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INJECTION LOCKED 1497 MHZ MAGNETRON *

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Abstract

A novel injection-locked 1497 MHz 13 kW AM magnetron design is presented. An anode designed to minimize eddy currents due to the modulated magnetic field is presented. Thermal calculations of two design options are also presented. An extra degree of freedom in the anode construction is made possible by the fact that the magnetron is injection locked; as a result some additional design details that can be utilized in the cooling network for the magnetron anode are presented.

INTRODUCTION

"Classic" magnetrons are manufactured as the lowest cost source of microwave energy and their designs are perfected for that goal. In the application of magnetrons as RF sources for accelerators there are design options that must be implemented. Injection locking the magnetron is a fundamental requirement in order to limit phase noise to less than a degree when driving superconducting cavities [1]. Taking into account the fact that an injected RF signal will be used can alter the design of the classic magnetron.

Amplitude modulation, by varying the magnetic field of the magnetron, requires a change in the material of the anode from copper to stainless steel to limit the negative impacts of eddy currents in the anode. Several studies have been made to understand and plan for this anode change [2-3]. It should be noted that the composite stainless steel / copper anode would of course be completely copper plated to reduce ohmic losses. Copper plating does not affect the eddy current reduction. In order to cool the anode vane tips two different design options are presented, but first, the cooling calculations.

VANE COOLING OPTIONS

Many design options were evaluated to cool the vane tips of the stainless-steel anode. Option 1 is adding a copper nose to the stainless-steel vane by explosion bonding copper onto stainless steel. Option 2 is an entirely new concept for the construction of the anode with an "external" tubing-cooling channel.

Option 1

To fabricate this design thick walled copper was explosion bonded to the ID of a stainless-steel cylinder. The result is shown in Fig. 1. The composite material is then EDM'd to form the anode proper. This provides for a copper vane tip on an anode wall and vane structure that is stainless steel. The cooling channel is internal to the vane structure and crosses the explosion bonded boundary, thus providing cooling directly to the copper vane tip.

Various thermal calculations made of this type of vane design are summarized in Fig. 2. The difference between each of the calculations is the degree to which the water through the channel is stirred by turbulence via the design of "plugs" inserted in the water channels. The best achieved resulted in a vane tip that was only about 50C° above the classic all copper anode design.

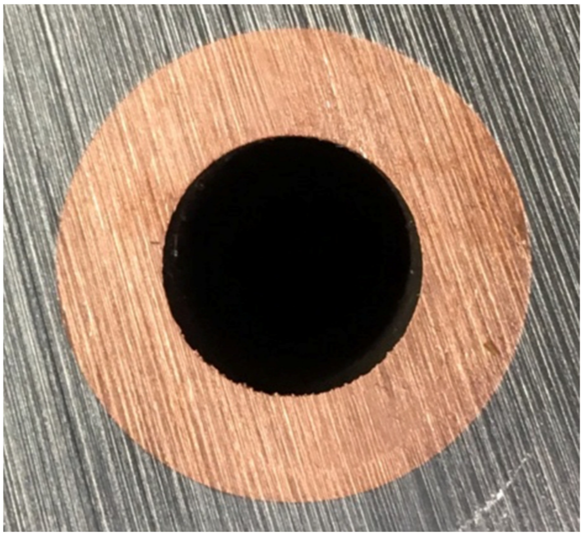

Figure 1: Explosion bonded copper tubing inside stainless steel tubing.

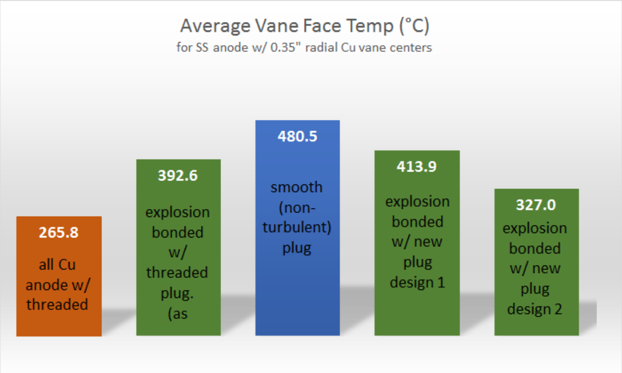

Figure 2: Calculations of the vane tip temperature compared to the classic all copper design (266°C).

Option 2

With the knowledge that an injection locked magnetron is the final result of this project, the design for the straps that cause separation between oscillating modes can be altered. For the standard design the separation between the operating π-mode and the next nearest mode is about

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1000 MHz as calculated by Comsol [4]. The purpose of this separation is to insure the magnetron self-oscillates at the π-mode and not at any other mode. But, since the magnetron is injected with a 1497 MHz signal, the need for this large separation is no longer as critical. This allows for a different design philosophy for the cooling channel and the placement of straps. The new design of the stainless steel anode is shown in Fig. 3 without the water manifolds in place.

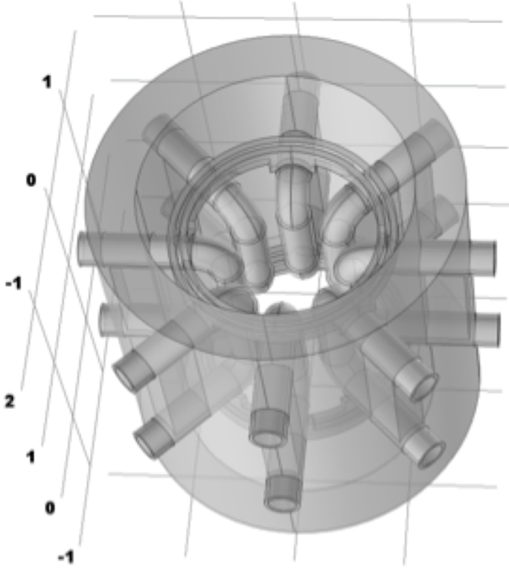

Figure 3: Option 2 design of the stainless steel anode with cooling channels.

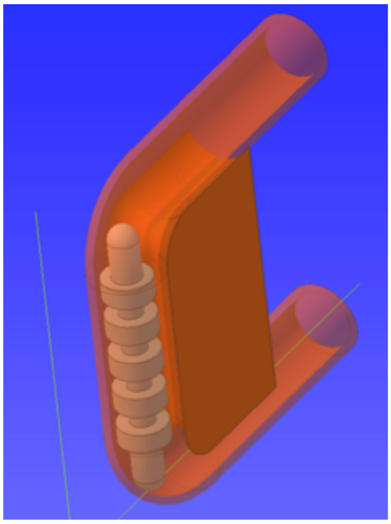

Figure 4: Cooling channel brazed to the vane with tubulence modifier in place.

The new concept design-requiring placement of the straps at a larger diameter (beyond the radius bend in the cooling channel) reduces the separation between the operating mode and next nearest mode by only about 20%. The configuration is shown in Fig. 3. What is unique about this design is the cooling channels are made from copper tubing that is formed around the outer edge of the vane and brazed in place. The sub-assembly with vane and cooling channel is shown in Fig. 4.

The assembly processes have been worked out and the design looks solid at this point. The fundamental requirement of "no braze joints between water and vacuum" is preserved. The turbulence plug is lodged in place by the bending of the soft copper forming an assembly that is then brazed to the vane.

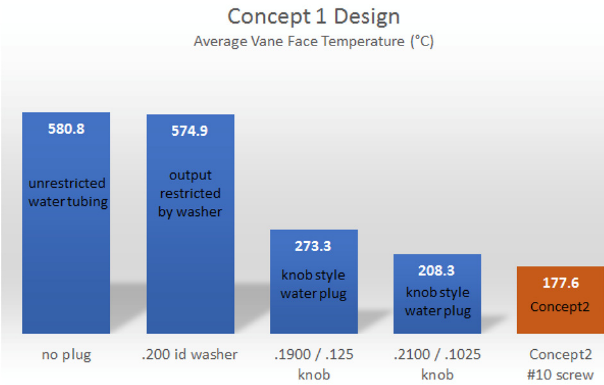

Figure 5: Calculations of the vane tip temperature for the stainless-steel anode with various cooling channel designs.

As shown in Fig. 5, the new vane tip temperature for the stainless-steel anode is almost 100 C° *below* the standard all copper design. This improvement in vane tip temperature for the 13 kW 1497 MHz magnetron is significant for both the stainless-steel anode as well as classic magnetrons that have lifetime issues related to heat dissipation on the vane tip.

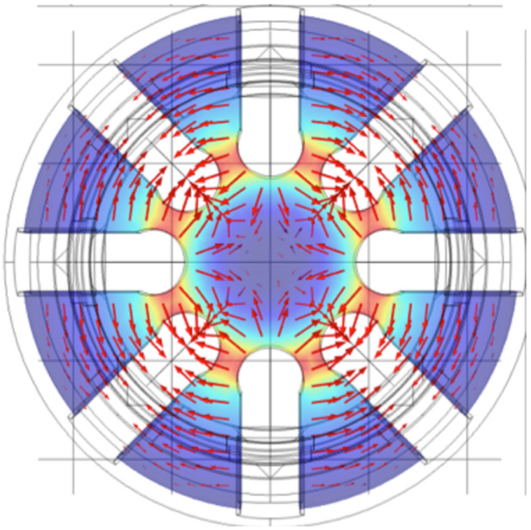

Figure 6: Eigenmode solution for the π-mode with the cooling channel tubing.

The eigenmode picture from Comsol is shown in Fig. 6. The separation between the π-mode and the next nearest mode was 830 MHz.

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DISCUSSION

The stainless-steel anode (or other low conductivity material that is relatively easy to braze to) is required to minimize damaging eddy currents. With any material other than copper for the anode, thermal considerations need to be made and designs implemented to bring down the temperature of the vane tip. Two options are being pursued: Option 1 is underway with parts in the machine shop that are already explosion bonded, Option 2 is in the design stage and offers significant improvement in the thermal management of the spent beam.

Option 2 presents a significant reduction in the vane tip temperature such that standard magnetrons that are currently used in applications such as medical accelerators could benefit from this design modification. Studies of magnetron failures by Siemens indicate that vacuum arcing encompassed 54% of their magnetron system failures [5].

FURTHER STUDIES

With the magnetron cooling channels as described in Fig. 3 and 4, a calorimetric measurement could be made of each individual vane to corroborate the thermal calculations made in Comsol. Instead of a plenum that would join together the output channels of each vane in parallel, individual connections could be made so that thermal measurements could be made of the heat gain in the water of each vane tip. With this data, one could corroborate the calculations. This was part of the proposal for the Phase IIA program.

Another important element in magnetron design and operation is the filament temperature. The temperature difference between the filaments and the van tip and the impact of radiant heating on the vane tip from the filaments could also be corroborated with the new cooling channels. Calculations indicate that this is a small proportion of the heating of the vane tip, and measurements would corroborate these calculations as well.

Injection locking of the magnetron requires the power of the injected signal being dissipated in the anode. Calorimetric measurements could help in determining the distribution of the power in the magnetron anode from the injected signal using the tubing cooling channels. For the 13kW magnetron at 80% efficiency, 3250 watts are dissipated in the anode. With an input signal of 30dB down from the output only 13 watts are dissipated, but with an input of 20dB down, 130 watts would be dissipated. During RF operation of experiments, thermal management of the anode would be required, and having individual monitoring and control of vane tip cooling might be an advantage.

In the Phase IIA proposal other accelerated life tests were proposed that tested the cooling efficiency of the various designs. They included operating into a mismatch, operating with higher filament voltage, and a continuous amplitude cycling test of the magnetic field on the thermal behaviour of the magnetron. These tests were designed and based upon failure modes that have been evident in magnetrons over their lifetime.

It is generally accepted that accelerated life testing is a means for informing all interested parties in the robustness of the final design of a new microwave tube. Without these accelerated life tests in the pre-production phase of the development process, results such as those at JLAB indicate the costs associated with “infant mortality” of the 5kW CW klystrons could have been ameliorated. Several system examples of increasing the MTBF of magnetrons and CFAs are listed in a recent study performed by the authors of this paper [6].

CONCLUSION

A 1497 MHz magnetron is being fabricated with explosion-bonded copper on the vane tips of the stainless-steel anode. There is an expectation that at full power the vane tips will exceed the temperature of a standard all copper magnetron by about 50C° and operate at temperatures greater than 300°C. It is possible that these temperatures may reduce the lifetime of the magnetron. An alternate cooling design has been studied that could reduce the temperature of the vane tips by 100 °C to operating temperatures less than 180°C. This is a significant improvement for any magnetron design. A provisional patent covers the magnetron cooling design disclosed here.

The improvement in vane tip temperature could be significant for magnetrons operating in systems such as medical accelerators as well as the proposed usage in high-energy physics.

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