PHASE AND FREQUENCY LOCKED MAGNETRONS FOR SRF SOURCES*

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Abstract

In order to make use of ferrite and/or garnet materials in the phase and frequency locked magnetron, for which Muons, Inc., received a Phase II award, materials must be tested in two orthogonal magnetic fields. One field is from the biasing field of the magnetron, the other from the biasing field used to control the ferrite within the anode structure of the magnetron. A test fixture was built and materials are being tested to determine their suitability. The status of those material tests are reported on in this paper.

INTRODUCTION

The Phase II award to Muons, Inc partnering with Fermilab and a company that builds magnetrons has allowed testing to begin in order to find the most suitable material for use in the magnetron. The optimum material is one that has a high loss at the frequency of the next nearest mode, and 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.

However, unlike the simple tests performed by Bush where a solenoid field was wrapped around a coax to measure the impact of the biasing field on TEM waves travelling though a sample of ferrite, in the case of the magnetron, the DC biasing magnetic field from the magnetron must also be considered. The DC biasing field tends to be in the 1000-1400 gauss range.

A test fixture was then designed to allow the testing of materials with two different DC fields. The test fixture is shown in Fig. 1.

TEST FIXTURE DESIGN

The solenoid field is designed for over 400 gauss. Its field lines are orthogonal to the TEM fields in the coax. In the magnetron application of the ferrites under test, they are assembled into the back part of the cavities that make up the anode structure. The RF magnetic field is in line with the axis of the magnetron and the ferrite biasing field is orthogonal to the RF magnetic field. In the test fixture, the same is true, although the RF fields are not part of a resonant structure, in the test fixture they are a TEM travelling wave. This portion of the test fixture is identical to the prior work of G. Bush and is shown in Fig.2.

The coax in the test fixture is EIA 7/8 coax and the ferrite sample is designed to be snug around the center conductor of the coax and snug to the ID of the outer conductor. Air gaps are minimized as they will introduce errors in the measurements

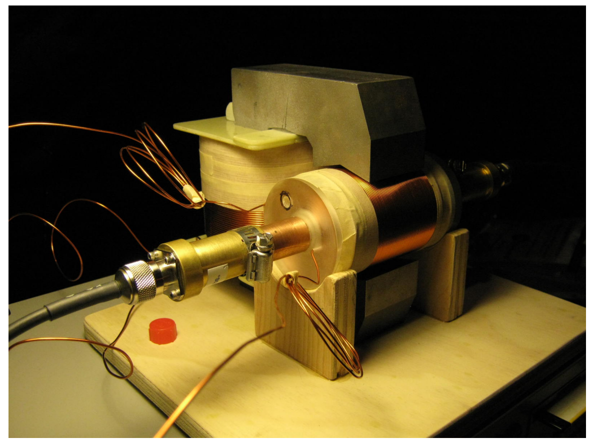

Figure 1: Test Fixture with a C-magnet duplicating magnetron operational biasing field.

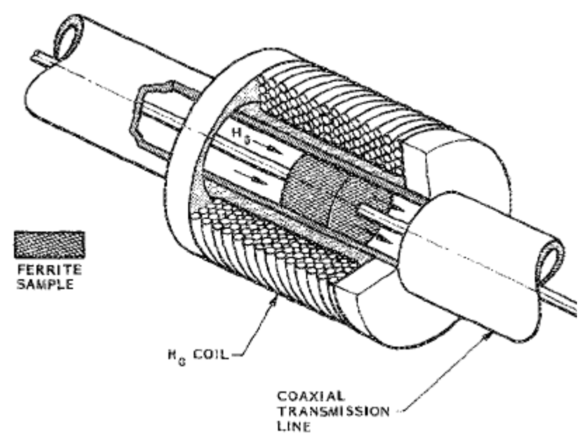

Figure 2: Schematic of the test fixture used by Bush [2].

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 were chosen to be tested based on their saturation magnetization and material characteristics. As mentioned above, the yttrium aluminum garnet seemed to have some ideal characteristics, but the observation that it has a low saturation suggested that with the biasing field of the magnetron the good characteristics may be unavailable.

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As a result, materials chosen have a range of saturation magnetization.

Table 1: Materials Chosen for the First Set of Tests

Material	model / part no.	Saturation Magnetizati on (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

Test Data and Calculations

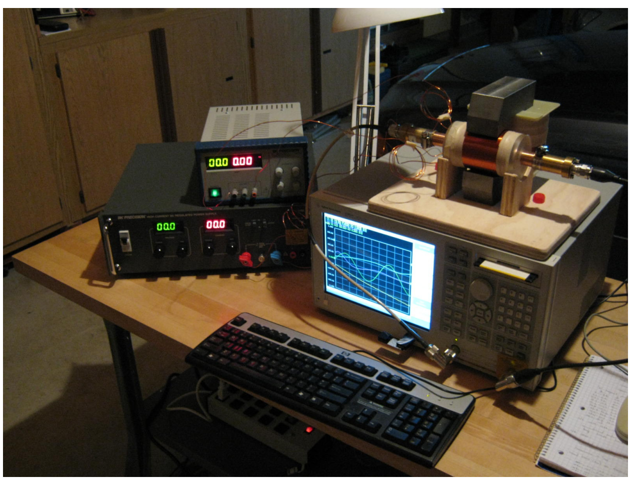

Figure 3: Test bench for the sample measurements.

Figure 4: The coax is 8 inches long and the sample .25 inches long in this example.

The test data involved collecting the S11 and S21 from the test setup for various fields in the two magnets and calculating the microwave properties from those values. The calculations followed the procedures described by W. Hartung et. al., [3].

Figure 5, shows the first results of these series of tests. The impact of the "C" or magnetron operating biasing field is the most pronounced, and is a mixed result. The insertion loss of the material is reduced from 5.5 db to less than 2 db for the frequency of magnetron operation. That is good. Unfortunately, it also reduces the losses at the high end of the band where the next nearest mode resides. And as shown in Fig 6, the effect of the "C" magnet at 960 gauss, has saturated the material, so that changes in the coaxial field have very little effect when the coax field was varied from 0 to 420 gauss.

The optimum material will not be saturated by the "C" magnet, reduce loss preferentially, and increase losses at around 1.5 GHz. Fig 6. identifies some of this attribute for the lossy part of the permeability which has abroad resonance at 900 MHz, unfortunately this is the planned operating frequency of the magnetron that will be build in the Phase II project. Also to be noted is the fact the S21 does not have this resonance, implying the dielectric losses are also playing a large part.

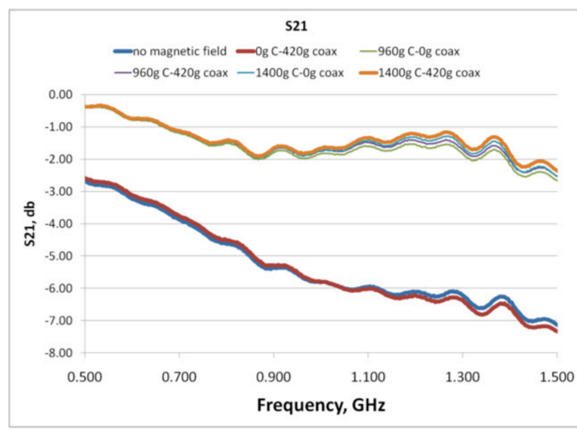

Figure 5: Test results for N40 NiZn material from Ceramic Magnetics.

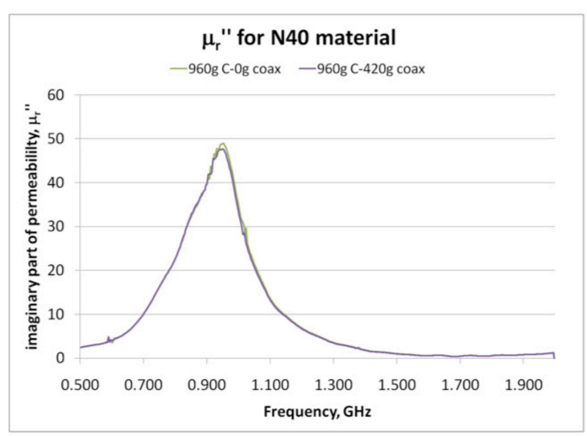

Figure 6: Test results for N40 NiZn material lossy part of permeability.

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 Fig 7, the next nearest mode of the 10-van 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.

It is also theorized that if this mode's is further away from the operating mode in voltage, then it will have the least amount of impact of the perfect azmuthal π-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.

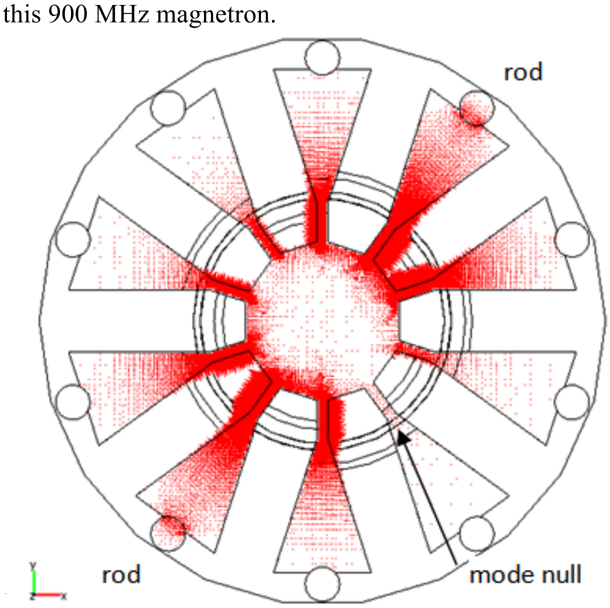

Figure 7: Next nearest mode locked in place by the ferrite/garnet rods. (The other circles in the back of the cavities are un-used with vacuum characteristics in this Comsole model).

Frequency Tuning the Magnetron

Results were shown in a previous paper [4], 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.

Therefore, as shown in Fig 5, while the losses were reduced by the magnetron's operational biasing magnet, the material was saturated (Fig 6), and further "tuning" of the magnetron could not occur with the N40 material.

CONCLUSIONS

A test fixture was designed and operated to begin the process of selecting the proper material for use in magnetron anode structure. More materials will need to 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