DESIGN OF THE CSNS DTL*

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Abstract

In the China Spallation Neutron Source project [1], the 324 MHz Alvarez-type DTL will be used to accelerate the H^- ion beam from 3 to 80.0MeV. The DTL linac has been designed as four tanks and the electromagnetic quadrupoles will be used for the transverse focusing inside the drift tubes. The geometries of the DTL cells were optimized by using SUPERFISH and the beam dynamics simulation was performed with PARMILA code. In this paper both the physical design and the engineering designs are presented.

INTRODUCTION

The China Spallation Neutron Source (CSNS) linac complex consists of an H^- ion source, LEBT, a 3MeV RFQ, MEBT and a DTL linac, as shown in Fig. 1. Both the operating frequency of RFQ and DTL are 324MHz. The output energy of the DTL linac is 80.0MeV with peak current of 15mA in the first stage. The beam current will increase to 30mA in the future upgraded stage. The duty factors have been design as 1.05% for all of the RF structures.

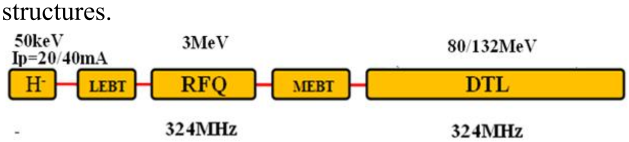

Figure1: CSNS Linac layout.

There are four independent tanks in CSNS DTL and the total length is approximately 35m. Each tank is supplied by one klystron. The transverse focusing is designed as the FD lattice utilizing electromagnetic quadrupoles (EMQs).

PHYSICAL DESIGN

The physical design of CSNS DTL was carried out some years ago [2] and the R&D activity started three years ago.

General Design

The general design philosophy of CSNS DTL aimed for a good transmission (<1W/m losses) and minimum emittance growth.

We had optimized the tank diameter, drift tube aperture and face geometry of the DTL by using SUPERFISH [3] code to maximize the effective shunt impedance and to avoid voltage breakdown by keeping the peak surface electric field below 1.3.times Kilpatrick [4] field for the energy range from 3 to 80 MeV.

The design parameters of the DTL are shown in Table 1.The average electric field ramp from 2.2 to 3.1 MV/m in the first tank and keep 3.1 MV/m in the rest tanks for high accelerating efficiency. The total RF power consumption with a 30mA beam in a tank is as large as about 2MW so as to leave enough operating region for a 2.5MW klystron. In order to sufficiently utilize the klystron of 2.5MW, we choice the cells number in each tank to make the RF power dissipation is approximately equal 2MW.

Table 1: Design Parameters of CSNS DTL

Tank Number	1	2	3	4
Output Energy (MeV)	21.76	41.65	61.28	80.0
Number of cell	61	36	29	26
Cavity RF power (MW)	1.41	1.41	1.39	1.45
Total RF power (MW)	1.97	2.01	1.98	2.03
Acc.field (MV/m)	2.2-3.1	3.1	3.1	3.1
Syn. phase(deg.)	-30--25	-25	-25	-25
Tank length (m)	8.10	8.56	8.79	9.05

The FD lattice was chosen for transverse focusing on the consideration of beam envelope stability and the control of the emittance growth.

Beam Dynamics Design

The beam dynamics simulation was performed with PARMILA [5] code. The simulation starts with 30 mA H^- ion beam at the entrance of the DTL with initial uniform distribution. The results have been iterated to obtain acceptable matching in TREACE-3D [6]. Further more, the match results were input into PARMILA calculating again.

The longitudinal beam dynamics is ramped the synchronous phase φ_s from -30 deg to -25 deg at the end of the first tank. The reason for this choice is that the larger longitudinal acceptance is needed in the first tank. And then it gradually ramps up to -25 deg, providing strong longitudinal focusing at low energy. The fields and phase remain constant over the rest tanks, increasing the acceleration efficiency at high energy.

In the first tank, E_0 starts at 2.2MV/m, then is linearly ramped to 3.1MV/m at the middle cell of the tank, finally is kept constant for the remaining cells.

For the transverse beam dynamics, the phase advance at zero current is limited below 90 deg all along the linac avoiding the resonance and beam blow up. The continuity of the phase advance for meter is also kept to avoid creation of transverse mismatch.

In all case the simulations are done with 50000 macroparticles without any losses. Because space-charge effect is obvious in low energy section, and reduce gradually as energy increasing, so the quadrupole field gradient also reduce gradually. Space charge interaction was calculated via the 2-dimensional PIC method with a 20×40 mesh. The mesh size is 0.05cm. The bore radius

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increases from 0.6cm in the first tank to 1.3cm in other tanks. At the exit of the DTL, the longitudinal RMS emittance increases 2.45% compared with the initial value. The transverse emittance decrease 0.28%. The ratio of the aperture to the RMS beam size is 4 in the first tank and higher than 7 in all rest tanks. Figure 2 shows the distribution at the exit of the DTL.

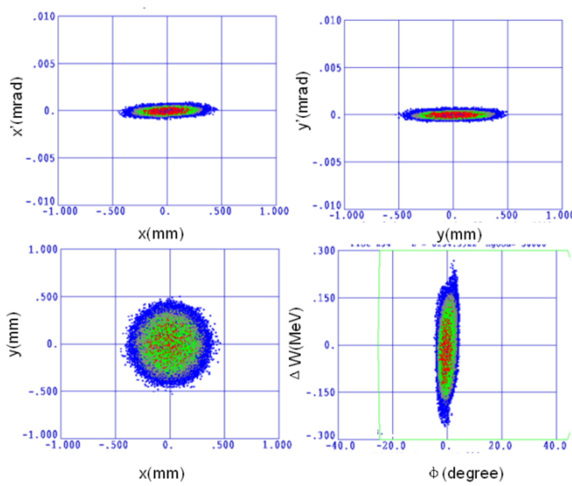


Figure 2: Phase-space distribution at the exit of the DTL.

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

EMQ DESIGN

For transverse focusing the electromagnetic quadrupole (EMQ) is the most common method used in linac [7, 8]. In CSNS DTL, every drift tube contains a EMQs. The diameter of the magnet is 138 mm and the tube width is 49.89mm in minimum. The total number of EMQs is 156 and will be divided into two groups for some standardisation.

The R&D of the quadrupole for the lower energy section of the DTL is a critical issue for the DTL structure because the size of the drift tube for this section is so small that it is not possible to apply the standard techniques for installation the electromagnetic quadrupole. The details can be referenced [9].

RF DESIGN

Each DTL tank will has a single waveguide coupler for 2.0MW peak power, and a maximum average power for 30kW. The commercial waveguide will be used and the RF power will be fed into the cavity via the iris from a tangential waveguide (as shown in Fig. 3). Using the analytical and numerical methods to correlate the coupling coefficient with the size of the coupling in a “dog-bone” shaped iris coupler, the coupling coefficient is optimized to deliver the RF power into the DTL tank efficiently.

On the tank walls the power losses decrease from 4.49 W/cm^2 at lower energy section to3.83 W/cm^2 at the higher energy part. And the power losses on the stem increase from 14.42W/cm^2 to 17.37 W/cm^2 correspondingly. The total copper losses are 62.21 kW (26.38 kW on the stems and drift tubes and 35.83 kW on the tanks walls and end caps). RF power will produce the highest axis fields 3.1 MV/m of the DTL in both four cells. The vacuum system is also the nominal one with a design vacuum of 5.×10^{-6} Pa.

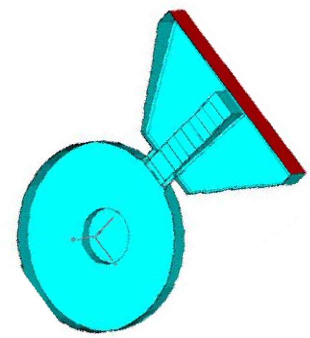


Figure 3: 3D simulation of the waveguide coupler.

MECHANICAL DESIGN

General Design

There are 156 drift tubes, ranging from49.89 to 236.1 *mm* in length, will be installed into the 80-MeV DTL. The inner diameter of all DTL tanks is 566mm and each tank is divided into three short unit tanks about 3m in length for manufacturing.

Tank Design

The main concern of the tank design is to manufacture easily and minimize thermal expansion avoiding frequency drifts and axis electric field tilts. Figure 4 is the design model of Alvarez-type DTL cavity.

For the resulting average shunt impedance of 42 MΩ/m, the DTL can be fed by five 2.5 MW klystrons, leading to a quite logical splitting of the structure into 4 mechanical sections each about 8.8 m long and fed by one klystron. There are twelve straight water cooling channels embedded into tank out-wall.

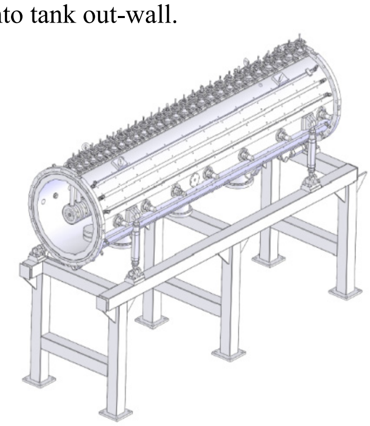
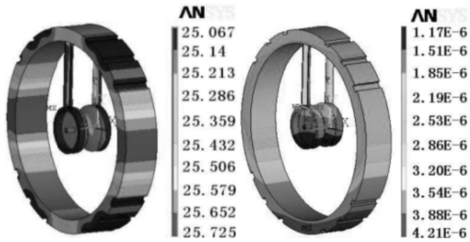


Figure 4: The design model of Alvarez-type DTL cavity.



(a) (b)

Figure 5: Temperature distribution (a) and thermal expansion (b) of the DTL tank wall.

RF power dissipation on the tank surface will create temperature rising of the tank wall. Furthermore the temperature rising will cause a thermal deformation of the structure and the frequency shifts. Thermal deformations have been studied carefully to analysis the structure stability. The average RF power dissipation on the tank surface in each tank is 6.6kW. Figure 5(a) shows the temperature distribution on the tank wall. When the temperature of cooling water is 25 ^{o}C, the maximum temperature 25.725 ^{o}C occurs at the side of the tank. Correspondingly, the thermal deformation is 4.21μm (Figure 5(b)) of diameter which causes the frequency shift -1.903kHz. And the frequency shift sensitivity is about 2.625 kHz/^{o}C.

Drift Tube Design

There two size of the tube outer diameters, 140mm and 148mm. Although the use of smaller drift tubes can achieve the higher shunt impedance but the drift tube should be large enough to have space for housing the electric quadrupole magnets inside. In addition the larger face angle of the drift tube can increase the shunt impedance, but also increases the surface field. So the diameter of the DT is the compromise solution between the size of the EMQ and the RF property requirement. Finally, the face angles α range from 0^{o}to 60^{o} are designed as shown in Fig. 6. Face angles on the drift tubes increase even further the efficiency, still keeping the peak surface field below 1.3 Kilpatrick.

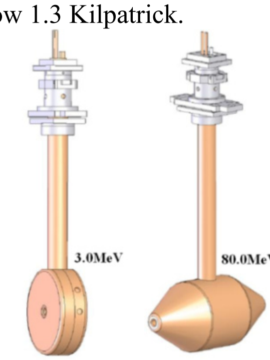


Figure 6: CSNS DTL drift tubes at 3.0 and 80.0MeV.

The DT shell and stem will be made of Oxygen Free Copper (OFC), and cooled via the supporting stem. All components of DT will be wed using electron beam method. The drift tubes are mounted on a single port and their positions can be adjusted individually. The junction suppleness is provided by OFHC copper bellows. Copper beryllium spring RF seals will be also used to avoid loss of Q factor.

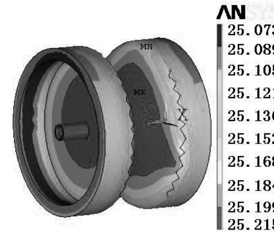


Figure 7: Temperature distribution on the tube surface.

The analysis of thermal deformations caused by heat load dissipated on the tube surface was also carried out. The maximum temperature of the drift tube is 25.215^{o}C, which appears at the centre of the tube, as shown in Fig. 7. Correspondingly the maximum deformation 1.36μm occurs at the centre of the drift tube.

CONCLUSION

The design of CSNS DTL has been finished and the R&D of the DTL has been carried out in IHEP. Physical and engineering designs are presented in this paper. The ratio of the aperture to the RMS beam size is large enough and the beam loss (<1W/m losses) is satisfied. RF power loss on the RF structures and the deformation is calculated were studied. Theese results are required to check from the test.

ACKNOWLEDGEMENTS

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