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DESIGN AND LOW POWER TEST OF A PROTOTYPE HOM LINAC

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Abstract

Normally, drift tube linacs (DTLs) are used following RFQ linacs for beam acceleration in middle and high energy region. The acceleration efficiency of DTLs is decreasing with beam energy increasing. Using resonated higher order mode (HOM) of cavity, DTLs can achieve a higher effective shunt impedance. We proposed a 325 MHz DTL with TE_{115} mode and finished the 1st HOM-DTL assembly. In this paper, the designs and results of low power test of the 1st HOM-DTL will be reported.

INTRODUCTION

As shown in Fig. 1 [1], in the low energy region, the interdigital H-mode (IH) type DTLs have a higher shunt impedance and suitable accelerating structure for heavy ion acceleration, thus the DTLs operated in TE_{111} mode are commonly used following the RFQ type linac [2-3]. However, in the medium and high energy region, the Alvarez type DTLs operated in TM_{010} mode are commonly used although its shunt impedance reduces rapidly [4], as shown in Fig. 2, because its shunt impedance is higher than the IH-DTLs in those energy regions.

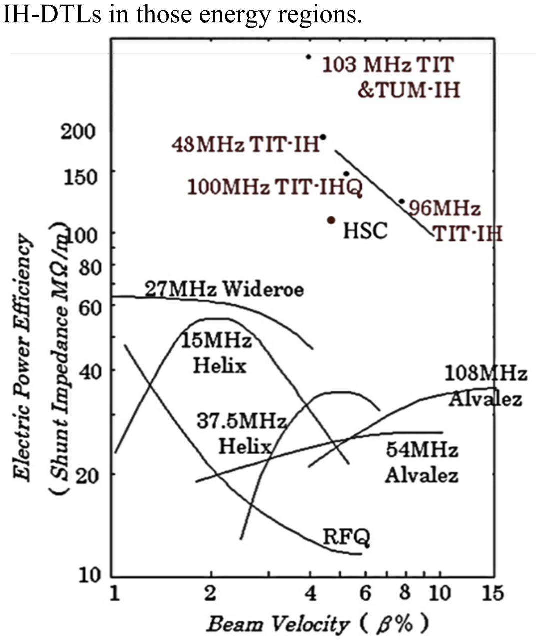

Figure 1: The shunt impedance of the low beta linacs.

Since the IH DTLs operated in TE_{11n} mode of the higher order mode have a property which is suitable to accelerate ions in medium and high energy region [5]. We proposed a 325 MHz DTL operated in TE_{115} mode. Our proposed IH type HOM-DTL is designed as a prototype buncher and its structure is shown in Fig. 3.

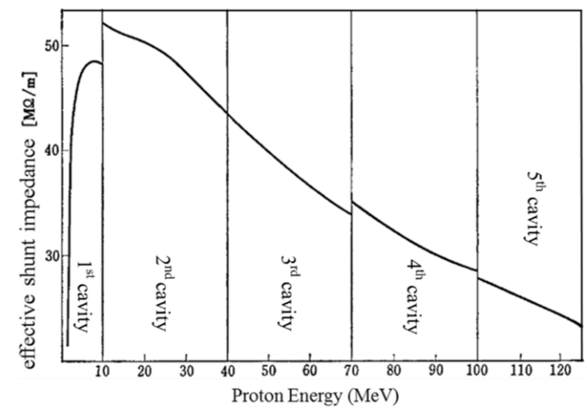

Figure 2: The shunt impedance changing of the Alvarez type DTLs in medium and high energy region.

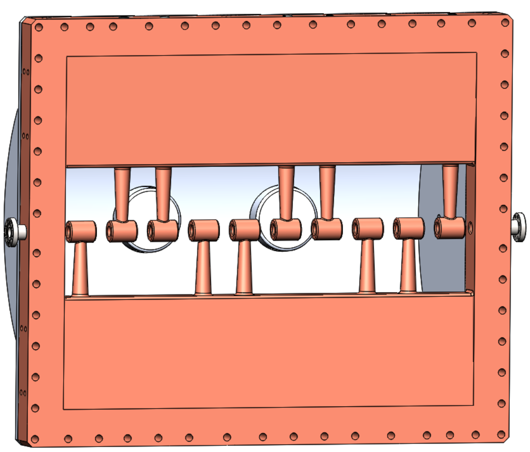

Figure 3: The inner structure of proposed HOM-DTL.

ELECTROMAGNETIC DESIGN

The frequency of proposed HOM-DTL is 325 MHz which is 4th harmonic of the frequency of 81.25 MHz. This HOM-DTL is a prototype research for future heavy ion buncher. The estimated peak voltage is rather high as several mega-voltages. The Microwave Studio (MWS) code and ANSYS code are used to calculate the cavity electromagnetic simulation and mechanical simulation [6-7]

As shown in Fig. 3, the HOM-DTL has normal DTs and ridges that is same to the normal type IH-DTLs with TE_{111} mode and Alvarez type DTLs with TM_{010} mode, however, the resonated frequency of cavity can be tuned to TE_{115} mode by configuring directions of the stems. As shown in Fig. 4, the biggest feature of the HOM-DTL is

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that the axial accelerating electric fields of gaps are quite flat, even in the two end gaps. But in normal DTLs, the field in two end gaps are lower than center gaps. The flat electric field distribution makes the field tuning of cavity very easy. The proposed HOM-DTL adopts 10 stems and 11 gaps, and the total length is 1m. Shown in the table 1, when the Kilpatrick factor adopts 1.5, the simulated total voltage of the HOM-DTL is 1.93MV, and the shunt impedance of the HOM-DTL is calculated as 91.8 MΩ /m that is better than other structure linacs in same beam beta region shown in Fig. 1 and normal DTLs shown in Fig. 2. That indicates the 325 MHz HOM-DTLs has a better power efficiency in the medium energy region.

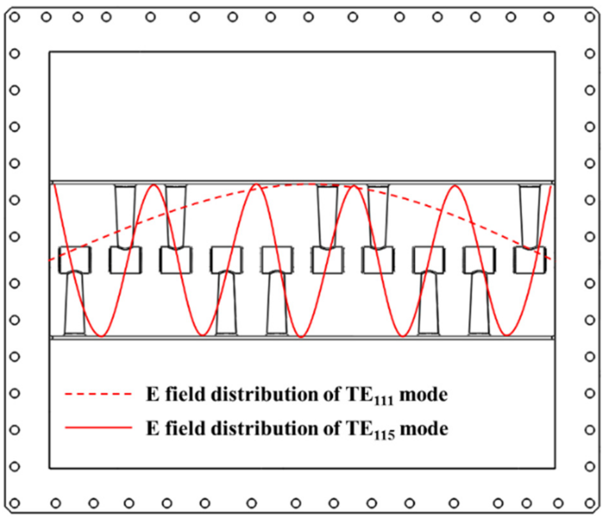

Figure 4: RF property of TE_{115} mode (solid line) in the HOM-DTL. Dot line shows TE_{111} in IH-DTLs.

Table 1: the Simulated Parameters of the HOM-DTL

Items	Value
Frequency / MHz	325.008
Gap No.	11
DT No.	10
Cavity diameter / mm	660
Beam bore / mm	20
DT diameter / mm	40
β	0.173
Inner length / mm	800
Total voltage / MV	1.93 @ 1.5 Kp.
Dissipated power / kW	50.6 @ 1.5 Kp.
Q value	9167
Shunt impedance / MΩ /m	91.8

Because an existing mainly copper frame (copper-colored part in the Fig. 3 was adopted for simulations and fabrications of the 325 MHz HOM-DTL, the optimization of the RF structure design is limited.

The RF properties of proposed HOM-DTL are confirmed by MWS, as shown in Fig. 5, according to the resonated TE_{11n} order, the frequency shows an uptrend and the Q value shows a downtrend. The downward Q indicates that the RF mode is higher, the higher RF power is needed. Based on our calculations, the ridges have a big effect on the cavity RF property. The height of the ridges is higher, meanwhile the stems are more longer and the Q value is higher. The TE_{114} is 308.223 MHz, the desired resonated RF mode is 325 MHz which is totally separated from the neighbor mode.

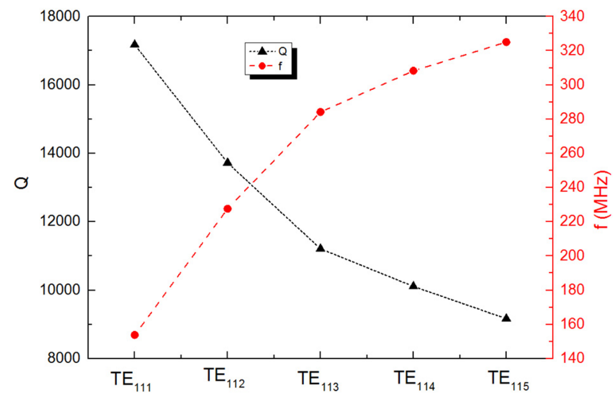

Figure 5: Resonated RF mode and Q values of calculated HOM-DTL. According to the TE_{11n} order, the Q shows a downtrend and the frequency shows uptrend.

And same with the normal IH-DTLs [8], the hottest part of the HOM-DTL is the stem. As shown in Fig. 6, the surface current concentrates in the stems. Though we are limited by budgets, and the HOM-DTL will be carried out with low power test and aimed to test the integrated shaping method without welds and alignments. However, the cooling designs of the main frame was considered for possibilities of future use. However, only the ridges and the stem-bottoms were designed cooling loops. According to the ANSYS calculations, with 10 water routes for stem cooling and 10% duty, the maximum deformation is occurred in the cavity (between two tuners) and the maximum temperature is about 40^0C and locates in the first tube.

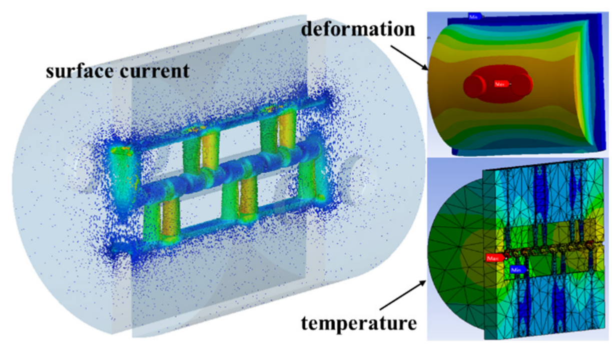

Figure 6: Images of surface current (left part) and multi-physics analysis. The intensity increases as the color changes from blue to yellow and to red.

The frequency tuning is being designed using four tuners. Both sides of the main frame have two tuners, and the tuners are uniform distribution in the beam direction. The diameter of tuners is 60mm, and the preset inserting length of the tuners is 35mm. According to our simulations, the adjustment region of frequency is ±1.56 MHz which is enough for frequency tuning.

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FABRICATION AND LOW POWER TESTING

The HOM-DTL was fabricated and assembled by a manufacturing company in Shanghai. As shown in Fig. 7, although the main frame is being shaped from a block copper by using a numerical-controlled machine tool, the cavity wall is being bent from an aluminum sheet because of the budget limitation. The stand supports the main frame directly by using two stainless holders. And two tuner-supports fixes the four tuners. The tuners are also made from aluminum material. We are applying a national science fund for supporting copper cavity fabrication instead of aluminum cavity, and finally, the HOM-DTL could be used as a heavy-ion buncher in high intensity heavy-ion facility.

The initial low power test was done in the fabrication company. The frequency and Q were measured by using a network analyzer. The four aluminum tuners were inserted 35 mm which was the designed volume. As shown in Fig. 8 and table 2, the measured frequency and Q of the TE_{115} mode were 325.008 MHz and 7219, respectively. Here, measured frequency meets the design well and the measured Q is about 78% of calculation simulated by using perfect electrical conductor in CST. The TE_{114} mode was measured as 307.875 MHz which was also same to the designed volume.

The second low power test was done in our institute. The HOM-DTL was re-assembled without calibrations and alignments. The measurements show some deviations from first low power test. the TE_{115} mode was measured as 325.16 MHz without tuners. There is 1.71 MHz difference between two measurements. We supposed that the aluminium cavities had occurred displacements in transportation and had not well assembled with the main copper frame. Figure 9 gives the measured and simulated normalized electric field distribution of the TE_{115} mode, and shows that the measurements (red line) is not well match the simulations (green line), especially, the fields in two end gaps are very low. As mentioned above, the reason of causing unmatched field may be the same as the frequency shifting.

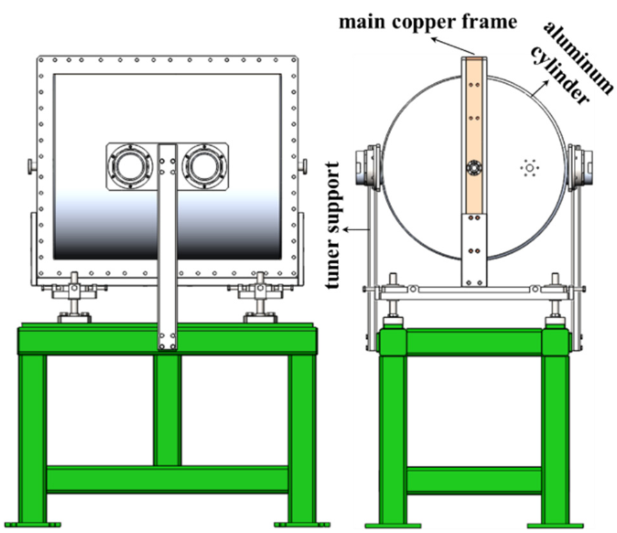

Figure 7: Assembly image of the HOM-DTL. The main frame was made from oxygen-free copper material. The other cavity parts (walls and the tuners) was made from aluminium material.

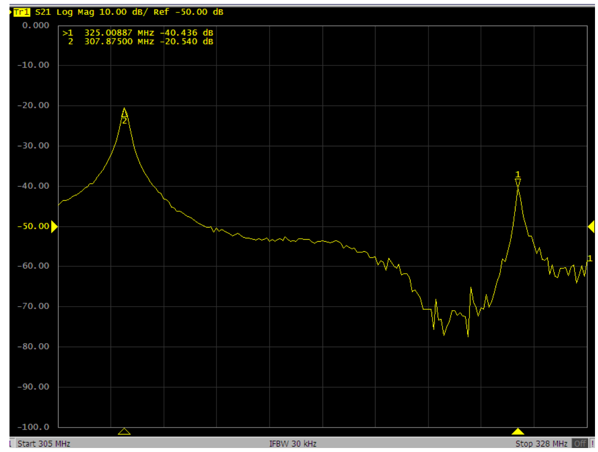

Figure 8: Measured frequencies of TE_{115} and TE_{114} mode.

Table 2: The Results of Low Power Test

Items	**Value**
Frequency / MHz	325.008
without inserting the tuners /MHz	323.45
Q value	7219

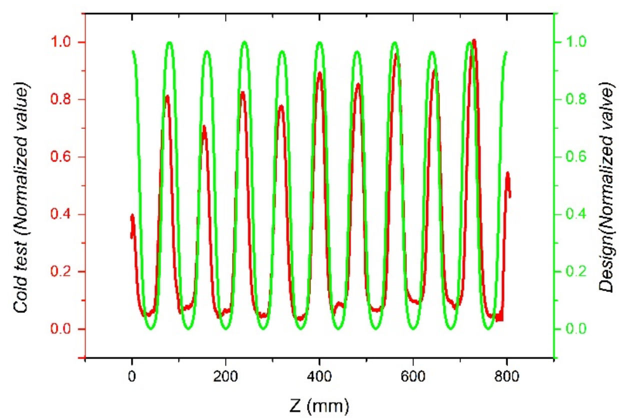

Figure 9: The measured (red line) and simulated (green line) field distributions.

SUMMARY

A HOM cavity driven by TE_{115} RF mode was calculated and simulated for high energy beam bunching. Its shunt impedance is 91.8 MΩ/m which is higher than TE_{111} type IH-DTLs and Alvarez type DTLs in medium energy acceleration. Along the 800-mm axis, the designed 325 MHz HOM-DTL buncher was expected to induce 1.93 MV with a flat electric field distribution along the axis. However, the measured field of the prototype HOM-DTL was a unflat distribution. The prototype HOM-DTL was made from copper and aluminium. In this research, the aluminium cavity was deformed and made the second measured frequency different from the first measurements. We are planning to repair and re-assemble the aluminium cavities, and measure the cavity properties again.

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