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MAGNET SYSTEM FOR A 1.497 GHz INJECTION-LOCKED MAGNETRON*

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Abstract

An injection-locked amplitude modulated magnetron is being developed as a reliable, efficient RF source that could replace klystrons used in particle accelerators that have superconducting cavities. This paper will describe the magnet system which is designed to provide a reasonably uniform field over the magnetron interaction region (IR). Most of the field in the IR is provided by a large solenoid. A smaller trim coil inside the larger coil provides the ability to vary the field within a certain range. In anticipation of a large number of magnetrons needed for an accelerator the large solenoid would be replaced by permanent magnets to provide the IR field. This paper will describe the magnet system both with solenoid coils and with the permanent magnet option.

INTRODUCTION

Magnetrons normally have efficiencies of the order of 90% which is much higher than typical klystrons [1]. A 1.497 GHz phase-locked magnetron as a power source for SRF accelerators was simulated [2] as a replacement for use with CEBAF. A design of an amplitude modulated magnetron where the current and the power output of the magnetron is accomplished by varying the magnetic field is described in Ref. [3]. Figure 1 shows a CAD picture of the magnetron. The magnetic field is adjusted to control the current that passes from the filament cathode to the anode. This is accomplished with two solenoids: The larger main small coil magnet controls the operating point and the smaller trim coil controls the amplitude modulation [4]. The trim coil is primarily used to compensate for microphonic noise in superconducting cavities by maintaining a constant gradient in the cavities [5].

ELECTRO-MAGNET OPTION

During the R&D phase of this project, solenoid electromagnets were used. A prototype magnetron has been fabricated during this phase. The trim coil magnet must be electromagnet (EM) to be able to respond rapidly to changes. Figure 2 shows a sketch of the magnet system. The center of the main coil is positioned in a space below the middle of the IR so as not to interfere with the outgoing wave guide. The steel pole pieces that surround the coils are designed to conduct the field to the IR. The main coil provides a 0.25 T DC field. The maximum trim coil field is 0.025 T.

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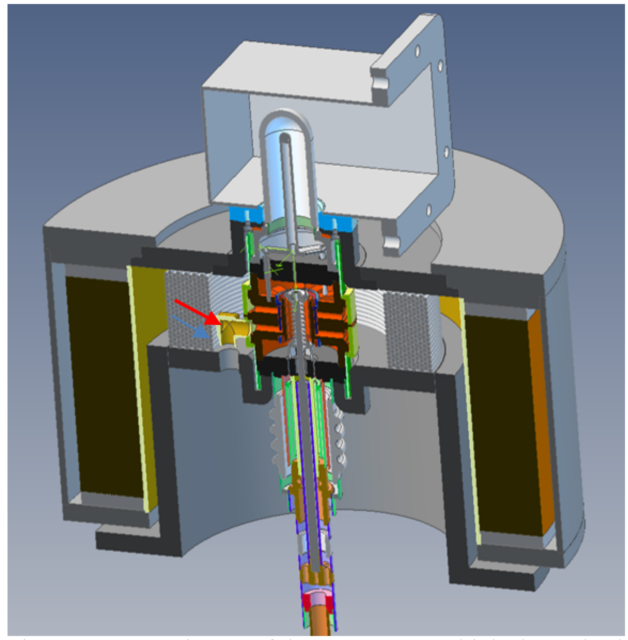

Figure 1: CAD picture of the magnetron which shows both the main coil and trim coil. The red arrow points to water manifold to cool anode.

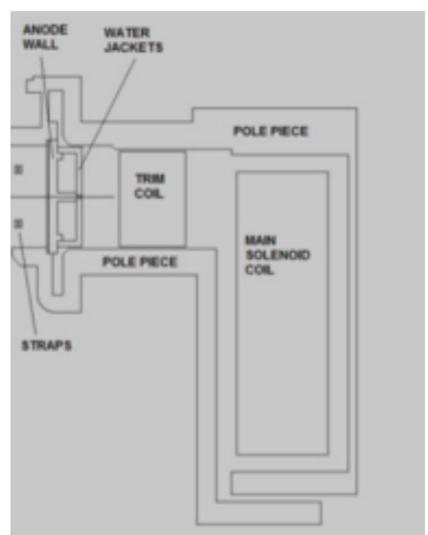

Figure 2: Sketch of the magnet system showing both the main and trim electro-magnets.

The trim coil which surrounds the anode provides a tuneable field to add to the IR field. Table 1 shows the parameters describing the trim coil. The parameters show the case for 10 A per turn which would be wound with insulated 12 gauge wire. The transient time constant associated with the magnet inductance and coil resistance is 83 ms which is independent of the number of turns as long as the

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coil cross section area is fixed. This transient time is too long to react to very short time disturbances.

The trim coil inductance is large because the coils are placed outside of the water-cooling system of the anode. If the water manifold could be positioned on the axial side of the anode as shown by the red arrow in Fig. 1 the transient decay time could be reduced, however the inner radius of the trim coil cannot be less than the anode outer radius.

Table 1: Trim Coil Parameters

Parameter	Value
Field from the Main Coil	0.25 T
Maximum Field from Trim Coil	0.025 T
Number of Turns	124
Current per Turn	10 A
Inductance	0.0071 h
Coil Resistance	0.069 Ω
Transient Time Constant	83 ms
Cross Section Area	21.05 cm^2

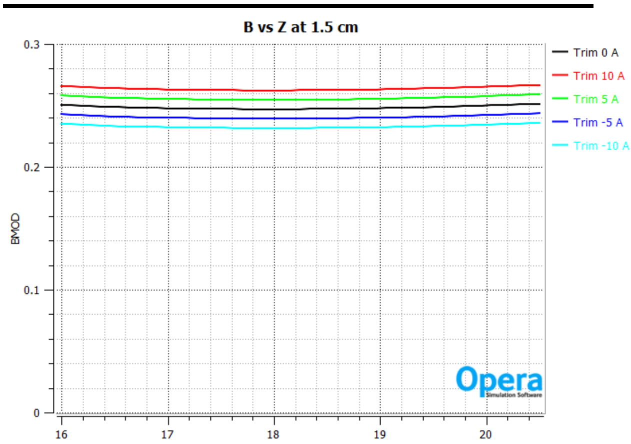

Figure 3: Field in the center of the IR as a function of axial position.

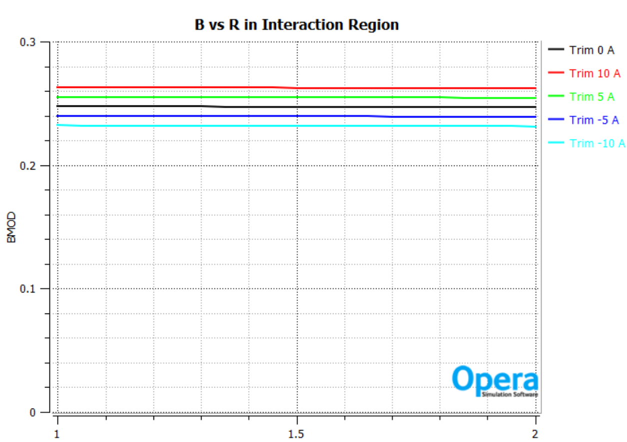

Figure 4: Field as a function of radial position in the in IR at mid-distance between the poles.

Figure 3 shows the field in the IR midway between the anode and the cathode filament as a function of the axial position. The field is dependent on the current trim coil as shown in the figure for different currents in the trim coil.

There is a slight non-uniformity present which is attributed to the pole pieces and the relatively long distance between them. Figure 4 shows the field as a function of radial position midway between the poles.

PERMANENT MAGNET OPTION

As part of a path to commercialize the magnetron for accelerator applications the main coil could be replaced with a permanent magnet. This would reduce the size of the magnetron and power required. The trim coil will remain EM so as to be able to adjust the field as needed. The required field in the IR provided by the permanent magnet should be at least 0.18 T with a field uniformity in the IR similar to the EM option. In this analysis we have used a 2D axial symmetric model assuming cylindrical symmetry. (A 3D simulation is in progress). Figure 5 shows the geometry of the magnet system used in a COMSOL finite element study. The permanent magnet material (PMM) is shown in black. The steel pole is shown in blue and the trim coil and anode which are made of copper are shown in orange. The inner part of the pole structure is chosen to be close to that of the current EM magnetron. This study looked at using ferrite (SrFe2O3) and Nd2Fe14B (Neo) for the PMM. The ferrite did not produce enough field in the IR to be satisfactory. N-42 Neo [6] with Br=1.33 T and Hc=10800 Oe was chosen for this analysis. The PMM is assumed to have a Z-oriented magnetization.

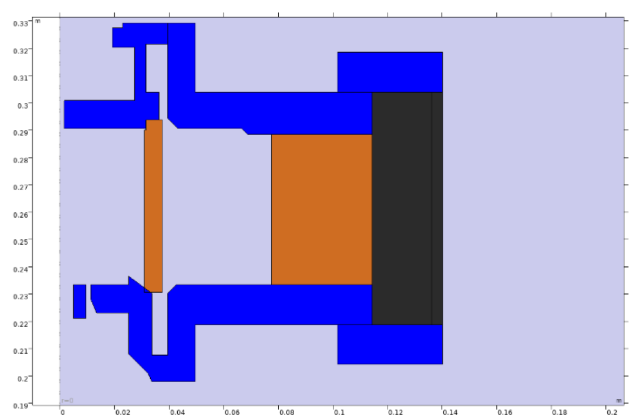

Figure 5: Geometry of the permanent magnet system. PMM is shown in black, the steel pole is shown in blue and the copper anode and trim coil are shown in orange.

To build a prototype magnetron with neo we would like to use commercially available magnets. A ring-shaped magnet with a large enough radius would need to be made to order and likely to be too expensive to build a single prototype magnetron. The permanent magnet can be made up with blocks or cylinders with a geometric correction for the field calculation. Figure 6 shows a contour plot of |B|. The peak field in the iron is 1.55 T which does not show significant saturation. The field in the IR for this configuration is 0.21 T.

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The operation of the trim coil with a permanent magnet is more complex because of the demagnetization of the PMM. The field in the IR from the trim coil alone is 90 G.

The H-field from the trim coil in the PMM region varies from 30 Oe to 50 Oe. Using the demagnetization curve associated with N-42 Neo it is estimated that there will be a loss of 47 G in remnant field. This will reduce the range of the trim coil correction with the PPM main magnet option to half that of the EM main coil option. The demagnetization should have a small effect on the operation field.

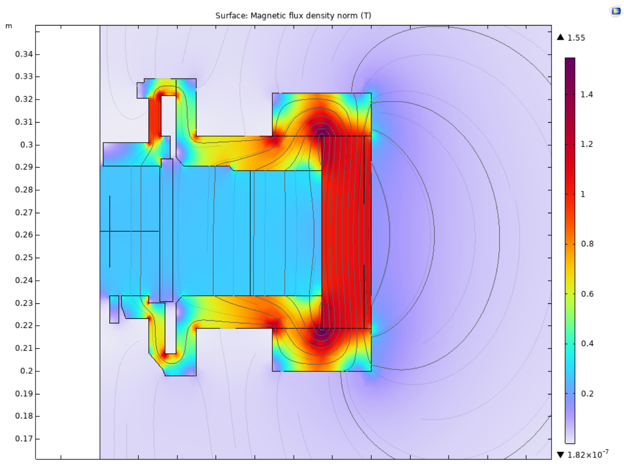

Figure 6: Field contour plot using Neo PMM.

CONCLUSION

This document describes the magnet system to provide the magnetic field in the IR of the magnetron. A coil-based system is compared to a permanent magnet system. Neo PMM is favored over ferrite to produce the required IR field. However, the correction range of the trim coil is reduced significantly by the demagnetization of the neo by the field of the trim coil.

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