RESEARCH ON A TWO-BEAM TYPE DRIFT TUBE LINAC*

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Abstract

The very high intense heavy-ion beam is a high attraction for heavy ion researches and heavy-ion applications, but it is limited by heavy-ion production of ion source and space-charge-effect in acceleration. There is one way, accelerating several heavy-ion beams in one cavity at same time and funneling them, which could achieve the acceleration of very high intense heavy-ion beam with existing ion source and accelerating technology. The research purpose is to design a two-beam type drift tube linac (DTL), which could be used as high intense heavy ion injector, such as a driver of heavy ion inertial fusion. In this paper, we will introduce our designs, calculations and simulations.

INTRODUCTION

In the last decades, three breakthroughs were invented and developed for high intense heavy ion acceleration [1]: the 1st one is the invention of radio frequency quadrupole (RFQ) type accelerator, which could accelerate more than one dozens of milliampere ion beam [2-3], the 2nd invention is the direct plasma injection scheme (DPIS), which provide a way to produce a very high intense heavy ion beam [4-6], and the 3rd invention is multi-beam IH-RFQ type accelerating structure, which accelerated 108 mA carbon ions successfully in 2010 by using DPIS [7].

These inventions, especially, the invention of multi-beam RFQ, which is suitable for accelerating heavy ions in the very low energy region, make the production and the acceleration of very high intensity heavy ion beam possible such as an injector of heavy ion inertial fusion. In this paper, we propose a 2-beam type DTL for accelerating very high intense heavy ion beam in low-middle energy region. This 2-beam DTL can double the existing beam current and can be used as a post-accelerator to accelerate two high intense heavy ion beams which could be funnelled from four accelerated heavy ion beams after a 4-beam type RFQ [8]. Our proposed 2-beam type DTL is a totally normal interdigital-H (IH) DT structure, using TE_{111} resonated mode and the acceleration will be occurred between drift tubes. The two beam tunnels are off-set from the center of the DT, and both are located in the vertical direction of cavity axis. The image of a proposed 2-beam type DTL is shown in Fig. 1.

Our goal is to design and fabricate a proof of principle (PoP) 2-beam type DTL which could accelerate ions from 50 keV/u up to 1.5 MeV/u in one meter. The focusing method we adopted is the alternative phase focusing (APF) method, which had already accelerated 1.5 MeV P^{2+} CW beam and 7.4 MeV (1.5 MeV – RFQ + 5.9 MeV - DTL) 10 mA-proton beam in 2009 and 2010 [9].

STRUCTURE SIMULATIONS

The beam orbit calculation is used Pi Mode Orbit Calculation (PiMLOC) [10] to calculate the profiles of the DTs and gaps. And the Microwave Studio （MWS）[11] was utilized to perform electromagnetic simulations of the cavity.

In this researcher, the structure, especially the DT structure and location of beam channel were firstly studiedby using MWS. The structure shown in the Fig. 1 is not the first idea, the first thing of our design is to check

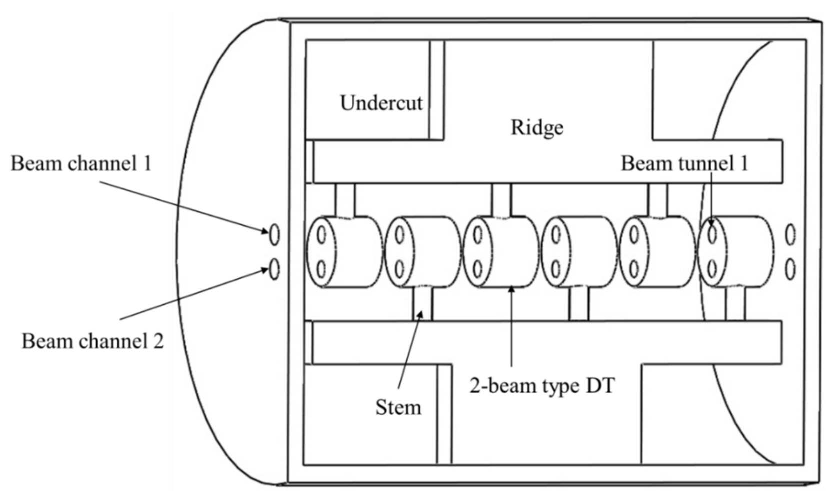

Figure 1: An image of the designed 2-beam type IH-DTL.

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the position of the beam channel, and. The initial structure we designed is shown in the Fig. 2, in which, two DTs were installed on one stem, one DT have only one beam channel, both two beam channels are on the y direction (same direction with stems) and have a same distance from the cavity center. This structure has a merit for beam injection because the two beam channels have an enough distance for beam matching before DTL. Figure 3 shows the electric field along the beam axis and cavity axis. The field distributions show that the expected accelerating voltage will be not produced between the gaps shown in Fig. 2. From Fig. 3, it can be seen clearly the excited electric field will be only concentrated in the cavity axis, and produce a zero field on the DT's axis.

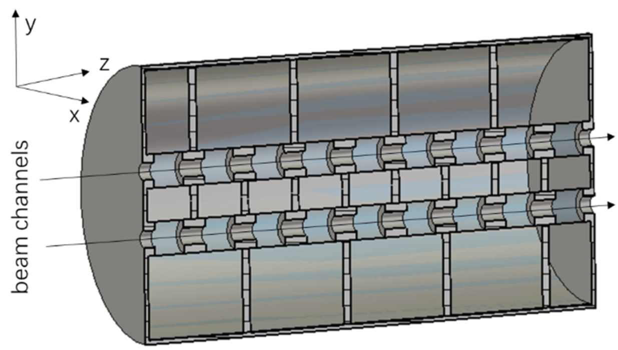

Figure 2: A cut-view of the initial designed structure of a two-beam DTL.

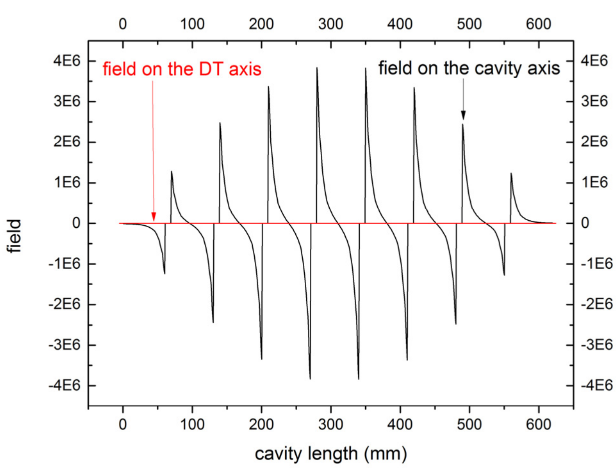

Figure 3: Field distributions on the beam axis and cavity axis in the structures shown in the Fig. 2. The value shown in the y axis is calculated out from the MWS.

And other structures shown in Fig. 4 show very good uniformities in the electric field on the beam axes. In Fig. 4a and Fig. 4b, one DT have two beam channels on either side of the DT axis, both two channels are in the horizontal direction in Fig. 4a but in vertical direction in Fig. 4b. The structure shown in the Fig. 4c shows a 4-beam type DTL. One DT have four beam channels. These structures were only used to check the electric field on the central DT. And these structures have demerit about injection space, but suitable for direct plasma injection scheme [11].

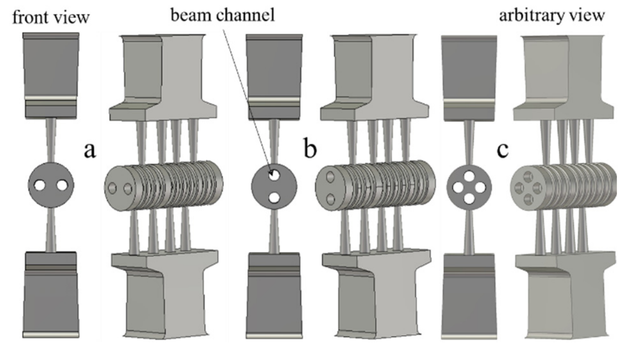

Figure 4: There structures were used to check the electric field distribution.

The electric field distributions shown in Fig. 5 show the structures of Fig. 4a and Fig. 4b have a same resonated property with normal DTL cavity, and both two field distributions on the beam channels meet very well. As shown in Fig. 6, all the field distributions on the beam axes sown in Fig. 4c are almost same. The simulated field distributions in Fig. 5 and Fig. 6 imply that the structures shown in Fig. 4 are suitable for multi-beam acceleration, and the properties of the resonated mode are total same with normal DT linac, which means the APF method can be adopted in the multi-beam type DTL structure.

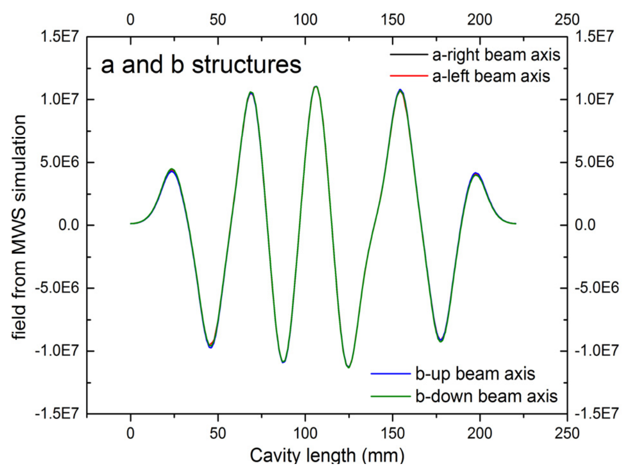

Figure 5: Field distribution on the beam axis in the structure shown in Figure 4-a and Figure 4-b.

Finally, we adopted the structure of Fig. 4b, because this type may adopts an ellipse DT (semi-major axis is in vertical direction), which is more flexible to design a better distance between two beam channels. Further, the core parts of the elliptical DT, including ridges, stems and DTs, can be shaped from a block copper by using numerically-controlled machine tools (NC). This NC shaping method from a block copper has a high accuracy with few assemblies and a better cooling effect [10].

And same to normal DTLs, the highest temperature in a two-beam type DTL is shown in the stem. Thus, the cooling loops in the stems should be designed as good as possible.

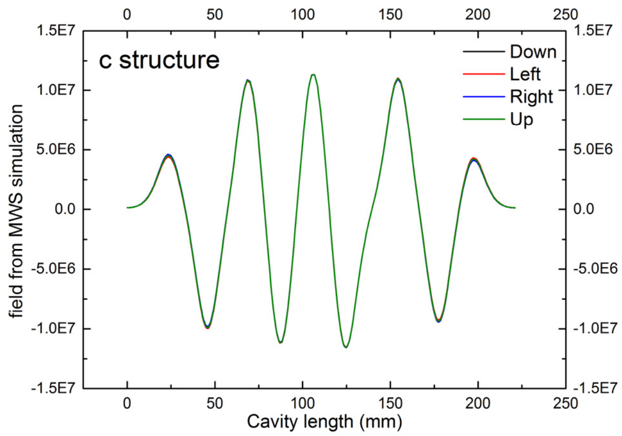

Figure 6: Four field distributions along the beam axis in the structure shown in Fig. 4c.

INITIAL BEAM DYNAMICS SIMULATIONS

The PiMLOC is a good simulation code for DTL designs, a CW operated DTL was designed by suing PiMLOC and successful operated in 2009. The designed initial parameters of the 2-beam type IH-DTL are listed in the Table 1. The whole inner length of cavity is designed to be less than 1 meter, and the cavity will be operated in pulse mode with a resonated frequency of 81.25 MHz. A 50 keV proton beam will be injected to the cavity and will be accelerated up to 1.5 MeV.

Table 1: Main Parameters of the Two-Beam Type DTL

ions	H^+
Frequency (MHz)	81.25
Inner cavity length (mm)	< 1 m
Beam channel No.	2
Bore	20
Synchrotron phase	-70, -30, 30, 30……
Input energy (keV/u)	50
Output energy (MeV/u)	1.5
Operation mode	Pulse

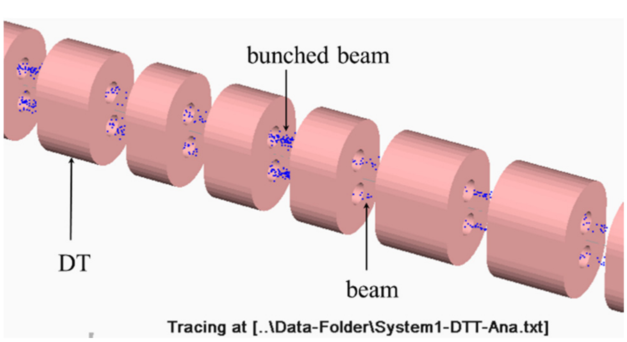

Figure 7: A calculation image of two-beam dynamics simulated by PiMLOC.

According to the latest calculation shown in Fig. 7, the transmission was only 60% which is not perfect yet, but it showed a good start of designs of the two-beam DTL and also gave us a confidence to design a better structure of the two-beam DTL. Our goal is to design a power-efficient two-beam DTL with over 80% transmission. From Fig. 7, the influence between two beams is also not been observed.

FUTURE PLAN

For an immediate-term planning, we have to finish all designs of two-beam type DTL in next June and finish the fabrications and assemblies in 2019, and the high power acceleration must be done in the 2020. For a long-range planning, we want to finish a design of a beam line shown in Fig. 8: a 4-beam type LIS, a 4-beam IH-RFQ with a beam funneling system and a 2-beam DTL, 1-beam DT cavities and superconducting cavities.

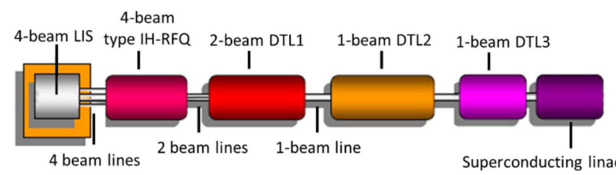

Figure 8: A layout of multi-beam cavity injector.

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REFERENCES

[1] L. Lu, T. Hattori, *et al.*, Nucl. Instrum. Methods Phys. Res. A 729 (2013) 133-137.
[2] K. R. Crandall *et al.*, Proc. 1979 Intn. Linear Accelerator Conf. (1979) 1.
[3] R. W. Hamm *et al.*, Proc. Intn. Conf. Low Energy Ion Beams 2, LA-UR-80-091 (1980) 14.
[4] M. Okamura, T. Hattori, *et al.*, Nucl. Instrum. Methods Phys. Res. B 188, 216 (2002).
[5] M. Okamura, T. Hattori, *et al.*, Rev. Sci. Instrum. 73, 761 (2002).
[6] H. Kashiwagi, T. Hattori, *et al.*, Rev. Sci. Instrum. 75, 1569 (2004).
[7] T. Ishibashi, N. Hayashizaki, *et al.*, Phys. Rev. Spec. Top. Accel. Beams 14 (2011) 060101 1-25
[8] L. LU, T. Hattori, *et al.,* in *Proceedings of the 20th International Symposium on Heavy-Ion Inertial Fusion, Design Study of a 4-beam type IH-RFQ for PoP HIF Injector with Laser Ion Source,* (HIF2014, Lanzhou, China, 2014), to be printed.
[9] K. Yamamoto, *et al.,* Nucl. Instrum. Methods Phys. Res. B 269 (2011) 2875-2878.
[10] L. Lu, T. Hattori, *et al.*, Nucl. Instrum. Methods Phys. Res. A 688 (2012) 11-21.
[11] https://www.cst.com/Products/CSTMWS

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