3D MODEL ANALYSIS OF CAVITY FOR CSNS DTL*

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Abstract

An Alvarez-type Drift tube linac (DTL) was utilized to accelerate an H^- ion beam from 3 MeV to 80 MeV of China Spallation neutron source (CSNS). RF field profile is always deviate from the design curve due to errors in fabrication and assembly of the structure cells, thus RF tuning of DTL is necessary. CSNS DTL operates at zero mode and has long tank, so accelerating field of which is unstable, this problem was solved through adding post couplers[1]. In order to speed up the schedule of DTL low power RF tuning, we analyzed the operating mode, field flatness with slug tuners, field stabilization with post couplers by CST Micro wave studio (MWS) mainly with eigenmode solver in advance. Considering saving the computer memory and increasing the calculation speed, we divided each tank model into three short units. Slug tuner depth and PC-DT gap of DTL-1 and DTL-3 by simulation were shown which improved the efficiency of CSNS DTL RF tuning.

INTRODUCTION

The DTL structure operates at TM010 mode. Field flatness should tune to be within ±2% and the standard deviation to ±1% with beam loss must be taken into account. Field stability should within ±100%/MHz so it can overcome beam loading effect and transient perturbation[2]. Two-dimensional (2D) simulations performed with SUPERFISH can get accurate calculation results only in symmetric structures. For a better research on field flatness and stabilization with slug tuners and PCs which are non-symmetric parts, three-dimensional (3D) simulation of the cavity was carried out by CST MWS in this article. Similar studies have already been done only with several acceleration cells[3]. CSNS DTL consists four tanks. Components and parameters of four are listed in Table1.

Table 1: Components and Parameters of Four Tanks

DTL	Length (m)	DTs	PCs	tuners	Field (MV/m)
1	8.507	63	31	12	2.86
2	8.558	36	36	12	2.96
3	8.781	29	29	12	2.96
4	8.821	25	25	12	3
Total	34.667	153	121	48	

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DTL TANK MODELS

3D model of CSNS DTL-1 was showed in Fig. 1. It has 63 drifts which were supported by stem and 2 half-drifts. 12 slug tuners were distributed below the cavity uniformly. PCs are alternated the drifts, angle between the two was 180 degree which can reduce the coupling effect of adjacent two. They are perpendicular to drifts but not contact with them and go through the cavity wall. The end of PC near drift has a rotating tab which function is fine tuning field after field stabilization tuning. Small figure ① and ② are magnification of the tank entrance and exit. Small figure ③ is the front view of tank from which we can see post couplers more clearly. Material of cavity was set as vacuum. Drifts, stems, PCs and slug tuners are all set as PEC. Background was a PEC rectangle box wrapped up tank. Electrical boundary conditions (Et=0) were set in X, Y, Z directions.

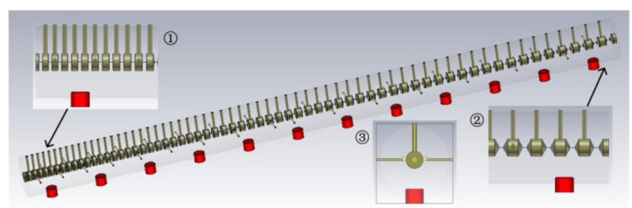

Figure 1: 3D model of CSNS DTL-1.

In addition to DTL-1 we also calculated DTL-3. 3D model was showed in Fig. 2. It has 29 drifts and 2 half-drifts. As cell length increased, each drift has a PC. Small figure ① in Fig. 2 enlarged the red box. The blue line through DT apertures indicates the beam axis. Frequency of the DTL-3 was far less than 324 MHz so the slug tuners were inserted too deep. To achieve field stabilization tuning, we limited the slug tuner insertion and added a tuning ring to each PC to compensate frequency[4]. Specific details see in small figure ③.

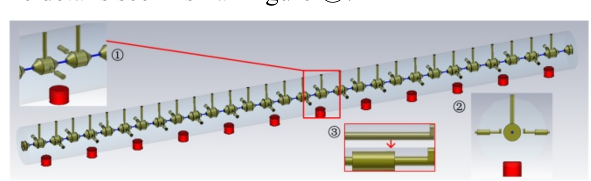

Figure 2: 3D model of CSNS DTL-3.

FIELD FLATNESS TUNING WITH SLUG TUNNERS

Eigenmode solver was chosen and mesh type was hexahedral. The method was AKS [5]. At first, we attempt to calculate entire DTL-1, but the meshcells arrived at 10,385,496 which are far beyond our computer running memory, so we change it into unit model. DTL-1 has 3 units we call them DTL1-1, DTL1-2 and DTL1-3. It has no PCs in field tuning. Upper chart in Fig. 3 was DTL1-1 and it is not a full cell at tail of model in red box. In DTL3-1 we cut last drift into two equal half-drifts and got rid of right-half and last stem, so all cells in DTL3-1 are complete. Below picture in Fig. 3 is DTL3-1. The grid number of each model in CST is about 2,700,000.

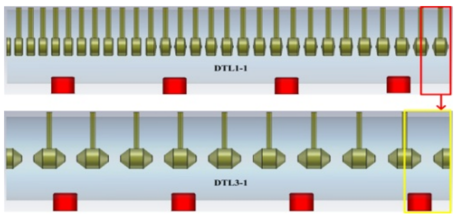

Figure 3: 3D model of DTL1-1 and DTL3-1.

Figure 4 exhibited the process of field tuning. We used simulation field to replace measured one. Since no machining and installation errors, simulation field was different with measured one. The tuning length of slug tuners will be different from the actual results but it is reasonable. Most important of all through the analysis we know the RF characteristic of slug tuners. The frequency increases and the field which around the tuners reduces when insertion length of tuner rises. On the other hand, frequency decreases and field rises when insertion length falls.

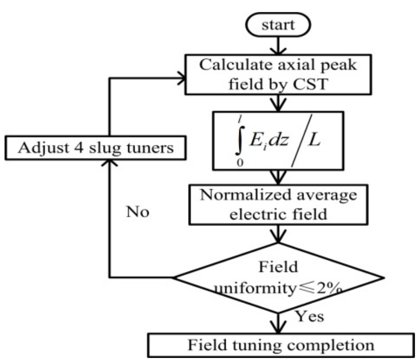

Figure 4: Procedure of field tuning.

CST carried out peak field of each cell which was converted to average field by equation $\frac{\int_0^l E_i dz}{L}$. We made normalization on average field with designed field and normalization field was called E_0. Eq. (1) told the definition of dz which stands for sampling interval. E_i represents field amplitude of each sampling point and L length of each cell.

$$dz = \frac{L_{cavity}}{N_{sample}}. \tag{1}$$

Here L_{cavity} is length of entire model. N_{sample} expresses the number of sampling points minus 1. For example we got peak field of DTL1-1 initial state and transform it to E_0 by this method. At beginning the depth of insertion of 4 slug tuners was all 50mm. Figure 5 showed the contrast diagram of peak field and E_0. Simulated E_0 was normalized according to designed field which was depicted as pink curve in Fig. 5.

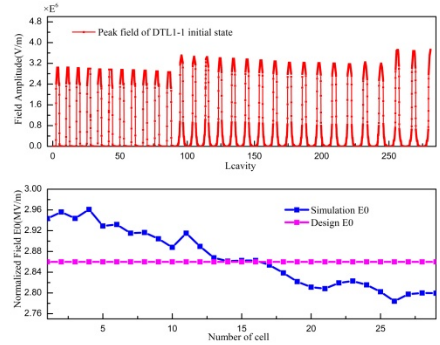

Figure 5: Transform peak field to E_0.

The derivative method[5] was used to tune the RF field in cavity model. The flatness of DTL-1 and DTL-3 are all within ±2%, which meet the tuning target. Figure 6 showed the tuning results. The process of field flatness tuning was realized by using CST, from which we also verified the effectiveness of derivative method.

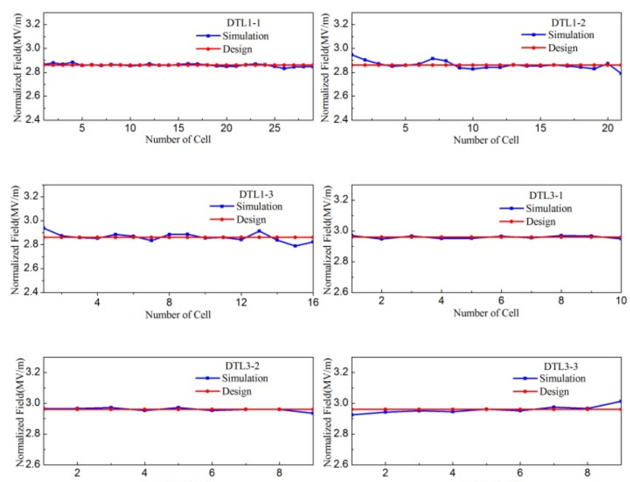

Figure 6: Normalized field after tuning of DTL1 and DTL3.

FIELD STABILIZATION TUNING WITH POST COUPLERS

CSNS DTL operates at zero mode which has the maximum effective shunt impedance and highest acceleration efficiency[6] but the minimum stability. To increase the stabilization of CSNS DTL we introduced PCs. Adjust PC-DT gap one by one then the whole cavity will achieve a coupled resonant state and electric field in the cavity will no longer be obviously affected by the external frequency perturbation. The index of field stabilization is usually through TS (tilt sensitivity). The definition of TS is as follows:

$$TS[\%/MHz] = \frac{E_{perturbed} - E_{unperturbed}}{E_{unperturbed}} \cdot \frac{1}{\Delta f[MHz]} \cdot 100\% \tag{2}$$

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Figure 7 showed the flow of field stabilization tuning. Each unit model has 4 slug tuners. The frequency variation caused by the increase of tuner insertion length near the lower energy end of the 10mm was defined as Δf in this paper. Adding perturbation was by this way: insertion depth of tuner near the low energy end increased by 10mm and near the high energy end decreased by 10mm. The resonant frequency of cavity kept constant before and after adding perturbation.

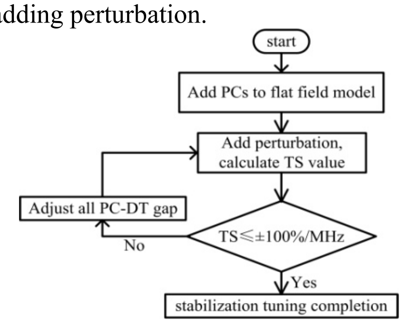

Figure 7: Process of stabilization tuning.

In each unit gaps were changed by uniform length. From 5mm to 50mm the stabilization tuning was completed. Figure 8 demonstrated the TS property of DTL1 and DTL3. Tuning target of TS is ±100%/MHz which means when the frequency of cavity changes 10 KHz the field will change 1% relative to designed one. If the TS slope is positive then the PC mode and TM mode are less-coupled and it means PC-DT gaps are not enough. If the TS slope is negative then the PC mode and TM mode are over-coupled and it means PC-DT gaps are too large.

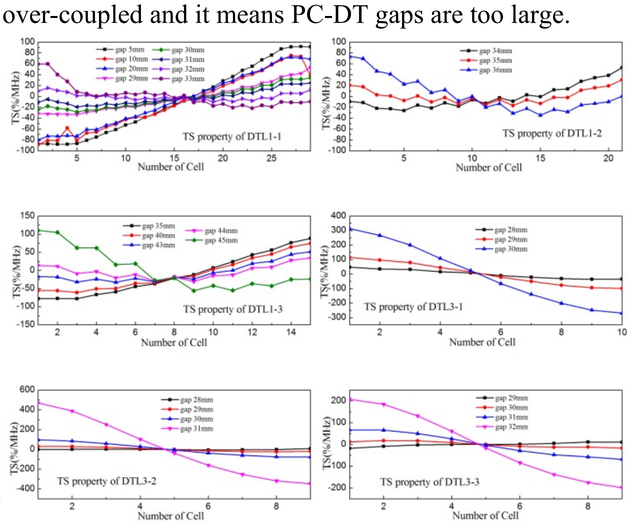

Figure 8: TS property of DTL-1 and DTL-3.

Simulation results of PC-DT gap of DTL1-1 to DTL3-3 were 32mm, 35mm, 44mm, 28mm , 28mm and 30mm. Simulated and measured value of PC-DT gaps of DTL1 and DTL3 were compared in Fig. 9, from which we found the gap of them has little difference and the changing tendency was similar. Through 3D analysis we know reasonable range of PC-DT gap for field stabilization in advance. It accelerated project process significantly.

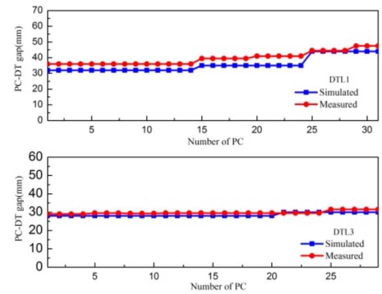

Figure 9: Comparison of simulated and measured value of PC-DT gap of DTL1 and DTL3.

CONCLUSIONS

We built and studied realistic 3D models of CSNS DTL1 and DTL3. Electromagnetic analysis of the model was performed using MWS. RF fields and frequency of tank were calculated. We explored the influence of the slug tuners on the field flatness and through simulation the field flatness within ±2% was achieved. We also analyzed the effect of post couplers on the field stabilization and at last the PC-DT gaps were got which are in agreement with the measured value. The simulation speeded up the project progress in low power RF tuning. Studying realistic models of DTL tanks is important for better understanding of the CSNS DTL. Future developments may include exploring linear part upgrade of CSNS.

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