MAGNETRON DESIGN FOR AMPLITUDE MODULATION*

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Abstract

The amplitude modulation (AM) of a magnetron is accomplished by varying the axial magnetic field which changes the current to the anode and thus the output power of the injection locked magnetron. The purpose of the AM is to compensate for microphonics in super conducting cavities by maintaining a constant gradient. The frequency range for the microphones is below 200 Hz. At these frequencies, eddy currents are encountered in the magnetron anode which reduces the effectiveness of varying the magnetic field on the magnetron current. A novel anode design is described which minimizes eddy currents and a method for manufacturing this novel magnetron anode is presented

INTRODUCTION

In order to provide an amplitude variation in the output of a phase-locked magnetron, we have proposed a technique that utilizes the magnetron magnetic field. The magnetic field is dynamically adjusted which controls the amount of current that passes from the filament to the anode. The proof of principle configuration will include two electro magnets: the main coil for controlling the operating point, and a second coil for controlling the amplitude modulation.

The idea of a trim coil is not new. The first application of this concept was describe by W.C. Brown with an injection locked magnetron [1]. The purpose in that application was to broaden the system gain for injection locking the magnetron. In our application, the trim coil is used to modulate the output amplitude of the magnetron oscillator by adjusting the anode current. The configuration for our proof of principle experiments is shown in Figure 1.

The application will be used to effectively stabilize the accelerating field in the cryomodule. This field typically varies at low audio frequencies due to vibration effects that change the dimensions of the superconducting cavity and hence the resonant frequency as shown in Figure 3. As the resonance of the cavity bounces around the fixed frequency of the drive signal, the accelerating gradient is essentially being modulated. However, if the frequency of this vibration, shown in Figure 4, can be matched by an in phase amplitude modulation of the drive signal, the beam will see a constant accelerating field strength.

In addition to the trim coil, the magnetron anode assembly will also need to be designed to minimize eddy currents. We have done several studies about the eddy currents and this paper describes several different techniques for building an anode to minimize those currents [2].

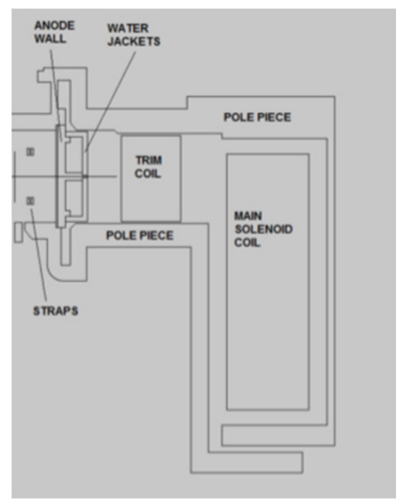

Figure 1: Trim Coil and Main Solenoid Coil layout.

TECHNICAL APPROACH

When modelling the magnetic circuit, including the copper anode of the magnetron, the resistivity of the copper showed the greatest impact on the amplitude of

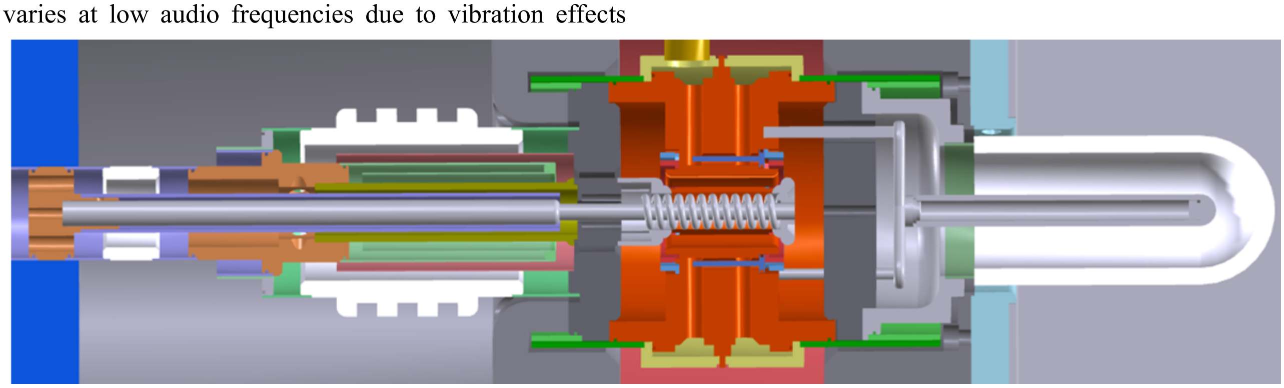

Figure 2: Cutaway of the magnetron with a view of the filament coil proximity to the tips of the anode vanes, and the cooling water channels with blue "flow pins".

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the eddy currents: the lower the resistivity the higher the eddy currents The bottom curve of Figure 3 is the anode structure designed using all copper components: vanes, straps, and body. The top curve in Figure 3 is with all the components modelled as stainless steel. The curves in-between show the slow migration from all copper to all stainless steel. The x-axis is the frequency of the trim coil modulation simulated at the peaks in the vibration frequency spectrum shown in Figure 3. The y-axis is the percentage of trim coil magnetic field that is seen in the interaction region with respect to the DC values of B_z.

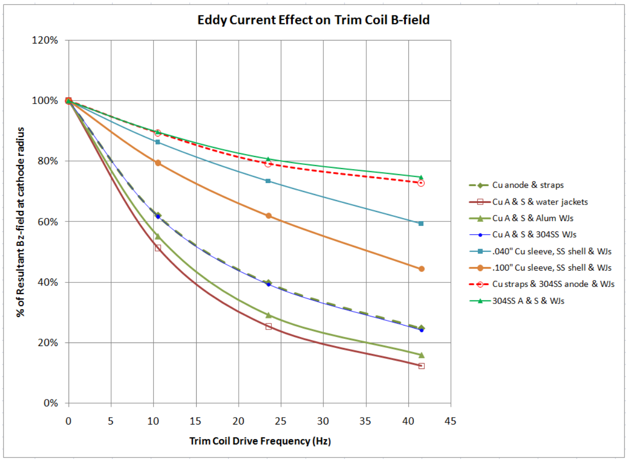

Figure 3: Impact of changing from copper to stainless steel in portions of the anode structure.

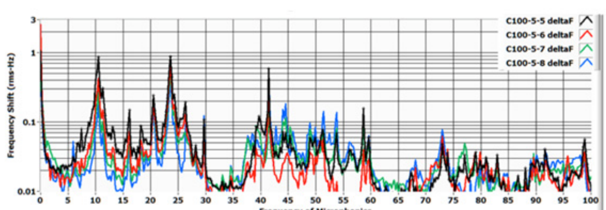

Figure 4: JLAB microphonics frequency spectrum for a cryomodule.

Use of laminated pole pieces in the construction of the magnetic circuit was examined. However, in order to minimize the eddy currents the laminations would have to be radial in nature on the perimeter of the anode; and this was considered to be a major and costly fabrication problem.

OPTIONS FOR THE ANODE

Once it was decided that the anode material conductivity was the major problem in the magnetron design for AC fields in the low audio range, techniques for building the anode were proposed and analysed based on cost and quality.

The first option was to use vanes made from copper brazed to a stainless steel ring. This would minimize eddy currents because the eddy currents were concentrated primarily in the perimeter of the anode. The problem with making a braze joint in that region was the risk of a failure from water leaking through pipes in the braze joint to vacuum. In microwave tubes, one of the fundamental design laws is: no-water-to-vacuum-braze-joints.

The second option was minimizing the thickness of the copper perimeter. A .100-inch thick copper perimeter allowed only 45% of the axial field strength at a 41.5 Hz drive rate, while a .040-inch thick copper perimeter allowed 60%. But such a thin copper "sleeve" is worrisome because the strength of the copper would be unable to maintain a rigid structure. Adding a stainless-steel strengthening ring surrounding the copper is an option as shown in Figure 5.

A third option was to make the anode from stainless steel and copper plate it. This would minimize the eddy current losses, but cooling of the tip of the anode vane may be a problem. Thermal conductivity of copper is about 210 (Btu/(hr-°F-ft)) and stainless steel is about one-tenth of that. This means that a water-cooling channel designed in copper to have .100 inches between it and the vane tip would have to be .010 inches from the vane tip in stainless steel, if the vane tip were to operate at the same temperature. But with stainless steel, the vane tip could operate higher in temperature. This would also reduce van-tip heating due to radiation from the filaments operating at close to 1000°C. With this in mind a thermal study was made of the vane tip with the two different materials (Cu and SS). The results are discussed below.

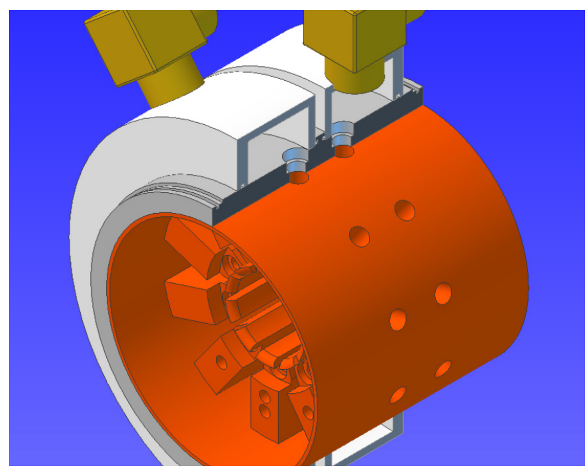

Figure 5: Option 2: Stainless Steel compression ring around a thin walled copper anode.

VANE TIP COOLING

Water-cooling in the vane tip region is designed to incorporate turbulent flow; providing a helical flow through the vane tip does this. The design is shown in Figure 2. The flow pins are brazed into the cooling channel. The heating of the vane tip occurs from the bombardment of electrons and radiation from the filament operating at close to 1000°C. Operating temperature of the vane tip is designed to be less than 200°C when the vane tip is all copper with water flow of 2 gpm in the plenum or .2 gpm per vane tip. Some magnetrons have tips made from refractory metals such as molybdenum to allow for higher operating temperatures and longer life [3].

Figure 6 is our latest Comsol evaluation of the cooling issues with stainless steel and water flow rate of 2 gpm through the plenum.

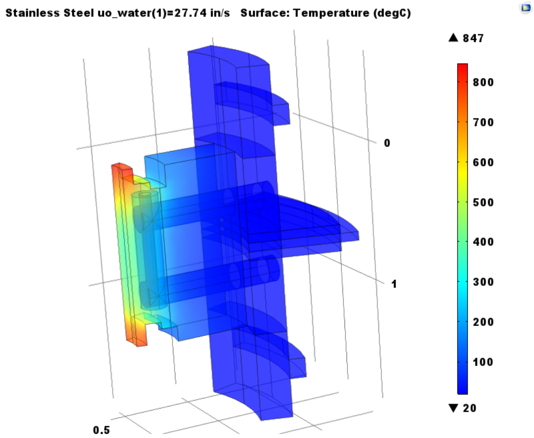

Figure 6: One-tenth model of anode with water-cooling.

For a ten-vane magnetron at 13 kW and 80% efficiency the power dissipated on each vane would be 325 watts. The maximum temperature seen in this case would be 847°C without the thermal effects of radiant heating from the filaments, which will be added later. At only 1 gpm the max temperature would be ~170°C higher. Future simulations will position the cooling water channels closer to the face (tip) of the vane.

CONCLUSIONS

Vane tip cooling of a stainless steel anode may be adequate for thermal performance. RF performance requires that the cavity be copper plated to maintain the required cavity Q of the magnetron. We will be experimenting with various plating techniques and models to make sure the plating is of the correct thickness in the required locations within the anode cavity.

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