DEVELOPMENT OF 3 MeV PROTOTYPE RFQ STRUCTURE FOR HIGH INTENSITY PROTON LINAC FOR ISNS

S.C.Joshi, G.V. Kane, N.K.Sharma, A.Chaturvedi, S.Raghavendra, K.K.Das, S.K.Chauhan, S.V. Kokil and B.Oraon

Raja Ramanna Centre for Advanced Technology (RRCAT), Indore, India

Abstract

Raja Ramanna Centre for Advanced Technology (RRCAT) has taken up a program on R&D activities for a 1 GeV, high intensity superconducting H- ion/proton linac for spallation neutron source programme. Front end of the linac will consist H- ion source, LEBT and 3 MeV Radio Frequency Quadrupole (RFQ). RFQ has been designed and fabricated to validate the design and manufacturing procedures. RFQ structure length of 3.49 meter has been divided in three segments for machining. Three segments have been machined and assembled for low power RF characterization. Frequency and field tuning exercise for the assembled RFQ structure is being carried out. The paper presents engineering design, fabrication issues and tuning studies carried on prototype structure.

INTRODUCTION

Four vane 3MeV RFQ has been designed to accelerate H^- ion beam from 50 keV to 3 MeV for 20mA beam current and a prototype has been fabricated. Prototype structure development involves engineering design, vacuum design, fabrication and assembly. RFQ has been designed for a duty factor of 1.25%. Important physics design parameters for RFQ [1] are listed in the table below.

Table1. Design parameters of RFQ

Design Parameters	Values
Input Energy	50 keV
Output Energy	3 MeV
Peak beam current	20 mA
Particle	H^- Ion
Operating Mode	Pulsed
Duty Factor	1.25%
Frequency	325 MHz
Structure	4-vane type
Total Length	3.49 m
Peak Power loss	300 kW
Material	OFE Copper

THERMAL DESIGN OF RFQ

The RF power loss in the structure will results in thermal deformations and RFQ structure will detune from its designed operating frequency. Therefore thermal stability of the structure is the main concern of engineering design. The thermal analysis of RFQ has been carried out for a maximum duty factor of 10 % where average power loss is taken as 42 kW. The power loss for the thermal 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. 12 mm circular cross section was selected for cooling channel considering machining feasibility. Studies were performed to optimize cooling channel locations and flow velocities for effective cooling of RFQ structure. Thermal analysis result reveals that using optimized parameters, the temperature gradient in RFQ structure is restricted within 1.2 deg C. The thermal induced frequency shift of 32 kHz was observed. 2D Thermal – structural - high frequency electromagnetic coupled sequential analysis has been performed to evaluate the effect of cooling water temperature on RFQ frequency. The analysis will help in thermal management of RFQ to control frequency detuning during operation.

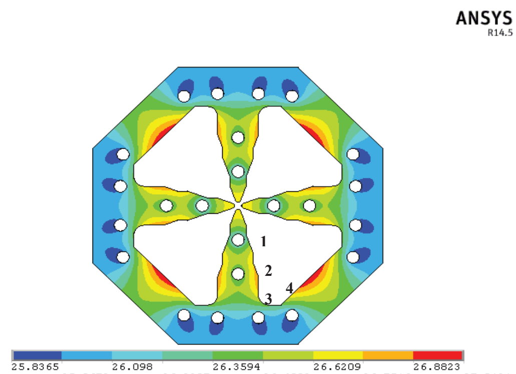

Figure 1: 2D Temperature distribution for RFQ

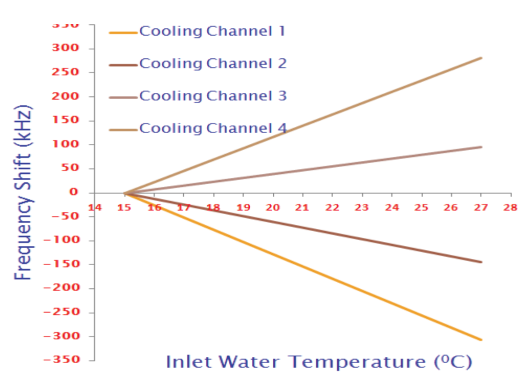

Figure 2: Effect of cooling water temperature on RFQ frequency.

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FLUID-THERMAL COUPLED ANALYSIS

3D fluid-thermal coupled analysis was performed to incorporate the effect of water temperature rise in the cooling channel of RFQ [2]. Parameters obtained from 2D optimization were used for 3D fluid-thermal coupled analysis. Appropriate heat fluxes were applied on various segments of RFQ. Parallel flow cooling schemes and Counter flow cooling schemes were considered during analysis. Fig. 3 shows the temperature distributions for Counter flow cooling scheme. Temperature gradient of 1.3 deg C in structure and rise of 0.45 deg C in bulk water temperature was observed.

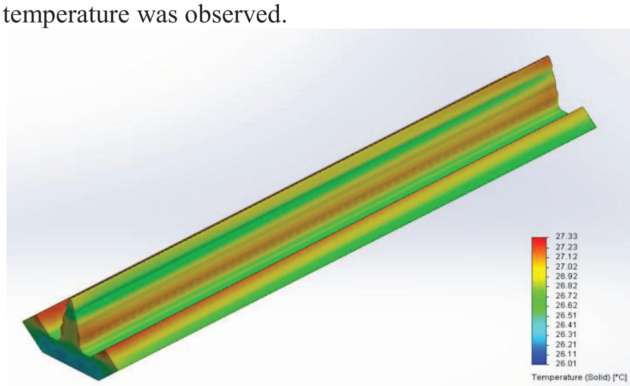

Figure 3: 3D Temperature distribution with counter flow

VACUUM SYSTEM FOR RFQ

Vacuum system has been designed for individual modules. Each module comprises of two segments. The gas loads which the vacuum system has to deal with for RFQ are gas load due to outgassing of the internal surface of the RFQ (OFE Copper), leakage from LEBT / Ion source and gas load resulting from proton loss. Each module will include one pumping station, which will have turbo molecular pumps / cryopumps of capacity 1000 l/s (total) and 1500 l/s respectively, one residual gas analyser, a set of low & high vacuum gauges, valves, vacuum seals and vacuum plumbing.

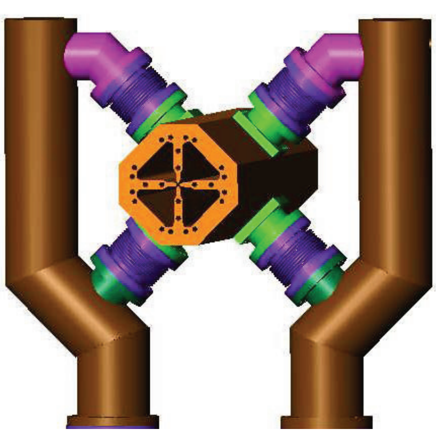

Figure 4: Vacuum envelope for RFQ structure

Each segment of the RFQ will have 4 vacuum pumping ports (Fig. 4). The pumping ports will have RF grill to attenuate the RF power leaking to the pumps. The RF power leaking through the vacuum port to the pump is around 1.5 nW for 3 % Duty factor of operation.

FABRICATION AND ASSEMBLY SCHEME

Fabrication is being planned in OFE copper. Assembly scheme shown in Fig. 5 having four joints has been selected for fabrication purpose [3]. This scheme offers more stability for machining process and ease in brazing.

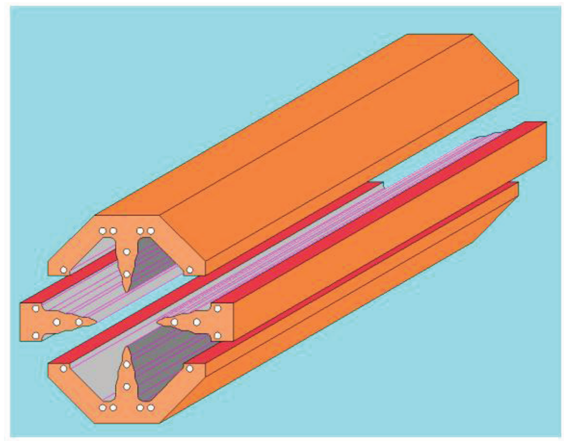

Figure 5: 3D Four joint type fabrication and assembly scheme.

PROTOTYPE FABRICATION OF FULL LENGTH RFQ STRUCTURE

Fabrication for full length prototype 352.2 MHz RFQ structure in aluminium alloy with modulated vanes was taken up to understand the fabrication difficulties and also to validate the physics design data [4]. The structure has a large number of ports for tuning, RF feeding and evacuation. For prototyping; various types of assembly schemes were studied and an eight joint type of assembly was chosen.

One of the important fabrication processes was to establish a procedure to perform machining of modulated vanes. Vane modulation data of software PARMTEQ-M provides information about the instantaneous vane tip radius and vane tip location in 3D co-ordinate system. The data has been used for preparation of solid models for vane modulation which was later used for machining of RFQ vanes.

Fabrication of Components

To check the correctness of CAD model, a CAD model for a small segment was provided to the fabricator in the form of an IGES file and machining trials were carried out. It was inspected by CMM and found to be within tolerance. Machining of all the modulated vanes was carried out with the use of ϕ 12 mm ball nose end milling cutter (Fig. 6).

Machining parameters were optimized for achieving surface finish $\leq$ 0.8 μm. Vane cut backs were machined at both the extreme ends. Stage wise inspection of machined components was carried out. Straightness of $\leq$ 90 μm, parallelism of ≤ 70 μm between two parallel faces and vane tip profile accuracy ≤ 50 μm could be achieved.

Manual tuners were also designed, fabricated and tested for operation. Tuners have a total stroke of 15mm with a provision of 10mm insertion in RFQ volume. Tuners are designed for tuning sensitivity of 1MHz / 3 mm.

Figure 6: RFQ vane under machining process & cutter used

Assembly and Testing

To check for assembly errors, assembly of all the segments were assembled at fabricator's works. Fig. 7 shows RFQ segment during assembly trials.

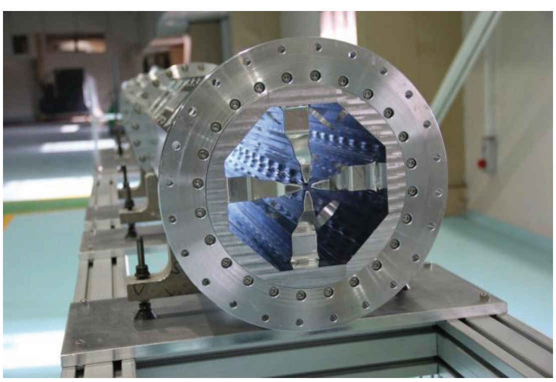

Figure 7: RFQ structure assembly

After receipt of all the machined components; chemical cleaning was performed. A bead perturbation test set up to characterize the RFQ structure has been developed. The setup is capable of performing bead pull testing of all four quadrants of RFQ structure in a single setting The test stand has also a facility to level and align RFQ segments. Individual segments were mounted, assembled and aligned on a bead pull test stand (Fig. 8)

Field distribution studies with the help of bead pull setup have been carried out. Fig. 9 shows electric field pattern for third module of 352.2 MHz RFQ structure. Tuning studies of RFQ structure with the use of 48 manual stub tuners is in progress.

Figure 8: 352.2 MHz prototype RFQ structure assembled on a bead pull test stand

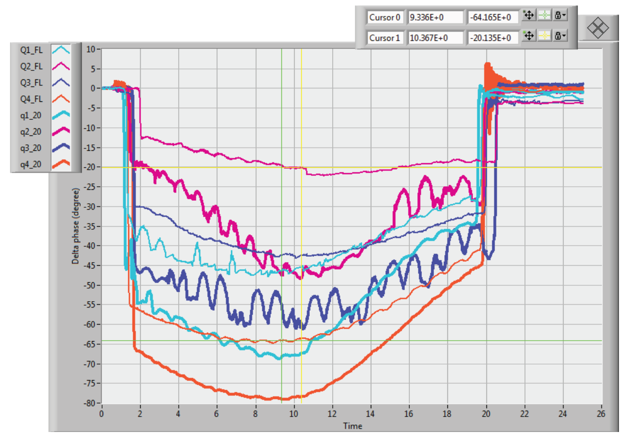

Figure 9: Study of electric field in RFQ structure moving stub tuners.

CONCLUSION

Thermal - Structural - Electromagnetic coupled analysis for 325 MHz RFQ structure has been carried out. The analyses results will be guiding input for fine tuning of the RFQ structure during high power operation at various duty factors. Prototype 352.2 MHz RFQ structure has been fabricated to establish the fabrication, low power RF testing and tuning procedures. Experience gained will useful for the development of full scale RFQ structure in OFE Copper.

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