RF THERMAL AND STRUCTURAL ANALYSIS OF THE 60.625 MHZ RFQ FOR THE ATLAS UPGRADE *

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Abstract

The upgrade for the ATLAS facility is designed to increase the efficiency and intensity of beams for the user facility[1,2]. This will be accomplished with a new CW normal conducting RFQ, which will increase both transverse and longitudinal acceptance of the LINAC. This RFQ must operate over a wide range of power levels to accelerate ion species from protons to uranium. The RFQ design is a split coaxial structure and is made of OFE copper. The geometry of the design must be stable during operation. Engineering studies of the design at different RF power levels were conducted to ensure that the geometry requirements were met. Frequency shift analysis was also completed to determine the effects of high power levels. Thermal stress analysis was completed to show that the structure frequency is repeatable.

INTRODUCTION

This RFQ is designed to replace the first 3 small-aperture SC cavities in the Positive Ion Injector (PII) of ATLAS. It is 3.81 meters (vane length) long and consists of 106 modulation periods. The acceleration section of the RFQ uses trapezoidal modulations to increase shunt impedance by 40% [3]. This design is an outcome of the developments from the successful Rare Isotope Accelerator (RIA) RFQ prototype that was tested in 2006 [4]. The split coaxial structure provides for a 60.625 MHZ resonator with a maximum transverse dimension of only 18 inches. Fabrication uses gun drilled cooling channels and is based on a two-step brazing procedure. The RFQ cavity consists of five nearly identical segments, the middle segment includes a drive loop. The input energy is 30 keV/u and the output energy is 295 keV/u. The vane voltage is 70 kV and the power is 60 kW. Fig. 1 is a CAD model of a single RFQ segment.

MODELING

Modeling and analysis consists of RF analysis where the heat loads are determined from the magnetic fields. The loads are transferred to a thermal model to determine temperatures. The temperatures are used in a structural model to determine displacements and stresses and then the displacements are input back into the RF model to get a frequency shift. The finite element model was a single segment of the rfq that included end caps. The effect of the coupler is local so it becomes more efficient to run the model with quarter symmetry enabling more elements per vane and a quicker solution. The CAD quarter model is shown in Fig. 2.

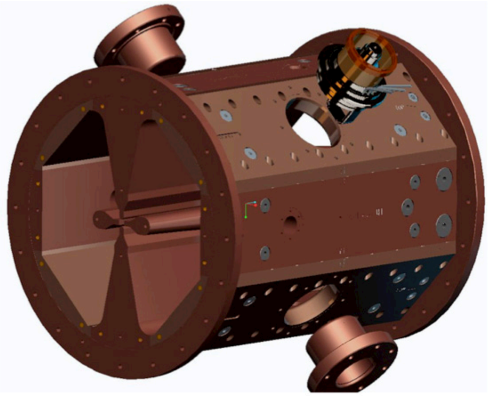

Figure 1: Segment of RFQ

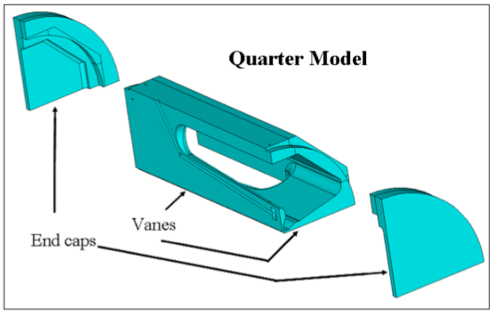

Figure 2: Quarter model of RFQ structure.

RF ANALYSIS

This was a collaborative effort with Argonne National Lab (ANL). ANL established the initial geometry to be analyzed and sent AES a CAD model of the RFQ that we transferred to ANSYS, a finite element solver. AES results with recommendations were then fed back to ANL to develop the final geometry. The RF space was extracted from the surfaces of the structure and an EM modal analysis was run. To correct the resulting fields, a vane to vane voltage scaling factor was determined by extracting the electric field between the vanes and integrating along the line. This is shown in Fig. 3.

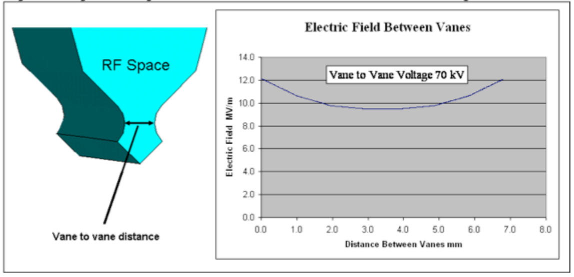

Figure 3: RFQ vane to vane voltage of 70kV.

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* This work was supported by Argonne National Lab under contract #0F-32402.

This scaling factor is also used on the magnetic fields. The scaled magnetic fields are shown in Fig. 4. These fields are used to map the heat loads on to the thermal model. The peak magnetic field occurs at the small radius of the undercut region of the vane.

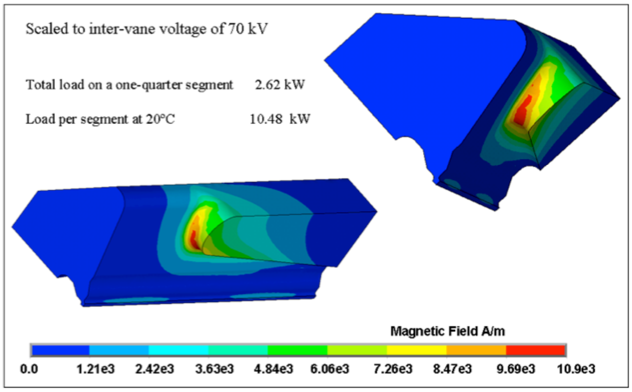

Figure 4: Scaled magnetic fields.

THERMAL ANALYSIS

The thermal model includes the cavity vanes, walls and all coolant channels. To determine the coolant temperature rise one-dimensional pipe flow elements were used. These elements have heat transport capability. Temperature dependent surface wall losses were accounted for by iterating the solution. After each temperature solution the heat loads applied to the surfaces were modified to account for the changes in surface resistance due to temperature. These iterations continued until the temperature converged. The heat loads including the effects of surface temperature are shown in Fig. 5.

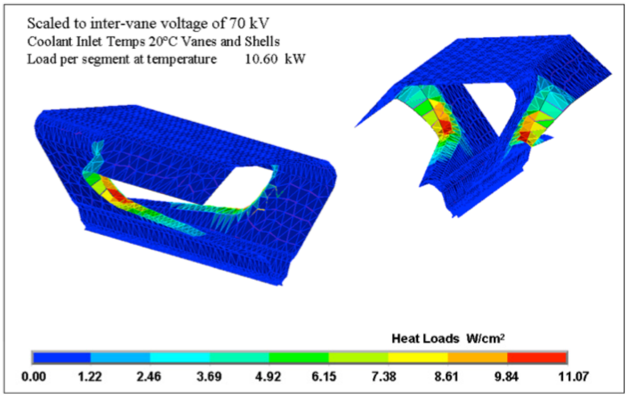

Figure 5: Heat loads mapped from RF model.

The coolant channels are shown in Fig. 6. The left side of the figure shows half the channels of one vane. On the right of the figure are half the channels of an adjacent vane. Between the two half vanes is the quadrant wall coolant channel. Upon close inspection of the channels, a true symmetry plane does not exist, however, based on analysis completed on the 57 MHz RFQ[5] the difference between a quarter model and a full model is not significant.

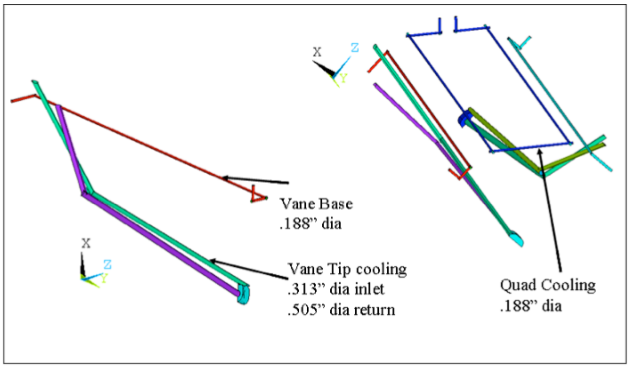

Figure 6: Cooling channels of vane and quadrant.

Fig. 7 shows the resulting temperature contours for a vane inlet temperature of 21.1ºC and a quadrant wall inlet temperature of 25.9ºC. These temperatures represent the inlet temperatures needed for cancelation of frequency shift. The frequency shift was determined for several inlet temperatures and is described later.

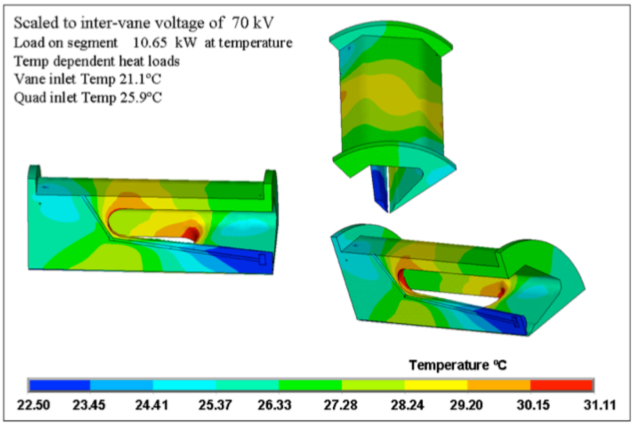

Figure 7: Temperature results.

The temperature results from the thermal analysis were mapped directly to the structural model. Pressure boundary conditions of 14.7 psi to the outside of the model and 70 psi coolant channel pressure were added to the structural model along with the temperature results. Vector sum displacement results are given in Fig. 8. The model was held on the beam axis near its axial center and the thermal growth is away from the center. These displacement results achieve the goals of the design.

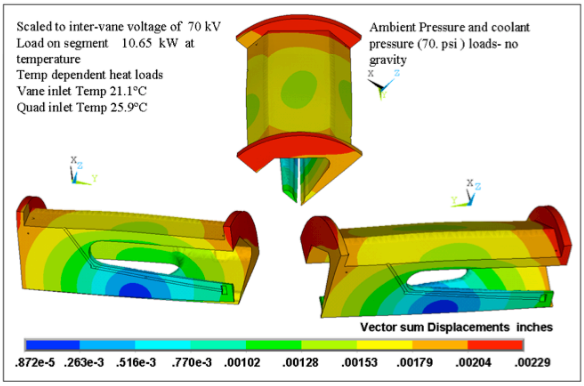

Figure 8: Displacement results.

Fig. 9 shows the stresses from the same analysis. These stresses are low and show that the design is robust. The highest stress is at the intersection of two gun drilled cooling channels. Stress on the RF surface and stresses that may cause distortion of the geometry are very small.

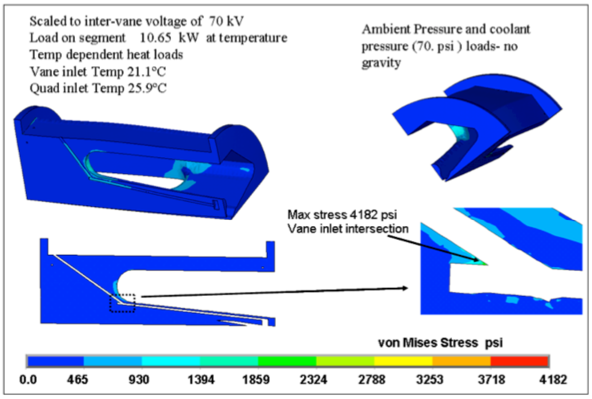

Figure 9: Stress results.

An important result found during the analysis concerned the location of the return coolant channel of the vane. Fig. 10 shows a comparison of the initial channel location and the final location. On the left is the original channel location showing the return channel near the vane tips. It results in a temperature gradient that tends to cause the vane to bow like a "bimetallic" structure. On the right is the final design where the temperatures near the vane tip are relatively warm. This tends to result in a straighter vane.

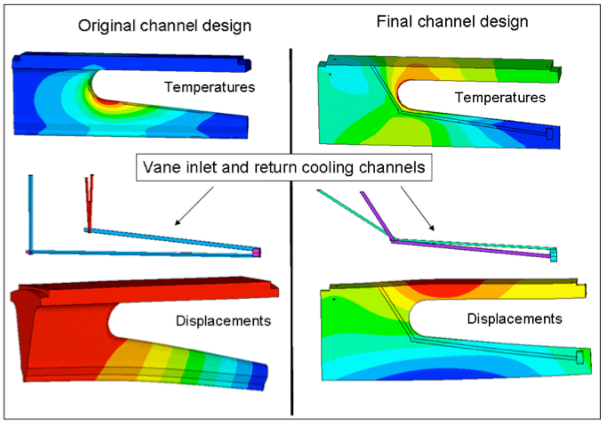

Figure 10: Return channel location effect on displacement of vane.

Frequency sensitivity of the inlet vane and quadrant wall temperatures are important for determining the cooling system details. Figure 11 shows the frequency sensitivity for varying the quadrant wall and vane inlet temperature.

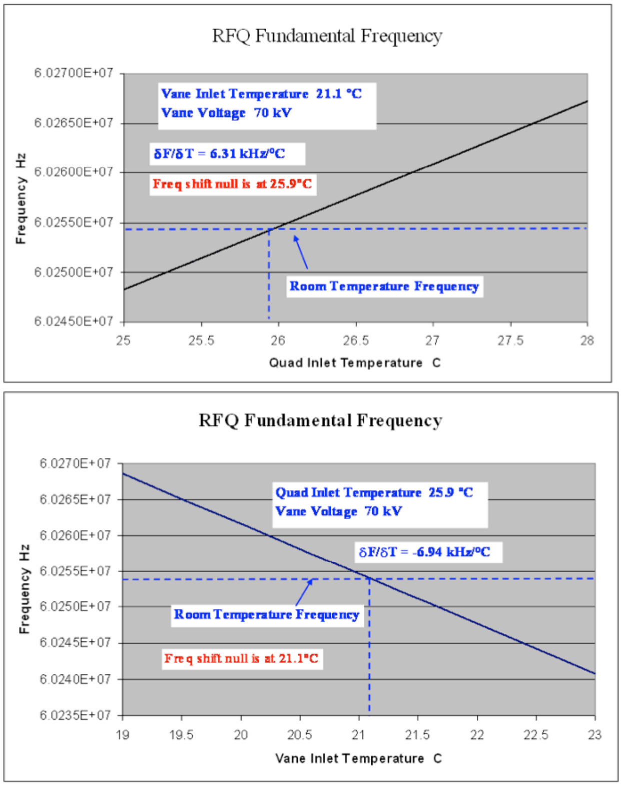

Figure 11: Frequency sensitivity to inlet temperature.

CONCLUSIONS

The required tip displacement was less than or equal to .006 inches. The final design results in tip displacement of .0023 inches. The maximum stress is local to the vane coolant channel intersection and is 4182 psi. The frequency sensitivities are 6.31 kHz/ºC around a quad inlet temperature of 25.9ºC and -6.94 kHz/ºC around a vane inlet temperature of 21.1ºC. The RFQ design is a robust design and will be tested with beam in the beginning of 2012.

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