THE SIMULATION OF THE ROOM TEMPERATURE CROSS-BAR H TYPE DRIFT TUBE LINAC*

Jinhai Li[#], Shuoyu Zheng, China Institute of Atomic Energy, Beijing, China
Zhihui Li, Institute of Nuclear Science and Technology, Sichuan University, Chengdu, China

Abstract

The room temperature Cross-bar H Type Drift Tube Linac (CH-DTL) is one of the candidate acceleration structures working in CW mode. In order to optimize the parameters, the 3 dimensional electromagnetic field of the CH-DTL cavity is simulated. The method of parameter sweeping with constraint variable is better than the method of parameter sweeping with only one variable during the optimization. In order to simplify the manufacture, the drift tube surface can be designed as spherical shape. The effective shunt impedance of the CH-DTL cavity with cylinder end cup is better than that with cone cup.

INTRODUCTON

An industrial scale ADS will require a 10 MW proton beam having an energy between 600 and 1500 MeV. To achieve the required power at this energy will require an average beam current of ≥10 mA. In2010, a study program was initiated to develop the design a 10 mA, 1.5 GeV, CW superconducting proton linac for ADS. The Institute of High Energy Physics (IHEP) and the Institute of Modern Physics (IMP) are both developing superconducting accelerating structures which would follow an RFQ [1].

Although low AC power consumption and a large aperture favour superconducting structures following a 2-3.5 MeV RFQ, normal-conducting accelerating structures have some advantages [2-5]. While the technology for normal-conducting structures in the energy range from 2 to a few tens of MeV is relatively mature, superconducting structures in this energy range are still under development. Normal-conducting structures in this energy range are more efficient than superconducting cavities and, when located downstream of the RFQ, can serve as a beam filter to reduce the potential for beam loss at higher energies.

Under the support of the National Nature Science Foundation of China, we have initiated the design of a 10 MeV CW proton injector, based on normal-conducting Cross-Bar H-type (CH) structure. The CH structure, initially proposed by IAP, Frankfurt University [6, 7] belongs to the π-mode family of accelerating structures and is typically characterized by a high shunt impedance, low stored energy and a stable geometry that is relatively easy to cool. We are evaluating this structure as a potential candidate for CW operation. In this paper we present the results of geometry optimization of the CH structure using the method of parameter sweeping with constraint variable (PSCV).

*Work supported by NSFC (91126003)
#lijinhai@ciae.ac.cn

OPTIMIZATION PHILOSOPHY

The final energy of modern proton RFQs is typically 3MeV, corresponding to a relativistic velocity β=0.08. The room-temperature CH-DTL can be used to accelerate the beam starting at this velocity. The CH structure belongs to the π-mode family of structures in which the cells are βλ/2 long, the cell length at β=0.08 being about 37mm. To save simulation time, the geometry of a single cell was first optimized followed by the optimization of the complete multi-cell cavity. The parameters of a single cell are shown in Fig. 1. The outer drift tube radius (TR) and the radius of the drift tube aperture (HR) are fixed during the optimization.

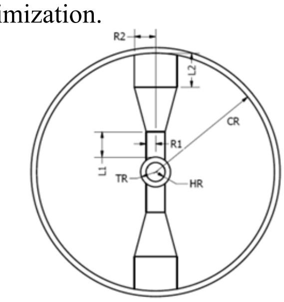

Figure 1: Geometry of a CH single cell.

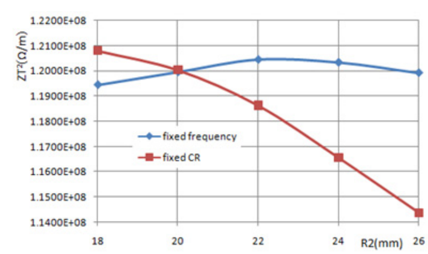

Figure 2: Shunt impedance as a function of outer stem radius using two methods of parameter sweeping.

Typically we would sweep a single parameter while monitoring the cavity's RF properties. For example, we know that changing the length of a drift tube causes a corresponding change in the cavity's Q value [6]. However, by changing the length of a drift tube, the resonant frequency changes. Our objective is to optimize the cavity geometry at a fixed frequency (325 MHz). If the frequency changes during the optimization, the optimized value of the swept parameter will differ from the value corresponding to the correct frequency as shown in Fig. 2. In Figure 2 we have swept the radius of the drift-tube stem base (R2) while fixing the cavity radius (CR). We see that the effective shunt impedance decreases with increasing R2 while the resonant frequency increases from 321.7 to 333.5MHz. It is convenient to use the cavity radius (CR) as a "constraint variable" to fix the resonant frequency to 325 MHz. By doing so we find that the maximum effec-

ISBN 978-3-95450-136-6

tive shunt impedance at the correct frequency occurs at R2=22. We refer to this method as "parameter sweeping with constraint variables" (PSCV). Other parameters can be selected as constraint variables, but we find that the resonant frequency is more sensitive to cavity radius than it is to other geometrical parameters.

DRIFT TUBE GEOMETRY

The drift tube in CH-DTL is typically much smaller than drift tubes in a conventional DTL, and there is little possibility to optimize the drift tube length and outer radius (TR). The small drift tubes have much smaller capacitance resulting in a higher shunt impedance however, because they are so small they are difficult to manufacture with integral cooling channels [7]. Traditional drift tubes are nominally cylindrical. By modifying the design to have a spherically shaped drift tube, the stem and drift tube can be manufactured (turned) in one step without welding or brazing. In Figure 3 we can see that axis of revolution for the stem is coaxial with that of the drift tube. The effective shunt impedance of the spherical drift tube is only slightly lower than that of the cylindrical drift tube (<1%) as shown in Fig. 4.

Figure 3: Spherical drift tube.

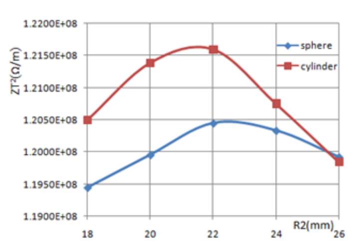

Figure 4: Shunt impedance for two different drift tube shapes as a function of the stem-base radius.

OPTIMIZATION OF A SINGLE CELL

The CH single cell is shown in Fig. 5, and is composed of one acceleration gap and two half stems and half drift tubes. The TE_{210} mode is established in the single cell, by imposing the boundary condition that the magnetic field, that encircle the stems, be perpendicular to the end planes.

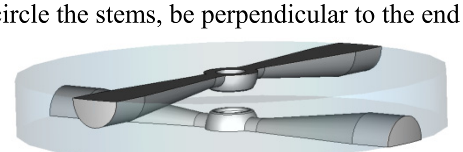

Figure 5: 3-D geometry of a single cell.

To optimize the shunt impedance of the single cell, we have adjusted the lengths of the inner and outer cylindrical stem segments, L1 and L2, as well as the radius of the stem base, R2, while using the cavity radius, CR, as the constraint variable to maintain the resonant frequency. The inner stem radius, R1, is physically constrained by the drift tube radius and can't be changed. For this calculation we have fixed the axial length of the single cell to be 37 mm, corresponding to a beam velocity β=0.08. We first swept the value of R2 from 18 to 26 mm as shown in Fig. 4, to find that the maximum effective shunt impedance is obtained at R2=22 mm.

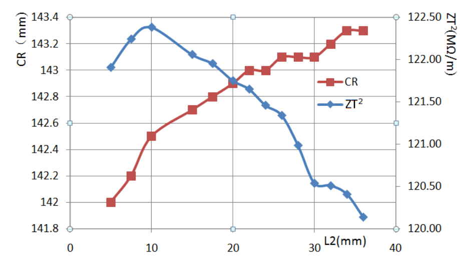

Figure 6: Shunt impedance and cavity radius at a fixed frequency as a function of L2.

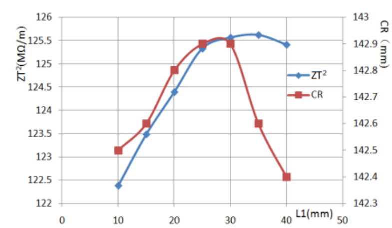

Figure 7: Shunt impedance and cavity radius at a fixed frequency as a function of L1.

Setting R2 to 22 mm we then swept L2 to find that the highest value for shunt impedance occurs for L2=10 mm as shown in Fig. 6. Finally, setting L2 to 10 mm, we swept L1 to find that the maximum effective shunt impedance occurs for L1=35 as shown in Fig. 7.

In each of these procedures we see that the maximum shunt impedance occurs at a different cavity radius, CR, which has been constrained to assure resonance at 325 MHz. Because the values of L2 and L1 have been changed, we sweep R2 again, to find that the maximum effective shunt impedance occurs at R2=27mm as shown in Fig. 8. Comparing Figs. 4 and 8 we can see that the maximum effective shunt impedance has increased from 121 to 128 MΩ/m while the optimized value of R2 has increased from 22 to 27 mm. We found that iterating this procedure a third time yields minimal improvement in the shunt impedance.

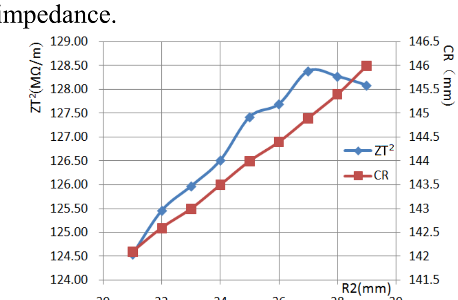

Figure 8: Shunt impedance and cavity radius at a fixed frequency as a function of R2.

ISBN 978-3-95450-136-6

OPTIMIZING THE MULTI-CELL CAVITY

Our multi-cell CH-DTL cavity model includes four drift tubes and five gaps as shown in Fig. 9. In addition to the parameters optimized above, the multi-cell cavity contains two additional geometrical features requiring optimization. These include the length and radius of the end cups (EL and ER). We first swept ER to find that the effective shunt impedance is inversely proportional to ER as shown in Fig. 10.

In this calculation we have considered only the central portion of the cavity containing the drift tubes. In other words, the cavity is assumed to be only 5 times the length of a single cell or 185 mm and only the faces of the end cups are included. In order to accommodate the magnetic elements needed for beam focusing, ER should not less than 60 mm.

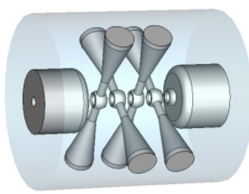

Figure 9: 3-D geometry of the 5-cell CH-DTL cavity model.

As we increase the end cup length(EL) we see that the effective shunt impedance(ZT^2) decreases rapidly due to the power dissipated in the end regions where no acceleration occurs as shown in Fig. 11.

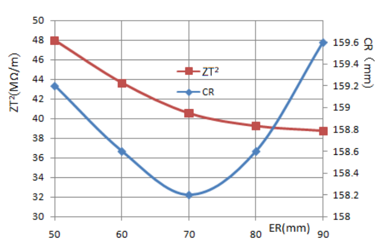

Figure 10: ZT^2 and cavity radius at a fixed frequency as a function of ER for a 5-cell cavity without end cups.

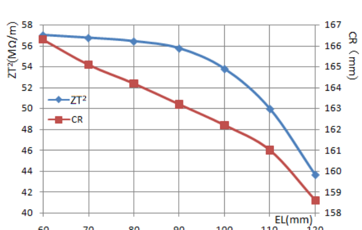

Figure 11: ZT^2 and cavity radius at a fixed frequency as a function of EL for a 5-cell cavity with end cups.

THE MANUFACTURE OF THE CAVITY

The material of the whole cavity is made of copper. The cavity wall, the end cell and the drift tube with the stem have been made as shown from Figs. 12 to 14.

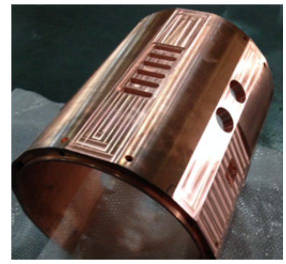

Figure 12: The CH-DTL cavity wall.

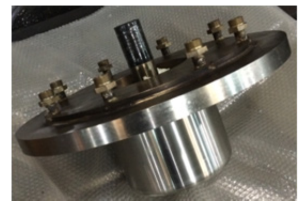

Figure 13: The CH-DTL end cell.

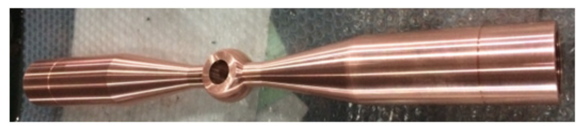

Figure 14: The drift tube with stem.

We will weld the drift tube to the cavity wall later and measure the RF property of the low power.

ACKNOWLEDGMENT

This work is supported by the National Natural Science Foundation of China (NSFC). I would show my best thanks to James Edward Stovall for his kind help.

REFERENCES

[1] WeimingYue, X. L. Guo, S. He, Y. He, R. X. Wang, P. R. Xiong, M. X. Xu, B. Zhang,S. H. Zhang, S. X. Zhang, H. W. Zhao, R&D of IMP Superconducting HWR for China ADS, proceedings of LINAC2012, 2012, TUPB055, pp 600-602.

[2] L. Ristori, G Apollinari, I. Gonin, T. Khabiboulline, G. Romanov, design of normal conducting 325 MHz crossbar H-type Resonators at fermilab, proceedings of LINAC2006, 2006, THP057, pp 710-712.

[3] L. Ristori, G. Apollinari, I. Gonin, T. Khabiboulline, G. Romanov, fabrication and test of the first normal-conducting crossbar H-type accelerating cavity at fermilab for HINS, Proceedings of PAC07, New Mexico, 2007, WEPMN110, pp. 2292–2294.

[4] W-M. Tam,G. Apollinari, T. Khabiboulline, R. Madrak, A. Moretti, L. Ristori, G. Romanov, J. Steimel, R. Webber, D. Wildman, proceedings of LINAC2008, Victoria, 2008, MOP012, pp 79-81.

[5] R.C. Webber,G. Apollinari, J. P. Carneriro, I. Gonin, B. Hanna, S. Hays,T. Khabiboulline, G. Lanfranco, R. L. Madrak, A. Moretti, T. Nicol, T. Page, E. Peoples, H. Piekarz, L. Ristori, G. Romanov, C.W. Schmidt, J. Steimel, W. Tam, I. Terechkine, R. Wangner, D. Wildman, proceedings of LINAC2008, Victoria, 2008, MO301, pp 36-40.

ISBN 978-3-95450-136-6

[6] Gianluigi Clemente, The room temperature CH-DTL and its application for the FAIR Proton injector, Ph.D. dissertation, University Frankfurt, 2007, p52.
[7] U. Ratzinger, R. Tiede, H. Podlech, G. Clemente, B. Hofmann, A. Schempp,L. Groening, W. Barth, S. Yaramishev, Z. Li, and S. Minaev, The 70 MeV p-Injector Design for FAIR, AIP Conference Proceedings 773, (2005), p249-253.

ISBN 978-3-95450-136-6