THERMAL-INDUCED FREQUENCY DETUNING OF 350 MHz RFQ STRUCTURE

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Abstract

A 350 MHz, 4.5 MeV RFQ structure is being developed for high power Proton Linac for Indian SNS. RFQ structure operated at higher duty factor will be subjected to thermal deformations and hence the detuning of resonating structure due to RF induced heating. A detailed Thermal-Structural-Electromagnetic sequential analysis of RFQ has been performed using Multi-physics ANSYS (Finite Element Analysis Software). A cooling scheme has been designed for efficient heat removal from the structure to minimize the thermal induced frequency shift. During analysis the parameters such as cooling water flow rate and bulk water temperatures are varied to study their effect on temperature distribution and associated frequency variation. The frequency shift is found highly sensitive to vane tip cooling parameters.

RFQ FOR LOW ENERGY H$^-$ ION LINAC

A 350 MHz integrated vane type RFQ structure has been selected for accelerating proton/H- ion from the ion source to 3- 4.5 MeV. The operating frequency 350 MHz is selected on the basis of available RF power sources. Higher output energy from RFQ like 4.5 MeV is preferred from the injection point of view into the following linac structures like DTL/ low beta SC cavities. An intervane voltage of 65 kV is selected for the high duty operation of RFQ. While lower inter-vane voltage in RFQ reduces the power dissipation per unit length in the structure, however it results in increased length of RFQ structure.

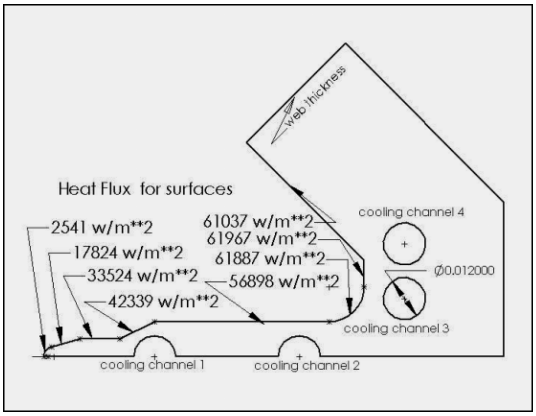

Figure 1: RFQ geometry with heat flux

COUPLED FIELD ANALYSIS OF RFQ

The RFQ cavity structure has been designed using SUPERFISH for the inter-vane voltage of 65 kV. The total power loss in the RFQ structure is 539 kW. Figure 1 shows the surface heat flux in RFQ. The power loss for the thermal analysis has been considered 50% more than the power loss calculated by SUPERFISH to compensate for the deviation in ideal surface conditions, theoretical electrical conductivity and joints etc. The material for the construction of RFQ is OFHC copper. The RFQ cavity has been analyzed using FEA software ANSYS considering six cooling channels per quadrant of RFQ cavity. Thermal analysis of RFQ has been performed to remove the RF induced heat from the structure The circular shape, 12 mm diameter of cooling channel is selected due to ease in machining. The relative locations of remaining five channels were determined by parametric thermal design optimization. Parametric studies are performed to evaluate the effect of cooling water flow rate and cooling water bulk temperature and their effect temperature distribution are shown in the figures.

Thermal-Structural-Electromagnetic sequential Analysis of RFQ

Thermal-structural-electromagnetic sequential analysis has been performed to evaluate the thermal induced frequency shift of RFQ structure. The RFQ geometry is modeled by using Plane 2D elements for OFHC Copper walls and a corresponding MESH 200 unsolved elements for cavity space. The temperature distribution obtained from the thermal analysis was taken as an input for the structural analysis. The displacement constraints were applied such that the RFQ structure is free to expand in the radial direction. The deformation due to self weight of the structure is also incorporated in the analysis. During thermal and structural analysis the MESH 200 elements act as a dummy element. The high frequency electromagnetic analysis is performed for resultant deformed cavity to evaluate the thermal induced detuning of the structure. During HF electromagnetic analysis, the unsolved MESH200 elements are converted into corresponding high frequency elements. Various multiple iterative ANSYS macros have been incorporated in the sequential analysis to evaluate the effect of cooling channel flow rate and bulk water temperature on resonating frequency. Figure 3 and Figure 4 shows the effect of flow rate and bulk water temperature in various cooling channels on temperature rise in RFQ.

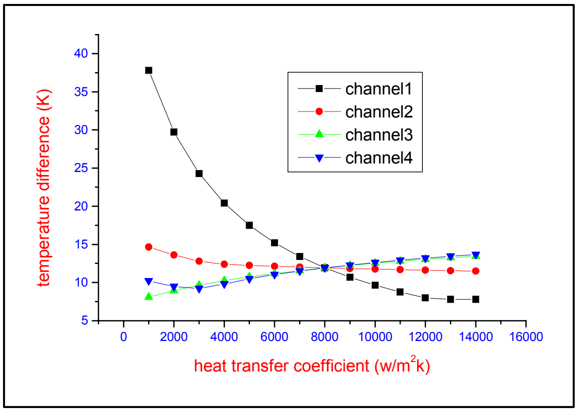

Figure 2: Effect of cooling channel flow rate on Temperature rise

Effect of cooling water flow rate on resonating frequency

To study the effect of cooling water flow rate on frequency shift, the heat transfer coeff in one of the cooling channel is varied from 2000 -12000 W/m*mK, while all other parameters are kept constant. The analysis is performed by varying the flow rate in each channel one by one and the frequency shift is evaluated. It is observed from the analysis that increase in flow rate of vane tip cooling channel increases the resonating frequency whereas frequency decreases with an increase in flow rate of web cooling channels. It is also seen that frequency sensitivity is highest for the cooling channel nearest to the vane tip as sown in Figure 4.

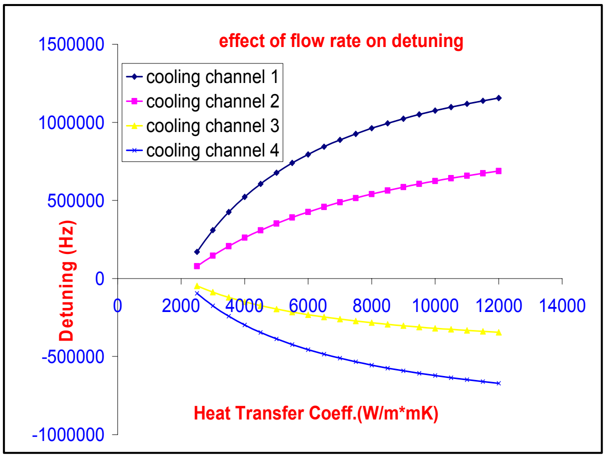

Figure 4: Effect of cooling channel flow rate on thermal induced frequency shift.

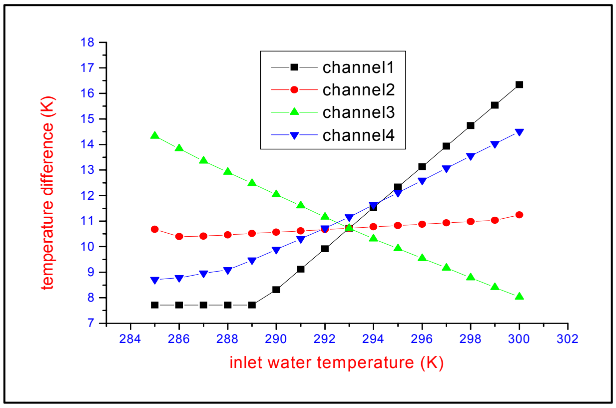

Figure 3: Effect of cooling channel bulk water temperature on Temperature rise in RFQ

Effect of bulk water temperature on frequency shift

To study the effect of bulk water temp on frequency shift, the bulk water temp of each channel is varied one by one from 288K to 300K, while all other parameters are kept constant. It is seen that increase in bulk water temperature of vane tip cooling channels decreases the resonating frequency whereas frequency increases with increase in web cooling channels bulk water temperature. The sensitivity for the vane tip cooling channel is maximum for thermal induced detuning. The structure is detuned about –17 kHz and –8.2 kHz with 1K rise in bulk water temperature of vane tip cooling channels and the frequency shifts about +6.5 kHz and +12 kHz with web cooling channels bulk water temperature. The variation of frequency shift with bulk water temperature is found linear in nature as shown in Figure 5.

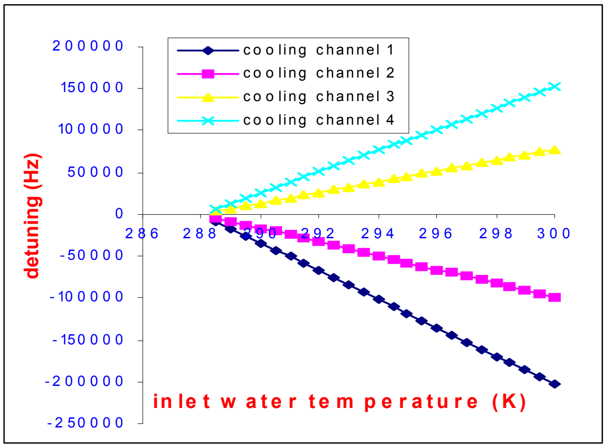

Figure 5: Effect of cooling channel inlet water temperature on thermal induced frequency shift.

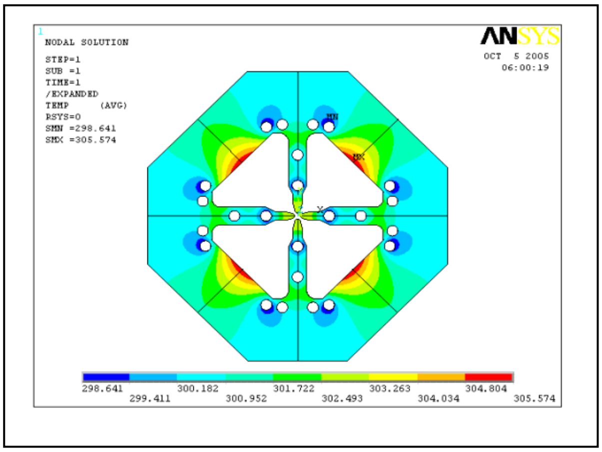

Figure 6: Optimized RFQ structure to minimize thermal induced detuning
Web thickness = 70 mm
V1 = 3.5 m/s T1= 288 K V2=3.5m/s T2=288 K
V3 = 1.4 m/s T3= 300 K V4=3.0 m/s T4=288 K

CONCLUSIONS

A sequential analysis has been carried out for a proposed 350 MHz RFQ geometry with various cooling parameters, scaled up heat flux from SUPERFISH analysis and suitable structure constraints. Results obtained from the structure analysis were taken as input to the high frequency analysis for estimation of thermal induced frequency detuning. The frequency sensitivity of resonating structure with cooling water flow rate and bulk water temperature has been investigated. It is inferred from the results that the cooling water flow rate and bulk water temperature in the cooling channels 1& 2 located near the RFQ vane tip has opposite effect on frequency detuning of RFQ structure as compared to their variation in cooling channels 3 & 4 located in the RFQ wall. The data obtained from the variation of cooling parameters will be utilized for the fine frequency control of the resonant cavity during high power operation.

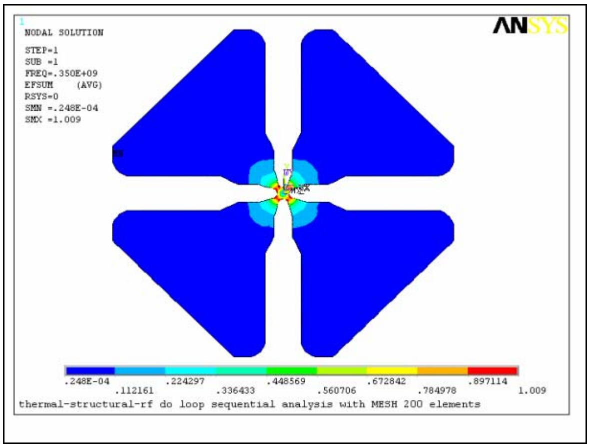

Figure 7: Electric field plot of the final optimized cavity. Frequency of undeformed cavity is 349.202 MHz and the frequency of deformed cavity is 349.536MHz giving detuning of 334.293 KHz.

REFERENCES

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