3D THERMAL-FLUID COUPLED ANALYSIS FOR 350 MHZ RFQ FOR INDIAN SNS PROGRAMME

S. C. Joshi, N. K. Sharma, N. Kumar, S. Raghvendra, S.A. Pande, G. V. Kane,
Centre for Advanced Technology, Indore 452013, INDIA

Abstract

An integrated vane-cavity type 350 MHz, 4.5 MeV RFQ structure is being designed for the low energy part of 100 MeV injector linac for the proposed 1GeV rapid cycling proton synchrotron[1],[2]. The details of the proposed RFQ structure and cooling circuits, designed for the pulse operation of RFQ with a provision to increase RF duty factor are presented. The thermal-fluid coupled analysis of one module of RFQ giving 3D temperature distribution in the RFQ cavity structure is also described.

100 MEV INJECTOR LINAC FOR ISNS

A 100 MeV, 50 mA, 25 Hz, H^- ion linac is being designed as an injector for the proposed 1GeV, 100 kW rapid cycling proton synchrotron for Indian Spallation Neutron Source (ISNS) at CAT as shown in Figure 1. The linac will consists of a 50 keV H^- ion source, 350 MHz, 4.5 MeV RFQ and 100 MeV DTL. Major emphasis in linac design has been given to the smaller beam emittance and lower energy spread at the output of the linac to maximize the beam injection efficiency in the synchrotron.

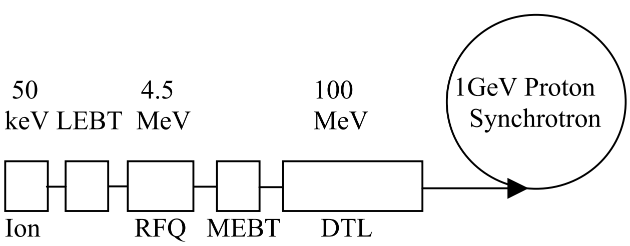

Figure 1: Schematic Diagram of Proposed Indian Spallation Neutron Source

RADIO FREQUENCY Q-POLE (RFQ)

The RFQ for 100 MeV injector linac for ISNS has been designed and optimized for a peak current of 50 mA with slightly higher inter-vane voltage for pulsed application. The choice of main parameters for the RFQ is mainly governed by the duty factor of operation. The higher inter-vane voltage would be advantageous as the transverse focusing strength and the acceleration efficiency depend directly on it. The operating frequency, like other designs for similar facilities is selected to be 350 MHz, which is mainly governed by the availability of the high power RF power sources. The input energy from the ion source is chosen to be 50 keV. Higher output energy from RFQ is preferred from the injection point of view into the following linac structure. An energy of about 4.5 MeV seemed to be appropriate for injection into following DTL linac structure.

Physics Design of RFQ

The multi-particle simulation code PARMTEQM is used for the beam dynamics design studies and optimization of the RFQ parameters. The parameters are optimized to have transmission efficiencies better than 96% with 10,000 particles when simulated with PARMTEQM.

Choice of higher inter-vane voltage improves the transverse focusing strength B but increases the heat dissipation in RFQ structure. For the pulsed 50 mA RFQ, with duty factor of 0.0125, the inter-vane voltage was chosen as 85 kV. The cooling circuits have been designed to suit the increased heat dissipation in the RFQ structure.

Table-I lists the parameters of 50 mA RFQ designs.

RFQ Cavity Design

The RFQ cavities are designed with SUPERFISH. Being high duty accelerator, the main consideration while designing the cavity for the pulsed 50 mA RFQ, the power dissipation is 1.1 kW/cm. The total peak power loss in the 50 mA RFQs is estimated to be 600 kW and the average power loss would be 7.5 kW.

Table 1: Main Parameters of RFQ

Parameter	Value	Unit
Total length of the accelerator	550.601	cm.
Total length of the vanes	549.401	cm.
Length of the RMS gap	0.68423	cm.
Length of the Fringe Field gap	0.51525	cm.
Minimum aperture radius	0.2397	cm.
Transverse radius of curvature	0.3573	cm.
Minimum longitudinal radius of curvature	1.4224	cm
Total No. of section	5	
Length of each section	110.1202	cm
Modulation	1.890	
Breakout angle	15	°
Vane voltage	85.95	kV
Power loss in one quadrant	273	W/cm
Total power loss in whole structure	600	kW
Duty Factor	$1.25x10^{-2}$	
Material for Fabrication	OFHC	
Operating temperature	30	°C

ENGINEERING DESIGN OF RFQ

Structure Design of RFQ Cavity

The RFQ will be a octagonal shape integrated four vane-cavity type structure, machined from OFHC copper extruded bar for construction. Advantage of symmetry is taken in the machined pieces before vane tip modulation. This will offer inter-changeability in the basic machined segments of RFQ. The cooling channels will be machined as closer to the vane tip as possible. The structure will be machined in smaller segments of length of 1~ 1.1 meter and joined together by furnace brazing to make an individual RFQ module. The module-to-module joining will be performed using metal gaskets by mechanical fastening to insure a good RF and vacuum tight joints.

Thermal Analysis of RFQ Cavity

The peak power loss in the proposed RFQ structure is 600 kW. The measured shunt impedance and quality factor are usually about 80% of theoretical values. 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 proposed RFQ cavity has been analyzed using FEA software ANSYS considering the option of six cooling channels per quadrant of RFQ cavity. The circular shape 12 mm diameter of cooling channel is selected due to ease in machining. The cooling channel below the vane tip was located as close as possible to the vane tip. The relative locations of remaining five channels were determined by parametric thermal design optimization.

Optimization of RFQ Cooling Circuit

The respective modified heat load is applied to the various segments of the RFQ surfaces for initial steady state thermal analysis of the RFQ geometry. The thermal analysis was performed with a constant flow rate of about 2.5 m/sec and water temperature of 300 K. The spacing of the five cooling channels with respective to the top cooling channel and the water flow rate were varied for the parametric optimization. The corresponding range of heat transfer coefficient was varied from 1000 – 14,000 $W/m^2.K$. The results obtained in initial optimized steady state thermal analysis were taken for the 3-D Fluid-Thermal coupled analysis for 1 meter long RFQ structure.

Fluid-Thermal Coupled analysis for RFQ

Utilizing the results of initial optimized thermal analysis i.e. optimized positions of cooling channels and the flow rate, the Fluid-Thermal coupled analysis was performed using ANSYS/Flotran CFD module of Ansys Multi-physics. The coupled analysis was performed on 1 meter long RFQ geometry. The coupled Fluid-Thermal analysis is performed in two steps. Initially the turbulent flow analysis is performed to calculate the flow velocity distribution in the channel and the pressure variation in the RFQ module of 1 meter long. The Flotran thermal analysis calculates the temperature distribution based on the heat fluxes applied to the RFQ surfaces and appropriate heat transfer coefficient calculated as per the flow patterns on the wall of flow channels. The counter flow scheme of water flow in the adjoining cooling channel was considered to reduce the temperature gradient along the length of the RFQ structure. Figure 2 gives the 3-D temperature distribution in 1-meter long RFQ geometry based on surface heat flux and the optimized value of the heat transfer coefficient for the flow channels. Figure 3 gives the 3-D temperature distribution in RFQ model considering the Fluid-Thermal coupled analysis.

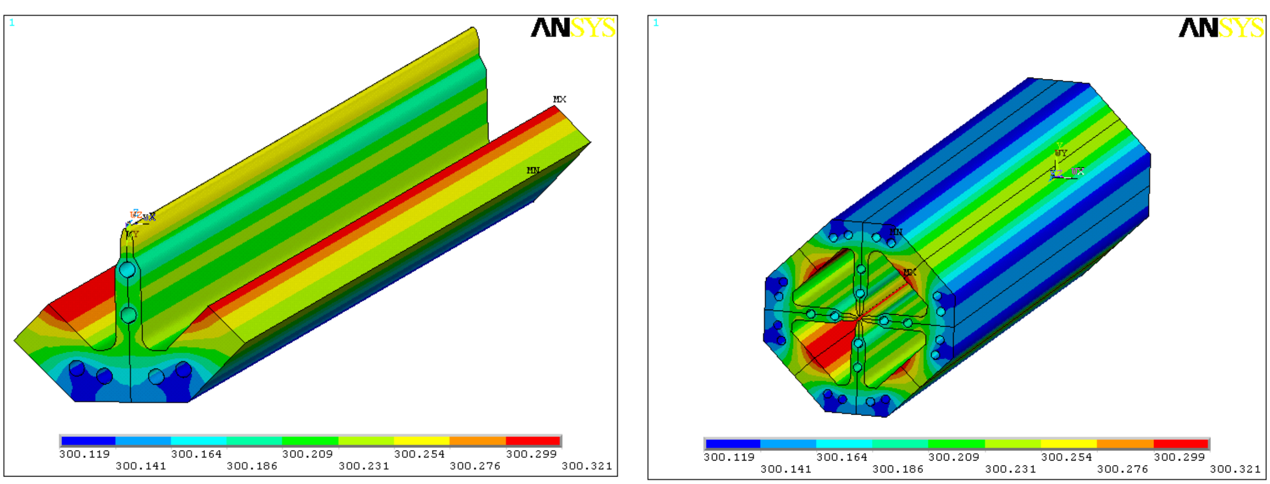

Figure 2: Result of the optimized Steady State Thermal Analysis of the RFQ Structure.

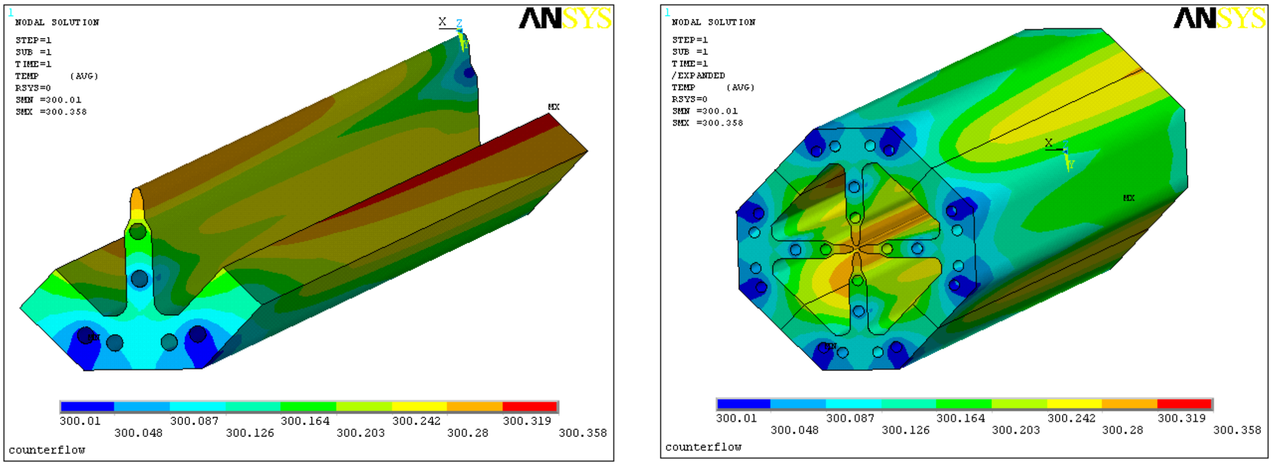

Figure 3: Result of the Fluid-Thermal Coupled Analysis of the RFQ Structure.

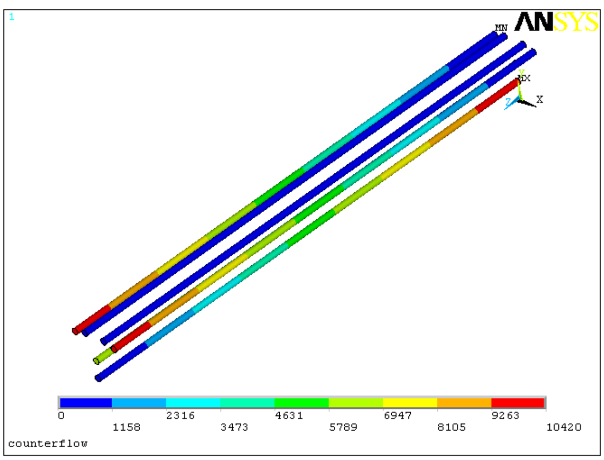

Figure 4: Pressure distribution in the flow channel

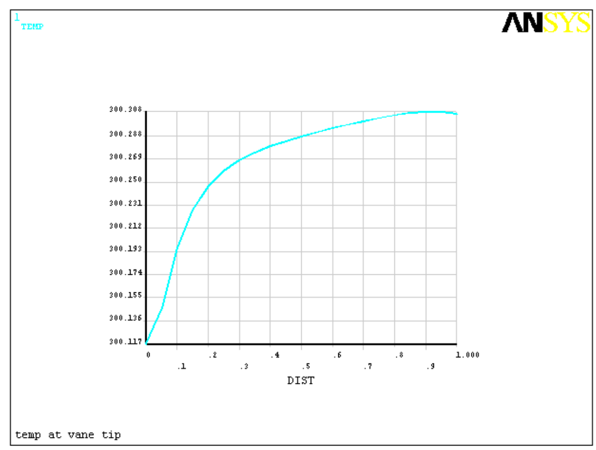

Figure 5. Vane tip Temperature variation along the length

Figure 4. shows the pressure distribution in the Fluid Analysis and Figure 5 shows the temperature variation of the RFQ vane tip for 1 meter length.

CONCLUSION

With the optimized Thermal Analysis, the temperature distribution is more uniform in the cross-section of RFQ structure. The Thermal Fluid coupled analysis reveals the possible temperature gradient along the length of 1 meter RFQ structure due to increase in the water temperature along the flow channels. The rise in temperature of 1-meter long RFQ structure for 1.25% duty factor is about 0.36 deg. Celsius. It is well within the required temperature stability of +/- 0.5 deg C. The 3-D temperature distribution in the RFQ will also help in the estimation of the structure deformation and possible frequency shift in the RFQ. This will also be of very high importance in estimation of the frequency shift for the operation of RFQ at high duty factor.

REFERENCES

[1] D. D. Bhawalkar, et al., “Indian Spallation Neutron Source,” InPAC-2003, February 2003

[2] S. A. Pande, et al., “Design Optimization of 100 MeV Injector Linac for ISNS,” InPAC-2003, February 2003

[3] S. C. Joshi, et al., “Engineering Design & Analysis of 350 MHz, 4.4 MeV RFQ for proposed Low Energy part of High Power Proton Linac,” InPAC-2003, February 2003.