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AFFORDABLE, EFFICIENT INJECTION-LOCKED MAGNTRONS FOR SUPERCONDUCTING CAVITIES*

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Abstract

The cost of a klystron for the SNS is estimated to be in the $200K range. A magnetron with the same power level is about one-fourth the cost. With ancillary equipment to functionally duplicate the performance of the klystron and allowing for the reduced lifetime of the magnetron compared to the klystron, about half the cost. Additional operational cost savings are related to the 805 MHz magnetron 90% efficiency, which for some applications is twice that of a corresponding klystron.

INTRODUCTION

A 700 kW 10% duty 805 MHz magnetron was designed for use as a drop in replacement for a klystron of the type VKP-8291 made by CPI Microwave Power Products and used at the ORNL SNS. In next couple months, this magnetron will be built at Richardson Electronics (RELL) and tested at high power at Oak Ridge National Laboratory. The 805 MHz magnetron uses similar cooling designs as the 600 kW 915 MHz magnetron built and tested by California Tube Labs (CTL) at greater than 90% efficiency [1]. COMSOL calculations were used to tune the magnetron to 805 MHz and also used for thermal calculations to confirm the cooling design would be adequate for 700 kW. COMSOL was also used to further develop the magnetic circuit for the 700 kW 805 MHz magnetron. The engineers responsible for the CTL design of the 915 MHz tube are consultants for this project. The frequency of the tube we had first suggested for this proposal was 650 MHz that would be useful for FNAL. However, there was little interest at FNAL since the international PIP-II project included the agreement that the 650 MHz RF power system will use solid state amplifiers provided by the Indian Government. The ORNL SNS staff have been very supportive of this 805 MHz magnetron project and are enthusiastic about working with us. We also note that the heavy beam loading (over 50 mA) of the SNS operation renders the control of microphonics mostly irrelevant compared to the JLab CEBAF operation (<1 mA). So in some sense, the SNS problems are different from those at JLab and more relevant to our hopes of eventually making high beam current CW magnetrons to drive subcritical nuclear reactors like our Mu*STAR design. Muons, Inc. demonstrated the first operation of a 1497 MHz magnetron prototype that it designed to replace the klystrons of the CEBAF Linac and delivered it to JLab for testing. The second 1497 MHz magnetron prototype with a special anode to enhance its amplitude control has been baked out and is being tested with the help of RELL in LaFox, IL, very near Fermilab and Muons HQ.

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THE ANODE DESIGN

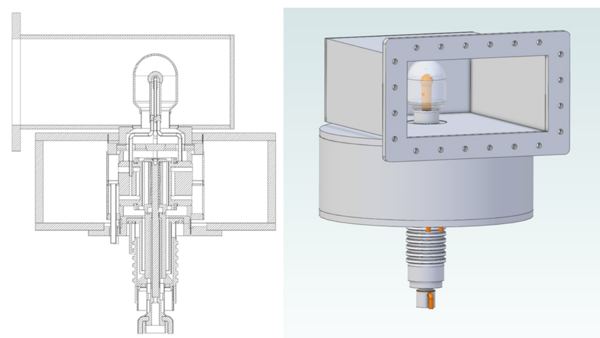
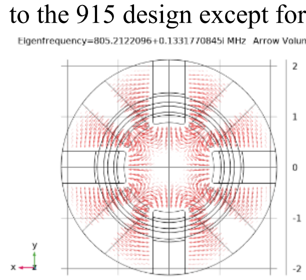


Figure 1: The complete 700 kW 805 MHz magnetron

When assembled, the tube with launcher and magnet is shown in Fig. 1 The basis for the design is the 915 MHz magnetron built by California Tube Lab (CTL) with the support of Tony Wynn and Ron Lentz who are our consultants on this project. The 915 tube was built for operation at 300 kW and modified to operate at 600 kW. During the design phase of project an anode was designed for operation at 805 MHz. The number of vanes was chosen to be eight in order to provide enough room for water channels and cooling. The results are shown in Fig. 2. It was found during the COMSOL analysis of the anode that the corner of the vanes (at the inside diameter of the anode) when rounded with a radius of 0.050 inches, the COMSOL calculation of Q increased by 25%. This design was used in all subsequent analysis. The gap between vanes is similar to the 915 design except for the radius on the corner.



805.21+0.13318i	3023.1
1077.9+0.24495i	2200.3
1312.1+0.43208i	1518.4
1312.3+0.43207i	1518.6
1602.2+0.52815i	1516.8
1602.4+0.52783i	1517.9
1759.6+0.47489i	1852.7
1863.7+0.22646i	4115.0

Figure 2. COMSOL calculations of the anode for 805 MHz modes and Q's for the modes.

The location and size of the antenna was varied in order to determine the dimensions required for a Qext in the range of 150-200. The results are shown in Figure 1.

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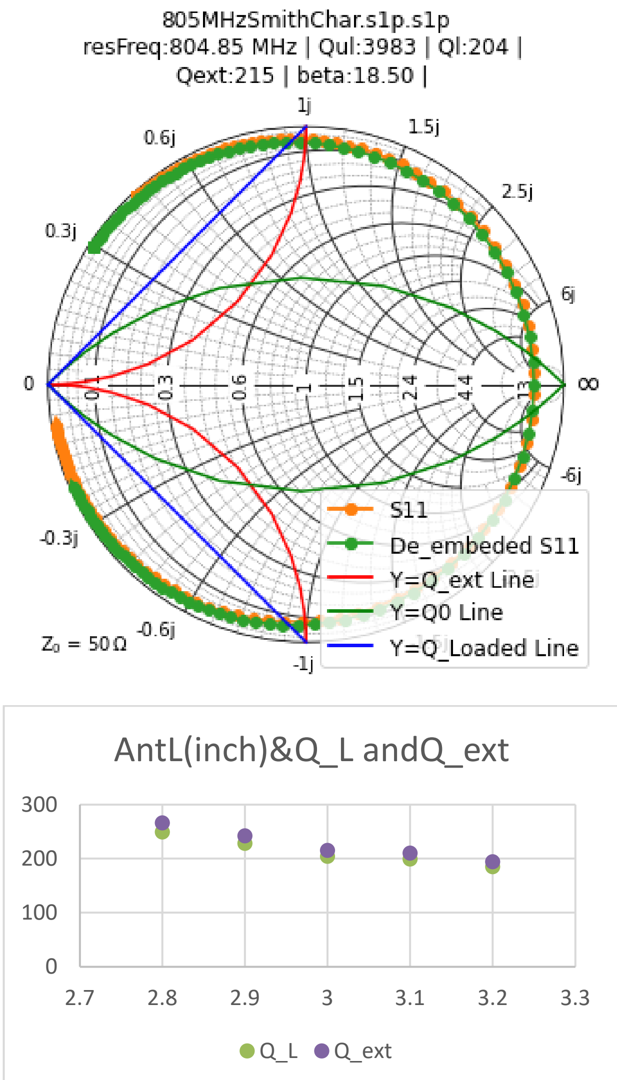

Figure 1. COMSOL calculations of Qext as a function of antenna height with three legs.

FILAMENT DESIGN AND THERMAL ANALYSIS

The filament was chosen to provide nearly the same size interaction gap as that found in the 915 MHz tube. The ratio of filament outside radius to anode inside radius is approximately 0.42 leaving a large interaction gap. It is theorized this large interaction gap is the basis for this type of tube operating at greater than 90% efficiency. The cathode stalk was modeled in COMSOL as shown in Fig 4. Cooling of the cathode stalk was experimented with using two different cooling loops: one in the Filament End Support and one loop in the Filament Rod Support Assembly. About 1 gpm was adequate to bring the cathode stalk from 500 C to under 50 C while radiating to the environment. The temperature of the molybdenum support rod in the region of an internal iron polepiece was 400 C, well below the curie point of 600 C.

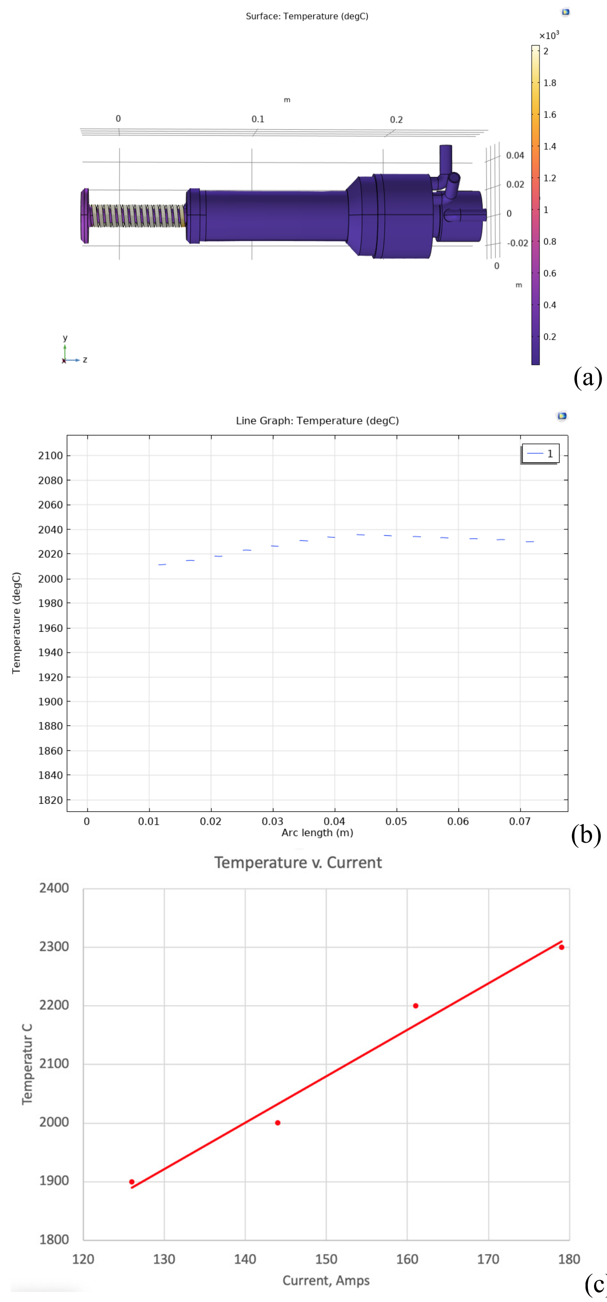

Figure 4. The cathode stalk (a) with a current of 140 amps (b) produces a filament temperature profile with about 20 C variation along the length, (c) temperature as a function of current.

ANODE AND ANTENNA COOLING CIRCUITS

At 700 kW and 10% duty, 70 kW is the average power provided by the 90% efficient magnetron. Several scenarios were investigated to determine the power handling of the water circuits with a flow rate of 2.2 gpm. Shown in Figure 2a is 14 kW absorbed in the anode, and in Figure 2b 14 kW in the anode and 1 kW absorbed in the antenna. Clearly the weak link is the antenna and its power handling capability. The temperature of the antenna could reach 600 C if there were power dissipation on the antenna of about 2 kW. The

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outlet water temperature with 1 kW on the antenna is 30 C greater than the inlet water at 2.2 gpm.

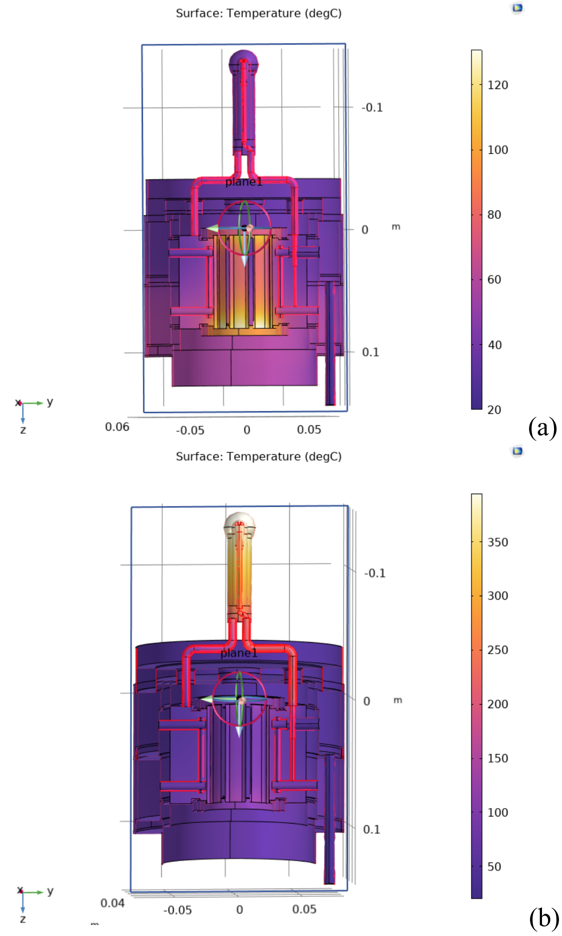

Figure 2. (a) 14 kW dissipated on the vane tips in the anode, (b) 14 kW in the anode and 1 kW in the antenna. Cooling water flow 2.2 gpm

MAGNETIC CIRCUIT DESIGN

As shown in Figure 3, the magnetic field in the region of the interaction space is about 2.4 kgauss, which is the expected design value for the 805 MHz magnetron. The flatness of the field depends on the proper location of the internal polepiece on the cathode stalk. The location chosen is in the region where the molybdenum support rod is about 400 C, well below the curie point.

OPERATING CONDITIONS OF THE MAGNETRON

It is anticipated that the magnetron will operate with at least 20 db of gain with an injected signal. This is based upon the results of a 915 MHz magnetron injection locked at JLAB, 26 db gain was achieved [2]. For a fully functional replacement of a klystron an additional 20 db of gain is required from a pre-amplifier.

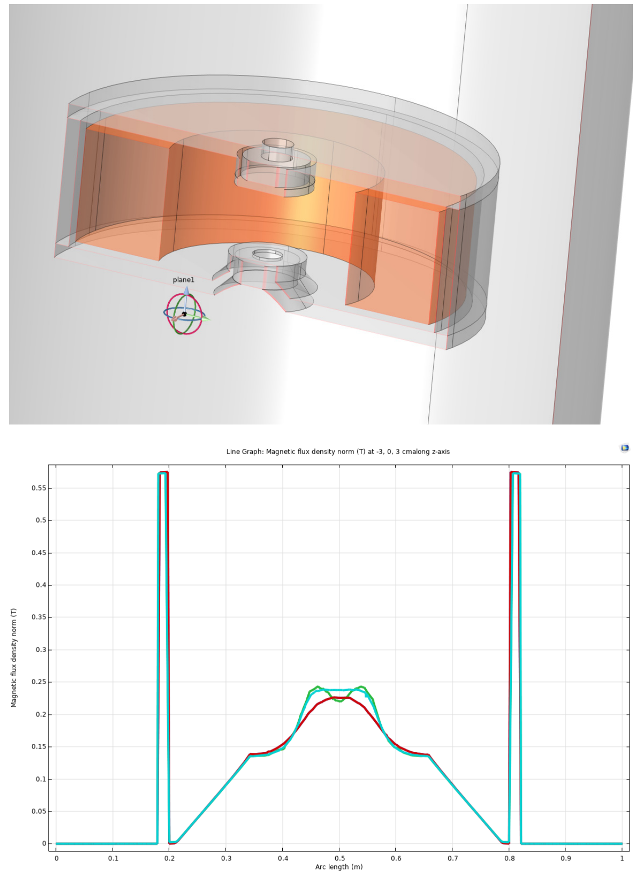

Figure 3. Comsol calculations of the magnetic flux density. The anode interaction region is about 10 cm.

The back bombardment of the filament will increase its temperature and reduce the lifetime, so a feedback circuit to reduce the filament voltage of the power supply will need to be implemented. This is a standard procedure and is crucial for extended magnetron lifetimes.

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