PRIMARY DESIGN OF DTL FOR CPHS*

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Abstract

The Compact Pulsed Hadron Source (CPHS) has launched at Tsinghua University to develop a neutron source based on a 13-MeV, 50-mA proton linac, consisting of an ECR ion source, LEBT, RFQ, and DTL. The primary design of the DTL for the CPHS is presented in this paper, which includes the dynamics calculation, RF field optimization, and error analysis. This DTL accelerates a 50-mA proton beam from 3 MeV to 13 MeV with 1.2 MW of RF power. The DTL directly follows the RFQ with no Medium-Energy Beam-Transport line (MEBT). Transverse focusing is provided by PMQs housed in the drift tubes. The focusing lattice is designed to continue the transverse phase advance of the RFQ to preserve current independence while avoiding mismatches and parametric resonances.

INTRODUCTION

Large scale proton-accelerator-driven neutron sources have been built world-wide. More and more successful experiments, such as neutron scattering, have achieved wonderful results. For education and development in research and industrial applications, we prefer a flexible and compact neutron source. Tsinghua University has launched CPHS, which is a compact yet expandable neutron complex based on a 13-MeV proton accelerator [1]. The 13-MeV accelerator consists of a high-intensity proton source, a 3-MeV radio frequency quadrupole (RFQ) linac, and a 13-MeV drift-tube linac (DTL). The DTL connects directly to the RFQ without a Medium-Energy Beam-Transport line (MEBT).

The main parameters of the DTL and key points of the physics design are introduced in this paper.

MAIN PARAMETERS OF THE DTL

The DTL for CPHS accelerates a proton beam from 3 MeV to 13 MeV. The RFQ and DTL have been designed in concert in an attempt to preserve a continuous transverse and longitudinal phase advance. As a result no MEBT is required to match the beam between the two structures and the DTL directly follows the RFQ. Based on the successful operation of SNS, we use permanent-magnet quadrupoles (PMQs) for the DTL focusing. The magnetic focusing lattice of the PMQs provides restoring forces that just match the transverse restoring forces at the end of the RFQ.

The main parameters of CPHS DTL are shown as Table 1.

Table 1: CPHS DTL main parameters

Species	proton	
Extraction energy	13	MeV
Extraction peak current	50	mA
RF frequency	325	MHz
RF peak power	1.2	MW
Beam pulse length	0.5	ms
Emittance (norm. rms)	0.2	μm
Entry beam energy	3	MeV
Beam duty factor	2.5	%
Average beam current	1.25	mA
RF duty factor	3	%
Synchronous phase	-30 to -24	degree
Accelerating field	2.2 to 3.8	MV/m
Focusing magnet type	PMQ	
Quad focusing gradient	6.9~8.9	kG/cm
Cell number	40	
Length	4.4	m

PHYSICS DESIGN

The main goal of the physics design for DTL is to capture the proton beam from the RFQ and accelerate it to 13 MeV. At the same time, beam loss should be kept as low as possible [2]. The principle design was completed by, J. Stovall and others.

Drift Tube Optimization

For ease of fabrication, we keep the bore and outer diameter of the drift tubes constant throughout. We adjusted the drift-tube face angle and gap length to optimize for maximum shunt impedance, minimize the risk of multipactor and to keep the peak surface electric field below 1.6 Kilpatrick. Fig. 1 shows T and ZT^2 versus proton velocity β.

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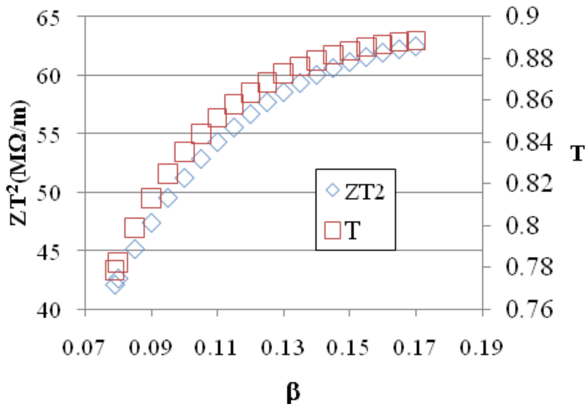

Figure 1: Optimized T and ZT^2

Longitudinal Dynamic Design

The longitudinal focusing strength K_{0l} at the beginning of the DTL matches, by design, the exit properties of the RFQ. Continuity of K_{0l} minimizes longitudinal mismatch and helps assure a current independent design.

The synchronous phase ϕ_s starts at the final RFQ value of -30° capturing the entire beam longitudinally. We then ramp ϕ_s to -24° thereby increasing the acceleration efficiency. The initial value of E_0=2.2 MV/m is chosen to meet K_{0l} requirement. We linearly ramp E_0 to 3.8 MV/m. The final design of ϕ_s and E_0 is shown in Fig. 2.

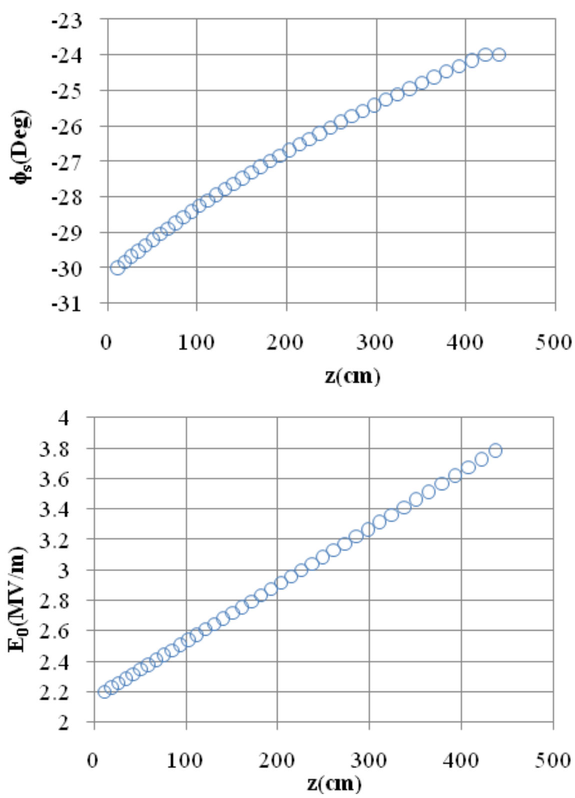

Figure 2: Phase (top) and average axial electric field (bottom) of the DTL.

Transverse Dynamic Design

The transverse focusing strength K_{0t}, is, by design, also continuous at the RFQ-DTL interface to avoid mismatch and help assure a current independent design.

The quadrupole law is chosen to meet standard design guidelines, which include keeping the equipartitioning ratio ≈1.0 at full current and avoiding known parametric resonances.

An FD lattice structure in the DTL minimizes the discontinuity in periodicity with the RFQ in which the length of a single focusing period is half that of the DTL.

The length of the PMQs is constant. The design magnetic field gradients of the PMQs are shown in Fig. 3. The gradients of the first two PMQs are used as matching elements to compensate for the fact that RFQ and DTL cannot physically be placed as close together as we would like.

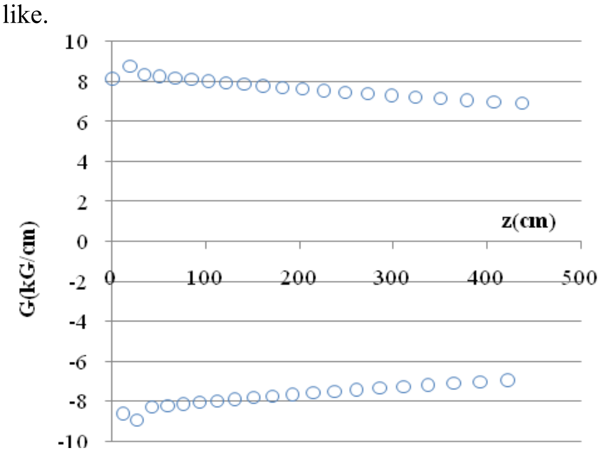

Figure 3: Gradient of the PMQs in the DTL.

RF Breakdown Analyze

The maximum Kilpatrick factor in the DTL is 1.6 and occurs in the last cell. The Kilpatrick factor of first cell is only 0.95 where the value of the electric field is 17 MV/m. The strength of the magnetic fringe field at this point on the drift tube nose is 0.067T for a PMQ length of 4 cm. This set of data is well below the "Moretti criteria"[3], an empirically observed rf breakdown threshold for collinear E and B fields.

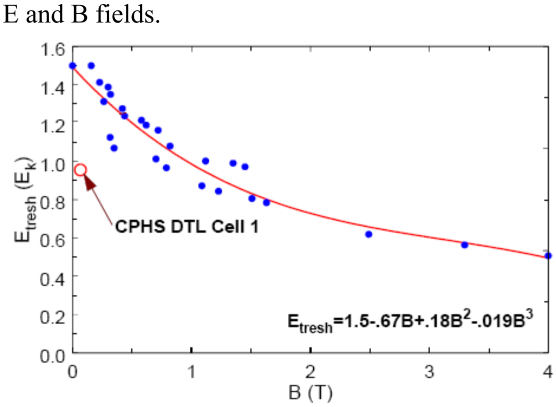

Figure 4: Moretti criteria and CPHS cell 1.

ERROR ANALYSIS

We analyzed two kinds of errors. Alignment errors affect the transverse dynamics and RF phase and amplitude errors affect the longitudinal dynamics.

Alignment Error

This design is very robust for alignment errors. We assume a PMQ alignment tolerance of σ = ±0.1 mm and an RFQ-DTL alignment tolerance of σ = ±1.0 mm. By simulation using 1000 linacs randomly misaligned within this tolerance, we conclude with 99% confidence that the beam will not touch the bore at $3\sigma_r$.

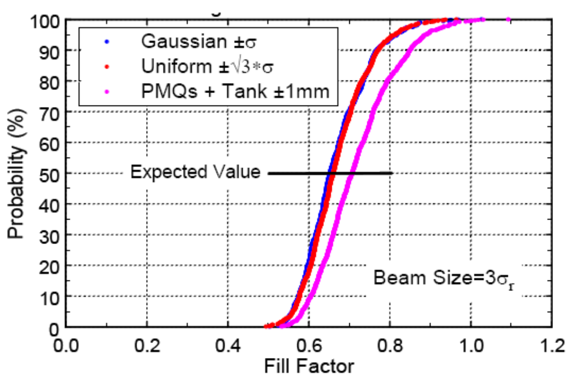

Figure 5: Fill factor analyze with alignment error.

RF Phase and Amplitude Error

With a phase tolerance of ±2°, an amplitude tolerance of ±2%, and a field-tilt tolerance of ±2%, we see by a similar simulation that the expected output energy will be low by only 5 keV.

MECHANICAL DESIGN

We are carrying out the mechanical design under the guidance of our consulting committee by combing several advantages of the SNS and CERN LINAC4 project [4] DTLs. The DTL consists of a copper plated steel cavity, with girder support of the drift tubes (Fig. 6). We will use electron beam welding exclusively in the drift tube fabrication.

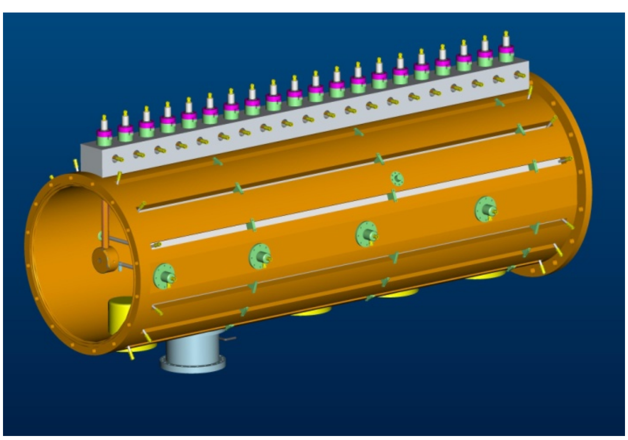

Figure 6: First section model of CPHS DTL cavity.

We are now building a model cavity to test our mechanical design

PMQ DESIGN

We have designed the permanent-magnet quadrupole lenses. Because the maximum magnetic field gradient is high (about 9 kG/cm), we have adopted a design that uses bullet shaped magnet sections.

CONCLUSION

We have finished the primary design of the CPHS DTL. This design meets the requirements of CPHS project well. Error analysis shows that the design parameters are robust with mechanical errors under 0.1 mm and E_0 field errors under 2%.

The mechanical design for this DTL is underway. A model cavity is now under construction.

ACKNOWLEDGEMENTS

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