# DESIGN AND ANALYSIS OF SFDTL STRUCTURE FOR 100 MeV PROTON LINAC

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*Abstract*

A 100 MeV proton Linac consisting of an Ion source, RFQ followed by RF accelerating structures is under design at CAT for application in ADSS. Different schemes for accelerating structure after RFQ stage are under consideration. One of the options is 700 MHz Separated Function Drift Tube Linac "SFDTL". About 91 SFDTL tanks interposed by focusing Quadrupole triplets will accelerate 10 mA cw proton beam from 4.5 MeV to 100MeV. This paper describes mechanical design and analysis of SFDTL tanks. The cooling channels geometry of the drift tube having maximum heat flux, is optimized for best possible heat removal. Extensive 2D and 3D thermal analysis is performed on the high energy SFDTL tank and then a coupled field analysis (thermal followed by Structural) is done using ANSYS 5.7. The displacements in the drift-tube and the tank at operating conditions are reported and cooling scheme of the SFDTL is discussed in this paper. Typical two SFDTL tanks are proposed to be fabricated as prototypes for the " cold model tests". One will be tested at high energy (high heat dissipation) and another at low energy that is relatively more sensitive to resonating frequency drifts.

## 1 INTRODUCTION

Typical architecture of 100 MeV Proton Linac with SFDTL option is shown in fig.1. Preliminary beam dynamics design is performed with PARMILA code and electromagnetic RF simulation is done by SUPERFISH code, which provided heat input for thermal and structural analysis. The number of drift tubes per tank are being optimized for improved beam performance. Manufacturing of two prototype tanks are in process. Fig 2 illustrates the pictorial view of SFDTL tank.

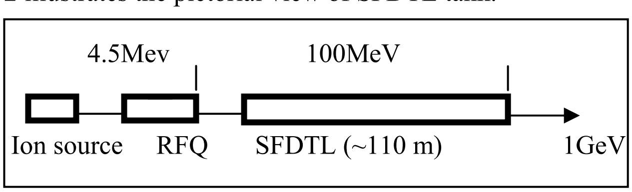



Fig 1. Architecture of 100MeV Linac with SFDTL option.

Out of 91 tanks, two are selected for preliminary design and analysis based on their specific characteristics. Tank 19 is low heat flux tank (490 mm long), but relatively more sensitive to changes in dimensions, affecting resonating frequency. On the other hand 91st tank is high-energy tank (1100 mm long) and maximum heat is dissipating through this tank and drift tubes. Detailed thermal and structural analysis for 91$^{st}$ tank is reported here.

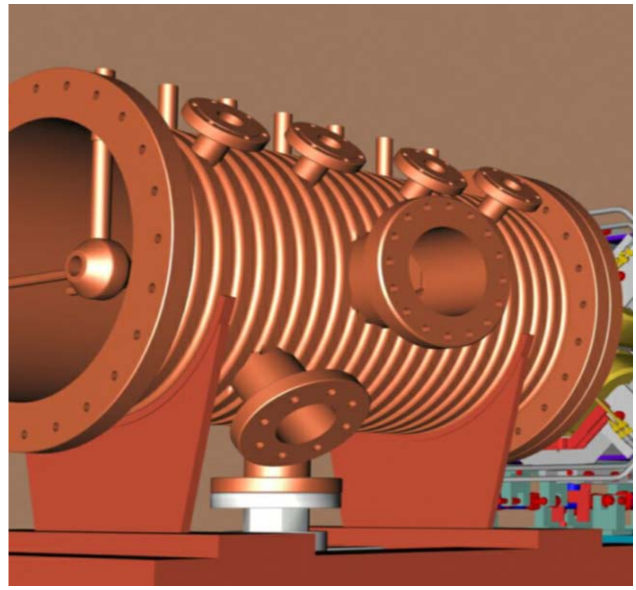


Fig. 2 A typical SFDTL tank

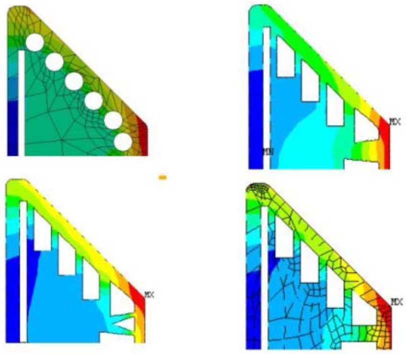
## 2 THERMAL AND STRUCTURAL ANALYSIS

A 2D and 3D thermal analysis is performed for SFDTL model. Further coupled field analysis (Thermal followed by structural) is done using ANSYS-5.7

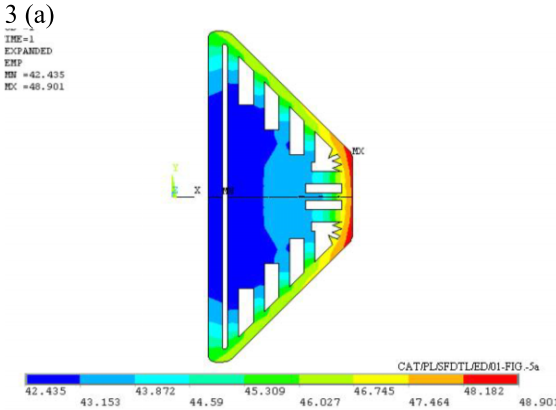
Heat load data from SUPERFISH to ANSYS code is transferred using a C program. Total 110kW of heat will be generated on 91$^{st}$ tank. Convective heat transfer coefficient is estimated for different water velocities 2, 3 and 4m/sec with 40$^{o}$ C as inlet temperature considering the curved duct effect [1, 2]. Maximum temperature rise in water is 5$^{o}$ C at 3m/sec velocity in the drift tube section.

### *2.1 2D Thermal Analysis*

With the help of 2D thermal analysis, we could finalize the design of cooling channels in Drift tube, finned structure in Stem, flange and cooling tube size and pitch on shell (tank). 2D axis-symmetric analysis of drift-tube using PLANE55 element with many option (geometry) were tried for best cooling, some of them are illustrated in fig.3a, while fig.3b shows the optimum geometry with temperature distribution. Similarly the cooling geometries of stem, flange and shell were also optimized for best cooling. These geometries were examined from the manufacturing point of view. After optimizing the Stem geometry to finned internal structure, it was found that the maximum temperature is coming on stem, so the same stem structure is further modified by twisting (increasing the area of contact) it by hot-working methods, which results in ~3 $^{o}$C decrease in temperature.



3 (a)




3 (b)

Fig.3 (a) Different cooling geometries for drift tube.
(b) Optimized geometry of drift-tube cooling.

A prototype drift-tube-out of copper is fabricated. Fig.4 shows four parts of drift-tube and its assembly which is made by brazing.

Fig.4 A Prototype Drift-tube assembly and its four parts.

## *2.2 3D Thermal Analysis*

A 3D model of 91st SFDTL tank was made with the help of Mechanical Desktop. A 1/8 symmetric FE model was considered for this analysis using Solid87 (10 noded tetrahedral element) and Solid95 (20 noded bricked hexahedral element) which is shown in fig.5. Fig. 6 gives the results of 3D thermal analysis of optimized geometry with cooling water velocity 3 m/sec. Maximum temperature difference on SFDTL tank is found to be 7$^{o}$ C. This analysis also confirms the results of 2D analysis except at joint locations of two components. It is also observed that the cooling of stem prior to drift-tube is beneficial i.e. the coolant cools the stem first, and then cools the drift tube and returns through a stainless steel (SS) tube, which is co-axial to stem.

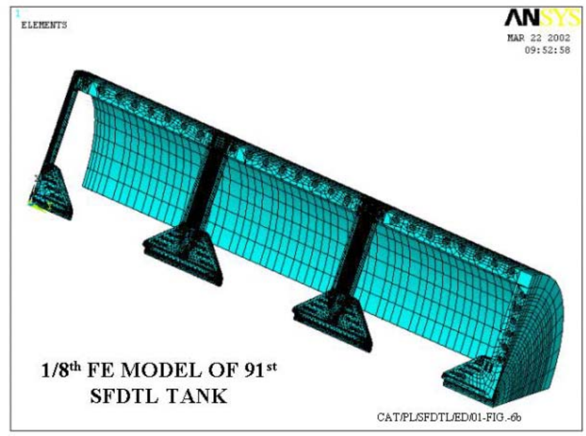



Fig. 5 1/8 symmetric FE model of SFDTL

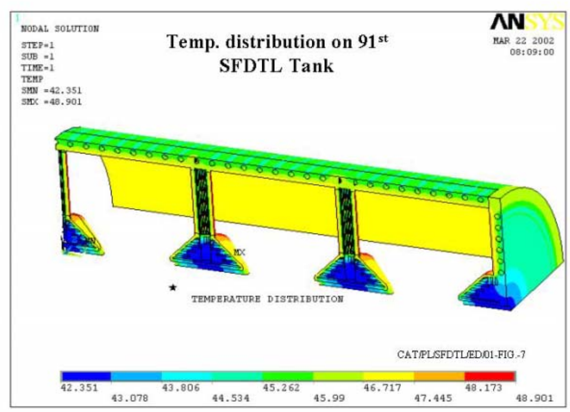



Fig. 6 Temperature distribution on the 91st tank

## *2.3 3D Structural Analysis*

In the same 3D model, the thermal elements were changed to structural elements using Solid92 (10 noded) and solid90 (20 noded bricked hexahedral). The temperature from the thermal run is transferred to the model and 1 atmosphere pressure is given on outer surface of the model in-order to simulate the vacuum. The Cut-boundary of the shell and flange is taken assymmetric surfaces as boundary condition. Fig 7. shows the displacement plot at operating conditions. The line shown in figure indicates the un-deformed shape, while solid model shows the deformed shape.

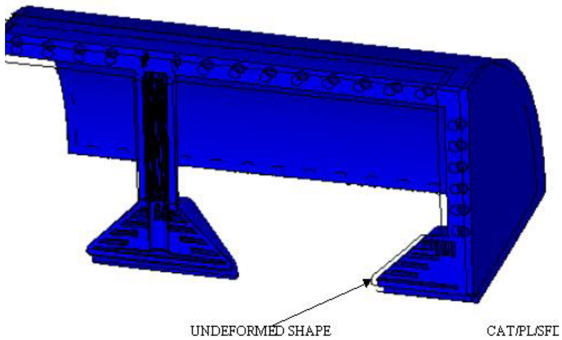



Fig.7 Displacement plot of a typical portion of SFDTL

## 3 COOLING SCHEME

Maximum heat density is 22 W/cm$^2$ on outer most diameter of the drift tube of 91$^{st}$ tank. The cooling geometries were optimized as per analysis results. Maximum 5 $^o$C temperature rise in water at 3 m/sec water velocity is estimated in drift-tube and stem. Normally with water/copper system a limit of 3m/s coolant velocity is standard, however velocity up to 4.8 M/s is also reported [3]. The cooling water enters through stem to drift tube and returns through a SS tube placed concentrically inside the stem as shown in fig.8. Similarly 5 $^o$C temperature rise is considered on shell and flanges to decide the number of cooling circuits.

## 4 RESULTS

Different results of coupled-field analysis are summarized below:

**(a) Temperature**: for different components are given in table –1.

Table -1

| Tank component | Temperature Max / min $^o$C |
|---|---|
| Shell | 47.4/44.8 |
| Flange | 48.4/42.4 |
| Drift Tube | 48.9/42.4 |
| Stem | 48.6/45.0 |

**(b) Displacement**: Changes in the dimensions are as follows:

Gaps between Drift tubes (90 mm) = 0.0085 mm
Drift tube aperture change (20 mm) = 0.004 mm
Stem expansion (90 mm) = 0.012 mm
Radial expansion of tank (140 mm) = 0.014 mm
Axial expansion of tank (1100mm) = 0.08 mm

**(c) Stress**: Maximum ~ 10 MPa (Von Misses Stress)

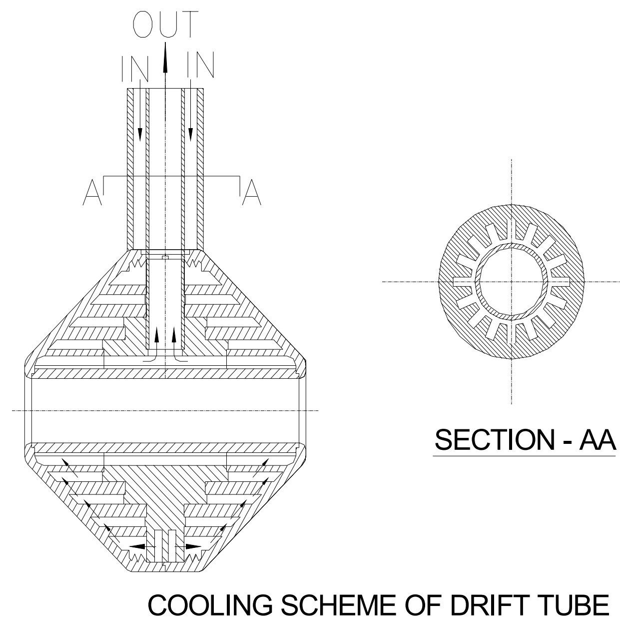



Fig.8.Cooling passages for effective cooling based on the FE analysis. Section A-A shows internally finned cross-section of stem

## 5. CONCLUSION

It is seen that the SFDTL structure in low energy regime, due to low heat flux will be relatively simple to cool. The design of high-energy section tank is governed by high heat load and depends on the possible flow channels, coolant velocity, and operating regime. For 91$^{st}$ tank with about 3m/s coolant velocity, the heat removal looks to be feasible to maintain the required dimensional tolerance for frequency stability. The effect of changes in the dimensions of SFDTL structure on frequency were examined and it is found that the shift in frequency is within the range of tuners. The prototype fabrication is initiated and the verification of the analysis results will follow.

## 6. ACKNOWLEDGEMENT

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