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750 MHz IH-DTL FOR A PROTON THERPY LINAC

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Abstract

750 MHz inter-digital H-mode drift tube linac (IH-DTL) with the capability to accelerate protons from 3 to 10 MeV was proposed for the compact therpy linac that now under development in the institute of Modern Physics, Chinese Academy of Science (IMP, CAS). Four drift tube sections were housed in a single vacuum chamber and coupled with three large drift tubes which housing focusing triplet lens inside. In each drift tube section, there were 9 to 10 drift tubes, supported by the separated ridges. This cavity will be powered by a 1 MW klystron at 0.1% duty cycle, the k_p factor is about 1.7 at the operation power level. The overall cavity design is presented in this paper.

INTRODUCTION

Compact linac with high working frequency and a consequent high accelerating gradient has been widely studied and developed around the world [1-2]. In the proposed designs, the compact linac begin with a P-band RFQ that nicely cover the first MeV/u energy range, providing both acceleration and bunching, followed with a P-band IH-DTL to accelerate the proton bunches to 10 MeV/u. Energies higher than 10 MeV/u is covered by different S-band structures, such as side-copuled drift tube linac (SC-DTL), coupled cavity linac (CCL), backward traveling wave structure (BTW) and other S-band standing wave structures, depending on the specific application.

Low velocity particles acceleration is the most critical part in the proton and heavy ion accelerator. Several structures were studied, constructed and tested in the last several decades, including the Alvarez drift tube linacs (DTL) that operating in the TM_{010} mode, H-mode linacs operating in the TE_{110} mode (the inter-digital H, IH), or in TE_{210} mode (the cross-bar H, CH). Compared with the Alvarez DTL and the CH structure, the IH structure is more compact in size for the same operating frequency, and has no competitor with respect to efficiency and shunt impedance in the low energy range from beta = 0.01-0.2.

A similar linac is now under development in IMP, which comprises a 3 MeV 750 MHz RFQ, a 3-10 MeV 750 MHz IH-DTL, two 3 GHz SC-DTLs that further accelerate the proton bunches to 30 MeV, following with S-band standing wave structures to boost the energy to 230 MeV.

The 750 MHz 3-10 MeV IH-DTL was designed with KONUS beam dynamic, consists of 42 accelerating cells and three quadrupole magnet triplets. The gap voltage, gap length, drift length and the synchronous phase at each gap were optimized to get a small envelope, high transmission efficiency and small energy spread for the output beam.

RF DESIGN AND OPTIMIZATION

The RF properties of the 750 MHz IH-DTL was optimized using CST Microwave Studio. With the gap length and cell length from beam dynamics design, a 3D model of the IH-DTL could be built and optimized. The effective acceleration voltages of each gap were calculated and compared with the gap voltages from the beam dynamics design. If the gap voltage error is large, the beam dynamics design is then updated with new gap voltage distribution, gap length and drift length. With several iterations of the RF design and beam dynamics design, a good consistency could be achieved between the voltage distribution from CST simulation and that from the beam dynamics design.

Single Cell Slice Optimization

During the simulation, a single cell slice with medium particle beta was firstly investigated to optimize the geometry in terms of shunt impedance, RF frequency, peak surface field and the dipole component, as shown in Fig. 1. Main RF parameters are summarized in Table 1. Here K_p is defined as the ratio of peak surface electric field to the Kilpatrick limit, R_{sh} is the effective shunt impedance per meter, dipole component is defined as the ratio of transverse kick voltage to the longitudinal acceleration voltage.

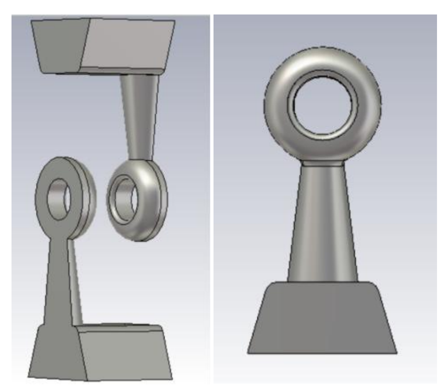

Figure 1: Layout of the single cell slice of the IH-DTL.

Table 1: RF Parameter of the Single cell Slice

Parameter	Value	Unit
K_p	1.76	
R_{sh}	135	Mohm/m
Q	7755	
Dipole	6%	

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Full Cavity Optimization

After the single cell slice was optimized, the full cavity was then built and optimized to get a uniform field distribution, as shown in Fig. 2 and Fig. 3. The 750 MHz IH-DTL is divided into four acceleration sections by three internal lenses. Drift tubes in each acceleration sections are supported with separated ridges. Radius of each drift tube section and lense section are different to get a uniform field flatness. Synchronous phases of each gap are plotted in Fig. 4. Gap voltages of each acceleration cells are plotted in Fig. 5.

Gap voltage errors were calculated as $(V_{cst}-V_d)/V_d$, where V_{cst} is the gap voltage calculated in CST MWS and V_d is the voltage from beam dynamics design. The gap voltage errors of the 42 gaps are shown in Fig. 6. Maximum error is within 1.5% and met the beam dynamics requirement. Major parameters of the full cavity is summarized in Table 2.

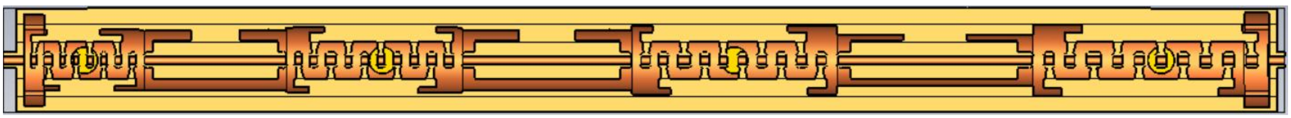

Figure 2: Full cavity model with internal lenses. Drift tubes are supported with separated ridges.

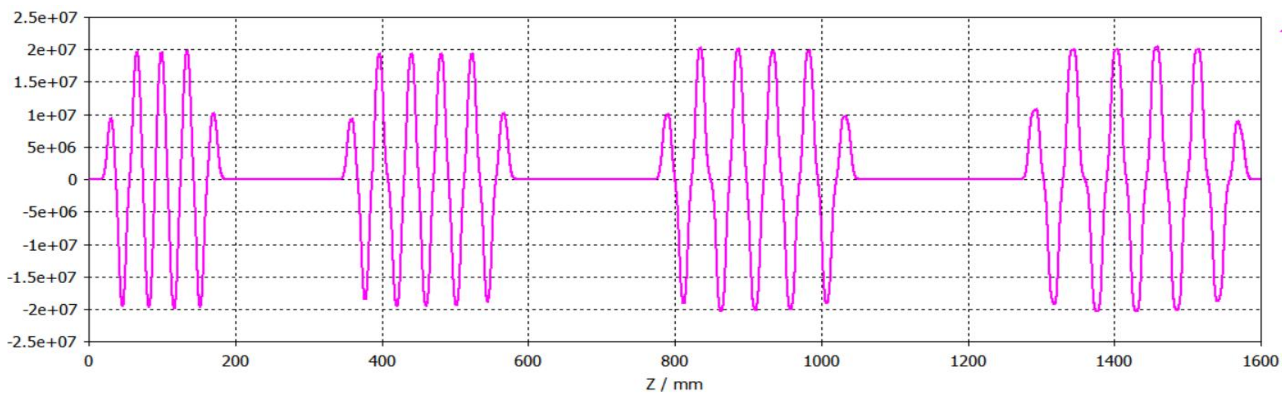

Figure 3: Longitudinal electric field along the beam axis as function of the longitudinal position.

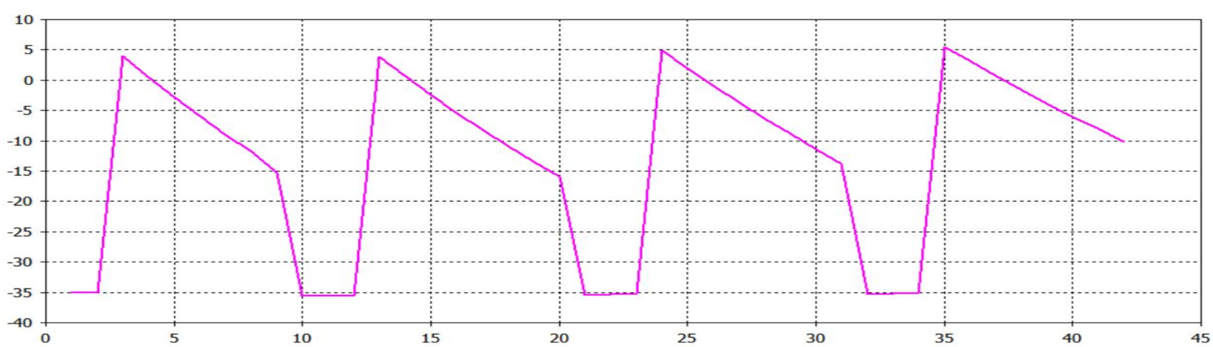

Figure 4: Synchronous phase as a function of gap number.

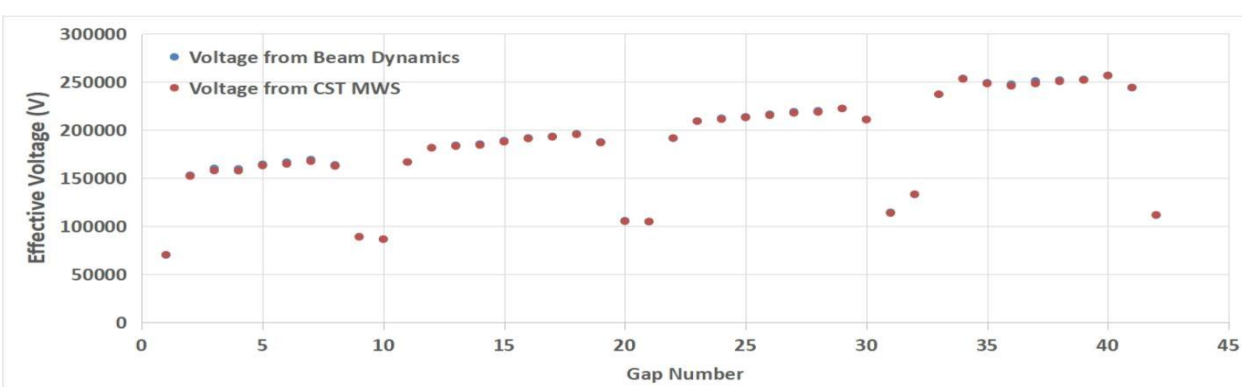

Figure 5: Gap voltages along the beam axis from beam dynamics and CST MWS as function of the number of acceleration gaps.

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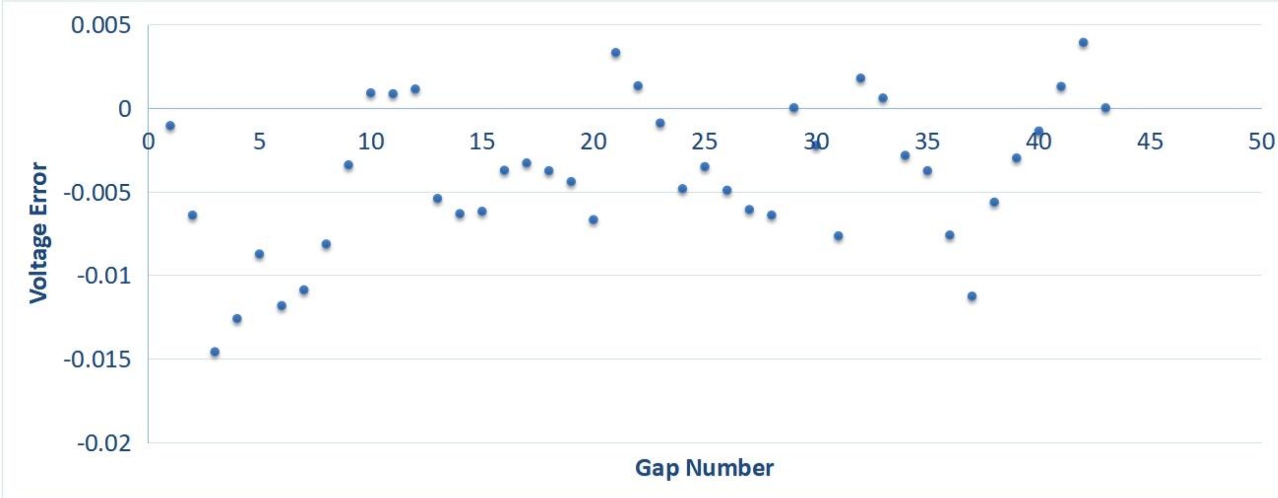

Figure 6: Gap voltage errors between beam dynamics and CST MWS along the beam axis as function of the number of acceleration gaps.

Table 2: Major parameters of the full cavity

Parameter	Value	Unit
Operating frequency	750	MHz
Total length	1600	mm
Input energy	3	MeV
Output energy	10	MeV
Number of cells	42	
Bore of the drift tube	10	mm
Q	6737	
P	645	kW

CONCLUSION

The RF design and study of a compact 750 MHz 3-10 MeV IH-DTL for a proton medical accelerator was described. Multi-physics analysis and the mechanical design is on the way.

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