# RF AND PRIMARY BEAM DYNAMICS DESIGN OF A 325 MHz IH-DTL

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*Abstract*

An interdigital H-mode drift tube linac (IH-DTL), which is aimed at proton medical facilities, has been proposed and developing at Tsinghua University. Considering following 3 MeV RFQ in the platform of CPHS (Compact Pulse Hadron Source at Tsinghua University) and XiPAF (Xi`an Proton Application Facility) project, the input energy of IH-DTL is 3 MeV and the RF frequency is 325 MHz. 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. In order to simplify the fabrication, A KONUS structure without focusing element in the cavity is chosen. The RF design of single CELL and the primary dynamics design is done. The co-iteration of dynamics simulation and RF calculation of whole cavity is undergoing.

## INTRODUCTION

Facilities used for proton and carbon therapy become more and more popular. IH DTL has been used widely in the injector of clinical synchrotrons because of its high RF power efficiency at low beam velocity (beta<0.1) [1]. A 216 MHz IH-DTL has been developed for HICAT (Heidelberg Heavy Ion CAncer Therapy) project [2]. 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]. Those two kind of beam dynamics are both applied in IH cavity widely.

Considering the platform of CPHS (Compact Pulse Hadron Source at Tsinghua University) and XiPAF (Xi`an Proton Application Facility) project, a 325 MHz IH-DTL is proposed and developing. The main parameters of this linac is shown in Table1.

In order to simplify the fabrication, there is no focusing elements in the cavity. That makes the need of short length and high effective gradient. The total length of this IH-DTL is less than 1.2 m. That motivates the optimization of single cell geometry to get high acceleration gradient and high shunt impedance. The design and optimization process of single cell is described in the 2nd section.

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Almost all the KONUS dynamics design is done by LORASR code (LOngitudinale und RAdiale Strahldynamikrechnungen mit Raumladung). A new and simple Matlab code has been developed to produce the primary structure of an IH-DTL with KONUS lattice. The process of code development and primary design results are described in the 3rd section.

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 |
| Normalized RMS emittance | 0.15 π mm• mrad |

## DEISGN OF SINGLE CELL

Raztinger has proposed a theoretical model to estimate some main parameters (frequency, shunt impedance, Q factor) of an H mode cavity, see [5]. Based on this model, a simple single cell model is constructed with CST code to simulate its 3D RF field map and calculate its RF parameters. The geometry is shown in Fig.1. $R_c$ is the radius of the cavity. $\emptyset_1 - \emptyset_2$ is the angle of two ridges. L is the length of this cell. $L_{gap}$ is the length of gap. $R_{drift}$is the outer radius of drift tube. Those geometry parameters is included in the theoretical model. $L_{stem1}$ , $L_{stem2}$ and $H_{stem1}$are used to determine the geometry of the stems. They are unimportant and ignored in the theoretical model.

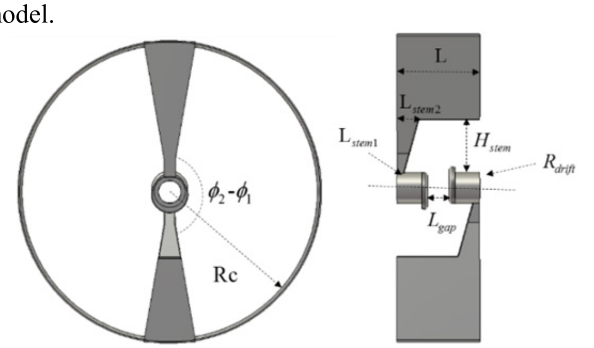


Figure 1: Primary geometry of single IH-DTL cell (left: front view, right: side view).

A great advantage of an IH-DTL is its high shunt impedance. In general, the shunt impedance increases as $R_{drift}$ decreasing. There are constraints for $R_{drift}$ decreasing because of the intense peak current. Finally, $R_{drift}$=11 mm (the inner radius of drift tube is 8 mm, the other 3 mm is the thickness of copper). The length of cell is determined by rf frequency and particles` velocity（$L=1/2\beta\lambda$）. Beside these two parameters, the geometrical parameters are scanned to get the high shunt impedance of single cell. The final results of those parameters are in Table 2.

Table 2: Geometrical Parameters of Single Cell (L=56.8 mm)

| **Parameters** | |
|---|---|
| $R_c$ | 108.2 mm |
| $\emptyset_1 - \emptyset_2$ | 2.8 rad |
| $L_{gap}$ | 22.7 mm |
| $L_{stem1}$ | 5 mm |
| $L_{stem2}$ | 15 mm |
| $H_{stem1}$ | 36.7 mm |

There are also two bulges in the cell to compensate the dipole electric field. The radius of the bulge is 13mm. The deviation of the bulge center and drift tube center is 2 mm. The electric field map on y-z plane is shown in Fig.2. The maximum dipole electric field component is about 1.0% of the accelerating electric field.

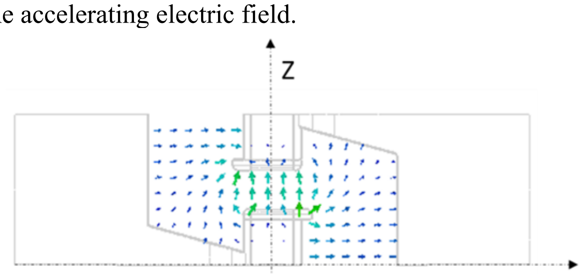


Figure 2: Electric field distribution on y-z plane.

The cell model above is constructed and optimized from a theoretical model. Considering the fabrication process, another two models are proposed, shown in Fig.3. In the model A, the size of stem is small, it`s very difficult to connect the stem with the ridge. A new platform is added to conquer this problem. As well, the thickness of the bulge is too small to fabricate while the material is copper. So, the bulge is extended to the whole drift tube. That makes the center of the new drift tube deviates from the beam line. Considering these two changes, a new model is constructed shown in the middle plot of Fig.3. To make the fabrication easier than model B, the inner hole of the drift tube is extended and the center of the hole is set to be the same with the deviated drift tube. The model with this change is shown in the bottom plot of Fig.3.

After simulating these three different model, the RF results are shown in Table 3. Epeak is the maximum electric field on the surface and E0 is the average electric field on z axis. Ey/Ez is the dipole electric field component over the accelerating electric field.

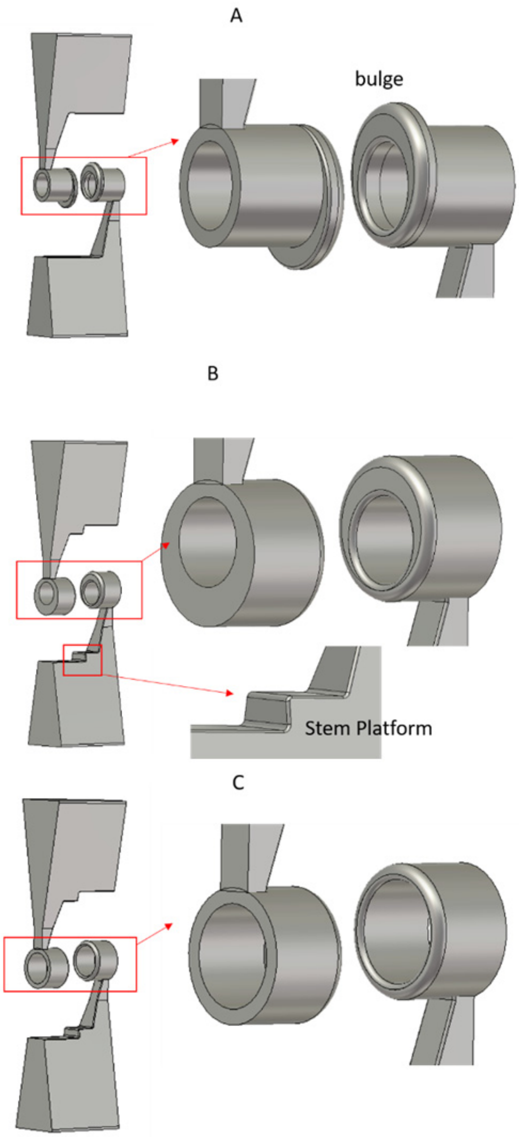


Figure 3: Three kinds of model of single cell.

Table 3: RF Results of Three Kinds of Cell Model

| | **A** | **B** | **C** |
|---|---|---|---|
| Q | 13573 | 13350 | 13471 |
| R(MΩ/m) | 197.98 | 184.41 | 184.83 |
| TTF | 0.8805 | 0.8807 | 0.8614 |
| Epeak/E0 | 9.08 | 7.82 | 8.15 |
| Ey/Ez | 6.4% | 6.2% | 10.1% |

There is a little difference between these three models in Q factor. The model A has the largest Epeak/E0. The model C has the largest dipole electric field. The effective shunt impedance of model A is about 7.3% bigger than


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the model B, while it is much more complicated in fabrication. The model B is the best choice for a 325 MHz IH-DTL.

## DYNAMICS DESIGN

Almost all the KONUS dynamics design is done by LORASR code. A main feature of this code is the calculation of the gap field. It can rebuild the field map according to the geometry of gap and drift tube [6]. Different from LORASR code, the new developed code with Matlab depends on a very simple model shown in Fig.4.

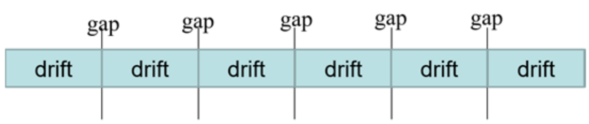


Figure 4: A simple model of IH-DTL.

The linac is composed of drift sections and RF gaps. The phase change of reference particle between two neighbouring gaps is determined by the length of drift and the velocity of reference particle. The TTF (transit time factor) of gap is determined by interpolation with some typical cells like Parmila code. The voltage of gap depends on the simulation results of the whole cavity, while the whole cavity geometry depends on the dynamics results. Thus, the co-iteration of whole cavity simulation and dynamics simulation is necessary for an IH-DTL design. This simple Matlab code can design a linac in a KONUS way. The designed structure is imported into Tracewin code to do multiparticle transport simulation.

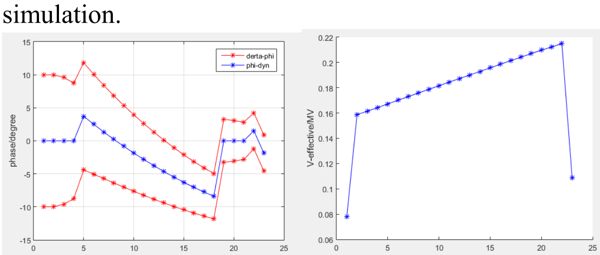


Figure 5: Phase and effective voltage variation along gap number.

A primary dynamics design has been done with the linear assumption between the gap voltage and gap number. The variation of the RF phase and the effective voltage is shown in Fig.5. After importing the structure into Tracewin code, the multiparticle dynamics simulation results is shown in Fig.6. The input longitudinal normalized RMS emittance is 0.1 degree*MeV. The output longitudinal normalized RMS emittance is 0.122 degree*MeV. The maximum envelop is 6.13 mm which is smaller than 8 mm. Thus the transport efficiency of this linac is 100%.

## CONCLUSION

The motivation and design process of a 325 MHz IH-DTL is introduced in this paper. The design process is divided into RF design of single cell and dynamics design with KONUS lattice. The effective shunt impedance of single cell is optimized to be larger than 143 MΩ/m. The Epeak/E0 is smaller than 7.82. At 325 MHz, Kilpatric factor equals 2 is reasonable [7]. Thus the average accelerating field can be larger than 4.55 MV/m. Depending on a simple model, a new Matlab code is developed to design KONUS lattice. It has been checked with LORASR code. Based on the code, a primary dynamics design with KONUS lattice is proposed in this paper. The total length of the linac is about 1.12 m. The co-iteration of dynamics simulation and RF calculation of whole cavity will be carried out in the future.

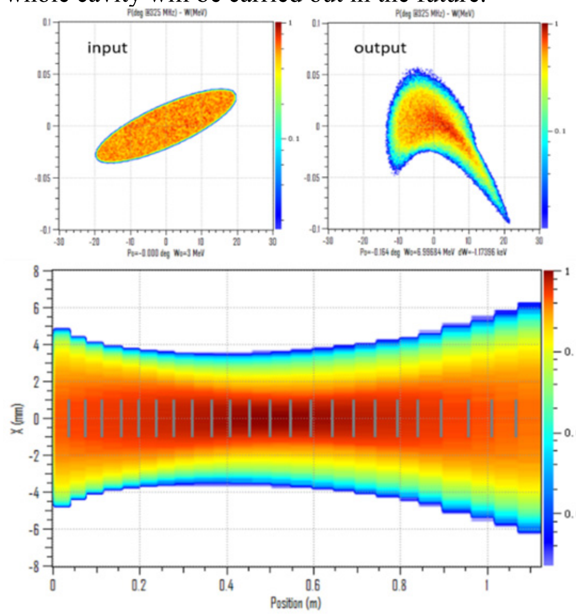


Figure 6: Multiparticle simulation results.

## ACKNOWLEDGEMENT

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