# THERMAL AND STRUCTURAL ANALYSIS OF PWT LINAC STRUCTURES

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*Abstract*

Thermal and structural analysis of 20-cell, 12-cell, and 8-cell Plane Wave Transformer (PWT) type LINear ACcelerator (LINAC) structures have been carried out using the finite element software ANSYS to find out the maximum temperature rise, temperature distribution, and structural deformations resulting from temperature rise and self weight in these structures. This paper presents detailed results of the thermal and structural analysis.

## INTRODUCTION

Standing wave PWT Linac structures are being developed at RRCAT to serve as an injector for a far Infra-Red Free Electron Laser (IR-FEL) [1]. Induced wall currents due to the applied RF power at 10μs pulse width at 10Hz repetition rate with an average field gradient of 25MV/m result in heating of the Linac structure. The RF resonant frequency of the structure changes because of structural deformations. Cooling of PWT Linac structure is necessary to keep the RF resonant frequency of the structure within range.

## PWT LINAC STRUCTURE

Typical 8, 12, and 20 cell PWT Linac [2] structures consist of 8, 12, and 20 oxygen free electrolytic (OFE) copper disks respectively (see Fig. 1). Four stainless steel hollow tubes support the disk array and also carry flowing water to cool the structure. Tubes are brazed to an OFE copper reservoir at one end and have propped support at another end reservoir. Reservoir to which tubes are brazed serve as water storage. Both reservoirs are brazed into beam-port flanges made of stainless steel (SS316L), which connect with the end flanges of a tank made of SS316L. Tank serves as outer boundary and vacuum envelope for the structure. RF port and vacuum port are connected to the tank. Beam ports are connected to the beam-port flanges at both ends of the Linac. Two cooling pipes are connected to reservoir to carry the water from chiller pipe to reservoir.

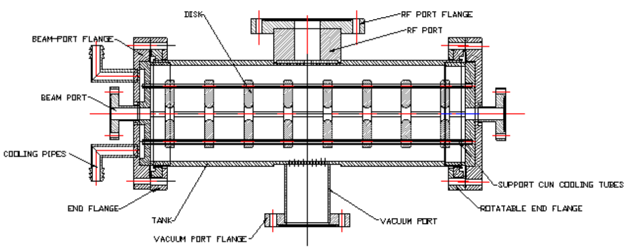


Figure 1: 8-CELL PWT LINAC SCHEMATIC

## THERMAL AND STRUCTURAL ANALYSIS

### *Thermal-hydraulic analysis*

Thermal-hydraulic analyses were performed for PWT Linac structures with considerations given in Table 1.

Table 1

| Sr. No. | Parameter | Value |
|---|---|---|
| 01. | Ambient temperature | $20^{\circ}$ C |
| 02. | Thermal conductivity of OFE copper at $20^{\circ}$ C | 391 Watt/m.K |
| 03. | Thermal conductivity of SS316L at $20^{\circ}$ C | 16 Watt/m.K |
| 04. | Water velocity in tubes | 2 m/s |
| 05. | Tube Inner diameter | 3 mm |
| 06. | Tube outer diameter | 6.5 mm |
| 07. | Disk outer diameter, inner diameter, and thickness | 90 mm, 16 mm and 12 mm respectively |

Thermal-hydraulic analyses of the 8-cell, 12-cell, and 20-cell PWT Linac structures were performed in ANSYS which mainly covers calculation of maximum temperature rise and temperature distribution in the Linac (see Table 2 and Fig. 2), and compared with theoretical calculations which were performed considering heating and cooling in a single disk. Analyses were performed considering steady state one directional heat flow. Cooling water enters at 20º C temperature through two tubes located at 90º angle from the centre of disk, and comes out from remaining two tubes through the last disk. Total heat load data for Linac structures were obtained from RF simulations in SUPERFISH. Variable convective film heat transfer co-efficients are determined considering temperature rise of water between consecutive disks. Following Dittus-Boelter equation was used to determine convective film heat transfer co-efficients.

$$h = 0.023K_W(Re)^{0.8}(Pr)^{0.4}/d$$

Where
h: Convective film heat transfer coefficient
$K_W$: Thermal conductivity of water
Re: Reynolds's number
Pr: Prandtl number
d: Inner diameter of tube

In ANSYS model, heat flux and convective film heat transfer co-efficient (see Fig. 3) were applied on all disk surfaces and inner diameter of tubes respectively.

Table 2: PWT Linac structures thermal analysis results

| No. of cells | Heat load, (Watt) | Heat flux (Watt/m$^2$) | Temp. rise of water at outlet by theoretical calculations (˚C) | Max. Temp. rise in disk by theoretical calculations (˚C), A | Max. Temp. rise in disk by ANSYS (˚C), B | Difference (A-B) (%) |
|---|---|---|---|---|---|---|
| 8 | 367.40 | 2860.31 | 3.12 | 19.40 | 15.60 | 19.59 |
| 12 | 483.48 | 2509.35 | 4.10 | 17.00 | 14.10 | 17.06 |
| 20 | 722.00 | 2268.00 | 6.10 | 15.24 | 14.10 | 07.48 |

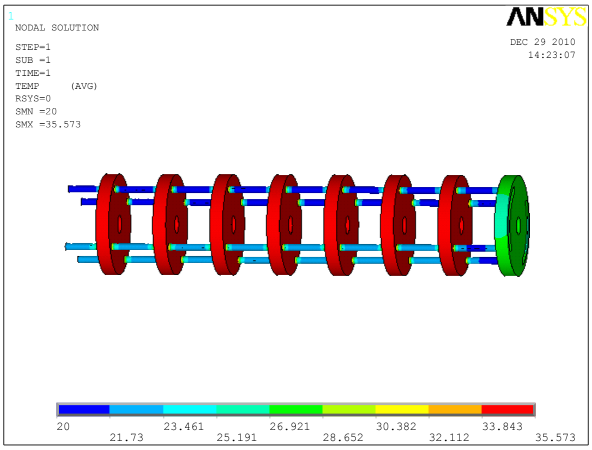


Figure 2: Temperature distribution in 8-cell PWT Linac.

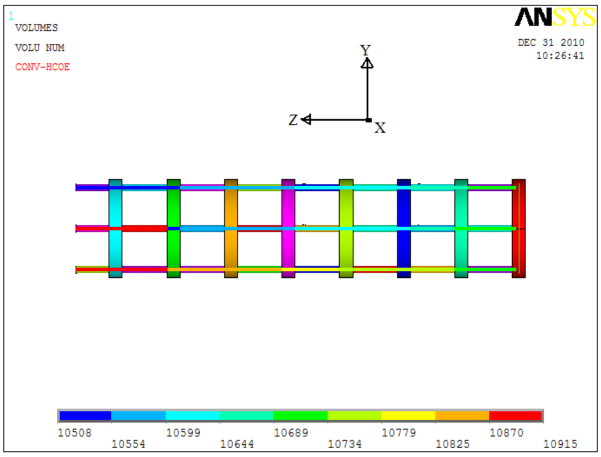


Figure 3: Convective film heat transfer co-efficient

### *Thermal-Structural coupled analysis*

Thermal-Structural coupled analysis were carried out in ANSYS to determine the structural deformations in PWT Linac structures (see Table 4 and Fig. 4), with considerations given in Table 3. Structural deformation shown in Fig. 4 is scaled to 400 times.

Table 3

| Sr. no. | Parameter | Value |
|---|---|---|
| 01. | At one end of Linac array | X, Y, Z displacements = 0 |
| 02. | At another end | Y displacement = 0 |
| 03. | Load | Self weight and temperature |

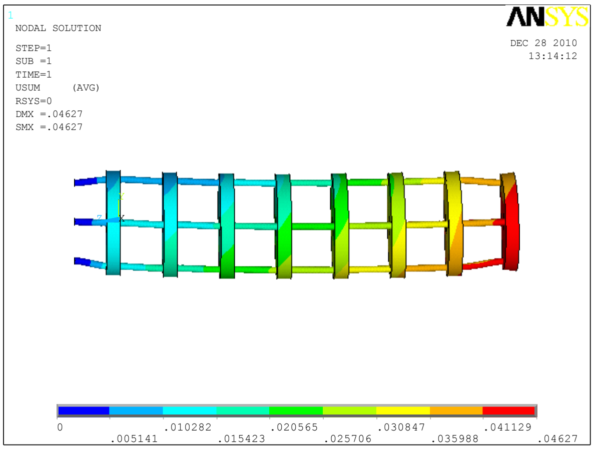


Figure 4: Structural deformation in 8-cell PWT Linac.

Table 4: PWT Linac structures thermal- structural coupled analysis results

| No. of cells | Maximum deflection (μm) | | | | | | |
|---|---|---|---|---|---|---|---|
| | X+ | X- | Y+ | Y- | Z+ | Z- | XYZ |
| 8 | 11 | 37 | 10 | 22 | 02 | 39 | 47 |
| 12 | 11 | 94 | 08 | 38 | 02 | 62 | 103 |
| 20 | 12 | 365 | 09 | 121 | 0 | 422 | 550 |

## CONCLUSIONS

Results of thermal analysis obtained from ANSYS are matching reasonably with our theoretical calculations and estimations. These results shall be used to finalize cooling plan of the PWT Linac structures. Structural deformations obtained from thermal-structural coupled analysis in ANSYS shall be used to determine frequency drift of the PWT Linac structures. Authors thank to Shri Vikas Kumar Jain and Shri Navneet Kumar Sharma for their help and guidance.

## REFERENCES


[1] Pant K.K. et el., “Status report on the FEL project at RRCAT”, Indian Particle accelerator Conference, InPAC-06, BARC/TIFR, Nov., 1-4, 2006

[2] K. K. Pant et el., “Fabrication and RF studies on a prototype PWT linac structure”, Proceedings of LINAC2002, Gyeongju, Korea.