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A TRANSFORMER SEPTUM MAGNET*

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Abstract

A pulsed transformer septum magnet is under development for the Intense Pulsed Neutron Source (IPNS-I), 500 MeV accelerator. The septum consists of a copper sheet and a steel sheet. The copper sheet is one side of the shorted single turn transformer secondary. The steel sheet, which is on the stray field side of the septum, is part of the transformer core. External support and cooling structures, as well as the septum itself, can be grounded, which simplifies the design. The design construction and operation will be discussed. The transformer primary is driven by a condenser discharge. A reverse discharge a few ms later recharges the condenser and demagnetizes the septum. Details will be discussed.

Introduction

Extraction septum magnets have long been recognized as critical components in accelerator systems. They are required to meet many, often conflicting, requirements. It is desirable that they have good field homogeneity in the gap and a minimum stray field. Due to geometrical limitations, the septum conductors are often required to run at high current densities and with poor cooling facilities. The proximity of the septum conductor to particle beams causes the septum to be exposed to very high radiation doses which must be tolerated for a reasonable time by the electrical insulation that might be used here. As if these are not enough, the magnet must usually operate in a reasonably good vacuum. In addition to these formidable requirements, rapid cycling synchrotrons require that the septum magnets operate at pulse rates of up to 60 Hz or maybe even higher.

Our desire at Argonne was to design and build a magnet that could meet these requirements better than the magnets currently used.[1,2] This would require a magnet that was fairly simple in structure and one that minimizes or even eliminates the use of electrical insulation in or near the septum conductor. Designs were considered which incorporate a single-turn coil which is welded to the septum edge of the gap,[1] thus eliminating the insulation in the septum. Our problem, however, is complicated by the fact that we require gap fields of at least 10 kG which requires a driving current of around 50 kA in this single-turn for our 2.4 inch high gap. This results in power dissipation problems in the septum conductor and problems in delivering this current into the vacuum box. In order to provide the required cooling hardware to the outside of the conventional septum, however, the desired field properties would be seriously degraded. As a result, we chose to develop a transformer septum magnet.

Basic Concepts for This Magnet

The schematic drawing in Fig. 1 shows the basic components of this magnet. The core is constructed of C-laminations plus a solid steel septum plate. The multiturn primary coil is tightly wound around the back yoke. The shorted single-turn secondary also encircles the back yoke, but is not as closely coupled as the primary. The beam deflector field is the leakage field inside the gap between the primary and secondary windings.

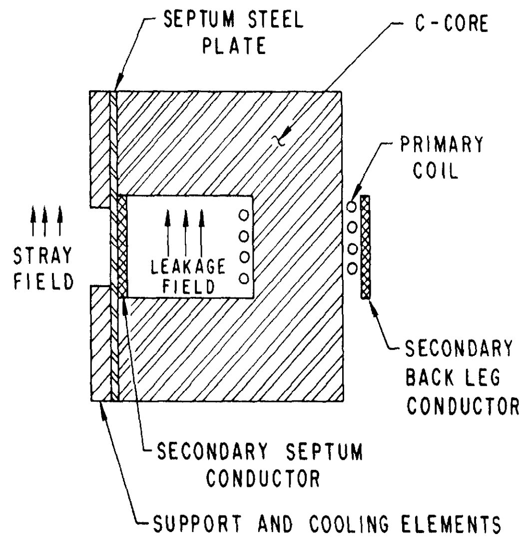

Fig. 1 Cross-sectional View of Magnet Showing the Basic Components

The volt-seconds required to drive the secondary is provided primarily by the flux in the septum steel plate. Cooling and support elements on the outer side of this plate will not have any flux linkage, and, therefore, no induced currents during the short time prior to the peak field.

In the design in Fig. 1 the secondary is a conducting (shield) box which confines the pulsed field. The septum conductor can, therefore, be grounded to the core without serious alterations in the current distribution. In fact, there is no need to isolate the secondary conductor from the core at all. The insulation required for this magnet, therefore, is only around the primary coil.

The gap field is not too dependent on the length of the excitation pulse, but the stray field is. The gap field will eventually penetrate the septum conductor and steel plate, and leakage fields will result.

Power Supply

The primary current pulse is provided by a capacitor discharge power supply. This supply produces a pulse which is approximately a half-sine wave with a base width of about 2 ms. In order to reset the septum steel, a reset pulse is generated by the power supply a few milliseconds later and fed to the magnet. This pulse is also approximately a half-sine wave of reverse polarity, with an amplitude slightly less than the first pulse.

Prototype Magnet

In order to gain a better understanding of this type of magnet, a full sized prototype was built with provisions for modification. Modification 5 of this magnet is shown in Fig. 2 and Fig. 3, and the dimensions are listed in Table I.

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TABLE I. Magnet Dimensions (inch)

Septum Conductor Thickness	.06 to .25 (tapered)
Septum Steel Plate Thickness	.09
Lamination Thickness	.015
Core Length	6.88
Gap Height	2.4
Return Yoke Thickness	2.4
Shield Box Thickness	0.5
Gap Window in Shield End	2H x 3W

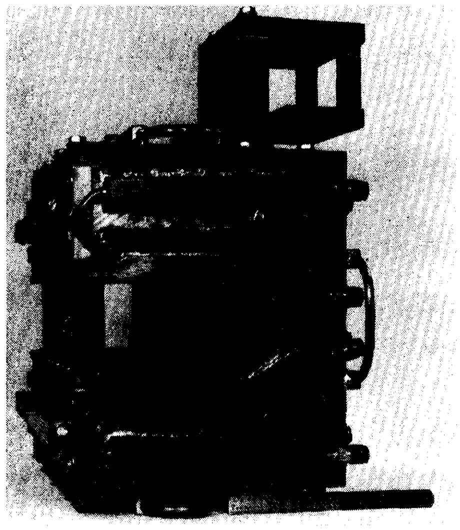

Fig. 2 Transformer Septum Magnet, Mod 5

It is shown to be bolted together. This facilitates changes but is not a reliable fastening method for a pulsed magnet. The core shown removed from the shielding box in Fig. 3 has 0.5 inch x 45^{o} bevel at each pole end. It also shows the four turn primary wound with .38 x .24 conductor with a .064 x .20 hole. The laminated core and primary coil were vacuum impregnated with a DER 332 & NMA epoxy.

There were several modifications of this magnet that were tested. These were made up of one or combinations of the following changes:

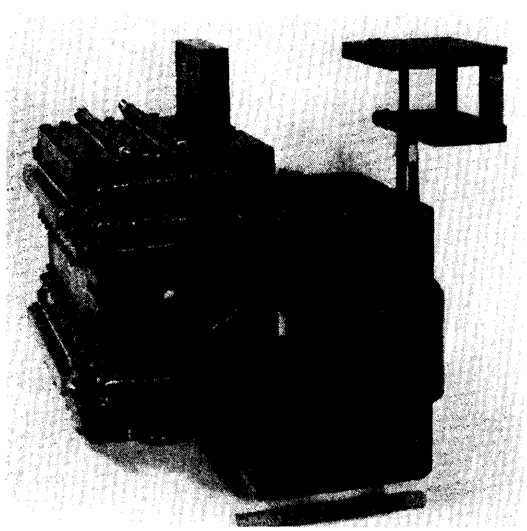

Fig. 3 Magnet, Mod 5, with Laminated Core Removed From Shield Box

A. Replace the copper back on the shield box with a 1/4 inch x 2-1/2 inch copper bar.

B. Place a laminated C-core around the copper bar in A. This core was in contact with the back surface of the original core, forming a flux path around the back leg of the secondary turn.

C. Replace the copper top and bottom covers on the shield box with solid 1018 steel, 5/8 inch thick.

D. Place a solid 1018 steel plate extending between the top and bottom steel covers in C and just behind the copper bar in A.

E. Electrically insulate the top and bottom shield covers from the shield end covers and septum plates.

F. Replace the septum face elements with a solid copper and steel, hard soldered assembly. The copper was .19 thick and the steel was machined from 0.5 down to 0.09 in a 2 inch region at the midplane.

The basic modifications tested were for the following collections of the above changes:

Mod 1 - A, B, E, F
Mod 2 - A, C, D, F
Mod 3 - A, C, D, E, F
Mod 4 - F
Mod 5 - Original

Test Results

There were a number of modifications other than those above which were tested during the entire program, but those listed above were run during a single operating period. This facilitated direct comparisons by eliminating the changes in test results that were due to variations in the power supply settings. All of the tests which will be discussed here were done using only an oscilliscope, 4 inch long and 25 inch long search coils, and an electronic integrator. The waveforms shown in Fig. 4 represent (a) the voltage across the capacitor bank in the power supply, (b) the integrated signal for the gap field, and (c) one of our better results for the stray field at a point about 0.2 inch from the septum outside surface. This signal represents the output of the search coil before being integrated.

The peak current in the primary was about 10.4 kA, which produced a central gap field of 9472 G. The stray field signal, Fig. 4c, was graphically integrated showing a field of 53 G at 1.2 ms after the current pulse was initiated. The field integral showed the effective length of this magnet to be 7.921 inches. The voltage difference, ΔV_C, shown in Fig. 4a is a measure of the losses for this type of system. This was measured for each of the above modifications, and was essentially the same for each.

The time delay, T_d, in Fig. 4b between the initial and reset pulses was changed and the stray field was monitored. Values of almost zero to 5 ms were tried with the best results for the 5 ms value. This was the maximum attainable value, but logic modifications in the power supply will be made in the future to allow further adjustments in the operating system.

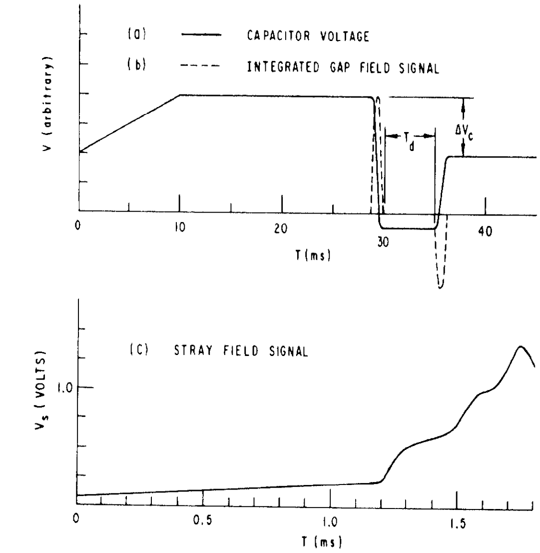

Fig. 4 Representation of Pulses Observed During Magnet Tests. a) Voltage drop across the power supply capacitor bank, b) gap field signal after electronic integration, c) stray field signal representing dB/dt.

The stray field pulses were used to compare the five modifications listed above. The tests were conducted at pulse rates between 3 Hz and 15 Hz, with the width of the pulse being about 2 ms at the base. We were seeking a design which gives a low field for at least 1 ms after the initial pulse starts to rise. The lowest pulses were obtained for Mod 5, indicating the better design for the septum face elements. There was no detectable differences between the results for Mod 1, 2, and 3. These results, however, were about 25% better than Mod 4. This indicates that we need a steel yoke behind the back leg of the secondary conductor, but it need not be laminated. Also, the top and bottom covers do not need to be insulated from the ends or front.

Some early runs were done with no water cooling on the shield box and secondary turn. The resulting temperature rise on the top cover was 17° C at 9 Hz. We also removed the top and measured the leakage field to be about 200 G near the surface of the core. These results indicate the need to have water cooled top and bottom covers. Temperature rises at 9 Hz were about 42° C on the inside of the copper septum.

The tests on the above listed five modifications were conducted with water cooling for the secondary turn and the shield box. In Fig. 2 the cooling tubes can be seen on all the outside surfaces of the magnet. Temperature rises of about 17° C were the highest observed for any point on the shield box or primary coil for runs at 15 Hz. The septum, of course, was much hotter. For the brazed steel and copper septum, change F above, temperature rises of up to 83° C were measured. The original septum, however, gave rises of less than 36° C showing again the merits of the original design. The temperature gradient between the inside and outside surfaces of the original septum, however, were up to 20° C at 10 Hz, but were generally less than 10° C for the brazed septum at 15 Hz.

Final Magnet Design

The design of an operational magnet is now underway utilizing the results of the tests described above. The core will use the same laminations as the prototype but will have a five-turn primary coil. The shield box top, bottom, and back covers will be made from 1006 steel, 0.09 inch thick and 0.38 inch thick copper brazed together. The ends of the shield box will be machined from solid copper. The septum will be a brazed laminate. The secondary conductor will be about 0.18 inch thick copper brazed to the inside of a 0.09 inch thick piece of 1006 steel with 0.5 inch thick copper bars brazed to the outside surface at the top and bottom edges. These outer bars will contain the water cooling channels for the septum. We will weld and silver alloy braze all the joints between the six sides of the box surrounding the steel core. The core will be located inside the box by solid metal spacers before the last side of the box is installed. We intend to operate this magnet at 10 kG at repetition rates of up to 45 Hz. Only some experience will tell us how long this design will be able to withstand the beating, but we are confident that it will be able to last significantly longer than the magnets with more conventional designs.

References

1. H. Edwards, E. L. Hubbard, and R. Juhala, "A Radiation Resistant Laminated Septum Magnet", Proceedings of the Fourth International Conference on Magnet Technology, CON-720908, p. 153-156 (1972).
2. A. J. Gorka, R. J. Lark, and L. G. Ratner, "Edge-Cooled High Current Septum Magnet", IEEE Trans. Nucl. Sci., NS-18, No. 3, p. 878-882 (1971).