PHASE AND FREQUENCY LOCKED MAGNETRONS FOR SRF SOURCES*

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Abstract

Magnetrons are the lowest cost microwave high-power sources in dollars/kW, with high efficiency (typically greater than 85%). However, the frequency and phase stability of magnetrons is inadequate when used as power sources for accelerators. Novel variable frequency cavity techniques have been developed which will be used to phase and frequency lock magnetrons, allowing their use for either individual cavities, or cavity strings. Ferrite or YIG (Yttrium Iron Garnet) materials will be attached in the regions of high magnetic field of radial-vaned, π−mode structures of a selected ordinary magnetron to control the frequency of the magnetron. These results will be presented and an optimum material chosen.

INTRODUCTION

The STTR Phase II award to Muons, Inc partnering with Fermilab, and a company that builds magnetrons, has allowed testing to determine the most suitable material for use in magnetrons. The optimum material is one that has a high loss at the frequency of the next nearest mode along with the lowest loss at the operating mode. Previous work by G. Bush [1] has identified such a material that is not commercially available at this time. This material was $Y_3Al_{.66}Fe_{4.34}O_{12}$ a yttrium aluminum garnet. Similar materials are available and will be tested.

Material Choices for use in the Magnetron

At this time it is still not known which of the many different materials will prove to be optimum for operation within the anode of the magnetron. Materials tested were chosen based on their saturation magnetization and material characteristics.

Table 1: Materials Chosen for the First Set of Tests

Material	model / part no.	Saturation Magnetization (4pMs)	Supplier
NiZn	N40	2500	CMI
NiZn	CM48	4400	CMI
similar to: $Y_3Al_{0.66}Fe_{4.34}O_{12}$	G-810	800 ± 5%	Trans-Tech
YIG	G-113	1780 ± 5%	Trans-Tech
Nickel Spinel	TT2-111	5000 ± 10%	Trans-Tech
Yttrium (narrow line width)	YG-1780	1780	NMG
Aluminum Doped	AL-1200	1200	NMG
Magnesium Ferrites	MF-3000	3000	NMG

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As mentioned above, the yttrium aluminum garnet appeared to have some ideal characteristics, but since it has low saturation magnetization, in the biasing field of the magnetron these good characteristics may be lost. As a result, the materials chosen for testing are ones that have a range of saturation magnetizations.

In an attempt to continue with the yttrium aluminum garnet as the material of choice, we have launched a number of studies to find a way to shield the ferrite from the main magnetic field. We have also started work on designing a control circuit for biasing the magnetic field. The remainder of the paper will describe the ferrite based magnetron and the work related with these efforts.

PURPOSE OF THE FERRITE/GARNET

The theory behind the use of these materials in the anode of the magnetron is to "lock" the free-running competing mode's ability to rotate and move azimuthally about the anode structure. This may result in the phase stability of the magnetron. It is theorized, that in the free-running mode which it normally operates, the null position will move about in a random manner distorting the azimuthal RF field that generates the gain and power of the magnetron. A perfect azimuthal π-mode field with a reversal centered at each vane is expected to have no phase noise. As shown in Figure 1, the next nearest mode of the 10-vane magnetron anode has a null field in one of the 10 gaps, and will be located in only one gap based upon the location of two ferrite/garnet rods.

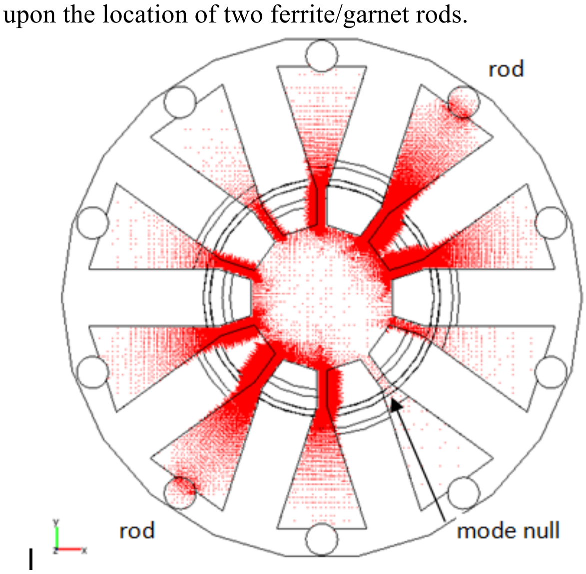

Figure 1: Next nearest mode locked in place by the ferrite/garnet rods. (The other circles in the back of the cavities are unused with vacuum characteristics in this Comsole model).

It is also theorized that if this mode's is further away from the operating mode, then it will have the least amount of impact of the perfect azmuthal p-mode fields. That is the reason for strapping the magnetron and increasing the separation between the modes. That is the additional reason for having losses in the ferrite/garnet fine tuned to maximize their impact at around 1.5 GHz in this 900 MHz magnetron

Frequency Tuning the Magnetron

Results from a previous paper [4] showed that with two rods in place, a magnetic field orthogonal to the RF fields in the magnetron's anode resonant structure can influence the permeability of the material and the frequency of the resonant structure.

Figure 2 below shows the configuration for the prototype tests.

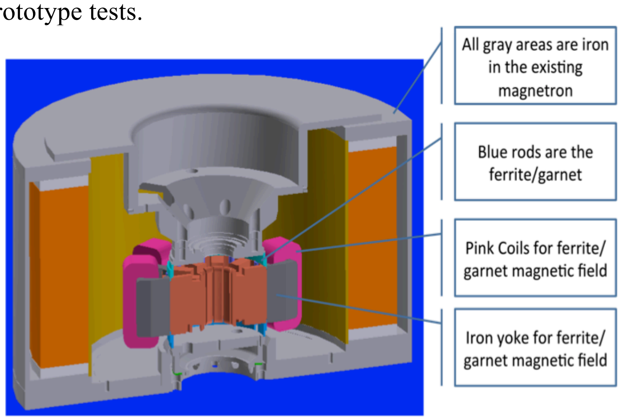

Figure 2: Cross section of magnetron tube with control magnet coils and ferrite roads

MAGNETIC SHIELDING

The need to have a biasing magnetic field opens up the possibility that the two fields can interfere with each other at the place where ferrite rod will be positioned. A series of studies have been done using Poisson code that suggest a modification of the existing main magnet structure as shown in Figure 3.

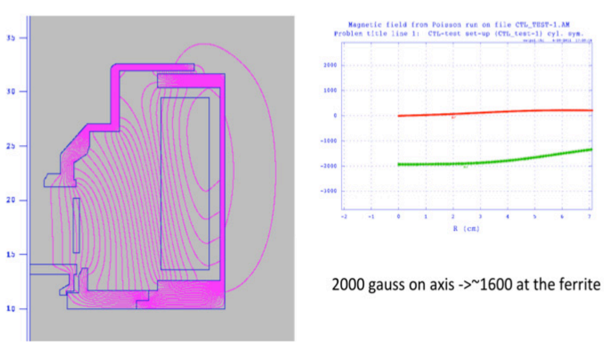

Figure 3: Present test configuration, Poisson run and magnetic field of the main magnet at the center of magnetron cavity.

At present, the main magnetic field is around 2K Gauss at center and 1.6K Gauss at the position of the ferrite rod. This high magnetic field at the rod will fully magnetized ferrite and remove any possibility for controlling the amount of magnetization of ferrite. The series of studies done using the Poisson code have indicated that the main magnetic field can be redirected and shielded so that it is reduced at the position of the ferrite. Figure 4 shows the Poisson run with modified geometry and iron joke needed for control coils.

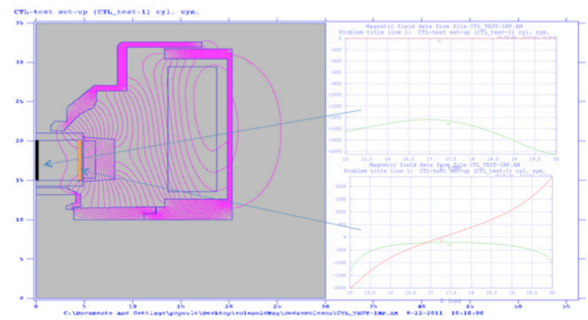

Figure 4: Modified test configuration, Poisson run and magnetic field of the main magnet, here shielded near the ferrite.

The figure also shows values of vertical and azimuthal components of the magnetic field at two different locations. The upper plot on the right shows the field at near the center of magnetron, at the position of cathode. The red line, with the value around zero is the azimuthal field and the green curve is the vertical component with values ~1.5kG. The plot in the bottom shows value of the field at the location of the ferrites, with values ~300G.

We have also started the design of a control circuit for the core biasing. At this point we assume that the error signal will come from the phase detector and that the biasing power supply will have a control input from zero to ten volts. Assuming that the set point will be in the middle range of the control voltage, a simple circuit was designed to track changes in the phase, shown in Figure 5.

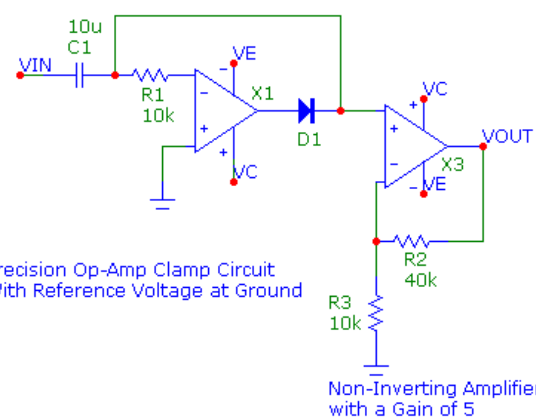

Figure 5: Two stage amplifier. First stage takes the input from -1V to 1V and shifts it to the range of 0V to 2V. The final stages amplifies it to the range of zero to ten volts

FERRITE TESTING

Test Data

The test data involved collecting the S11 and S21 from the test setup similar to Bush [2] for various fields in the coax magnet, assuming the magnetron biasing field was completely shielded, and calculating the microwave properties from those values. The calculations followed the procedures described by W. Hartung et. al., [3].

Figures 6 and 7 show the results of a series of tests on the material G810 from Trans-Tech. The optimum range of operation for the YAG magnetic field is shown in Figure 8. At around 600 gauss, the loss at the operating frequency of the magnetron is low and the loss at the next nearest mode is the highest. The operating conditions are dependent on the frequency of the gyromagnetic resonance and the amorphous nature of the sintered G810 material.

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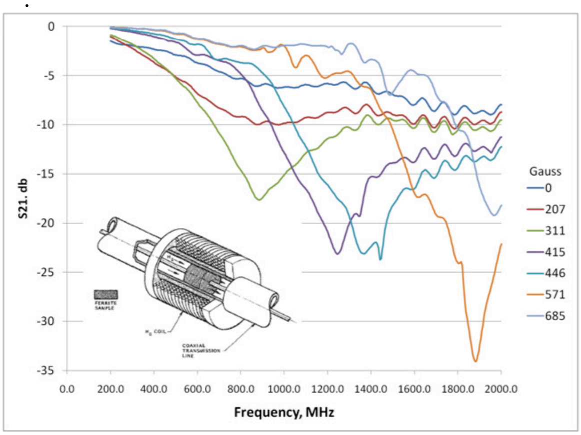

Figure 6: Test results for G810 YAG material from Trans-Tech. S21(db) in a coax line with coaxial magnetic field as a function of frequency and magnetic field.

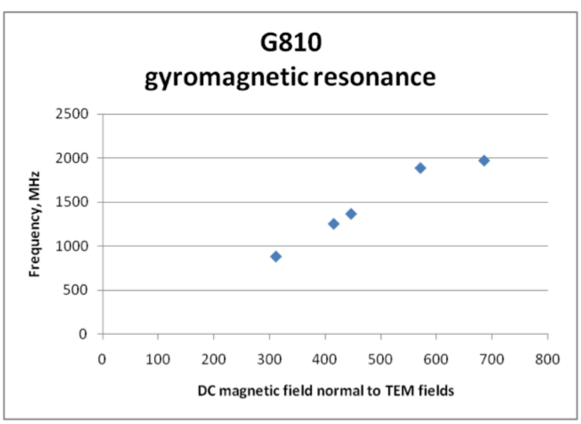

Figure 7: The gyromagnetic resonance of the YAG material as a function of the DC magnetic field in the coax test fixture.

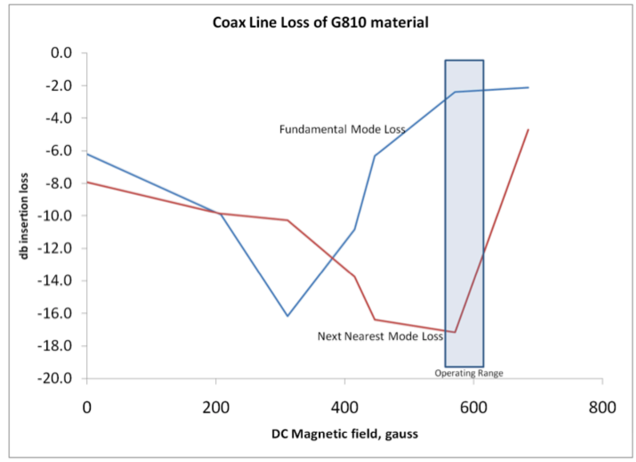

Figure 8: The loss at the fundamental frequency of the magnetron, and at the next nearest mode. The optimum level for operation is around 600 Gauss in the garnet.

Future Tests

The actual value of the loss in the fields of the magnetron anode with the YAG magnetic field will be determined in the next series of tests. In those tests, the shielding design will be completed, as well as the out-gassing test of the desired material. The out-gassing test will be performed at the bake-out temperature of the magnetron, about 450C, and the material retested to verify that the magnetic characteristics have remained unchanged.

If needed, more materials will be studied to find the desired microwave characteristics that will allow the material to be used in the π-mode resonant structure of the magnetron anode.

The optimum material will have low losses, perhaps lowered by the fields from the magnetron's operational biasing magnet. These axial DC fields will not saturate the material, so that a magnet that produces a field orthogonal to the RF magnetic field can further change the permeability of the ferrite/garnet, and tune the frequency of the resonant structure.

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[4] M. Neubauer, et. al., "Phase and Frequency locked Magnetron," IPAC10