3-D THERMO-STRUCTURAL AND MECHANICAL RESONANCE STUDIES FOR 352.2 MHZ, 3 MEV RFQ

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Abstract

RRCAT is involved in the development of 352.2 MHz, 3 MeV pulsed RFQ structure for low energy part of H- ion injector linac. Thermal structural coupled studies to minimize rf heat induced detuning and mechanical resonance aspects are the crucial steps during the design and engineering phase of RFQ structure. The 3-D finite element model for RFQ structure consisting of three segments with various vacuum ports, tuner ports, rf ports, vane cut backs and connecting flanges has been developed and detailed fluid-thermal-structural coupled studies have been carried out. An optimized water cooling scheme has been designed for the efficient heat removal from the structure. The temperature distribution due to rf induced heating and thermal deformations in the RFQ structure has been evaluated. The cooling of vane cut back has also been studied. Studies carried out to evaluate the structural frequency and deformation pattern of the mechanical oscillation modes of the RFQ in longitudinal and transverse directions will be presented.

INTRODUCTION

The 352.2 MHz, 3.0 MeV RFQ, a part for front end of 100 MeV injector linac for ISNS has been designed and optimized for a peak current of 50 mA with inter-vane voltage of 79.97 kV for pulsed application [1]. The design requirements of RFQ include efficient cooling due to rf induced heating, ensure mechanical stability of the structure and fine tuning of the resonance frequency during the operation of RFQ. A three dimensional CAD model of the RFQ structure with various ports and vane cut backs has been developed and an integrated fluid thermal structural coupled finite element analysis for the structure has been carried out to ensure the thermal and structural stability of the RFQ structure.

RFQ STRUCTURE

The RFQ will be an octagonal shape integrated four vane cavity type structure, machined from OFHC copper bar. The two W and two T shape pieces will be joined to form the cross section of the RFQ [2]. The 3.46 m long RFQ structure will be divided into three segments. For finite element analysis, the RFQ structure model has been developed which includes the three segments of the RFQ with various tuner ports, rf ports, vacuum ports and the connecting end flanges to join the three segments. The vane cut backs at the beginning of the first segment and at the end of third segment has been provided for thermal analysis to evaluate the vane stability. Each segment of the RFQ consists of 24 circular cooling channels of 12 mm diameter to remove the rf induced heat from the structure. The cooling channel next to the vane tip was located as close as possible to the vane tip. The relative locations and size of remaining cooling channels were determined by parametric 2D thermal design optimization of the structure.

Figure-1: 3-D CAD model of RFQ

FLUID THERMAL COUPLED ANALYSIS

The total power loss in the RFQ structure is about 9.6 kW at 3% duty factor. The power loss for the analysis has been considered 40% more than the power loss calculated by SUPERFISH to compensate for the deviation in ideal surface conditions, theoretical electrical conductivity and joints etc. The rf heat loads were applied to the appropriate surfaces as heat flux. The cooling channel inlet and outlet of every module is independently connected with the water manifold. The water velocity in each cooling channel is considered as 2m/s with an inlet bulk water temperature of 298 K. At the outlet of each cooling channel, the pressure conditions of one atmospheric pressure are applied. To incorporate natural convection, all these surfaces are provided with a heat transfer coefficient of 10 W/m^2 K and a bulk temperature of 298 K. The integrated 3-D fluid thermal coupled analysis has been performed for RFQ where mass momentum and energy equations are solved simultaneously to evaluate flow pattern, pressure distributions inside the coolant channels and temperature distribution in the structure [3]. It is seen from the results that localized heating of vane tip occurs at the vane cut backs, as the heat is not sufficiently removed by cooling channels at these locations. The temperature in the RFQ cross section increases from inlet to outlet due to the continuous increase in the temperatures of cooling water along the length of cooling channels. However, the results show a very small water temperature rise (~0.3 K) at the outlet of RFQ due to large thermal mass of the water flowing along the coolant path.

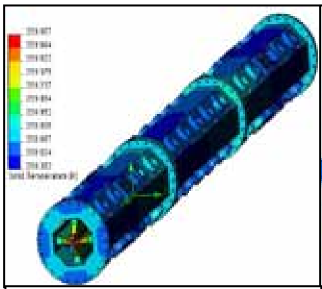

Figure-2: Temperature distribution in RFQ. The maximum and minimum temperatures are 299.807 K and 298.382K respectively, resulting ΔT of 1.425K in RFQ.

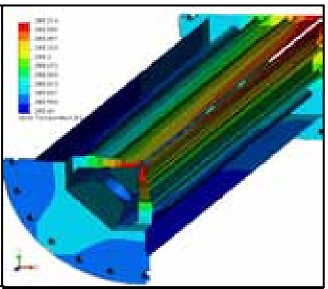

Figure-3: Temperature variation along the length of first segment of RFQ. The maximum temperature in the RFQ cross section is 299.714 K at outlet of RFQ.

THERMAL STRUCTURAL COUPLED ANALYSIS

A coupled thermal structural analysis for RFQ was performed for thermal deformations and stresses induced in the structure. The temperatures obtained during fluid-thermal coupled analysis were applied as a body load in the FE model. To include self weight, the gravity loading is incorporated in the analysis. As constrained, RFQ was fixed at one end and supported on the rollers on the bottom surface. The reference temperature is taken as 298 K. The maximum displacement of 5.1 microns in radial direction and maximum thermal induced von mises stress of 4.9 MPa was observed, which indicates that the structure will be in elastic region and there will not be any permanent deformation in the RFQ cavity during steady state operation.

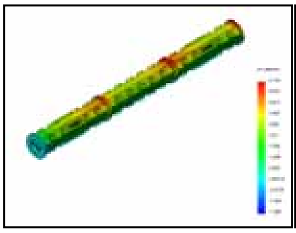

Figure-4: Deformation pattern for RFQ in radial direction. The maximum deformation in the structure is 5.1 microns.

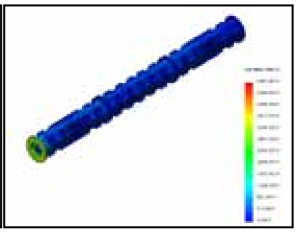

Figure-5: Von Mises stress distribution for RFQ structure. The maximum stress induced in the structure is 4.9 MPa.

MECHANICAL RESONANCES

To ensure the mechanical stability of the RFQ structure, the natural mechanical frequency and deformation patterns of the RFQ has been investigated. The RFQ has been considered to be fixed at one end and supported on the rollers at the bottom surfaces. The frequency and deformation maps associated with first two natural mechanical frequencies in transverse as well as in longitudinal directions are evaluated.

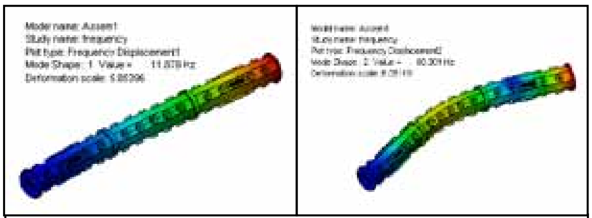

Figure-6: First and second mode shapes for longitudinal mechanical frequencies. The natural frequencies are 11.8 Hz and 69.9 Hz respectively.

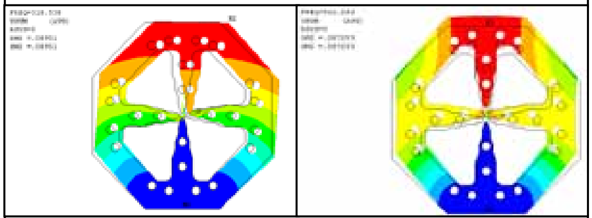

Figure-7: First and second mode shapes for transverse mechanical frequencies. The natural frequencies are 318.5 Hz and 861.2 Hz respectively.

CONCLUSIONS

The principal design requirements of effective cooling and thermal structural stability of RFQ has been investigated. The temperature gradient evaluated in RFQ structure at 3% duty factor is less than 1.5 K. The 3 D fluid-thermal-structural coupled analysis of the full RFQ structure is more realistic and the predicted thermal induced deformations will be of very high importance in the estimation of the rf induced frequency shift during the operation of RFQ.

ACKNOWLEDGEMENT

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