MECHANICAL DESIGN AND 3-D COUPLED RF, THERMAL-STRUCTURAL ANALYSIS OF NORMAL CONDUCTING 704 MHZ AND 2.1 GHZ CAVITIES FOR LEREC LINAC*

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Abstract

Two normal conducting cavities operating at 704 MHz and 2.1 GHz will be used for the Low Energy RHIC electron Cooling (LEReC) under development at BNL to improve RHIC luminosity for heavy ion beam energies below 10 GeV/nucleon [1]. The single cell 704 MHz cavity and the 3-cell 2.1 GHz third harmonic cavity will be used in LEReC to correct the energy spread introduced in the SRF cavity. The successful operation of normal RF cavities has to satisfy both RF and mechanical requirements. 3-D coupled RF-thermal-structural analysis has been performed on the cavities to confirm the structural stability and to minimize the frequency shift resulting from thermal and structural expansion. In this paper, we will present an overview of the mechanical design, results from the RF-thermal-mechanical analysis, progress on the fabrication and schedule for the normal conducting RF cavities for LEReC.

INTRODUCTION

Exchanging information between electromagnetic software and structural/thermal software can be difficult and lead to errors. It is highly desirable to build a single model to carry out these analyses.

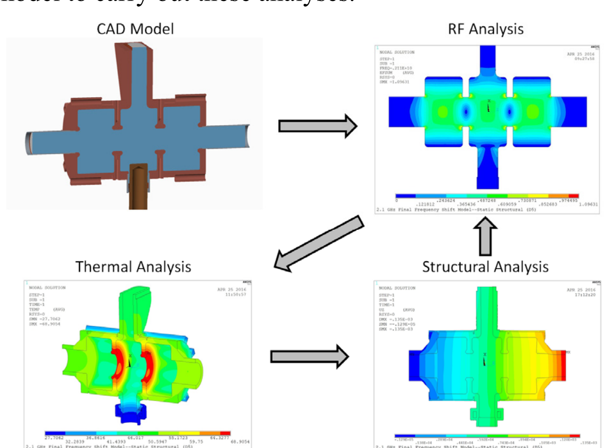
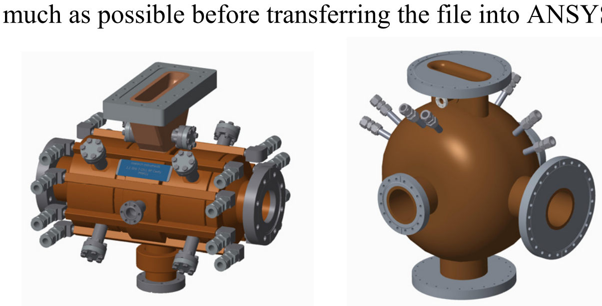


Figure 1: Simplified analysis procedure.

For the two normal conducting cavities for LEReC, a single ANSYS (multi-physics) [2] 3-D model has been developed to perform electromagnetic, thermal and structural analyses in a multistep process. A simple description of the analysis procedure is shown in Fig. 1. Using this process, it is possible to determine the resulting frequency shift due to thermal and structural distortion of the cavity. The sequence of analysis steps and the associated results are presented in this paper.

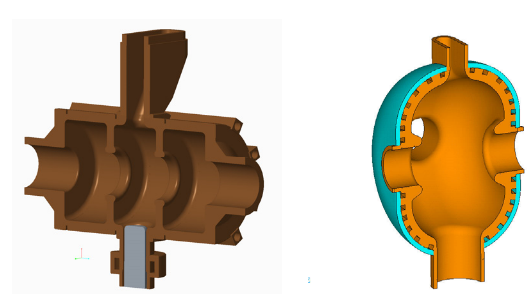
MODELING

The initial phase of this process consists of creating a 3-D model for the analysis. The mechanical designs of the cavities shown in Fig. 2 were created from a 3-D modeling software (such as Pro/Engineer) [2]. Symmetry conditions as well as removing components that are not needed for the analysis (such as bolts and flanges) were used in order to simplify the solid models (Fig. 3) as much as possible before transferring the file into ANSYS.



2.1 GHz 704 MHz

Figure 2: Mechanical design of 2.1 GHz and 704 MHz cavities.



2.1 GHz 704 MHz

Figure 3: Simplified 3-D Model of 2.1 GHz and 704 MHz cavities.

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RF SIMULATION

Using ANSYS, the cavity vacuum volume was created from the imported solid model for the electromagnetic simulation. The resulting vacuum volume was meshed with tetrahedral RF element (HF119) with a higher mesh density in critical areas such as the nose cones, waveguide and tuner port. An acceptable mesh was generated using an interactive process with the goal to reduce run time and memory usage, while keeping the electromagnetic and surface heat flux results accurate. ANSYS normalizes the results from the electromagnetic simulation. The normalized electric (E) field and magnetic (H) field results for the 2.1 GHz and the 704 MHz cavity are shown in Fig. 4 and Fig. 5 respectively.

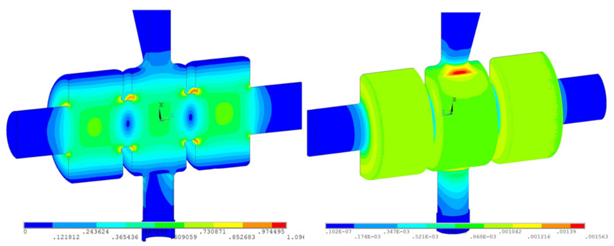

Figure 4: E-field [V/m] (left) and H-field [A/m] (right) for the 2.1 GHz cavity.

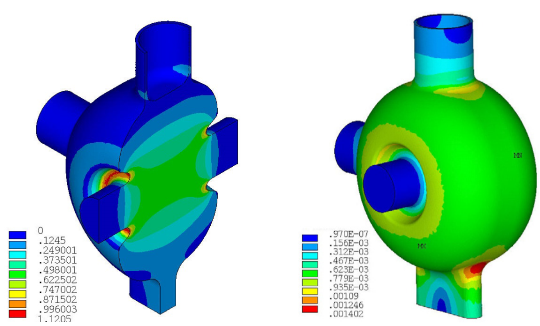

Figure 5: E-field [V/m] (left) and H-field [A/m] (right) for the 704 MHz cavity.

THERMAL ANALYSIS

The results from the RF simulations were used as an input to the thermal simulations. In this phase, the elements from the copper volume and only the elements from the vacuum volume in contact with the node on the shared surface between the copper and the vacuum volume are meshed with tetrahedral solid elements (SOLID87). The convective boundary condition was applied to the surfaces of the cooling channels. The cooling parameters used for the thermal simulation are shown in Table 1.

The appropriate scaling factor corresponding to the designed operating voltage for each cavity were determined in order to scale the heat flux across the elements faces (shared between the vacuum and cavity volume) caused by surface power losses (HFLXAVG). The total RF power loss on the inner surfaces of the 2.1 GHz cavity is 9.5KW and 35.5 KW for the 704 MHz. The resulting temperature distributions are shown in Fig. 6 and Fig. 7. The maximum temperature is 68.9 ^{o}C on the nose cones of the 2.1 GHz and 64 ^{o}C on the waveguide port for the 704 MHz.

Table 1: Thermal Analysis Cooling Parameters

Parameters :	Flow Rate	Water Temperature	Heat Transfer Coefficient, h
2.1 GHz Body	4 GPM	25.5 ^{o}C	14090 W/m^2.k
2.1 GHz Tuner	3 GPM	25.25 ^{o}C	13200 W/m^2.k
704 MHz Body	20 GPM	32 ^{o}C	13500 W/m^2.k

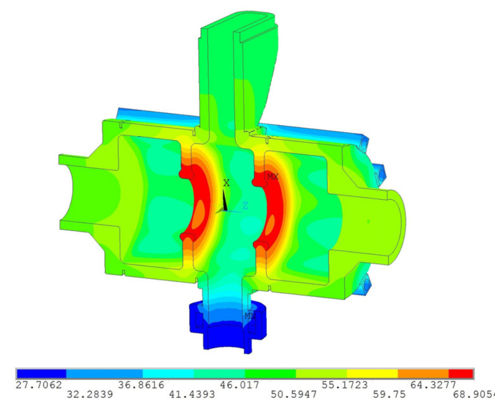

Figure 6: 2.1 GHz cavity temperature distribution.

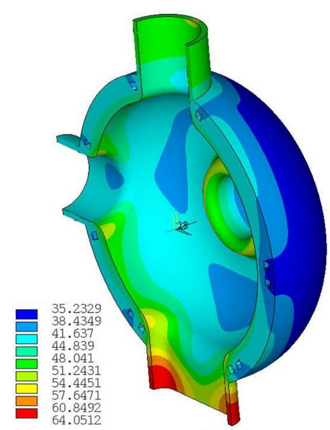

Figure 7: 704 MHz cavity temperature distribution.

STRUCTURAL ANALYSIS

For the structural simulation, in order to obtain the stress and displacement solutions, the thermal elements were converted directly to structural elements (SOLID187). All the boundary conditions such as support constraint, symmetry and vacuum forces are applied to the structural model. Based on the coefficient of thermal expansion of the copper used for the cavities, the maximum radial (0.0016") and axial (0.0053") deformations for the 2.1 GHz are shown in Figure 8. The average thermal stress near the nose cone (7000psi) in the 2.1 GHz cavity is shown in Fig. 9.

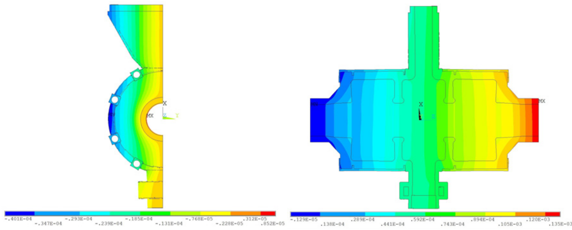

Figure 8: 2.1 GHz radial and axial displacement.

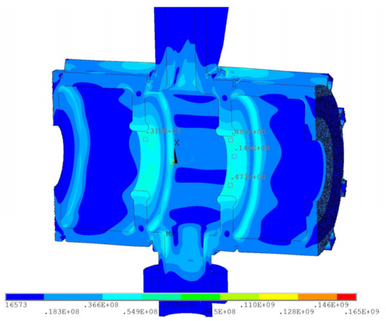

Figure 9: 2.1 GHz von Mises Stress.

Similarly, the results for the 704 MHz cavity are shown in Fig. 10. The thermal expansion of the 704MHz is 0.0055” and the corresponding von Mises stress is 4954 psi.

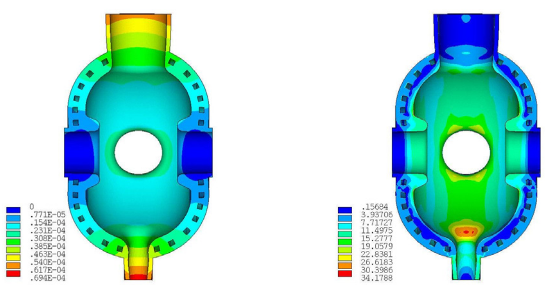

Figure 10: 704 MHz thermal deformation (left) and von Mises stress (right) results.

RF FREQUENCY SHIFT

The operating frequency of a normal RF cavity changes due to thermal deformation. It is important to determine the thermal frequency shift in order to compensate for the drift by changing the manufacturing dimensions of the cavity prior to fabrication, changing the temperature of the water or by using the tuner during operation. The computed frequency shift for the accelerating mode due to structural deformations is found to be 1.222 MHz for the 2.1 GHz and 0.142 MHz for the 704 MHz cavity. Although the manufacturing dimensions for the cavities were changed in order to compensate for the frequency shift, it was determine that the frequency shifts are within the tuning range of the main tuners for the cavities.

FABRICATION

The 2.1 GHz and 704 warm RF cavities are being designed and fabricated in collaboration between BNL and Research Instrument (RI) in Germany. In order to validate the RF simulations from Microwave Studio, measure the Q of the cavity and study the effect of the folded tuner design, BNL manufactured a 1:1 scale cold model of the 2.1 GHz cavity in aluminum (Fig. 11).

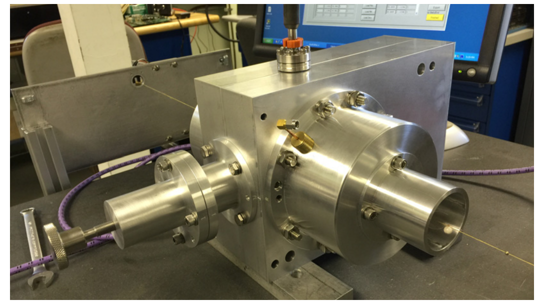

Figure 11: 2.1 GHz bead-pull measurement.

A final design review of the 2.1 GHz was completed in March and RI began the manufacturing process. Figure 12 shows the components of the end cells for the 2.1 GHz cavity at RI. A pre-brazing room temperature RF measurement is scheduled for May of 2016 with a deliver date at the end of June 2016.

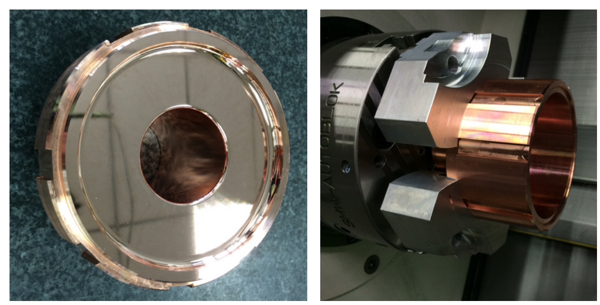

Figure 12: End cell components of the 2.1 GHz cavity.

BNL and RI are working closely to finalize the manufacturing design of the 704 MHz cavity. A final design review is scheduled for May of 2016 with a delivery date in August of 2016.

CONCLUSION

A single ANSYS model was used to perform and validate the RF, thermal and structural behaviors of the 2.1 GHz and 704 MHz warn RF cavities for LEReC. The RF simulation results from ANSYS showed good agreement with CST MWS [3] simulation results. The RF measurements from the cold model are very promising. We are currently performing RF test of the cold model in a vacuum chamber in order to study multipacting. Both cavities are scheduled to be installed during the RHIC summer shutdown 2016 and we plan to begin conditioning by the end of the 2016.

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