# Development of Numerical Model for Cooling System of 10MeV LINAC using ANSYS Fluent

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*Abstract*— When electron beam is generated in linear accelerator (LINAC) huge amount of heat is dissipated, which causes distortions and ultimately frequency detuning. Numerical model of cooling system of 10 MeV LINAC is developed in ANSYS Fluent and temperature distribution developed is exported to static structural package. Maximum temperature gradient at equator is 4.4 K while maximum transverse deformation is 10.3 microns. So corresponding frequency shift of LINAC structure is equal to -372.70kHz.

***Key words:*** Cooling System, LINAC, CFD, ANSYS, Fluent

## I. INTRODUCTION

During linac operation, significant part of RF power fed to accelerating structure to set up electric field in the cavities is dissipated on internal surfaces of cavities due to finite resistivity of OFE copper. The RF power dissipated on these surfaces is to be efficiently removed to minimize temperature rise and thermal detuning of cavities during operation.

A thermally stable operation of the linac is required to prevent from temperature induced frequency shifts and phase errors, which in turn are converted into reduced energy gain and increased energy spread of the beam. Hence the thermal design and cooling layout has to be optimized.

Firstly numerical model is developed using ANSYS packages and then further modifications are done. Three dimensional model of the LINAC is created in Design Modular (DM) extension of workbench. Turbulent model K-ω is used to converge governing equations as the flow is turbulent. Different boundary conditions are applied to predefined locations such as inlet, outlet, inner surfaces etc. Temperature distribution is found out in ANSYS Fluent and is applied as load in Static Structural to find out thermal distortions. These thermal distortions have direct relations to frequency detuning, so using those values maximum frequency shift phenomena can be plotted. Fundamental frequency of 10 MeV LINAC is 2856 MHz with injection energy of 50 keV and 300 pulse repetition rate (PRR).

## II. MODEL DESIGN DESCRIPTION

### A. *Model and Meshing*

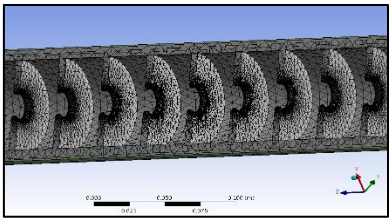

Fig. 1: Meshed model

Meshed model developed in 'Fluent-Meshing' is shown in Fig. 1. Fine mesh is preferred with advanced sizing function on proximity and curvature as dominating surfaces in this model are curve shaped.

### B. *Setup and Boundary Conditions:*

Following set of boundary conditions is applied to model:

- Inlet: Mass Flow rate: 1.6 kg/s
- Outlet: Pressure outlet
- Surfaces: Heat flux values are obtained from SUPERFISH software
- LINAC structure is made up of OFE copper so all the properties are input in material properties.

## III. THERMAL ANALYSIS

### A. *Contours and Results*

Solving proposed numerical model in ANSYS Fluent resulted in following contour:

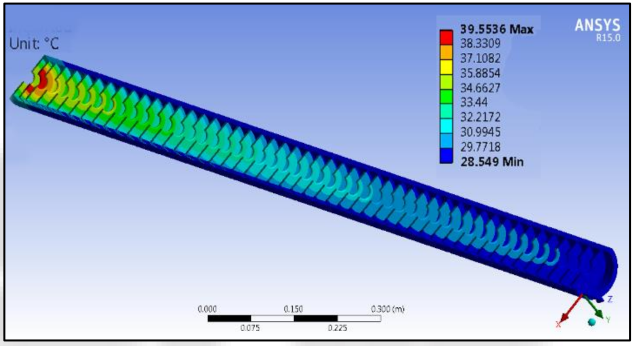

Fig. 2: Temperature Contour

This temperature contour is for complete structure but dominating surface in detuning is equator diameter [2] so temperature distribution at equator diameter is important.

Heat transfer coefficient for this geometry was found to be 9982.352 W/m$^2$K.

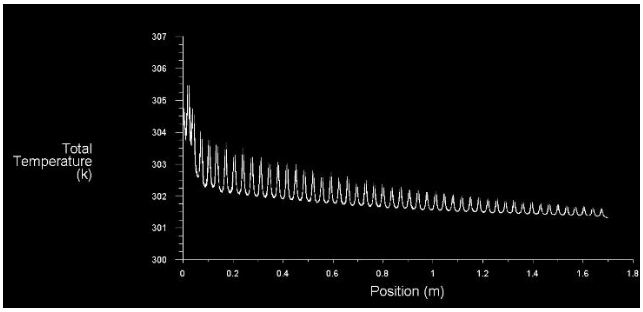

Fig. 3: Temperature distribution at equator diameter

It can be observed from above plot that maximum temperature at equator of second cell is 305.5 K and minimum temperature at last cell is 301.4 K. so maximum temperature gradient for this structure at equator is 4.4K. Static structural package of ANSYS delivered transverse deformation values as shown in fig. 4.

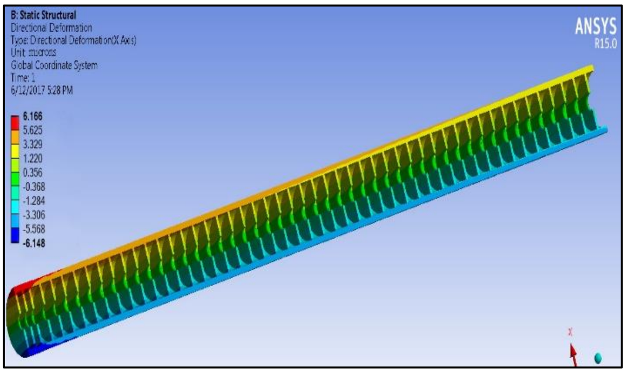

Fig. 4: Deformation contour in ‘Static Structural’

Maximum deformation of 6.166 microns is obtained at outer diameter of LINAC structure. This deformation is radial and hence diametrically it is 12.33 microns. But this deformation is at extreme diameter, and our location of interest is equator. Deformations at equator line can be represented in fig. 5

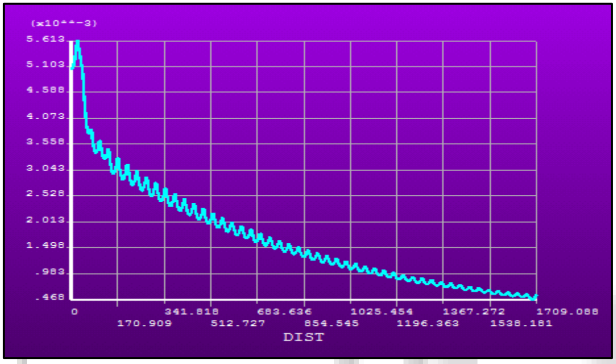

Fig. 5: Deformation of LINAC at equator line in ‘Static Structural’

Frequency detuning gradient for equator diameter is -36.185 kHz per micron [2] fig. 5 gives the maximum value of deformation at equator as 5.613 microns and minimum as 0.468 microns. These are radial deformation values hence maximum diametrical deformation (d) is 10.3 microns.

So maximum frequency shift or phase error for developed numerical model is equal to:

$$\Delta F = (\partial F/\partial d) \text{ x } d \qquad (1)$$
$$= -36.185 \text{ x } 10.3 \text{ kHz} = -372.70 \text{ kHz}$$

## IV. THEORETICAL CALCULATIONS

In current problem average heat flux value is obtained from SUPERFISH software. Heat flux value is 1.873 W/cm$^2$.

$$Q = q.\ A. \qquad (2)$$
$$Q = 0.82 \text{ x л x } D \text{ x } L$$
$$Q = 0.82 \text{ x л x } 8.2 \text{ x } 170$$
$$Q = 3589 \text{ W}$$
$$Q_{conv} = m.\ C_p .(dT) \qquad (3)$$
$$3589 = 1.5 \text{ x } 4810 \text{ x } (T_0 - 300)$$

$T_0$ = 300.49 K

$$\text{Bulk mean temperature} = (T_0 + T_i)/2 \qquad (4)$$
$$= (300 + 300.49)/2 = 300.245 \text{ K}$$

- Properties at bulk mean temperature (300.245 K)
- Viscosity: $\mu$ = 0.000855 N.S/m$^2$
- Thermal Conductivity: k = 0.6194 W/m.K
- Density: $\rho$ = 1000 kg/m$^3$

$$\text{Area of flow} = \text{л}/4 \text{ x } (D_{out}^2 - D_{in}^2) \qquad (5)$$
$$= 3.14/4 \text{ x } (0.105^2 - 0.1^2) = 0.000804625 \text{ m}^2$$
$$\text{Flow Velocity: } V = m/\ \rho \text{ x } A \qquad (6)$$
$$= 1.5/1000 \text{ x } 0.000804625 = 1.863 \text{ m/s}^2$$
$$\text{Prandtl Number} = \mu \text{x } C_p/k \qquad (7)$$
$$= 0.000855 \text{ x } 4180/\ 0.615 = 5.8$$
$$\text{Reynolds Number} = (\rho \text{ x } V \text{ x } D_H)/(\mu) \qquad (8)$$
$$= (1000 \text{ x } 1.863 \text{ x } 0.0050)/(0.00086) = 10896.36$$

Dittus Boltier Equation can be rearranged as Heat transfer coefficient:

$$= 0.023 \text{ x } (k/D_H) \text{ x } (Re)^{0.8} \text{ x } (Pr)^{0.4} \qquad (9)$$
$$= 0.023 \text{ x}(0.615/0.005) \text{ x } (10896.36)^{0.8} \text{ x } (5.8)^{0.4}$$
$$= 9769.0388 \text{ W/m}^2\text{K}$$

## V. ERROR ESTIMATION AND VALIDATION

Heat transfer coefficient value obtained from numerical model is 9982.352 W/m$^2$K while theoretical calculations results in 9769.039 W/m$^2$K. So percentage error in calculation of heat transfer coefficient is 2.1 %.

## VI. CONCLUSION

Maximum temperature in LINAC structure is obtained to be 312.5 K at outer diameter and 305.5 K at equator diameter. Maximum heat transfer coefficient value is equal to 9982.352 W/m$^2$K while maximum transverse deformation gradient is 12.33 microns at outer diameter and 10.3 at equator diameter. Maximum frequency shift of LINAC cavities is -372.70 kHz.

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