ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-TUPO004

RF DESIGN AND COLD MODEL MEASUREMENT OF AN IH-DTL FOR HIMM INJECTOR*

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Abstract

An interdigital H-mode drift tube linac (IH-DTL) will be constructed as a postinjector linac for the Heavy Ion Medical Machine (HIMM). Its resonant frequency, injection and final energies are determined from beam dynamics and hardware parameters considerations of the entire machine to be 162.5MHz, 600keV/u and 4MeV/u, respectively. The beam duty cycle of the injector linac is less than 0.1% based on the injection requirements of the synchrotron. Beam dynamics and RF structure design and optimize of the IH-DTL has been finished. The maximum surface electric field is less than 2.0-times the Kilpatric limit for accelerating C^{4+} beam. This IH-DTL contains 41 accelerating gaps and two focusing quadrupole triplets. In order to examine the field distribution of the IH-DTL which reaches the length of 3.17m, an aluminium alloy 1:1 cold model cavity with 4 moveable tuners and 2 empty focusing magnet shell was constructed. The relative intertube-distance errors are less than ±0.05mm. The measurements show that the gap voltage values can match the CST-MWS simulating results within relative difference of ±3% by adjusting the 4 moveable tuners.

INTRODUCTION

To improve the performance and reduce the cost of the Heavy Ion Medical Machine (HIMM), Institute of Modern Physics designed a compact C^{4+} linac injector to replace the C^{5+} cyclotron injector [1,2]. This linac injector mainly contains an ECR ion source, a RFQ, an IH-DTL, two buncher cavity and several beam lines. KONUS beam dynamics design of the IH-DTL has been reported in the previous paper [3]. This IH-DTL cavity with a resonant frequency of 162.5MHz and a length of 3.17m will be constructed as the main accelerating section for the HIMM linac injector. Its total integral gap voltage on the beam axis is above than 10MV, which is fairly high as a normal conducting cavity. In general, it is difficult to design fabricate a long IH-DTL which contains several focusing quadrupole triplets. In the cavity design process, on-axis electric field distribution is tuned carefully by adjusting the cavity structure. On the other hand, nearest mode problem of a long IH-DTL cavity must be considered. In order to examine the on- axis electric field distribution and the nearest mode of such a long IH-DTL cavity, a cold model cavity of the IH-DTL has been constructed. The measurement results of this cold model will be discussed in this proceeding.

* Work supported by National Natural Science Foundation of China (11375243, 11405237) and Guangdong Innovative and Entrepreneurial Research Team Program (2016ZT06G373).
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RF STRUCTURE DESIGN OF IH-DTL

CST-MWS code [4] has been used to make the RF structure design and simulation. The optimized 3D RF structure is shown in Fig. 1. To make the on-axis electric field match with the dynamics requirement, end cut tuner, lens coupling tuner and local volume tuner are used and fine adjusted. Four movable plunger tuners are installed in the IH-DTL cavity, which has totally 0.9 MHz frequency tuning range. Remove the 4 plunger tuners, the H_{110} mode (operation mode) resonance frequency, Q0 value and RF power loss for C^{4+} is 163.0MHz, 14200 and 332kW respective. For the H_{111} mode (nearest mode), the resonance frequency and Q0 value is 165.4MHz and 12400. The on-axis electric field distribution compare between the H_{110} and H_{111} mode is shown in Fig. 2.

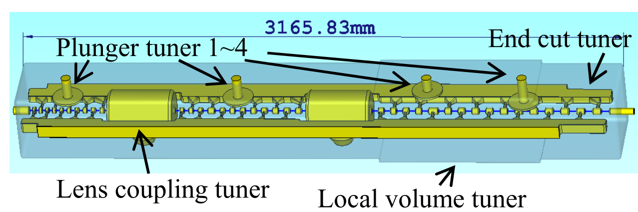

Figure 1: CST-MWS 3D model.

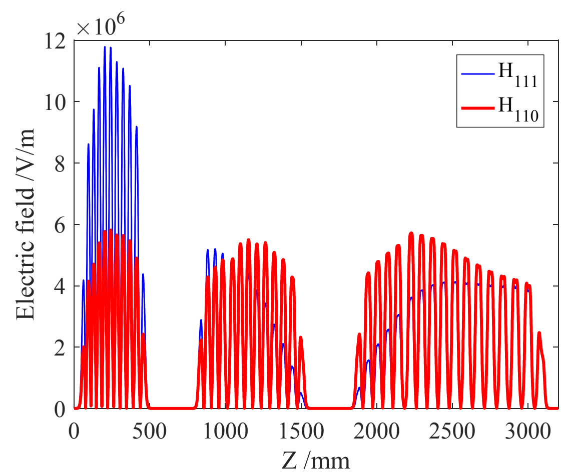

Figure 2: The on-axis electric field distribution compare between the H_{110} and H_{111} mode.

To avoid stimulating the H_{111} mode, the magnetic field distributions of both the operation and nearest mode are studied. As shown in Fig. 3, the magnetic field distributions are different between these two modes at the second focusing lens, so we can locate the power coupler here. When the coupler is tuned to the critical coupling for the H_{110}

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mode, the coupling coefficient for the H_{111} mode is near zero.

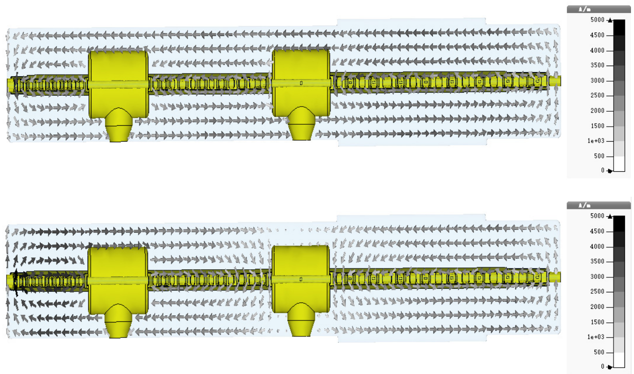

Figure 3: Compare of magnetic field distributions between the operation (up) and nearest mode (down).

BEAM DYNAMICS CHECK USE 3D EM-FIELD

The actual electromagnetic field in the IH-DTL can hardly be in full accord with the dynamics designed values. In order to check the 3D field generated by CST-MWS, a PIC (Particle in Cell) particle tracking code Beampath [5] is employed to simulate the transmission and acceleration situation of the beam in the IH-DTL. Because the 3D electromagnetic field from the CST-MWS corresponds with 1Joule stored energy, the field value must be scaled to the dynamic design value before imported to the Beampath code. This scale coefficient can be obtained by one particle tracking which with 0 emittance and 0 current.

Table 1: Phase Space Parameters at the Entrance of IH-DTL

Parameter	Value
$\varepsilon_{x/y,n,rms}$	0.24 πmm·mrad
$\alpha_{x/y}$	0.7
$\beta_{x/y}$	0.5 mm/mrad
$\varepsilon_{z,n,rms}$	30 πkeV/u·Deg
α_z	-1.0
β_z	1.76 Deg/(keV/u)

After the RF phase and scale coefficient of the 3D field are ascertained, multiparticle tracking can be launched. At the starting point of the simulation, 10000 macro particles with 500eμA beam current, the phase space parameters in table 1 and Water Bag distribution are generated. Beam transverse envelope (90% particles) is matched by tuning the focusing parameters of quadrupole triplets inside the cavity which shown in Fig. 4. The Fig. 5 shows the evolution of beam bunch length and energy spread in the IH-DTL. For the structure asymmetry of the IH-DTL in X direction, electric field in the drift tube is also unsymmetry in this direction. It will diverge the beam centre from the cavity axis, as shown in Fig. 6. This deviation of 0.5mm is acceptable in the operation. At the exit of the IH-DTL (including a quadrupole triplet subsequent), beam phase space distribution is shown in Fig. 7. Beam transfer efficiency of the IH-DTL is 100%. PIC particle tracking proves the validity of the RF design.

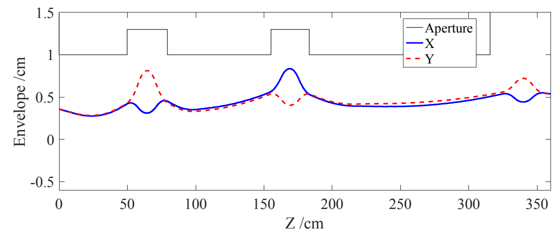

Figure 4: Beam transverse envelope in the IH-DTL.

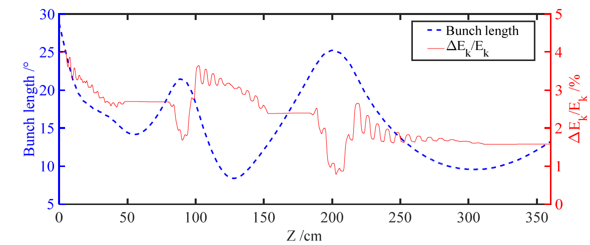

Figure 5: Beam bunch length and energy spread in the IH-DTL.

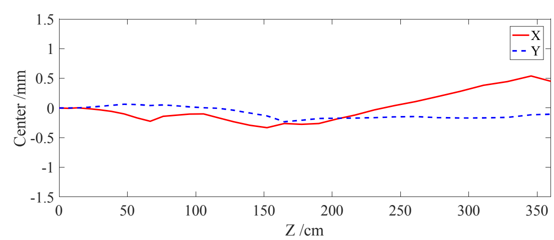

Figure 6: Beam centre deviation in the IH-DTL.

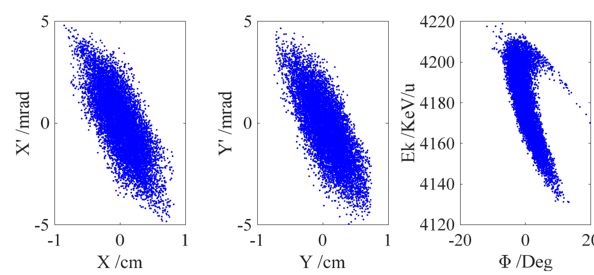

Figure 7: Beam phase space distribution at the exit of the IH-DTL.

COLD MODEL RF MEASUREMENT

A cold model cavity of the IH-DTL, as Fig. 8, has been constructed which machining precision of all the components is less than ±0.02mm. 4 plunger tuners and 2 shells of the quadrupole triplet are mounted on the upper and bottom cover. 40 drift tubes are installed on the middle frame by the stems and two girders. The final 3D installation accuracy of the drift tubes reaches ±0.05mm by using the FARO arm which one point accuracy reaches ±0.025mm, a high precision cylindrical rod which outer diameter

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equals to the inner diameter of the drift tube and some hollow cylinder which height equals to the each gap length respectively.

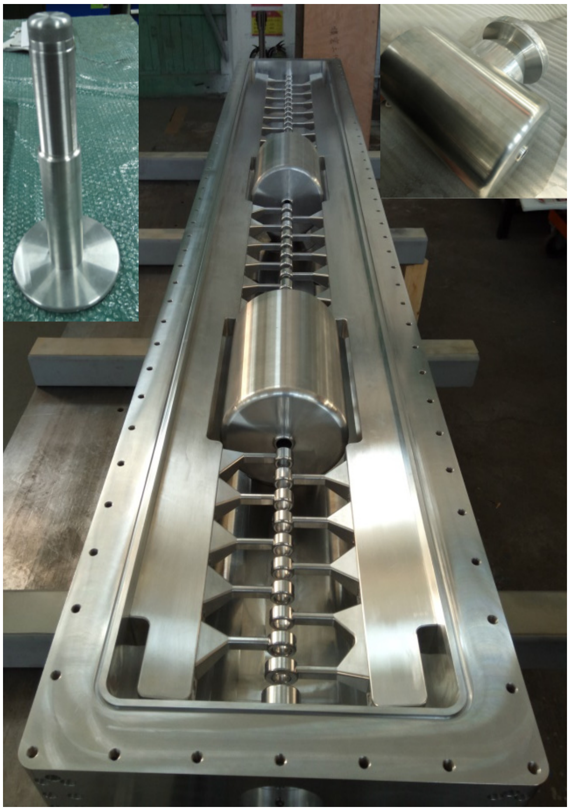

Figure 8: The assembled aluminium alloy cavity of the IH-DTL.

Before the low level RF measurement, a power coupler of test case has been adjusted to critical coupling state. And the resonance frequency without 4 plunger tuner is 162.86MHz which is 14kHz lower than the CST-MWS simulation result. The measured frequency adjustable volume of the 4 plunger tuners is about 0.9MHz, which is big enough to resist the frequency detuning during the high power operation of the formal cavity in future. The measured Q0 value is about 5100 which is much lower than the simulation value of 9000 with the conductivity of 2.0e7 S/m. It is mainly because the surface of the components has not been polished carefully. Because after local manual polishing of one girder, the measured Q0 value is enhanced slightly.

Frequency tuning ability of each plunger is slightly different which can be seen in Fig. 9. The most important is that the electric field distribution is effect by the plunger tuner severity. The perturbation method is used as usually in the low level RF measurement of the IH-DTL. By adjusting the 4 plunger tuner combined with each other, the resonance frequency reaches to 162.5MHz, and the on-axis electric field distribution, as shown in Fig. 10 matches with the beam dynamics design situation at the same time. Comparing the measured value and the simulation value of the integral voltage of each cell, the maximum error is less than 3%. In principle, above-mentioned error can be tuned smaller by more elaborate adjusting on the 4 plunger tuner. On the other hand, the field distributions corresponding to the different position (in 5mm step) of each plunger tuner are measured which will help the future beam commissioning.

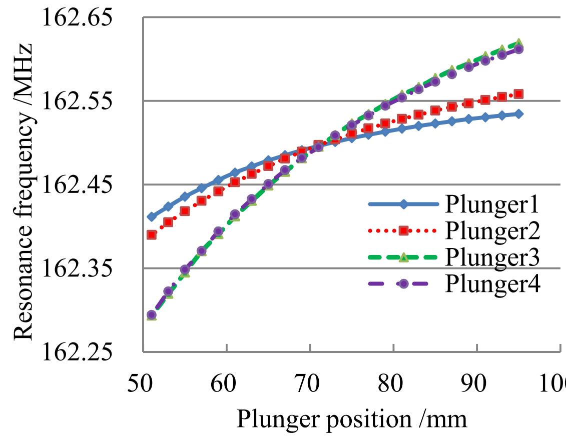

Figure 9: Frequency tuning ability of each plunger tuner vs. the distance between the plunger and the axis of the cavity.

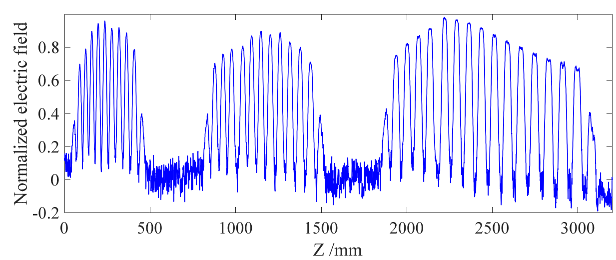

Figure 10: The measured on-axis electric field distribution.

CONCLUSION

RF structure design of the IH-DTL for the HIMM linac injector have been finished and proved to be effective to the beam dynamics design. The cold model of this IH-DTL is also constructed and tested. The LLRF measurement results can meet the design expectations. Power cavity and the internal quadrupole triplet of this IH-DTL are during the optimization process and will be completed in 2019.

ACKNOWLEDGMENTS

We are grateful to Y.R. Lu at PKU for his suggestions and would like to thank J. X. Wu and Z. Xu at IMP for their help.

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