PROTOTYPE ENGINEERING DESIGN OF 350 MHZ 4.5 MEV RFQ FOR PROPOSED PROTON LINAC FOR INDIAN ADS PROGRAM

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Abstract

In the first phase a 25 mA, 100 MeV CW Proton Linear Accelerator and 1 GeV Proton Synchrotron is being proposed at Centre for Advanced Technology, Indore for the Indian ADSS / SNS programme[1]. Development work on an ECR ion source, 350 MHz, 4.5 MeV CW RFQ, 10-20 MeV 350 MHz DTL, SDTL and low beta SC cavity are being initiated. A 350 MHz integrated vane-cavity type RFQ has been selected for the first prototype study. The Structural stability of a CW RFQ is the main concern of the thermal engineering design. A detailed thermal analysis performed for different heat load cases due to various inter-vane voltages will be presented. The proposed fabrication and joining schemes of CW RFQ will also be discussed.

1 HIGH INTENSITY PROTON LINAC FOR ADDS/SNS

Work has been initiated on the development of various sub-systems for the first phase of high intensity proton linac structure mainly; microwave type ion source for proton and H- ion, 350 MHz, 4.5 MeV, CW type of RFQ structure, 50 MeV, 350 MHz DTL and 100 MeV SDTL structure at CAT, Indore.

2 PHYSICS DESIGN OF 350 MHZ RFQ

Beam dynamics Design of four vane type 25 mA, 350 MHz, 4.5 MeV RFQ for Indian SNS and ADSS have been worked out and result of optimisation study are reported [2]. The operating frequency 350 MHz is selected on the basis of available CW 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/CCDTL/ low beta SC cavities. Another important part of RFQ design is the study of inter-vane voltage and associated penalties. A parametric study has been performed for various possible inter-vane voltages and power dissipation in the RFQ structure and raise in the RFQ temperature.

2.1 Beam Dynamics & RF Design of 4.5 MeV RFQ

The beam dynamics studies for optimising the RFQ parameters have been performed using multi-particle simulation code PARMTEQM. One of the prime objective of the beam dynamics and RF design is to put more emphasis on the lowering the power dissipation per unit length in the RFQ structure, important consideration for high duty factor / CW operation. Table 1 gives the result summary of possible RFQ designs for different inter-vane voltages and associative power dissipation in the 25mamp, 350 MHz RFQ structure in CW mode.

Table 1: Design summary of CW RFQ structures

$V\rightarrow$	65	70	75	80	85	kV
L	6.52	6.32	5.95	5.43	5.03	m
E_{smax}	28.7	28.0	27.8	29.8	31.0	MV/m
$P_{TOTAL}^{\dagger}$	539	556	589	616	620	kW
η_{Trans}	96.9	97.8	96.9	97.5	97.7	%
$\varepsilon_{x,rms}(n)$	0.20	0.20	0.20	0.21	0.21	$\pi\mu$m.rad
$\varepsilon_{y,rms}(n)$	0.20	0.19	0.20	0.22	0.22	$\pi\mu$m.rad
$\varepsilon_{z,rms}(n)$	0.10	0.11	0.10	0.11	0.12	degMeV

† Excluding beam power of 111.25 kW in each case It is very evident that the lower inter-vane voltage in RFQ reduces the power dissipation in the structure. The penalty imposed for the lower inter-vane voltage is increased in the length of RFQ structure. The optimised design parameters for a CW type RFQ for 65 kV inter-vane voltage is shown in Table 2.

Table 2: RFQ Design Parameters

Beam current (i_b)	25	mA
Inter vane voltage (V)	65	kV
Particle	H^+	
Total length (L)	6.52	m
Modulation Parameter (m)	1 – 1.915	
Minimum aperture radius (a_{min})	2.20	mm
Average radius (r_0)	3.30	mm
Synchronous phase (φ_s)	-90 – -30°	
Transmission efficiency (h)	96.3	%
Input emitt. $\varepsilon_{t,rms}(n)$	0.20	$\pi\mu$m.rad
Output emitt. $\varepsilon_{t,rms}(n)$	0.20	$\pi\mu$m.rad
Output emitt. $\varepsilon_{z,rms}(n)$	0.10	deg.MeV
Quality factor (Q_0)	9000	
Total power loss	539	kW
Max. surface E field (E_{max})	26	MV/m
Kilpatrick	1.4	

3 ENGINEERING DESIGN OF RFQ

3.1 Structural design of 350 MHz CW RFQ

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 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 circular and rectangle shape are being considered for the cooling circuit design optimisation. The structure will be machined in smaller segments of length of 1~ 1.5 meter and joined together by mechanical fastening or laser beam welding to make an individual RFQ module. The mechanical fastened RFQ structure will be housed in a external vacuum envelop. The laser beam welding is also being planned with the CO2 LASER group of CAT. The module-to-module joining will be performed using metal gaskets to insure a good RF and vacuum tight joints.

3.2 Thermal Analysis of CW RFQ Structure

The RFQ cavity structure has been designed using SUPERFISH for the inter-vane voltages ranging from 65 kV to 85 kV. The proposed RFQ cavity has been analysed using FEA software ANSYS considering five cooling channels per quadrant of RFQ cavity. The cooling water temperature of 27 deg C and a flow rate of 2 m/sec is assumed for the comparative study for various RFQ structure with different inter-vane voltage, the result is shown in Table 3. Based on the initial thermal analysis a detail analysis was conducted to study the effect of different flow rate and cooling channel geometry for temperature distribution in the RFQ geometry. The results of different flow rate for the 65 kV inter-vane voltage RFQ structure is presented in Table 4.

Table 3: Inter-vane voltage v/s Temperature distribution in CW RFQ structure.

Intervane Voltage, kV	Maximum Temperature in RFQ, 0C	Minimum Temperature In RFQ, 0C
65	60.53	35.50
70	63.62	36.43
75	68.32	37.96
80	74.41	39.57
85	78.40	40.72

Table 4: Cooling water flow rate v/s Temperature distribution in 65 kV CW RFQ structure with a circular cooling channel.

Flow rate m/sec	Cooling water temperature	Maximum Temperature in RFQ, ^{0}C	Minimum Temperature in RFQ, ^{0}C
1.5	27.0	64.46	38.54
2.0	27.0	60.51	35.57
2.5	27.0	57.53	33.77
3.0	27.0	56.06	32.55
3.5	27.0	54.50	31.64

The temperature plot for a optimised flow geometry and flow rate for a CW 65 kV, RFQ is shown in the Figure 1. The power loss in the RFQ cavity was considered to be about 800 watt/cm for the thermal analysis. The power loss in RFQ cavity for thermal analysis is higher then the calculated by SUPERFISH.

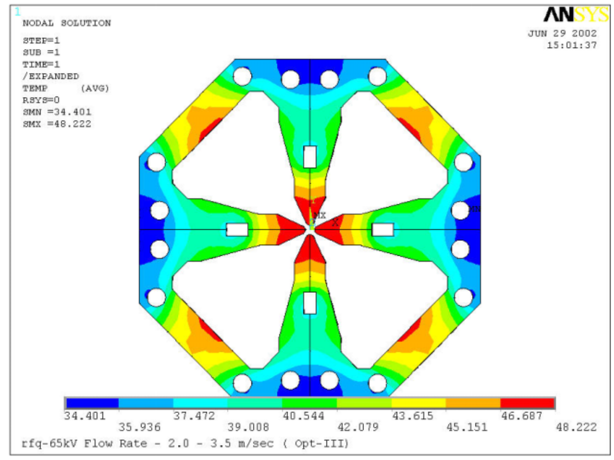

Figure 1: Temperature Plot of 65 kV CW RFQ structure. Flow rate near the vane tip is 3.5 m/sec and near the vane base is 2.0 m/sec. Maximum temperature is near the vane tip of 48.22 deg C and the minimum temperature of 34.40 deg C close to the cooling channel.

The reduction in the maximum temperature of RFQ vane tip is due to the increase in the heat transfer coefficient in the cooling channel near the vane tip by increasing the flow rate and shaping the cooling channel. Moving the cooling channel towards the vane tip can further reduce the vane tip temperature. The limit will be imposed by the position of the field stabilizing devices like Pie stabilizing loop (PSL) etc. The slot of PSL will restrict the machining of cooling channel by milling operation from the bottom side of the vane as shown. The other possibility for positioning a more closer cooling channel to the vane tip is as suggested by the LEDA RFQ [3], by machining a cooling channel in a separate machine vane tip piece and brazed it to the vane body.

3.3 Coupled Thermal Structural Analysis

A coupled thermal structural analysis was performed using ANSYS. The temperature distribution obtained from the thermal analysis was taken as an input along with the boundary constrains condition for the structural analysis. The displacement constrain were applied such that the RFQ structure is free to expand in the radial and longitudinal direction. The bottom plane was only constrained in one direction. It was observed that the vane tip will be displaced to be around 26 micron (μm) in the x and y direction. The maximum displacement of 45 micron (μm) was observed in the area near the vane base. The displacement in the longitudinal direction observed is about4 micron for a length of 1 centimetre. It was also observed that the temperature effect is more prominent in controlling the structural deformation and a selective structure deformation can be obtained by controlling the flow rates in the circular cooling channels of the vane base. A scheme of flow rate and water temperature for the 25 cooling channels will help in introducing a more efficient thermal management for the operation of the RFQ structure for high duty factor and CW mode.

3.4 Stress Analysis:

A stress analysis was also performed to study the thermal induced stresses in the RFQ cavity. Figure 2 illustrate the von Mises stress plot of one of the quadrant of RFQ cavity. The stresses indicate the structure will be in the elastic region and there will be not be any chance for the permanent deformation in the RFQ cavity during study state operation.

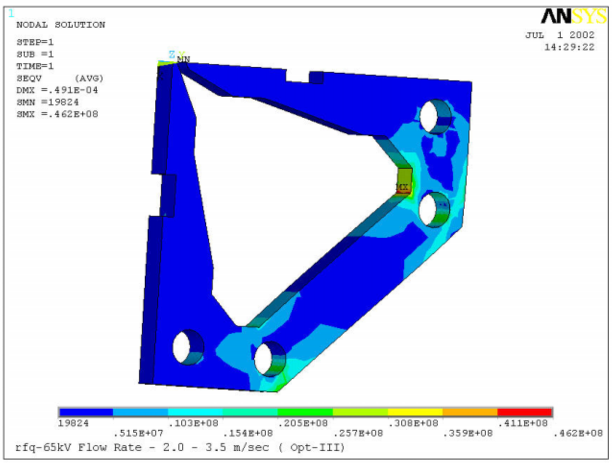

Figure 2: The von mises stress plot of RFQ quadrant. The maximum stress indicated is about 46 MPa in the corner region.

4 Frequency Shift:

The preliminary study using SUPERFISH has been carried out for the change in the resonating frequency of the RFQ structure. It was indicated that structural deformation after the coupled thermal structural analysis will result in changing the frequency by +182 kHz. Further optimisation and thermal management will bring down the frequency detuning of the RFQ structure within the limit tuners.

5 CONCLUSION

A preliminary design and analysis of a 350 MHz CW RFQ has been performed and prototype fabrication has been planned to verify the optimisation results and to develop a procedure for thermal management for operating a RFQ in higher duty factor required for initial study.

6 REFERENCES

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[2] S A Pande et al., ‘Design of 4.5 MeV RFQ for Proton/H^- ions’; this conference

[3] D. Schrage *et al.*, “CW RFQ Fabrication andEngineering,” Proc. LINAC98