DESIGN STUDY OF A LINEAR ACCELERATOR SYSTEM FOR NEUTRON CAPTURE THERAPY

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Abstract

A proton linear accelerator has been conceived to be used for Boron Neutron Capture Therapy (BNCT) and Neutron Radiography (NR) at the Korea Cancer Center Hospital in Seoul, Korea. The main accelerator is an RFQ which will accelerate protons from 90 keV to 3.5 MeV with a current of 50 mA in the present design. According to the PARMTEQ calculation, transmission efficiency is over 96 % for that current. Beam dynamics and rf properties of the RFQ have been studied along with beam transport and target systems. At present possibility of obtaining funding appears to be low, but we thought it is worthwhile to carry out the design study for the future proposal.

1 INTRODUCTION

The Korea Cancer Center Hospital (KCCH) in Seoul has used a MC50 cyclotron (Scanditronics) for neutron therapy since 1986 [1]. To extend the hospital's capability for cancer treatment, an accelerator system for BNCT has been proposed. A high current proton beam produces neutrons from the nuclear reactions such as ^{7}Li(p,n)^{7}Be or ^{9}Be(p,n)^{9}B, and then the neutron beam is moderated to epithermal energy (1 eV – 10 keV). The reaction process for treatment is ^{10}B(n,α)^{7}Li utilizing a high capture cross section of ^{10}B for thermal neutrons. The resulting reaction products produce the localized dose on the highly malignant cells [2].

Regarding to accelerators for high current proton acceleration, RFQ and RFD seem promising among others. We first chose to study on RFQ since the average current of near 80 mA has been already achieved by the Chalk River RFQ (to 600 keV) [3].

The proton beam energy needed for BNCT is related to the choice of target. A beam energy of 2.5 MeV along with Li target appears to be the best choice in the aspect of neutronics [4]. And we consider that the use of Be target with a higher beam energy of 3.5 MeV is worthy of pursuing as it allows a simpler target system, which fits better into the hospital environment. We chose the current of 50 mA in the present design, which will produce the epithermal neutron flux of 5×10^9/cm^2/sec with ^{7}Li target at 2.5MeV.

An RFQ to accelerate high current proton beam is highly demanding on diverse applications. As a result, designs of such RFQ accelerators are described by many authors [5] [6]. Our study here aims at obtaining our own design parameters. Besides the RFQ, the beam transport and the target systems have been studied, and some results are given in this report.

Table 1: Parameters of the RFQ

Frequency	352 MHz
Vane voltage	±45 kV
Kilpatric factor	1.7
Injection energy	90 kV
Final energy	3.5 MeV (2.5 MeV)
Length	4.9 m (3.8 m)
Power dissipation	720 kW (540 kW)

2 DESIGN STUDY OF AN RFQ ACCELERATOR

The accelerator system is composed of ion source, RFQ, low-energy and high-energy beam transport lines. A schematic view of the system is shown in Figure 1. The present design energy is 3.5 MeV with an intermediate goal of achieving 2.5 MeV. Design parameters are obtained using the PARMTEQ code [7] for both energies, and listed in Table 1. The cell parameters of the RFQ is shown in Figure 2 as a function of the longitudinal position.

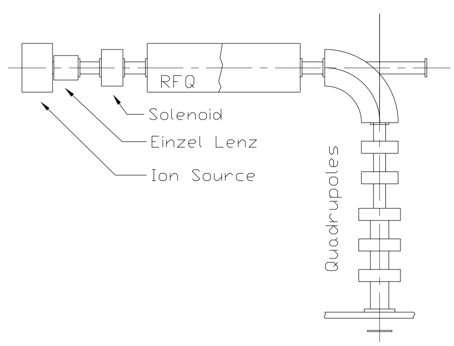

Figure 1: A schematic view of a linear accelerator system for BNCT

The transmission efficiency is over 96 % for 50 mA. The input rms emittance for this calculation is 0.2 π mm·mrad (normalized). When the emittance is 0.3 π mm·mrad, the transmission efficiency reduces by about 4 %. As indicated by other workers, a beam current of 100 mA may be needed for prompt treatments. The power loss and the transmission efficiency are 900 kW and 89 %, respectively for 100 mA. The locations of major particle loss are near the beginning and the end of the gentle buncher. Because of the higher energy damage is more severe near the end of the gentle buncher. A further study is needed to reduce the loss by increasing the transverse focusing possibly with superconducting solenoids.

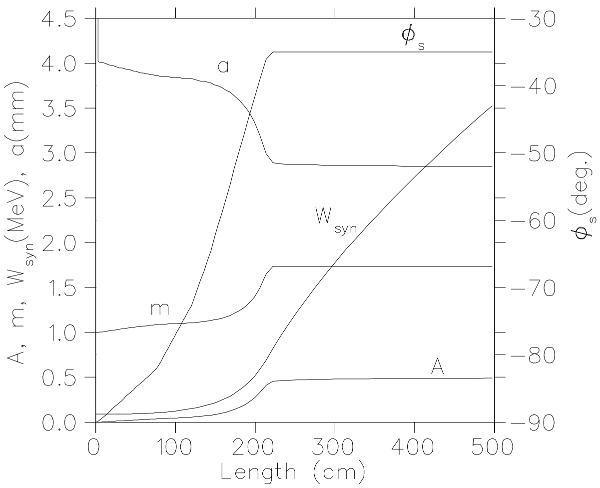

Figure 2: Cell parameters of the RFQ as a function of longitudinal position

The rf properties of the structure were calculated with the computer programs SUPERFISH and MAFIA. The Q value was about 12,000 with SUPERFISH, and 10,000 by MAFIA. The power loss obtained from RFQUICK is similar to that from the MAFIA calculation. A MAFIA model along with TE210 mode is shown in Figure 3.

The RFQ structure will be modular to ease manufacturing difficulties due to its long length. Each module will be roughly 1-2 m long. To improve the tuning stability, resonant coupling between modules [8] was tested with MAFIA. A wider mode separation could be achieved by adjusting the coupling capacitance, but a further investigation is needed. The vane voltage distribution was easily controlled by adjusting the vane undercut.

3 BEAM TRANSPORT LINE

The beam transport line was designed with TRACE3-D [9] which includes the linear space charge effect. The low-energy beam transport consists of an einzel lens and a solenoid, which is thought to reduce the space charge neutralization and to give flexibility in matching. The beam dynamics calculated with TRACE3-D is shown in Figure 4.

In the high-energy beam transport the beam is 90° vertically bent down to comfortably accommodate the target and modulator. Figure 5 shows the beam envelopes of high energy beamline. The radius of beam on target is 5 cm, the power density being 1.6 kW/cm^2 when the beam energy and current are 2.5 MeV and 50 mA. The beam is unidirectional, and its size can be easily controlled with upstream quadrupole triplet.

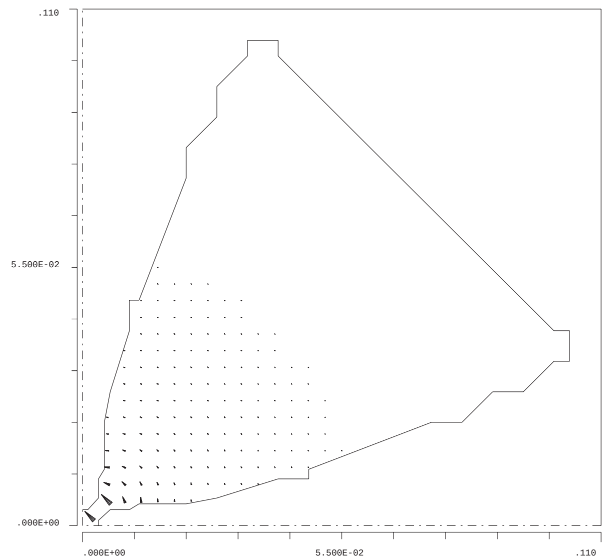

Figure 3: A MAFIA model shown with TE210 mode.

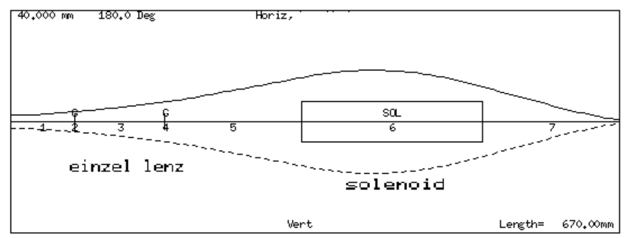

Figure 4: Beam envelopes of the low energy beam transport line.

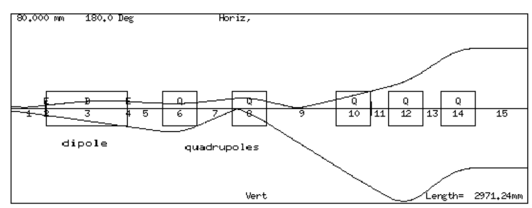

Figure 5: Beam envelopes of the high energy beam transport line.

To reduce the peak power density it seems important to make a uniform distribution of current [10]. Nonlinear elements are needed to change the beam current distribution. At the waists of transverse planes as shown in Figure 5 octupole and duodecapole components could be inserted, minimizing the x-y coupling [11].

4 TARGET DESIGN

The design of target depends on the beam power and the target material. First, pure lithium target with melting temperature of 179 °C can sustain only a low power beam. A preliminary design of the target system is shown in Figure 6. Material of the target frame is aluminum. Assuming that the beam diameter is 10 cm, the power density is 318 W/cm^2 for 10 mA. Finite element calculations with the ANSYS code were carried out for this target with the heat flux of 318 W/cm^2, and the result is shown in Figure 7. The cooling film coefficient used as an input was approximately calculated to be around 2.5 W/cm^2/K with a flow rate of 6 liter/sec, using the Dittus-Boelter empirical correlation for turbulent duct flow [12]. The maximum temperature on the lithium surface is 84 °C when the water temperature is 10 °C, and it becomes 125 °C for the heat flux of 500 W/cm^2. Hence it seems difficult to use over 20 mA of beam current. For higher power beam a rotating target [4] or Li_2O at the cost of lower neutron yield could be used.

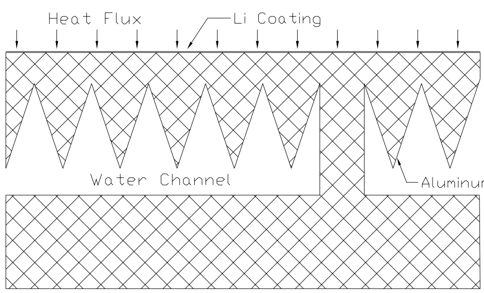

Figure 6: A preliminary design of a Li target.

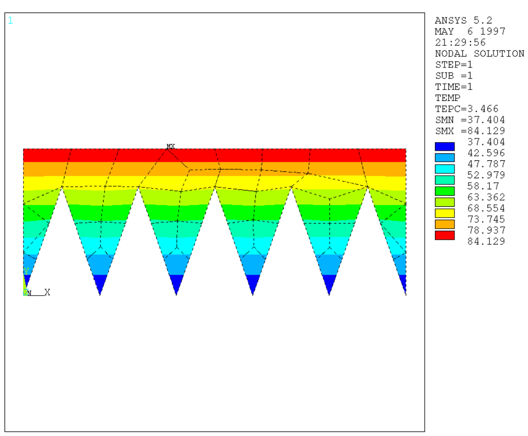

Figure 7: Temperature distribution on the Li target calculated with ANSYS. See text for details.

5 CONCLUSION

Several design aspects of the RFQ accelerator system for BNCT were studied, and we will continue the detailed design for the future proposal. The accelerator and the target designs are core parts of the study. We need to study accelerators other than RFQ's such as RFD and ESQ, and also different structures of RFQ. The target design can be further optimized with finite element programs.

6 ACKNOWLEDGMENTS

The authors would like to thank Dr. G.E. McMichael of Argonne National Laboratory for invaluable information.

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