DESIGN STUDY OF DRIFT TUBE LINAC FOR BNCT ACCELERATOR

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Abstract

A-BNCT accelerator is being developed as a proton accelerator with a high beam current of 50 mA for effective cancer therapy. Drift tube linac (DTL) with the length of 4.8 m is composed of 1 tank and 50 drift tubes (DTs). Proton beam is accelerated from 3 MeV to 10 MeV. Electromagnetic quadrupoles (EMQs) are inserted into every DT for transverse focusing. Slug tuners and post couplers (PCs) are used for accelerating field stabilization and resonant frequency tuning, respectively. The beam dynamics and engineering designs for the DTL are performed for effective beam acceleration, and the design results are in detail presented.

INTRODUCTION

A-BNCT, an accelerator-based BNCT (Boron Neutron Capture Therapy) facility, is under construction. The linear accelerator for the A-BNCT is composed of a 3 MeV Radio Frequency Quadrupole (RFQ) and a 10 MeV Drift Tube Linac (DTL) structure as shown in Fig. 1.

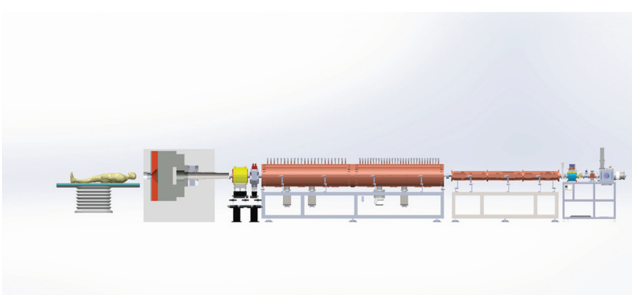

Figure 1: Schematic layout of A-BNCT structure.

DTL is efficient proton linac structure with a pillbox cavity operating at TM_{010} resonant mode in the velocity region of $0.05 \leq \beta \leq 0.5$ [1]. Table 1 shows main specifications for the A-BNCT DTL.

DRIFT TUBE LINAC

In order to get an efficient drift tube linac structure, 2D and 3D electromagnetic and beam dynamics simulations are performed. Detail consideration and results of the DTL design are reported in below.

Table 1: Main Specifications for DTL

Parameters	**Values**	**Unit**
Particle	H^+	
Input energy	3 (β=0.0798)	MeV
Output energy	10 (β=0.145)	MeV
Frequency	352	MHz
Average axial electric field	2.2	MV/m
Synchronous phase	−30	degree
Quadrupole type	EMQ	
Quadrupole magnet lattice	FFDD	
Quadrupole gradient	50	T/m
Quadrupole effective length	0.04	m
Peak beam current	50	mA
Duty cycle	20	%

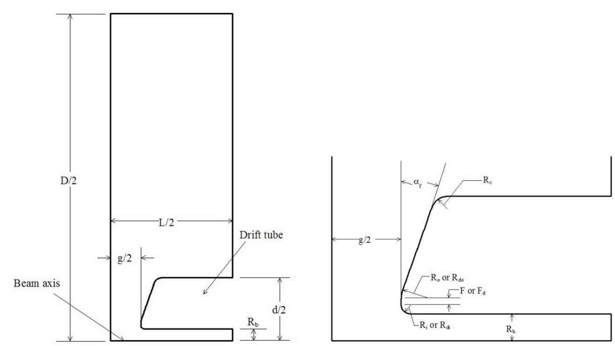

Figure 2: Parameters for one-quarter of DTL cell geometry.

Beam Line Between RFQ and DTL

The space between RFQ and DTL is about 8 cm excepting the flange lengths of RFQ and DTL, which is too short for use of medium energy transport line (MEBT). Thus one electrostatic quadrupole (ESQ) is positioned between RFQ and DTL for efficient use of a space and beam focusing. The effective length and strength is 4 cm and 50 T/m, respectively.

Cavity Geometry

DTLfish of Superfish code sets up and optimizes the parameters for DTL cell geometry [2]. The resonant frequency, magnet installation, voltage breakdown and convenience of structure fabrication are considered to select the geometrical parameters for the A-BNCT DTL. Figure 2 indicates each name of drift tube and tank. Tank diameter is adjusted for the resonant frequency and 0 degree face angle is selected for ease of the drift tube fabrication and insertion of quadrupole

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magnets, which are installed inside the drift tubes for the transverse focusing of the beam. The accelerating field value is 2.2 MV/m and maximum electric field value is less than about 0.7 times Kilpatrick in order to avoid excessive surface electric field on the drift tubes leading to sparking and thermal problems. The decided geometrical parameters for the A-BNCT DTL are listed at Table 2 and Fig. 3 shows the electric field distributions at 3 MeV and 10 MeV.

Table 2: Geometrical Parameters for DTL

Parameters	Values	Unit
Tank diameter (D)	444	mm
Gap length (g)	15.2 - 31.5	mm
Cell length (L)	68.5 - 123.0	mm
Drift tube diameter (d)	130	mm
Bore radius (R_b)	10	mm
Face angle (α_f)	0	degree
Corner radius (R_c)	6	mm
Inner nose radius (R_i)	6	mm
Flat length (F)	0	mm
Outer nose radius (R_o)	6	mm

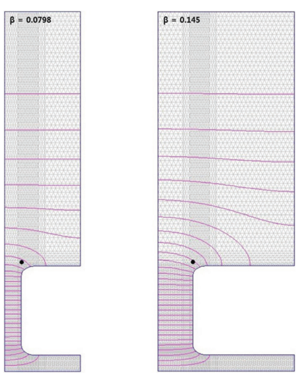

Figure 3: Electric field distributions at β=0.0798 (left) and β=0.145 (right).

Beam Dynamics

DTLfish assumes a symmetric cell to generate data including particle velocity β, the cavity time transit factor T, T′ etc. Parmila code generates asymmetrical drift tube cells using the result data and simulates the particle tracking. The aims of the beam dynamics are to achieve good transmission of the beam and low emittance growth. The simulation results using Parmila code are represented at Figs. 4 and 5. Fig. 4 shows the phase space plots for input and output beams. Fig. 5 shows the transvese and longitudinal 100 % beam envelopes along cells of the DTL. The transverse and longitudinal emittance growth is reduced by electrostatic quadrupoles positioned inside drift tubes and by change of synchronous phase in the early part of the DTL, respectively.

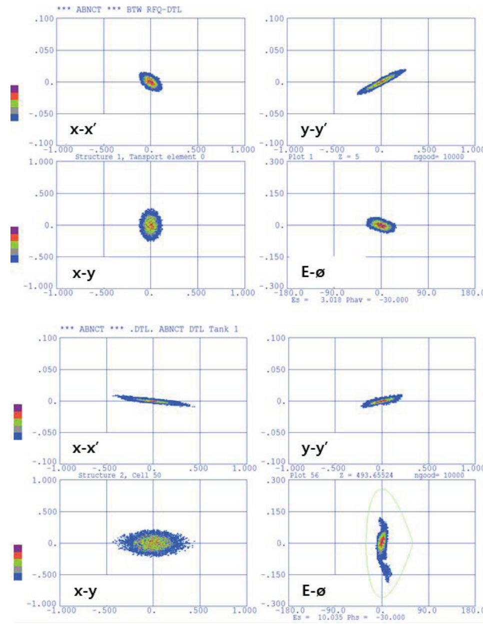

Figure 4: Phase space plots for input (top) and output (bottom) beam.

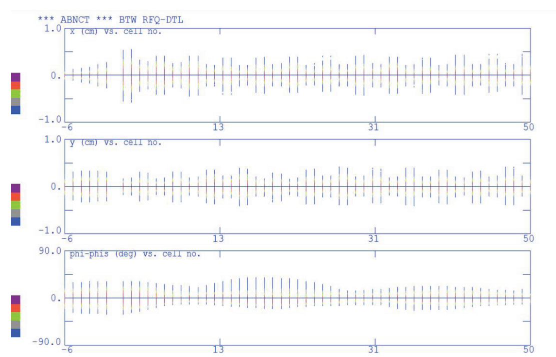

Figure 5: Transverse and longitudinal beam envelopes along cells of DTL.

3D Electromagnetic Modeling

To overcome the difference between the symmetry and asymmetry structure or 2D and 3D design of the DTL, the electromagnetic simulation of 3D asymmetry modeling is performed [3]. Stems on the top, post couplers on the side and slug tuners on the bottom of drift tubes break the symmetry feature and the entire DTL structure is represented at Fig. 6.

The flat field distribution along the cavity axis is a requirement of 3D electromagnetic simulation. Figs. 7 shows the normalized E_0 field profiles before and after field tuning using the first and last cell length changes. The maximum deviation of the field value is reduced from 123 % to 6.8 %.

The purpose of slug tuners is to adjust the resonant frequency. The volume of the DTL tank according to the tuner depth is changed and the resonant frequency at operating mode is varied. Fig. 8 shows the results of the frequency variation according to insertion depth of the tuner at five drift

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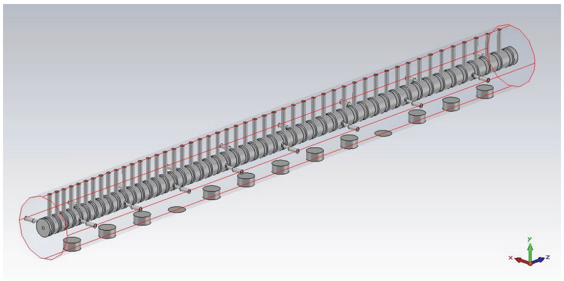

Figure 6: 3D plot including slug tuners, post couplers and vacuum ports.

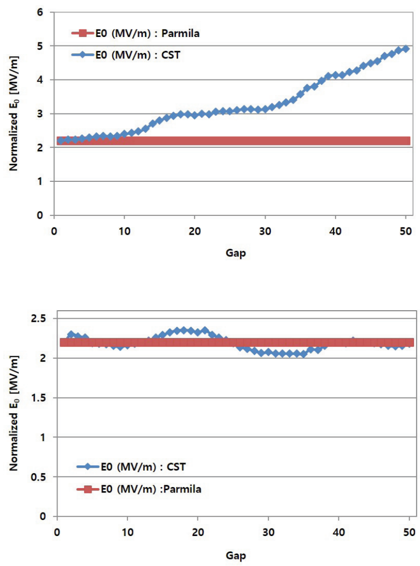

Figure 7: Normalized E_0 field profiles before (top) and after (bottom) field tuning.

tube cells. The tuner depth affects the electric field more than magnetic field, so the resonant frequency is increased linearly and is decreased at specific point.

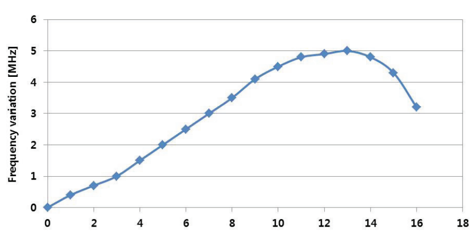

Figure 8: Frequency variation for the tuner depth with 60 mm radius.

Post couplers are inserted into the tank for stable mode operating as the post coupler mode offsets the π mode. Post couplers has rotating and movable design, and the field stabilization simulation is performed.

Tracking Simulation

The multi-particle tracking simulation is performed using the tuned electric fields and beam distributions, which is obtained at the end of the RFQ. Transmission efficiency is 100 % and the energy increases form 3 MeV to 10 MeV. Figs. 9 and 10 show the 100 % transverse and longitudinal envelopes and beam emittance growths, respectively. The transverse (red(x-x′), blue(y-y′)) and longitudinal (green(z-z′)) beam emittance increase about 24 % and 61 %.

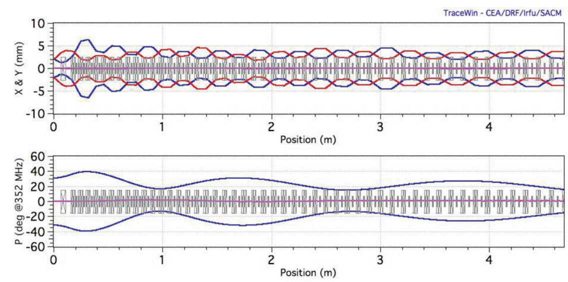

Figure 9: 100 % transverse and longitudinal envelopes.

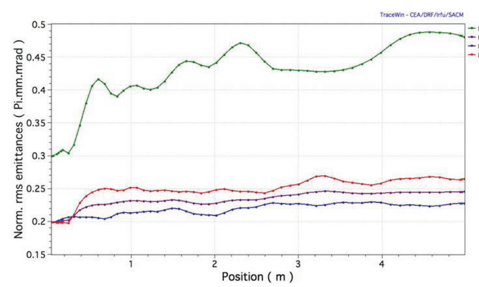

Figure 10: Growths of beam emittance.

CONCLUSION

The beam dynamics and electromagnetic design of the DTL for BNCT accelerator are being performed using 2D and 3D codes. The geometry parameters of the drift tubes are selected in consideration of the maximum electric field value and break down problems. The five cell lengths and synchronous phases in the beginning of the DTL are adjusted in order to reduce the longitudinal beam growth. The field tuning for the correction between the symmetric by only drift tubes and asymmetric features by stems, tuners and post couplers is performed. The particle tracking simulation using the tuned fields is also carried out and the beam transmission efficiency shows 100 %. The field stabilization simulation using post couplers is presently being investigated.

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