ANALYSIS OF A GRID WINDOW STRUCTURE FOR RF CAVITIES IN A MUON COOLING CHANNEL**

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Abstract

We report on the electromagnetic and thermal analysis of a grid window structure for high gradient, low frequency RF cavities. Windows may be utilized to close the beam iris and increase shunt impedance of closed-cell RF cavities. This work complements previous work presented for windows made of solid beryllium foil. An electromagnetic and thermal analysis of the thin wall tubes in a grid pattern was conducted using both MAFIA4 and ANSYS finite element analyses. The results from both codes agreed well for a variety of grid configurations and spacing. The grid configuration where the crossing tubes touched was found to have acceptable E-Fields and H-Fields performance. The thermal profiles for the grid will also be shown to determine a viable cooling profile.

1 INTRODUCTION

It was postulated that windows for closed-cell high gradient RF cavities could be improved by using a grid of thin wall round tube construction to replace a solid window. Closing the beam iris increases the shunt impedance. [1] The advantage of the grid over a window is that it could provide similar, or better performance to the beryllium window (Field attenuation, low scattering mass and low field distortion) but at a lower cost.

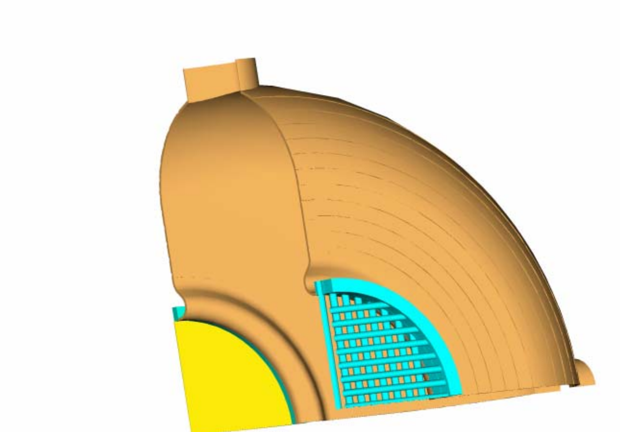

Figure 1: ¼ symmetry cutaway of 201MHz RF Cavity with closed irises using a beryllium window and a grid window.

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A concern is that even with relatively low heat flux the thin wall tube is insufficient to dissipate the heat. The tube radii will cause local heating from surface field concentration and may be subject to thermal distortion and stresses. Gaseous helium cooling will be provided to minimize the undesired affects from the heat loads. Using Finite element tools such as MAFIA4 [2] and ANSYS [3] several grid configurations were modelled to find the optimum geometry for heat dissipation, E-field attenuation and field uniformity in the cavity. The analysis showed that certain grid geometries had electromagnetic performance similar to a solid beryllium window. Using MAFIA4 simulations to tests these configurations, the 15x15 tube array with the tubes touching was selected as a viable option. This configuration was then modelled in ANSYS using High Frequency EMAG elements and a mesh density sufficient to solve for the grid thermal profile.

2 DESCRIPTION OF A GRID WINDOW

The basic non-touching grid window is shown in Fig. 2. It consists of a criss-cross pattern of 12.8 mm (0.5 inch) diameter thin-wall tubes, <0.25 mm (0.010 inch), either aluminium, or a low z material. The tubes will be brazed to an annular ring that provides both structural support and the cooling gas distribution channels. The base design for the grid uses a 15x15 tube pattern. The parallel tubes are coplanar with a centerline spacing of 25.4 mm. The two planes of parallel tubes are oriented orthogonal to each other with a gap sufficient to prevent arcing between tubes and terminate the field. The gap shown is 25 mm on centers, but the final design is with the tubes touching.

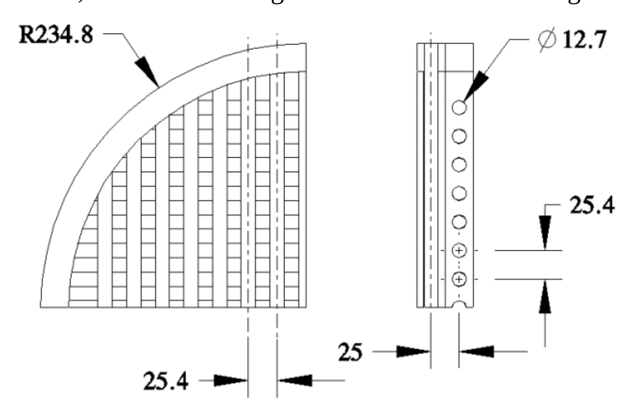

Figure 2: Layout of baseline grid window ¼ symmetry. Orthogonal grid tubes are spaced apart [units: mm]

Several configurations of grids were investigated. As shown in Fig. 3, case 1 is a 15x15 array of orthogonal grids not touching, case 2 is the same with the tubes touching and case 3 is a lower density (4x4 array) of larger diameter tubes. Three alternative concepts are shown in Fig. 4, two with non-orthogonal patterns and the third is a 15x15 fully overlapped tubes array on a single plane. Analysis had low field penetration for the fully overlapped grid configuration, but it is not apparent how to build it using conventional (low cost) methods.

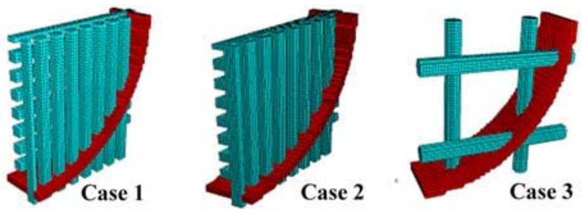

Figure 3: Gridded windows configurations modelled in MAFIA4. Left to Right: Case 1 - 15x15 grid spaced, Case 2 - 15x15 grid touching, Case 3 - 4x4 grid touching.

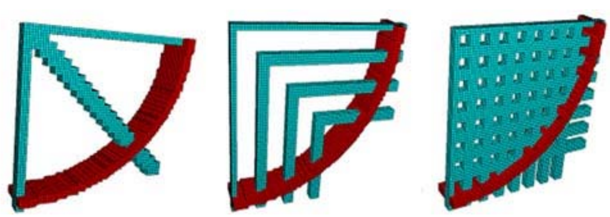

Figure 4: Other gridded windows configurations modelled in MAFIA4. Left to Right: Spider, "L" (HILAC), 15x15 grid fully overlapped.

3 RF ANALYSIS

The grid geometries shown above were evaluated using MAFIA4, a finite-integration code that simulates electromagnetic fields. The models were 1/8 cut with z and y-symmetry. Each of the models were built with a closed boundary behind the grid to provide an anteroom to model the amount of field that leaked past the grids. The field in the anteroom region has strong coupling to H_{phi}.

The MAFIA4 results give the E-field distortion in the main cavity body, the grid region and the anteroom region. The power density was also determined for the walls and grids. MAFIA4 generates a diagonalized rectangular mesh and cannot represent round tubes precisely, so the initial evaluation models were done with square tubes. A round tube model was tested and although it was modelled with fewer mesh points it gave electromagnetic results similar to the square tube simulations, which validate the square tube model.

The simulations for cases 1 to 3 demonstrated promising performance from each of the geometries. Case 1 shown in Fig. 5, the non-touching grid had good field quality, but had some field leakage past the grid. Case 2 shown in Fig. 6, the touching grid minimized the field leakage and had good field quality. An indication of the magnitude field leakage beyond the grid is given in results from a MAFIA4 solution for a touching round tube and was $2x10^{-5}$ along $E_z(0)$. The large tube lower density geometry given in case 3 also had promise as a window with good attenuation and good field quality in the cavity. A non-touching version of case 3 was also modelled, but had significant field penetration. The E field results for the non-orthogonal configurations given in Fig. 4 also showed significant field penetration past the grid.

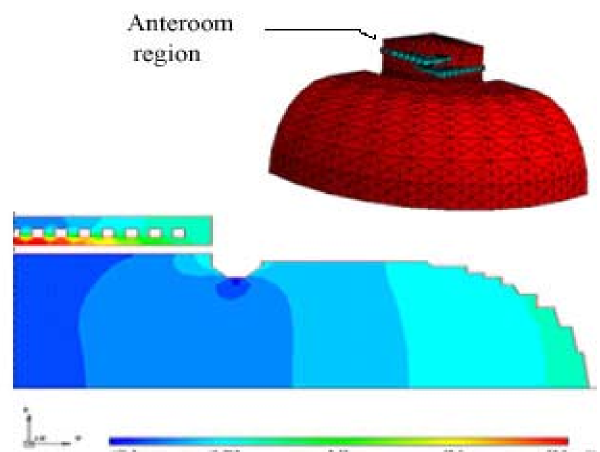

Figure 5: E_z field for case 1 15x15 array, grids not touching. Note the strong field past the grid in the "anteroom" region.

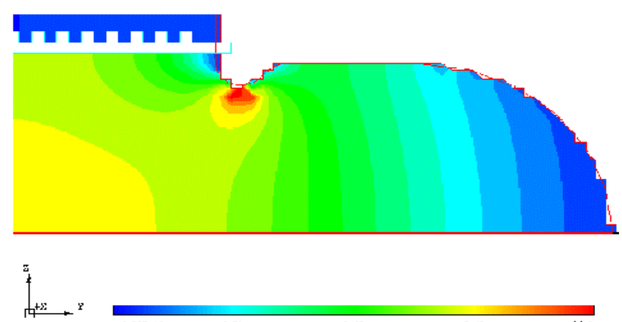

Figure 6: E_z field for case 2 - 15x15 array, grids touching. Excellent attenuation of fields past grid, excellent field quality near grids in cavity.

4 FEA THERMAL MODEL

The touching grid design had the best field attenuation with low distortion and seemed to be an excellent candidate for a window structure. A thermal model was the next step in characterizing its temperature profile.

The case 2 grid window was modelled using ANSYS and solved for both electromagnetic solutions and the temperature profile, Fig. 7. This technique has been used previously to model the thermal profile of the solid beryllium windows under RF heating. [4,5]. The grid geometry model provided some unique challenges due to the mesh density required to model the grid features.

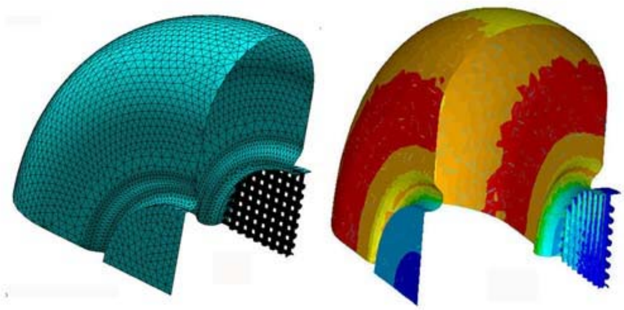

Figure 7: ANSYS FEA mesh and Heat flux results

The large RF tank and small grid tube features in the touching grid had a wide range of length scales. The areas of interest regarding the grid, such as the tube intersections, were on the order of a millimeter while the scale of the cavity itself was on the meter scale. The difference in length scale as well using a ¼ cut, z-symmetry cavity model required large regions within the cavity and grid and wall regions to be meshed with very small elements to get good heat flux results. Good results that matched well with the MAFIA4 solutions were achieved using element lengths of between 1 mm to 1.5 mm at the grids, which is about a 10:1 ratio to the tube diameter. Fully meshed the 201 MHz RF cavity model with a case 2 grid had over $1x10^6$ Degrees of Freedom. To run an ANSYS high frequency analysis of this size required more computer memory than the ~ 1.7 GB memory limit associated with ANSYS using 32-bit processors. This model was run successfully using a UNIX based computer with multiple 64-bit processors, 4 GB ram, 10 GB hard disk swap and the ANSYS default memory model and multiple processor options turned on.

5 THERMAL ANALYSIS

The MAFIA4 solution (Hf = <0.04 watts/cm^2) for power density on the cavity walls and grids shown in Fig. 8 was in good agreement with the ANSYS solutions (Hf = 0.03 watts/cm^2).

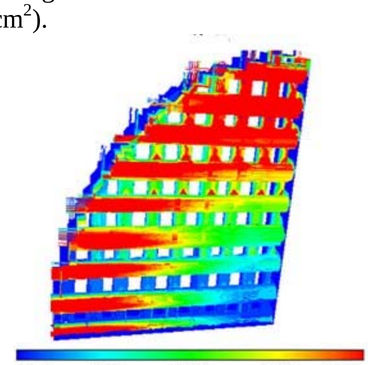

Figure 8: Power density for case 2 touching tubes using MAFIA4 Hf = <0.04 watts/cm^2.
Field gradient: 16 MV/m at $E_z(0)$, duty factor of $1.9x10^{-3}$

Using ANSYS, the heat flux distribution in the cavity and grid was solved for an average power of 10 kW. The heat flux was then applied to a thermal model to solve for the thermal profile of a helium gas cooled grid The model includes the water-cooling of the RF cavity body and the helium gas cooling of the grid tubes. Respectively, the film coefficients used for cooling were 15,000 watts/m^2 and 250 watts/m^2. The result of the thermal analysis shown in Fig. 9 gives a temperature rise in the tubes to be less than 8º C. The thermal stress and deformation will still need to be completed to determine if this temperature rise is undesirable, but it is apparent that further refinements to the model to match actual operation could reduce the temperature rise. One example to enhance the model would be to include the active cooling provided to the grid annular support ring by the cooling gas supply channels.

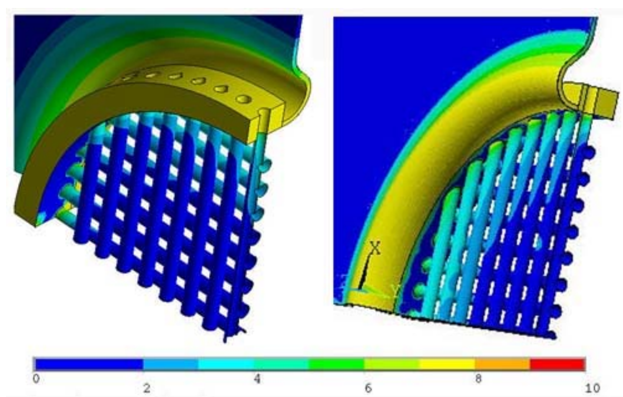

Figure 9: Temperature (ºC) profile of grid using ANSYS.

6 CONCLUSION

It was shown that a touching grid geometry would be the preferred geometry over the non-touching in a high gradient closed cell RF cavity. The heat flux results from both MAFIA4 and ANSYS had good agreement. ANSYS high frequency and thermal FEA can be used for developing the electromagnetic model and thermal models provided an adequate mesh density is applied. The temperature results are important for determining if the RF heating of the tubes could be sufficiently cooled using a gas. Further studies will examine the structural affect of non-uniform heating on the grid tubes. The development of a cost effective grid design will be facilitated by the ability to model the geometries adequately.

7 REFERENCES

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