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BEAM DYNAMICS OF A 325 MHz IH-DTL WITH KONUS

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Abstract

A 325 MHz interdigital H-mode drift tube linac (IH-DTL), which is aimed at proton medical facilities, has been proposed and developing at Tsinghua University. The proton beam can be accelerated from 3 MeV to 7 MeV and the peak current of the beam at the exit of the cavity is about 15 mA. A KONUS dynamics without focusing element is applied in this cavity. The co-iteration of dynamics simulation and RF simulation is done. The process and result of the design is presented in this paper.

INTRODUCTION

Since Munich University built the first IH-DTL accelerator at 1977, IH-DTL is widely used for heavy ion accelerators because of its high shunt impedance at low β range (beta<0.1) [1, 2]. As facilities used for proton and carbon therapy increase and the 3D RF simulation becomes reliable. IH DTL has been used widely in the injector of medical synchrotrons. A 216 MHz IH-DTL has been developed for HICAT (Heidelberg Heavy Ion CAncer Therapy) project. There are 4 KONUS (Kombinierte Null Grad Struktur) sections and three triplets in the tank. The proton beam can be accelerated from 0.4 MeV to 7 MeV in 3.76 m. The high effective gradient is 5.5 MV/m [3]. Another kind of proton IH DTL is developed via APF (Alternating Phase Focusing) beam dynamics. The length of this cavity is ~1.7 m. It can accelerate 10mA proton beam to 7.4 MeV at 200 MHz [4].

Considering the beam test on XiPAF (Xi`an Proton Application Facility) project, a 325 MHz IH-DTL is proposed and developing at Tsinghua University. The design parameters of this IH-linac is shown in Table1.

The optimization of single cell geometry and the dynamics model is introduced in reference [5]. To get high accelerating gradient and high shunt impedance, there is no focusing elements in this 1 m cavity. The power loss of the cavity is 145 kW and the average accelerating gradient is 5.45 MV/m. While the peak surface electric field is 2.25Kp, which seems a little higher [6].

For both APF and KONUS beam dynamics design, it needs the approximation of E field distribution (or voltage versus gaps) at first. And the synchronous phase calculated by beam dynamics at each cell determines the cell length which changes the E field distribution meanwhile. Thus, an IH-DTL design needs the co-iteration of beam dynamics and RF field simulation [4]. The design process and results is presented in this paper.

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Table 1: Parameters of 325 MHz IH-DTL

Parameters	
Particle species	proton
Frequency	325 MHz
Particle input energy	3 MeV
Particle output energy	7 MeV
Peak current	15 mA
Pulse width	40 μs
Energy spread	<±0.3%(>8mA)

BEAM DYNAMICS DESIGN

To design an IH-DTL, the gap voltage and the transit time factor (TTF) for different cell is necessary. The TTF of cell is determined by interpolation with some typical cells like Parmila code. The gap voltage is given by designers at first which is shown in Fig. 1. The code and model of the dynamics design is introduced in reference [5].

This 325MHz IH-DTL is divided into 3 sections: bunching, acceleration, de-bunching. There are 4 gaps used for bunching which`s synchronous phase is -80 deg. The phase spread of the beam becomes bigger than ±20 deg because of a long MEBT after RFQ. This bunching section can bunch this beam without big distortion in longitudinal phase space. The acceleration section is designed in a KONUS way [7]. The structure is designed with 0 deg synchronous phase and the designed injecting energy is a little lower than the real bunch central energy. The injecting phase is 8 deg. As the real bunch central energy is bigger than the synchronous energy, the RF phase of bunch center decreases as shown in Fig. 2. The synchronous phase at de-bunching section is 10 deg and there are 5 gaps. This section are used to suppress the beam envelop growth as there is no focusing elements in the cavity. Meanwhile, this positive synchronous phase design can defocusing beam at longitudinal phase space. The energy spread is too big for injection and a de-buncher is needed after the DTL. This de-bunching section makes the beam spread at the exit of IH-DTL widely, which decreases the drift length between the DTL and the de-buncher. There are 21 gaps for this design and the total length is 1m. The phase space evolution is shown in Fig. 3. The blue lines are the bucket plot. The red

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ellipses are calculated by linear matrices and the star lines are calculated by single particle tracking.

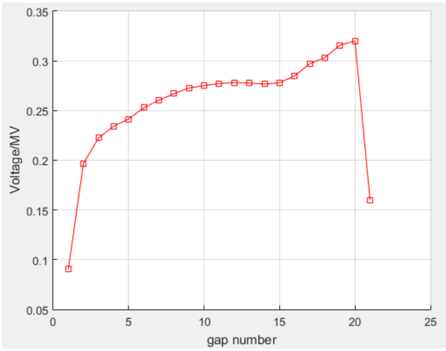

Figure 1: Voltage versus gaps.

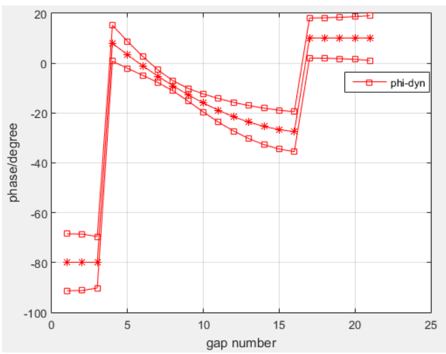

Figure 2: RF phase and phase spread for bunch centre versus gaps.

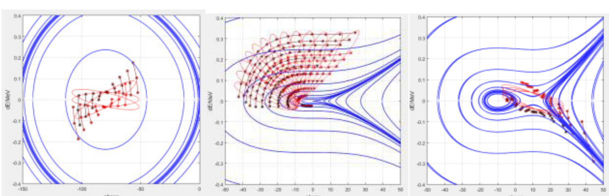

Figure 3: Phase evolution in bucket plot (left: bunching, middle: acceleration, right: de-bunching).

Those above are calculated with MATLAB code based on the simple model [5]. After getting the structure of this IH-DTL, it is checked with Tracewin code. The input parameter for multi-particle simulation is in Table 2.

Table 2: Beam Parameters at IH-DTL Entrance

Beam at IH-DTL entrance	
Peak current	15mA
$\alpha_{x/y}$	9.26
$\beta_{x/y}$	2.55mm/mrad
Normalized RMS transverse emittance	0.2π mm• mrad
α_z	-1
β_z	0.75mm/mrad
Normalized RMS longitudinal emittance	0.19deg*MeV

The simulation results are shown in Fig. 4. The biggest beam spot is Ø16 mm. The transmission of the IH-DTL is >99%. The phase ellipse in longitudinal direction seems strong nonlinear effect. The energy spread is bigger than 0.32 MeV and the phase spread is bigger than 35 deg. But if there is a de-buncher at the 500 mm distance from the DTL exit. The phase ellipse is shown in Fig. 5. The energy spread of almost all particles is <±50keV, which satisfies the design requirement.

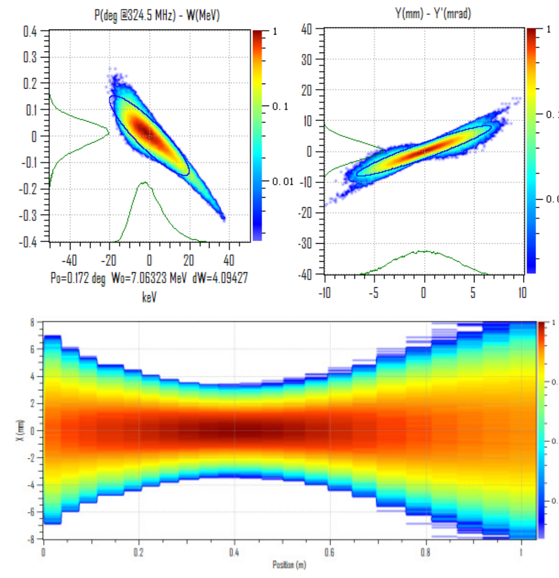

Figure 4: Multi-particle simulation results (left: longitudinal phase space, right: Y-Y' plot, bottom: beam envelop in X, X and Y are the same).

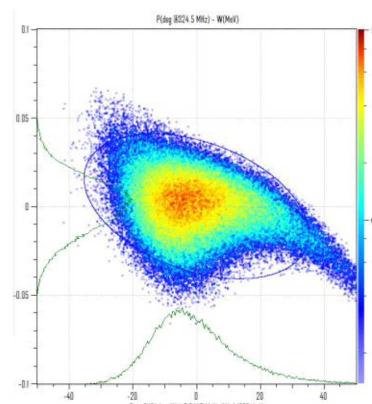

Figure 5: Longitudinal phase space after de-buncher.

RF SIMULATION

After the dynamics design, the structure (cell length and numbers) of IH-DTL is determined. Based on the single cell geometry, a cavity is constructed with CST code. 8 tuners and 1 coupler has been mounted in the cavity. The 3D plot of vacuum area is shown in Fig. 6. The field map and RF parameters are calculated with CST`s Eigen mode solver. The RF results are shown in Table 3. The magnitude of Ez on Z axis is shown in Fig. 7. There is a little difference between the voltage used for dynamics design and voltage calculated by RF simulation,

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shown in Fig. 7. If the difference is big, the re-design of the structure is needed to make the difference small enough. That`s the co-iteration process.

Table 3: RF Results of this 325 MHz IH-DTL

Parameters	
Frequency	324.87MHz
Power loss	145kW
Q0	11760
Cavity length	0.983m
Shunt impedance	201MΩ/m
Effective shunt impedance	112MΩ/m
Epeak	2.25Kp

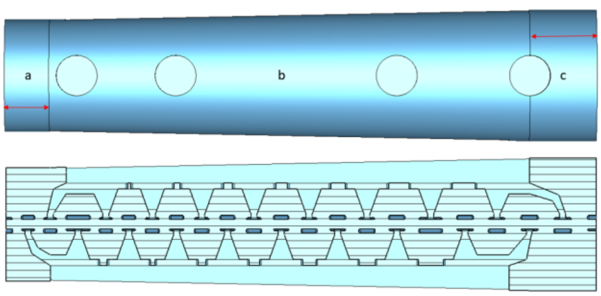

Figure 6: Vacuum area of the cavity(a/c: cylinder, b:cone).

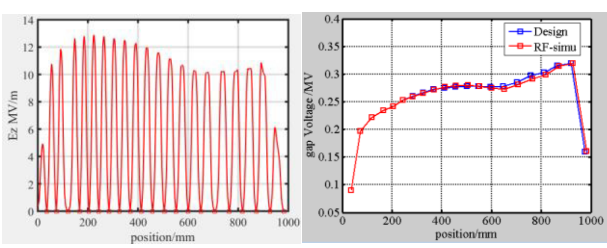

Figure 7: Ez distribution and voltage difference between the design and simulation.

As there is some difference between the dynamics design and RF simulation, 3D field map is used to do multi-particle tracking. The results seem similar to the dynamics design, which proves that this little difference is not important and the simple dynamics model is good enough to produce the structure of the IH-DTL. The tracking results is shown in Fig. 8.

CONCLUSION

The design process of a 325 MHz IH-DTL at Tsinghua University is presented. The co-iteration of dynamics design and RF simulation is the key of this design process. The dynamics design divides the cavity into 3 sections: bunching, acceleration, de-bunching. This design don`t need a re-buncher after RFQ and decreases the distance between the DTL and the de-buncher. The RF simulation results agree well with the dynamics ones. The power loss of this cavity is 145 kW and the average accelerating gradient is 5.45 MV/m. This makes it a high efficient DTL for such a short cavity.

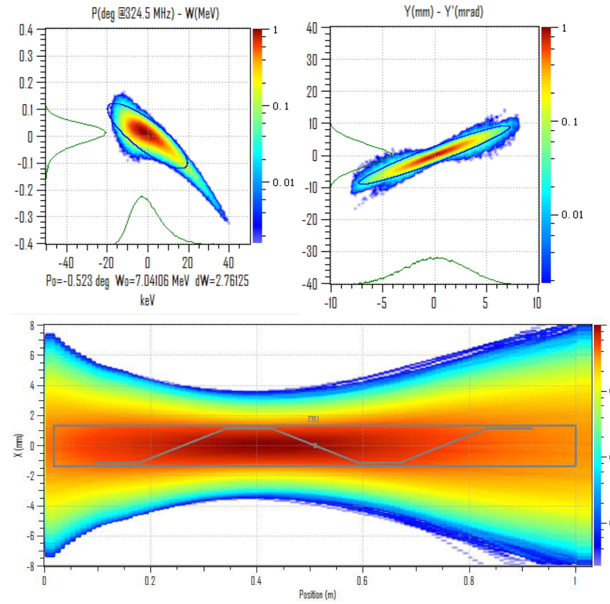

Figure 8: Multi-particle simulation results with 3D field map (left: longitudinal phase space, right: Y-Y' plot, bottom: beam envelop in X, X and Y are the same).

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