DESIGN OF 132MeV DTL FOR CSNS

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Abstract

In the China Spallation Neutron Source (CSNS) linac, a conventional 324 MHz drift-tube linac (DTL) accelerating the beam from 3MeV to 132MeV has been designed with 1.05% duty. Several geometry parameters change with β over sections of the DTL cavity. The DTL uses Electro-Quadrupole Magnet (EQM) inside the drift tubes arranged in a focusing defocusing (FD) lattice with the focusing period of 1 $\beta\lambda$ long. We have done the R&D on the 1st tank, and found the difference between the design average axial field calculated by PARMILA code and the real average axial field calculated by MDTFISH code. By tuning several cells' frequency and re-calculating the cavity, the real fields follow the design fields. Then we take the DTL of SNS for example and do the same tuning, more details are reported.

INTRODUCTION

Now a 132MeV proton linear accelerator for the CSNS has been designed. It consists of a 3-MeV radio-frequency quadrupole linac (RFQ), a 132MeV drift tube linac (DTL). The DTL has been proposed to construct in two phases. Its energy was chosen as 81MeV for phaseⅠand 132MeV for phase Ⅱ. The beam power is designed of 100 and 200 kW in two phases respectively. A frequency of 324 MHz and a duty factor of 1.05% have been chosen for all of the RF structures. The 132MeV DTL constitutes of 7 tanks and we started R&D on the 1st tank. Stems, post couplers, slug tuners and vacuum ports are taken into account in frequency perturbation in the cavity geometry design.

DTL CAVITY DESIGN

The specifications of DTL accelerator for CSNS are given as Table 1. The pulse current is 15mA in the 1st phase and 30mA in the 2nd phase. The design of the DTL is based on the 30mA pulse current.

Table 1: Specifications of CSNS DTL Accelerator

Ion	H^-
Input Energy	3MeV
Input Beam Un-normalized total emittance	12.46 π mm-mrad (Transverse) 571.5π deg-keV (Longitudinal)
Output energy	130MeV
Duty factor	1.05%
I_{peak} (mA)	15 (1st stage), 30 (2nd stage)

The design parameters of the DTL cavity are shown in Table 2. We choose an average electric field with linearly gradient from 2.2 to 3.1 MV/m in the 1st tank and keep 3.1 MV/m in other tanks for high accelerating efficiency and avoiding RF breakdown in low energy section. At the beginning of the DTL, -30^0 synchronous phase has been chosen for a large longitudinal acceptance. In order to sufficiently utilize the klystron of 2.5MW, we choice the number of cell in each tank to make the RF power consumption is approximately equal to 2MW.

Table 2: Design Parameters of DTL Tanks

Tank Number	1	2	3	4	5	6	7	Total
Output Energy (MeV)	21.76	41.65	61.28	80.77	98.86	115.8	132.2	132.2
Length (m)	7.99	8.34	8.5	8.85	8.69	8.57	8.67	59.6
Tank + tank-tank space (m)	8.19	8.61	8.82	9.21	9.09	8.99	9.12	62
Number of cell	61	34	29	26	23	21	20	214
RF driving power (MW)	1.41	1.41	1.39	1.45	1.45	1.45	1.49	10.05
Total RF power (MW)	1.97	2.01	1.98	2.03	1.99	1.96	1.98	13.92
Accelerating field (MV/m)	2.2-3.1	3.1	3.1	3.1	3.1	3.1	3.1	
Synchronous phase	-30--25	-25	-25	-25	-25	-25	-25	

By using SUPERFISH code to iteratively calculate the shunt impedance and surface field, we optimised the tank diameter, drift tube aperture and face angle of the DT. A larger face angle increases shunt impedance, but also increases the surface field. At the same time, we also should consider whether drift tube size is big enough to house an EQM. The bore radius increases from 0.6cm in the 1st tank to 1.3cm in the other tanks. The tank geometry parameters are summarized in Table 3.

Table 3 Geometry Parameters of the DTL Tank

Tank number	1	2	3	4-7
Face angle (degree)	0-30	35-50	50-60	60
Inner radius (cm)	0.2-0.3	0.3	0.3	0.3
Outer radius (cm)	0.2-1	1	1	1
Corner radius (cm)	0.6	0.6	0.6	0.6
Diameter of drift tube (cm)	14.8	14.8	14	14
Cavity diameter (cm)	56	56	56	56
Flat length (cm)	0-0.5	0.5	0.5	0.5

Notice that in different energy region, we choose different geometry. For example, the 61 drift tubes in 1st tank are separated into 5 sections with different geometry. We don't change geometry cell by cell like the situation in SNS [1], for easy fabrication and low cost. The accelerating field is a little bit high at 3.1MV/m, but the peak surface electric field is controlled less than 1.3 times Kilpatrick limit

RF TUNING

The resonance frequency and field profile of the DTL cavity can be tuned using slug tuners. We have twelve slug tuners in the 1st tank. Six vacuum ports are arranged between each 2 slug tuners. The post couplers are mounted every other drift tube in tank 1. These apparatus have been designed for the first tank, as listed in Table 4.

Table 4: Parameters of the Stem, Post Couplers, Slug Tuners, and Vacuum Ports

	Diameter (mm)	Number
Stem	34	60
Post coupler	20	30
Slug tuner	150	12
Vacuum port	120	6

Frequency Tuning

The end of post couplers has a 2cm distance to the drift tube. And the post couplers have a diameter of 20 mm. In our simulation, post couplers and stems are concerned together, by the precondition that the frequency changing caused by post couplers is smooth in the 1st tank. It makes 1.5 MHz frequency offset from design value. We also leave 1 MHz margin for slug tuner. The slug tuners are penetrated into the 1st tank for 5cm as a default insertion. The corner radius of slug tuners is 1cm. We put the slug tuner ports and vacuum ports on one side of tank with 45-degree departure from post couplers.

Average Axial Electric Filed Flatness Tuning

After we put cell data designed by PARMILA into MDTFISH for simulation, we found that the average electric field pattern (E0) calculated by MDTLFISH is different from the design field pattern (E0). From Figure 1 we can see the difference is rather large. In this figure,

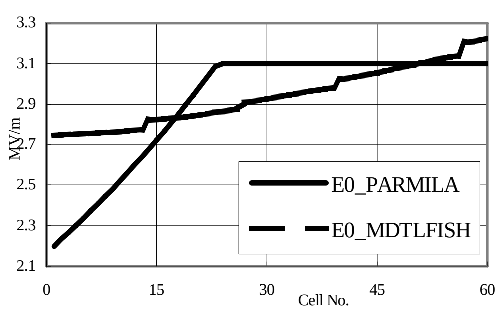

Figure 1: In the 1st tank of the DTL for CSNS, the design field pattern is different from the field pattern.

the solid curve shows the cavity design fields input in PARMILA, it ramps from cell 1 to cell 24, and then maintains constant until tank end. The dashed curve shows the actual field pattern calculated by MDTFISH with the cell data given by PARMILA. The actual field at the low energy end of the cavity are too high. We put the actual field into PARMILA for dynamics simulation, and then found that longitudinal emittance increase greatly.

So we need to tune the DTL cavity so that the actual fields follow the design fields. We adopt the technique tuning the frequency of some cells of the cavity [2]. It helps save the number of tuners and is easier for tuning. We tune the frequency of cell 1 from 324 MHz to 333.11 MHz and the frequency of cell 24 from 324 MHz to 318.2 MHz. Figure 2 shows the fields after tuning. The tuned field (dashed curve) becomes very close to the designed field (solid curve). The dotted curve show the actual field again according to PARMILA cell data but with the tuned cell design in the PARMILA input. These two curves (dashed and dotted) agree very well.

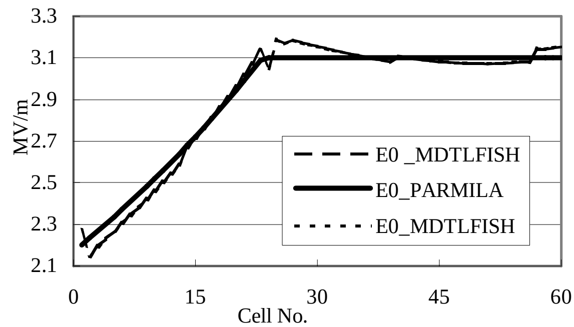

Figure 2: After tuning, in the 1st tank of the DTL for CSNS, the actual field becomes very close to the design field.

The same problem existed in the 1st tank of SNS DTL: the actual field is different from the design field before tuning. Figure 3 shows the difference. (We got SUPERFISH program control files for the SNS DTL in SUPERFISH installation subdirectory). The solid curve

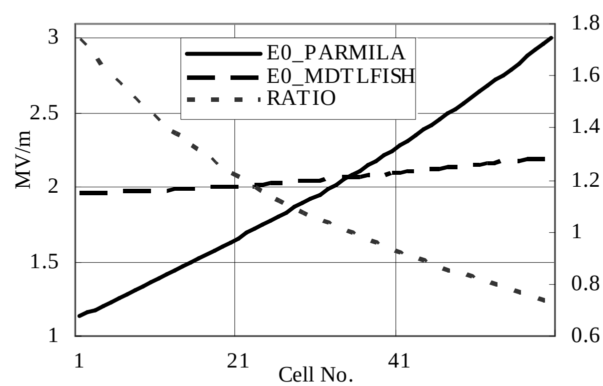

Figure 3: In the 1st tank of the DTL for SNS, the design fields are different with the real fields.

shows the design field used in PARMILA input, the dashed curve shows the actual field calculated by MDTFISH using the cell data from PARMILA output. The dotted curve shows the ratio of these two fields, which is so large that it may be impossible to tune the field just by tuners for a fabricated tank, as really happened in SNS DTL. The ratio is almost equal to the measurement result we found in the SNS DTL cavity tuning report [3].

We used the same method mentioned above to tune the SNS DTL cavity. Tuning the frequency of cell 1 from 402.5 MHz to 414 MHz and the frequency of cell 60 from 402.5 MHz to 396 MHz, the actual field approaches the design field, as shown in Figure 4.

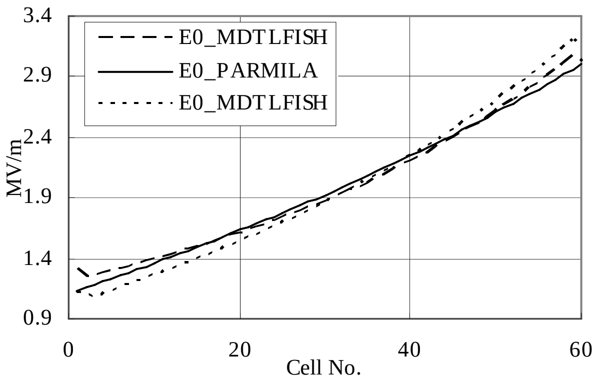

Figure 4: After tuning, in the 1st tank of the DTL for SNS, the design fields are close to the real fields.

BEAM DYNAMICS SIMULATION

FD lattice is chosen for focusing of CSNS DTL. Comparing to FFDD lattice, beam envelope oscillation becomes smaller; and therefore emittance growth can be controlled more effectively.

Because the space-charge effect is strong in low energy end, and reduces gradually as beam energy increases, quadrupole gradient should also reduce gradually. Two schemes for DTL transverse focusing is often applied: constant phase advance focusing and equipartitioning focusing [4]. Reference to these schemes, quadrupole gradient chosen for CSNS DTL is between them.

In DTL the space between tanks is chosen as 1 $\beta\lambda$ long, so the periodicity of the FODO focusing system is continued through the tank-tank space by choosing quadrupole gradient same as those adjacent quadrupoles. TRACE3-D is used for beam matching design.

Since the actual injecting beam may have a beam halo, the field of the accelerator and the space charge of the beam may have strong non-linearity effect beyond the code simulation. It's not enough just to have a zero beam loss in the simulation, but a conservative factor, aperture ratio, should be used in order to decreasing the risk of the actual beam loss. The aperture ratio represents the ratio of the radius of beam channel and the beam RMS radius. After simulation, we found that the beam envelope is much smaller than the bore radius owing to the sufficient transverse focusing. The bore radius of the DTL is 4-11 times of the beam RMS radius, and 2-6 times of the envelope of all the particles, and Figure 5 shows the bore radius and the beam radius.

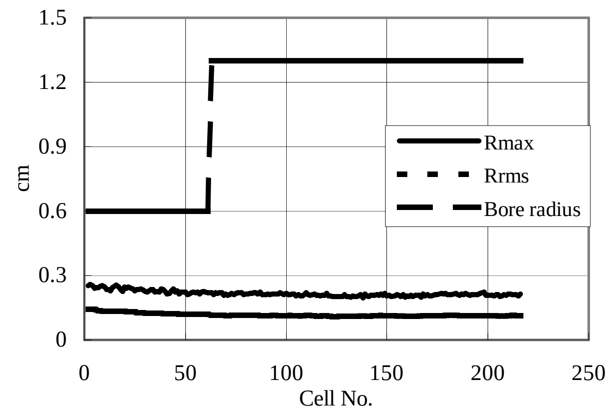

Figure 5: Beam radius and bore radius along the DTL.

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[3] C. Deibele, "DTL Cavity Tuning at SNS", SNS-NOTE-ENGR-74, June 2002, Figure 1.
[4] M. Reiser, "Theory and Design of Charged Particle Beam", Wiley, New York, 1994, p576.