, and the other is a Bragg peak with a high LET [1-3]. The energetic ion beams have utilized for their gradually varying LET region to produce various new mutants and to develop new profitable flowers and vegetables [4-7]. For similar applications of proton beams with lower LETs, we recommend using the Bragg peak for every sample depth to minimize the effects of LET difference between proton and ion beams. Therefore, the high LET around the Bragg peak should be distributed through a biological target by modulating the proton energy sequentially.

For the modulation of proton energy, two kinds of range modulators are usually used. One is a range modulating propeller with time-dependent dose distribution, and the other is a ridge filter with time-independent dose distribution [8-10]. So, the former should be used for CW beams but the later has no limitation. In this study we designed a large ridge filter with continuous cross-sectional line shape of ridges, and tested its performances.

DESIGN OF A RIDGE FILTER

In the design of a ridge filter to induce multiple scattering of proton beams on it and their mixing on an irradiation sample, a few materials such as carbon, PMMA, aluminium and copper were considered. Among them, aluminium was chosen since it could reduce the radioactivity induced by proton irradiation. The purity of aluminium is required above 99.8%.

To design a ridge filter, two kinds of Monte Carlo simulation codes were used, i.e., SRIM and MCNPX [11-13]. SRIM is effective to calculate the deposited energy along target-depth. According to the comparison between calculation results by SRIM and MCNPX, both Bragg curves in water matched well on the beam axis. SRIM saves the simulation time to find a set of beam weights, which gives us uniform depth-dose distribution from the surface to the range of 36 MeV proton in the irradiation sample. The minimum thickness of the ridge filter should be determined so that the penetrated protons are mixed completely on the sample. Therefore, the thickness depends on a ridge period and a drift distance between the ridge filter and the sample. We determined the minimum thickness of 0.3 mm. Then, the ridge period and the drift distance correspond to 6 mm and 35 cm more or less, respectively. The determined beam weights for each thickness of ridge filter is shown in Fig. 1.

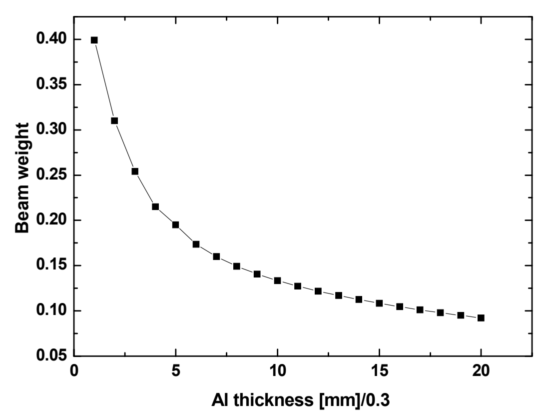

Figure 1: Beam weights determined by SRIM.

However, SRIM cannot simulate the multiple scattering of proton in the ridge filter and its energy deposition on the sample volume. So we adopted MCNPX with version 2.5.0 as 3-D Monte Carlo simulation code. Using MCNPX and starting a set of beam weights determined by SRIM, we found the optimized cross sectional line shape of the ridge and the depth-dose distributions. The optimized cross sectional line shape is shown in Fig. 2, and the depth-dose distributions at various positions on the surface of water-equivalent sample are shown in Fig. 3. The dose distributions are maintained uniformly along the depth, and the dose level drops apart from the center of incident beam since the beam shape is Gaussian.

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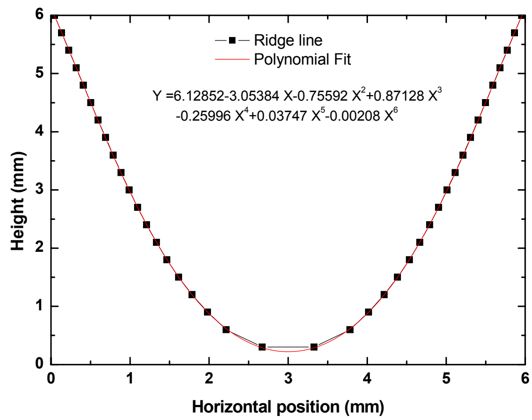

Figure 2: Optimized ridge shape.

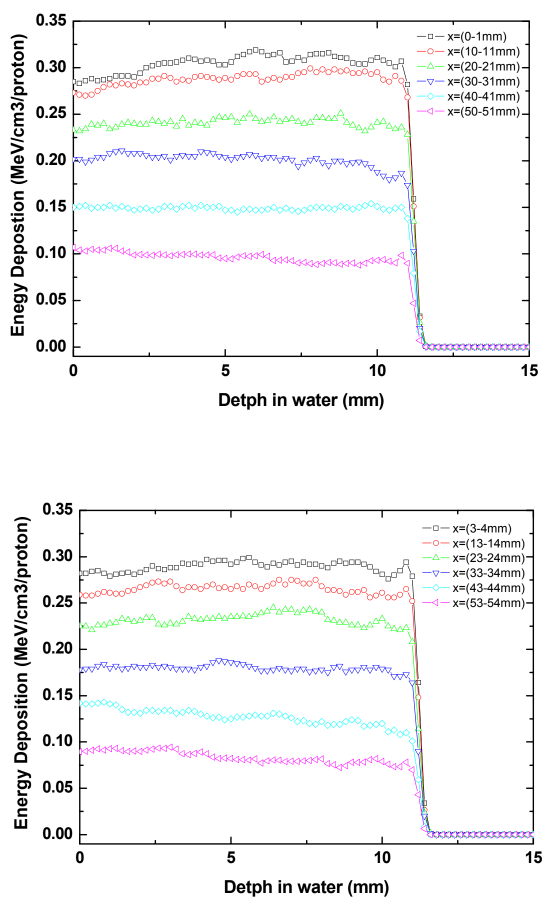

Figure 3: Depth-dose distributions simulated by MCNPX for the optimized ridge shape.

From the determined parameters and ridge shape a bar ridge filter was fabricated. It is able to accept a beam with small beam loss less than 1% on the edge. The diameter of the ridge filter is as large as 4σ of Gaussian beam. Fig. 4 shows the fabricated ridge filter.

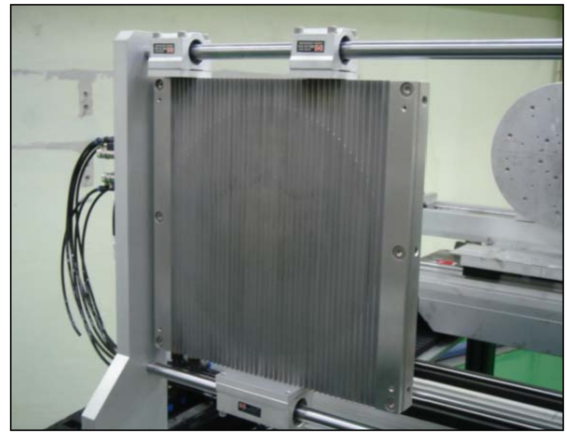

Figure 4: Photograph of the fabricated ridge filter.

EXPERIMENTAL RESULTS

The ridge filter was installed on a proton delivery system to test its performances for a spread-out Bragg peak (SOBP). At first the dependence on drift distance was measured. To measure the dose profile in depth direction, a pair of wedge-shaped PMMA phantom and an ionization chamber are used. Fig. 5 shows the depth-dose distributions for 35 cm, 40 cm, and 45 cm drift distances. We can see the uniformity is worse as the drift region is longer.

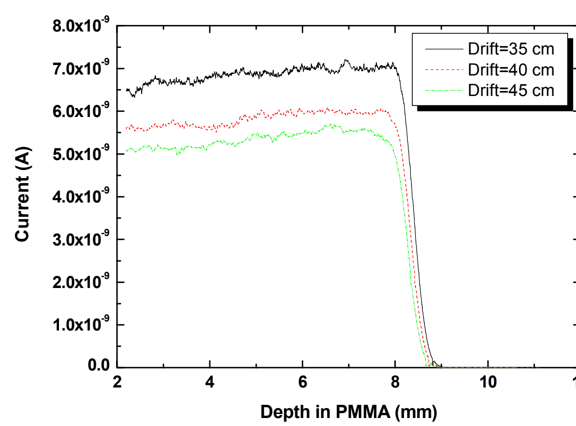

Figure 5: Dependence of depth-dose distribution on the drift distance.

In addition we measured the beam energy dependence of the ridge filter. For the experiment we changed the incident beam energy by using an energy degrading system, making a role of reducing the energy of penetrating beam by changing the thickness of a material on beam path. On the experiment 0 mm-, 1mm-, and 2mm-thick Al sheets were used. The obtained results are shown in Fig. 6.

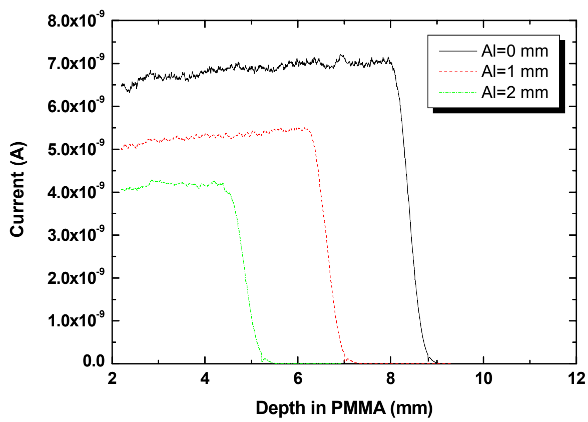

Figure 6: Dependence of depth-dose distribution on the incident beam energy.

SUMMARY

We designed and fabricated a bar ridge filter to form uniform depth-dose distributions, which may be useful for biological technology or space technology to simulate the space environment. The designed ridge filter has a continuous cross-sectional line shape of ridges so that the smooth depth-dose distribution can be maintained near the distal falloff for lower proton energy than 36 MeV. The diameter of the effective area on the ridge filter to form SOBP is 252 mm, which accept large beam from a proton accelerator. The uniform dose distribution in sample-depth is formed from the sample surface to the range of 36 MeV proton in the sample.

The uniformity of dose distribution depends on the drift distance between the ridge filter and the sample. The change of the incident beam energy has little effects on the uniformity of SOBP without the reduction of SOBP width. This means that the ridge shape is well designed for lower beam energies.

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