THERMO-STRUCTURAL ANALYSIS OF 400 KEV DEUTERON RFQ COMPONENTS

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Abstract

In this paper we are presenting Thermo-structural analysis of 400KeV, 1mA RFQ components i.e. RF Coupler, Tuner and Vacuum port. This investigation will help us to design local cooling schemes for these components. Parametric studies are also included in this paper. Feasible cooling schemes which meet cooling requirements of components will also be shown.

INTRODUCTION

The renewed interest in Accclerator Driven Systems (ADS) has spurred tremendous interest in developing high intensity proton accelerators, and has set challenging demands in terms of delivering high current (~ tens of mA) and high energy (≥ 1 GeV) required for the spallation process. In Indian context, ADS will be used for the utilization of thorium resources for the energy production. In view of the importance of ADS, a project to design and build a 20 MeV, 30 mA CW proton accelerator (LEHIPA) as an injector to 1 GeV Linac has been initiated.

The LEHIPA mainly consists of a 50 keV ECR ion source, Low Energy Beam Transport (LEBT) line, 3 MeV Radio Frequency Quadrupole (RFQ) accelerator, Medium Energy Beam Transport (MEBT) line and a 20 MeV Drift tube Linac (DTL). 400 KeV, 1mA prototype deuteron RFQ will be build in order to understand the accelerator technologies required for LEHIPA project mainly regarding handling of very large RF power at 350 MHz. This RFQ will be utilized to replace 14 MeV neutron generator presently working at BARC.

RFQ will be made of OFHC copper. Because of the surface resistance offered by RFQ materials a portion of RF power gets dissipated in cavity itself. Average thermal load resulting from the RF power for the 400 keV RFQ is 68 KW. Main Coolant channels [1] have been designed to take care of this dissipated power. But these Main Coolant channels are not capable of eliminating potential Hot-Spot in RFQ components i.e. RF Coupler, Tuner, and Vacuum Port. Hence, Local Cooling of these components is required.

THERMO-STRUCTURAL ANALYSIS

Analysis is performed with help of FEM code 'ANSYS'. Modelling is done in ANSYS itself, this will facilitate easy remodelling. Investigation of temperature rise can be carried out with Thermal analysis, and deformation and stress pattern can be investigated with help of structural analysis. But in our case results of thermal analysis affect loading conditions in structural analysis, so coupling of thermal and structural filed is done. In Thermal analysis load is Heat flux, which is applied on mesh nodes by importing heat flux files from physics design calculations. 30% extra Heat Flux is added for safety margin. After performing thermal analysis elements are switched to structural elements while keeping model, material, mesh pattern unchanged. Now, temperature at nodes of mesh (which works as structural load) is imported from thermal analysis result file. Other boundary conditions like symmetricity, restriction of movement on flange are also applied. In following discussions h denotes Convective Heat Transfer Coefficient (in SI units) and Temperature is in Celsius. All the temperature profiles are shown on half-symmetric model.

RF Coupler

Co-axial type of coupler [2] has been chosen for this RFQ. Coaxial coupler mainly consists of Inner conductor, Outer Conductor, Ceramic window, Loop and Flange. Power dissipation in each coupler is 1.2 KW and peak Heat Flux is 35 W/cm^2.

Analysis without local cooling channel shows that temperature of loop and nearby portions may rise up to melting point of OFHC copper. Hence, local cooling scheme has been designed based on temperature profile which we got without local cooling channels. Inner conductor will be cooled by coaxial coolant channel. Outer conductor will be cooled with help of jacket from outside. Analysis shows that portion of outer conductor which penetrates inside RFQ is not required to cool locally; still temperature rise may be kept in check. Inner cooling channel and cooling jacket is shown in Figure 1. Temperature profile (with deformations) with this kind of cooling scheme is shown below in Figure 2. In this case, convection heat transfer coefficient (h) is 15000 with coolant temperature 16^{O}C.

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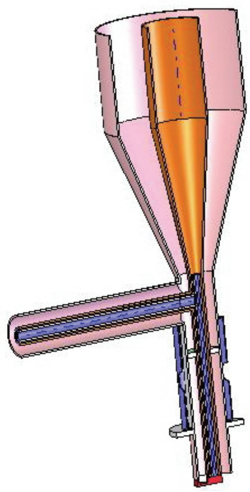

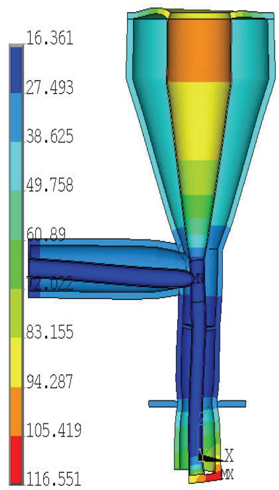

Figure 1: Cooling Scheme. Figure 2:Temperature Profile.

Maximum temperature rise is in loop and nearby portions on outer conductor. To minimize temperature parametric study has been carried out. Thickness of outer conductor has been increased (inner diameter of outer conductor is fixed by physics design) to maximum possible value while space constraints are kept in mind. Increased thickness of outer conductor facilitates cooling of loop by decreasing conduction resistance. Maximum deformation found is .64e-04m. Joint between Ceramic window and conductors was area of concern because of difference in thermal expansion characteristic of OFHC and Ceramic. But thermal gradient on ceramic plate and nearby zone is negligible. So, ceramic window will remain intact to conductors during RFQ operation.

Results of parametric studies are shown below:

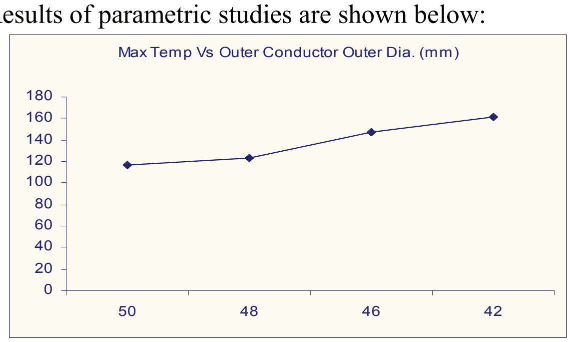

Figure 3: Max. Temp. Vs Outer Conductor Outer Dia.

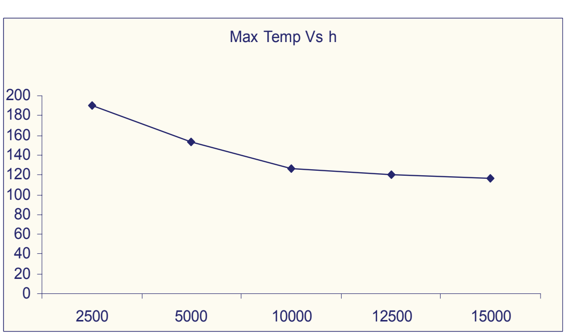

Figure 4: Max. Temp. Vs h.

With increase in h, maximum temperature in coupler body reduces. Temperature in loop is above 100 ^{O}C. So, h must be maximised but erosion of conductors because of high coolant flow will be the limiting factor.

Tuner

In order to correct the frequency slug type tuners will be used. Maximum 10 mm penetration [3] of tuner in RFQ cavity is allowed by physics design .In this case power dissipation per coupler is 800 W. Maximum heat flux is 25 W/cm^2 .Temperature rise without cooling is up to 1100 ^{O}C. Hence, local cooling channels are required. Resulting temperature profile, when h is 5000 and Inlet coolant temperature is 30 ^{O}C, is shown below in Figure 5. Pick-up loop will be incorporated in Tuner. Detailed design of pick-up loop is in progress. Coolant channels are made in such a way that central portion of tuner is left unused for pickup loop.

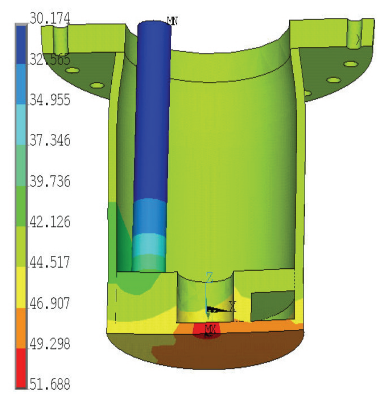

Figure 5: Temperature Profile.

Because of easy accessibility of coolant to the areas of high heat flux temperature rise is relatively lower. Hence, cooling requirement is not stringent in case of tuner. Relatively lower coolant flows with higher inlet temperature are acceptable in case of tuner.

Result of parametric study is shown below:

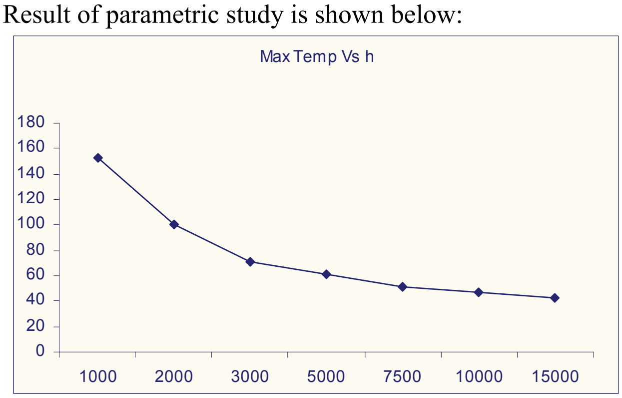

Figure 6: Max. Temp. Vs h.

From figure above it can be noted that even at lower h=5000 maximum temperature is sufficiently low.

Vacuum Port

Total power dissipated on vacuum port surface is 400W. Maximum heat flux is 35W/cm^2. Temperature rises up to 900 ^{O}C when there is no local cooling of vacuum port. Coolant path is shown in Figure 7. With h=2500 and 30 ^{O}C inlet coolant temperature profile is shown in Figure 8. Maximum Deformation found is .9e-04m.

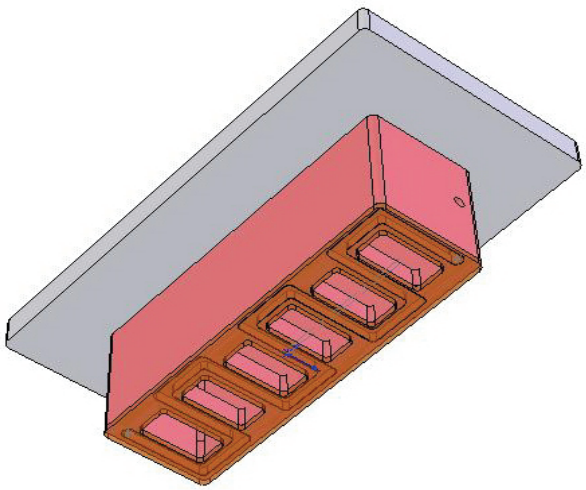

Figure7: Coolant Path.

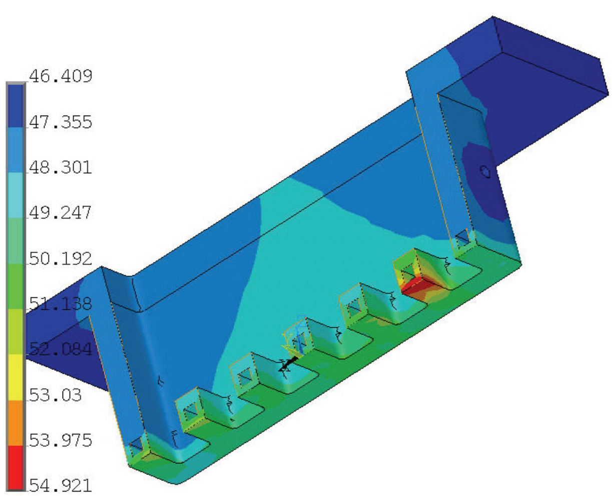

Figure 8: Temperature Profile.

Result of parametric study is shown below:

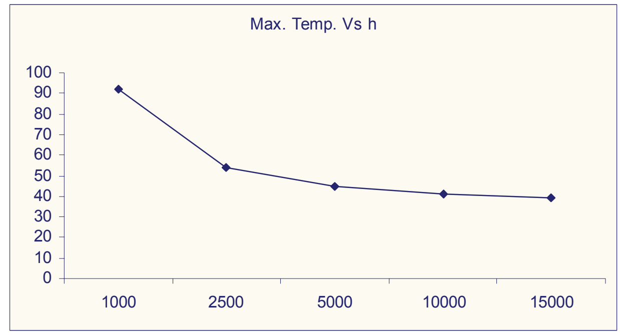

Figure 9: Max. Temp. Vs h.

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CONCLUSION

As analyses suggest, local cooling of Vacuum-Port, Tuner and RF port is essential for safe operation of RFQ. Cooling requirements for Vacuum Port and Tuner are not stringent. Hence, lower coolant flow at room temperature will suffice. But temperatures in RF port must be minimised by utilising relatively higher coolant flow rate at lower inlet temperature.

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