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MECHANICAL DESIGN AND ERROR ANALYSIS OF A 325 MHz IH-DTL TEST CAVITY

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Abstract

A 325 MHz interdigital H-mode drift tube linac (IH-DTL) test cavity with a modified KONUS beam dynamics is under fabrication at Tsinghua University. The inner diameter of the tank increases from 196.8 to 232.6 mm. The mechanical design is considered carefully because of its small geometry. A three-piece design has been adopted in the mechanical design. The error analysis is carried out to determine the error requirement of machining and alignment. The details of mechanical design and error analysis are presented.

INTRODUCTION

IH DTL has been proposed and studied since 1956. The first IH cavity is been fabricated at Munich University at 1977. The shunt impedance of IH DTL is very high when the beam velocity is low (beta<0.1). IH DTL has been adopted in the proton and ion accelerators widely because of this advantage [1]. The drift tube diameter of the IH DTL is smaller than those DTLs. It is difficult to house the quadrupoles in those slim drift tubes of the IH DTL. Thus, there are two kinds of beam dynamics design have been developed for the IH DTL: KONUS (Kombinierte Null Grad Struktur) and APF (Alternating Phase Focusing). Different beam dynamics designs lead to the different mechanical designs [2-4].

In recent years, IH DTL has been adopted in the medical proton and carbon accelerators. A 325 MHz IH-DTL is proposed and under development for medical purpose at Tsinghua University. A modified KONUS beam dynamics has been applied in this IH DTL design. The design results are shown in [5]. This short DTL tank is 1.4 m while there is no focusing element in it. The main parameters of this linac is shown in Table 1.

The mechanical design of IH DTL changes a lot when the frequency is different [6-8]. For this high frequency IH DTL, the inner diameter of the tapered cavity increases from 196.8 mm to 232.6 mm. There are some difficulties for fabrication due to the small diameter. The details of the mechanical design will be presented in 2nd section.

The errors of fabrication and alignment for the IH DTL are very important, which could influence the field distribution and the RF frequency greatly. Those errors have been studied carefully with the 3D RF simulation code. The results of the simulation and the error tolerance will be presented in 3rd section.

Table 1: Parameters of the IH-DTL

Parameters	Value
Particle species	Proton
Frequency	325 MHz
Injection energy	3 MeV
Exit energy	7 MeV
Peak current	15 mA
Tank length	1.14 m
Inner diameter of the cavity	196.8~232.6mm
Inner diameter of drift tubes	16 mm
Outer diameter of drift tubes	26 mm
Number of cells	21

MECHANICAL DESIGN

Based on the beam dynamics design and RF design of the IH DTL, the mechanical design has been done [5]. The dimension of the whole tank is 340 mm * 300 mm* 1143 mm. To lower the fabrication cost, a three-piece design is adopted for this IH DTL tank. The tank is composed of two tank half shells and one central frame. The drift tubes are bolted to the central frame. The tuners, co-axial RF coupler and vacuum pipes are mounted on the two tank half shells. The whole view of the mechanical design is shown in Fig. 1.

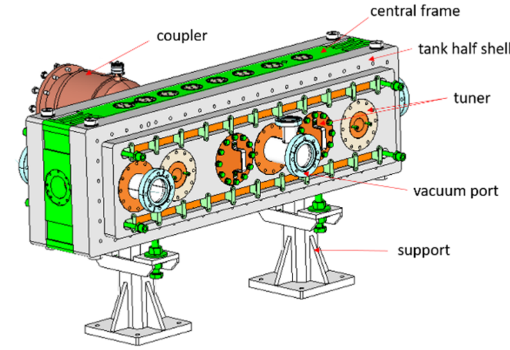

Figure 1: Assembly view of the IH DTL.

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The most complicated and difficult part of the IH DTL fabrication is the fabrication of the central frame. In Ref [9], the drift tubes, the ridges and the outer frame are machined from one piece of copper block. For this IH DTL, the ridges are machined with the outer frame in one piece from mild steel. The inner surface of the central frame is copper plated and the thickness of the copper is 150±20μm. The drift tubes are machined from copper blocks and bolted to the ridges. There are 16 cylindrical holes (Ø10 mm) on the ridges which are used to align the drift tubes. Because of the distance between the two flat surfaces of the ridges is too small to fabricate the alignment holes, there are 16 stepped holes are used to machine the alignment holes from outside. There is an Indium wire groove on each stem of the drift tube which is used to fullfill the RF contact. The vacuum is sealed by the o-ring grooves on the stepped holes. The layout of central frame is shown in Fig. 2.

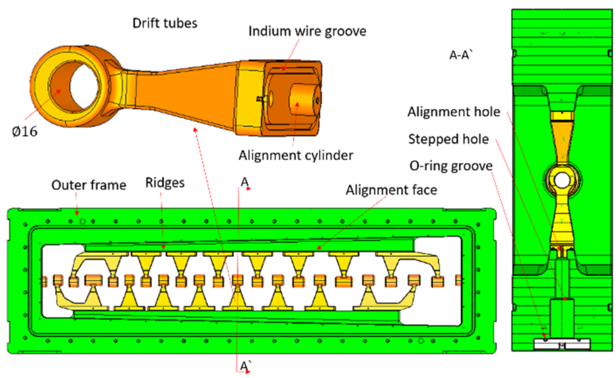

Figure 2: Schematic drawing of the central frame.

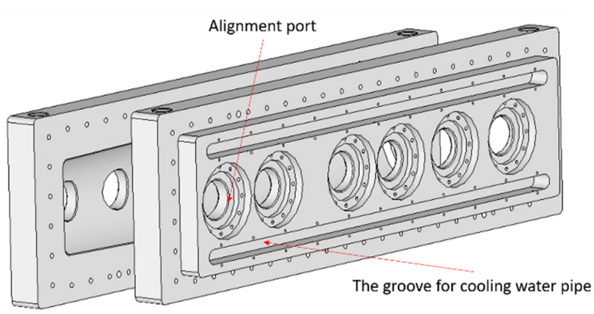

Figure 3: Schematic drawing of the tank half shells.

The two tank half shells are bolted to the central frame. The vacuum and RF contact are sealed by the aluminium wire. The o-ring groove is machined on the central frame which is a back-up for the vacuum seal if the aluminium wire is not sufficient for the vacuum seal. The schematic view of the tank half shell is shown in Fig. 3. The dimension of those alignment ports on the tank half shells are the same. Thus the tuners, RF couplers and vacuum pipes can exchange their positions with each other. Almost all the components are bolted together without copper plate, which can improve the accuracy of alignment as well as the power loss increases. The RF source is sufficient to cover the extra power requirement.

ERROR ANALYSIS

For the IH DTL, the electric field distribution is mainly influenced by the alignment and machining of those components, which will have effect on the beam dynamics. After the error analysis of the IH DTL beam dynamics, the error of gap voltage distribution should be smaller than±3%. To analyse the tolerance of the alignment and machining, an IH DTL model of CST is constructed, which is shown in Fig. 4.

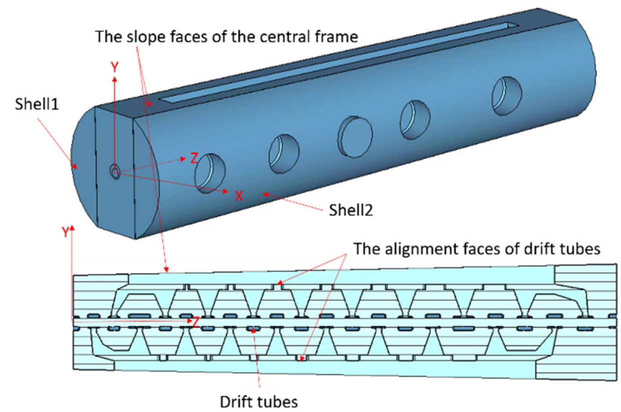

Figure 4: A CST model of IH-DTL for error analysis.

First of all, there is no error of alignment and machining is considered, 6 turns simulation with different meshes has been done, which are used to estimate the error of the simulation. The tetrahedron is used to mesh the cavity model and the maximum number of mesh is smaller than 200 million limited by the computer ability. The relative error of the gap voltage distribution is < ±0.4 %, which is shown in Fig. 5. Thus, there is a relative error of about 0.4 % which is caused by the code in the following error analysis results.

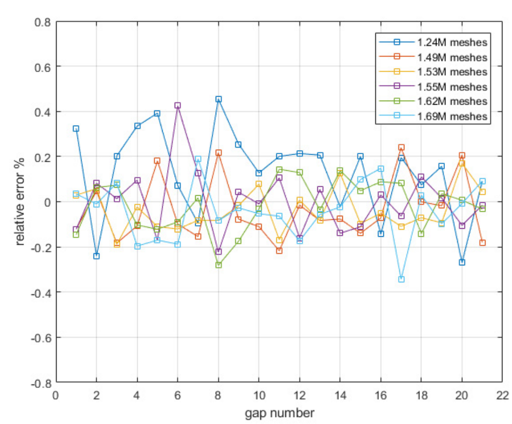

Figure 5: Relative error of CST simulation for different meshes.

Two kinds of errors have been considered in the error analysis. The first kind is the machining error, which includes the outer radius error of the drift tubes, the length error of the drift tubes, the distance error between the two alignment faces of drift tube, the distance error between the two slope faces of the central frame, the length error of the cavity and the radius error of the two shells. The other kind

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of error is the misalignment error, which includes the misalignment error of the drift tubes to the central frame as well as the two shells. Because of the large time cost of the 3D model simulation, only 6 turns of simulation with different errors have been done, which are used to estimate the range of the tolerance.

For the 1st run, the position deviations of all the drift tubes are random with the uniform distribution. The range of the deviation is ±0.3 mm, ±0.3 mm and ±0.14 mm for Z, X and Y directions separately. The length of the drift tubes are also random and the range is ±0.06 mm. The outer radius of all the drift tubes is extended 0.03 mm. The length of the cavity is extended 0.4 mm. The distance between the two alignment faces of the drift tubes is extended 0.4 mm. The distance between the two slope faces of the central frame is extended 0.2 mm. The radius of the two shells is extended 0.1 mm. The position deviation of the two shel1s to the central frame is 0.1 mm and 0.2 mm in Y and Z direction respectively.

For the 2nd run, the outer radius extension of all the drift tubes is changed to 0.06 mm. The distance extension between the two slope faces of the central frame is changed to 0.4 mm. The radius extension of the two shells is changed to 0.2 mm. The position deviation of the two shel1s to the central frame is changed to 0.2 mm in Y direction. The other errors are the same as the first run.

For the 3rd run, the outer radius of all the drift tubes is shortened 0.06 mm. The length of the cavity is shortened 0.4 mm. The distance between the two alignment faces of the drift tubes is shortened 0.4 mm. The distance between the two slope faces of the central frame is shorted 0.2 mm. The radius of the two shells is shorted 0.2 mm. The position deviation of shel11 to the central frame is 0.2 mm and 0.2 mm in Y and Z direction respectively. The position deviation of shell2 to the central frame is -0.2 mm and -0.2 mm in Y and Z direction respectively. The others are the same as the 2nd run.

For the 4th run, the distance error between the two alignment faces of the drift tubes is set to 0.0 mm. The others are the same as the 3rd run. For the 5th run, the radius error of the two shells is set to 0.0 mm. The others are the same as the 4th run. For the 6th run, the Y position deviation of all the drift tubes is 0.0 mm. The others are the same as the 3rd run. All the relative error of the gap voltage distribution is shown in Fig. 6.

From those simulations, the mainly requirements for the machining and alignment of the IH DTL is quite relax. Considering the ability of the manufacturer, the final fabrication requirements for the IH DTL are as following. The machining error of the cavity length is <±0.2 mm. The distance error between the two slope faces of the central frame is <±0.1 mm. The distance error between the two alignment faces is < ±0.1 mm. The alignment error of the shells and the central frame is <±0.1 mm. The radius error of the shells is <±0.1 mm. The outer radius error of the drift tubes is both <±0.03 mm. The length error of the drift tubes is both <±0.05 mm. The position error of the drift tubes is <±0.05 mm, < ±0.1 mm, < ±0.1 mm in Y, X, Z direction separately.

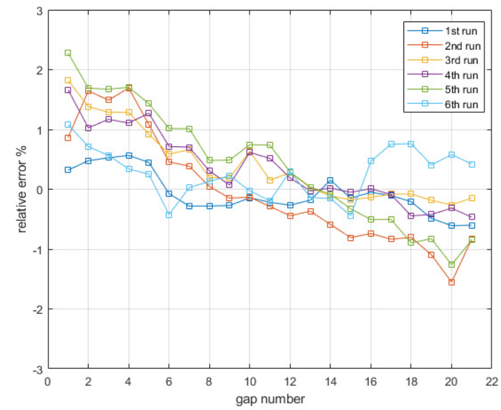

Figure 6: Calculated relative error of gap voltage distribution for different error setting.

CONCLUSION

The mechanical design of the 325 MHz IH DTL at Tsinghua University has been carried out. A three-piece design has been adopted in the tank. All the components are bolted together while the vacuum and RF seal are considered carefully. According to the mechanical design, an error analysis for both machining and assembly has been done with the CST code. The relative error of the gap voltage distribution caused by the simulation is <±0.4%. 6 kinds of error settings have been run and the maximum relative error is <±2.5% which is smaller than the beam dynamics criteria (< ±3%). The error requirement of the machining and alignment of the IH DTL tank is presented after the error analysis. The IH DTL tank is under fabrication now and will be finished at the end of June.

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REFERENCES

[1] U. Ratzinger, "H-Type Linac Structures", in CERN Accelerator School 2000, CERN Yellow Report 2005003, Geneva, Switzerland, 2005, pp. 351-380.
[2] Y. Lu, "Development of an IH-DTL Injector for the Heidelberg Cancer Therapy Project", (Ph.D. thesis), Physics Department, Frankfurt University, Frankfurt, Germany, 2005.
[3] K. Yamamoto, H. Tanaka, H. Harada *et al.*, "Experimental verification of an APF Linac for a Proton Therapy Facility[J]", *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, vol. 269(24), pp. 2875-2878, 2011.
[4] Y. Iwata *et al.*, "Model cavity of an alternating-phase-focused IH-DTL", *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment,* 566.2 (2006): 256-263.
[5] R. Tang *et al.*, "Beam Dynamics of a 325 MHz IH-DTL with KONUS", in *Proc. SAP2017*, Jishou, Hunan, China, 2017, paper MOPH12.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPAL075

[6] X. L. Du, "Design and Cold Test of IH DTL for Heavy Ion Linac", (Ph.D. thesis), University of Chinese Academy of Sciences, Lanzhou, China, 2013.
[7] D. Warner *et al.*, CERN heavy-ion facility design report. No. CERN--93-01, European Organization for Nuclear Research, 1993.
[8] P. Bricault *et al.,* "Tank1 of the ISAC-DTL Linac", in *Proc. PAC'99*, New York, USA, 1999, paper FRA66, pp. 3540-3542.
[9] M. Otani *et al.*, "Interdigital H-mode drift-tube linac design with alternative phase focusing for muon linac", *Physical Review Accelerators and Beams*, vol. 19, 040101, (2016).