A RADIATION RESISTANT LAMINATED SEPTUM MAGNET

H. Edwards, E. L. Hubbard, R. Juhala
National Accelerator Laboratory*
Batavia, Illinois 60510

Abstract

A pulsed septum magnet is used to inflect the 200 MeV beam into the booster synchrotron at the National Accelerator Laboratory. The magnet which is approximately 1 meter long is excited by a single turn coil to 3.3 kG at 10,000 amperes. Instead of supporting the septum with insulating material which is subject to radiation damage, the septum is welded to the magnet laminations. The current is confined to the septum by the insulation between the laminations which is a standard core plate material. The aperture is 1 1/2" high x 2" wide. The field is a half sine wave with a width of 400 μsec which provides a peak field uniformity of 0.1% for a duration of 12 μsec as required for injection.

I. Introduction

There are two points in the beam transport line from the 200 MeV linac to the booster synchrotron that require septum magnets. One is part of the chopper system used to select a short part of the linac beam pulse for transmission to the booster while the remainder of the linac pulse is deposited in a beam dump.[1] The other is used in the booster injection system.[2] The required bends of 8.3° and 9.3° being almost equal allowed the use of a single design to fulfill both requirements. Initially, eight turn DC septum magnets with 16 parallel water cooling circuits were built and used during the first year and a half of operation. During this period, however, each of these septa had to be replaced or repaired two or three times because of either water leaks developing in the manifolding or of failure of the septum coil itself. The rather substantial expense in constructing these septa and their relatively short lifetime led to the consideration of the single turn, pulsed septum magnet described here. Pulsing the magnet eliminates the need for water cooling, and septum insulation, which would be subject to radiation damage, has been eliminated.

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II. Magnet Design and Construction

To provide a uniform bending of ±0.05% for a duration of 12 μsec as required for 4 turn injection into the booster a half sine wave of 416 μs width could be used. With a bending length of approximately 1 meter, a field of 3.1 kG is required for the 8.3° inflection of the 200 MeV beam. The vertical aperture of 1 1/6" as provided in the DC septum was increased to 1 1/2" and requires approximately 9400A with one turn. The magnet is designed to be pulsed at a 15 Hz rate with a 50% duty cycle. Owing to the considerable reduction in average power (approximately 30 watts as opposed to 32 kW for the 8 turn DC septum), the pulsed septum would be operable even if it were cooled by radiation only, however conduction cooling to the lid of the vacuum box is provided by aluminum cylinders around the support rods which contacted both magnet and lid, and by the power connectors.

The magnet laminations were punched from 0.015" thick steel coated on both sides with standard core plate. A cross section of the magnet is shown in Figure 1. Both the septum and inner conductor were formed from 3/16" x 1 1/2" OFHC copper (the 3/16" dimension being adequate for the septum thickness). Stainless steel mounting straps were used to provide a better weld joint to the laminations than would be obtained by a copper to steel weld. They were oven brazed to the copper septum and this assembly was then finish machined to proper size. The stainless steel was notched and only a very short weld was made at several spots along the septum. Since the laminations are insulated from each other by the core plate, the current is constrained to flow along the septum. The magnet itself is electrically insulated from the vacuum box, and the inner return conductor is insulated from the core. From the photograph shown in Figure 2, it can be observed that the magnet is curved to increase the effective horizontal aperture. The ends of the magnet are parallel, and at the end where the two beams converge (or diverge as for as the 9.3° chopper bend at the end of the linac) the beam enters perpendicular to the face. The rather interesting feature of extending the coil and steel beyond the crossover connection between the septum and inner conductor was suggested by K. Halbach[3] as a way to minimize the fringe field outside the septum at the ends (Figure 3A). It was not convenient to do this at the lead end so this end was kept farthest from the circulating beam in the booster (Figure 3B). As can be seen from the test data, there was a substantial difference in the fringe field at the two ends. The magnet used in the chopper system must be mounted upside down from the one in the inflector to orient it so that the beam skims close to the end of the septum where the fringing field is small. The power connections to the magnet are symmetrical above and below the gap so that the magnet can be used in either location without modification.

After assembly the magnet was vacuum impregnated with an unfilled epoxy. The aperture was kept clear by an inflated rubber bag (actually a bicycle tube was used).

III. Testing and Performance

The magnet was measured using a 1/4" x 2" rectangular coil and an integrator. The integrated voltage was displayed on a Tektronix oscilloscope with a differential voltage capability. A plot of the fringe field at the ends is shown in Figure 4. The leakage field outside the septum at the lead end, taken at the worst spot which is just alongside the leads as they protrude from the steel, and measured 1/4" away from the copper, is approximately 1.2% of the central field. However, the field alongside the septum at most other positions is only 0.2% of the field inside again taken 1/4" away from the copper. This leakage field was opposite in sign to the field inside. The decay of this leakage field is shown in Figure 5. The first point was measured at the worst spot alongside the lead end and subsequent points are taken in 1/4" intervals moving away from the septum in a direction which would be toward the circulating beam in the booster. The leakage field from the lead end, decays to approximately 0.05% of the central field at the very edge of the booster circulating beam, but increases to 0.2% at the septum end nearest the closed orbit. It was noted that a 1/16" aluminum shielding plate placed outside the septum coil was sufficient to reduce leakage field by 50%.

The field was found to be uniform to 0.1% inside the aperture. The field alongside the inner coil was actually 0.1% higher than the field at the center. No change could be detected between the central field and the field alongside the septum inside the aperture. The variation from pulse to pulse of the peak field is $\leq$ 0.1% over the short term and the peak falls off by no more than 0.12% in the 12 μsec time interval required for 4 turn injection. The measured bending length along the center of the injected beam is 40.95 inches; and a field of 3.3 kG is produced by 10 kA.

The first septum of this type was placed in the transfer line as the booster inflector in March of this year and has been operating satisfactorily at a pulse rate of once per second. It has also been tested for several days at 15 Hz. The second magnet of this type has just been installed replacing the DC septum at the chopper near the end of the linac.

References

1. E. L. Hubbard, W. C. Martin, G. Michelassi, R. E. Peters, and M. F. Shea, "System for Transfer and Analysis of 200 MeV Linac Beam," Proc. 1970 Proton Linear Accelerator Conf., Vol. 2, National Accelerator Laboratory, Sept. 1970, p. 1095.

2. R. Billinge, E. L. Hubbard, R. Juhala, and R. W. Oram, "Injection Into the 8 GeV Booster Synchrotron," IEEE Trans. Nucl. Sci. NS-18, No. 3, 979 (1971).

3. K. Halbach, private communication.

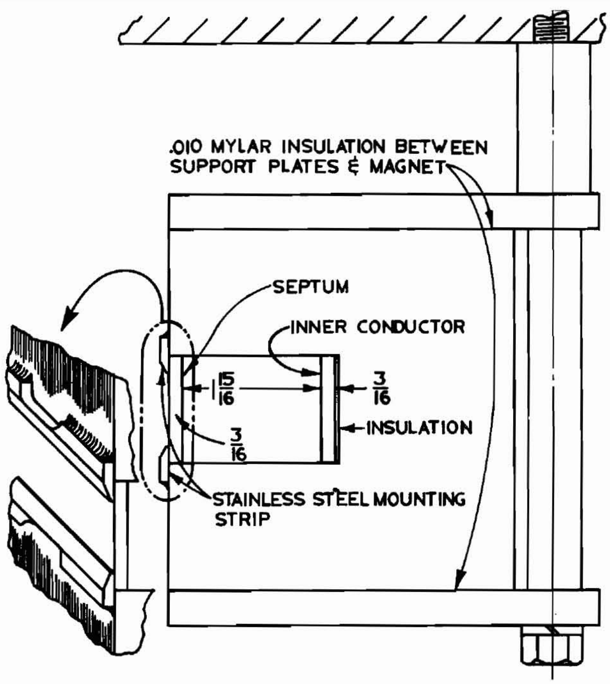

FIGURE-1
CROSS SECTION OF SEPTUM MIDWAY ALONG THE LENGTH

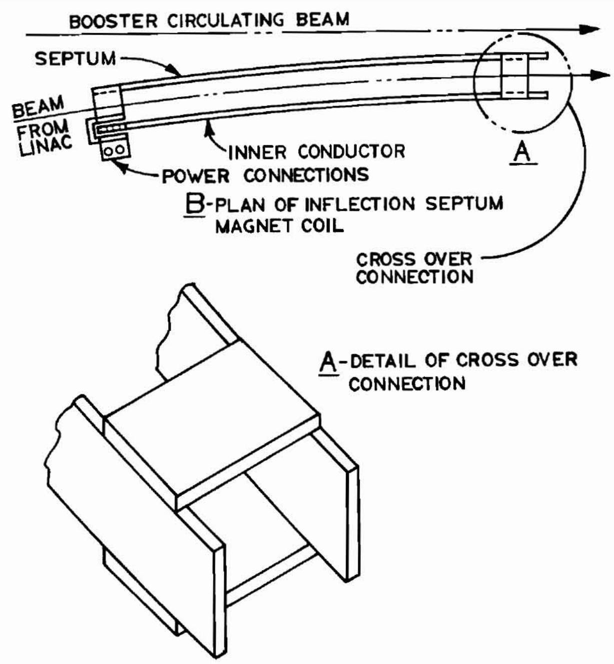

FIGURE-3
A-SEPTUM COIL CROSS OVER CONNECTION. B-PLAN OF INFLECTION SEPTUM MAGNET COIL.

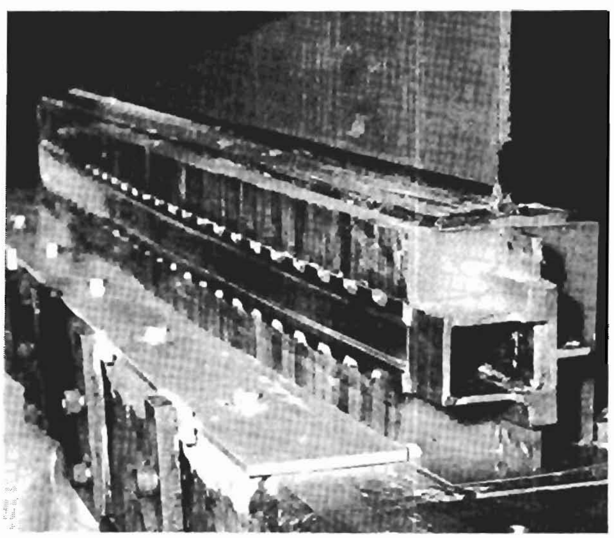

Fig. 2. Lead end of pulsed septum.

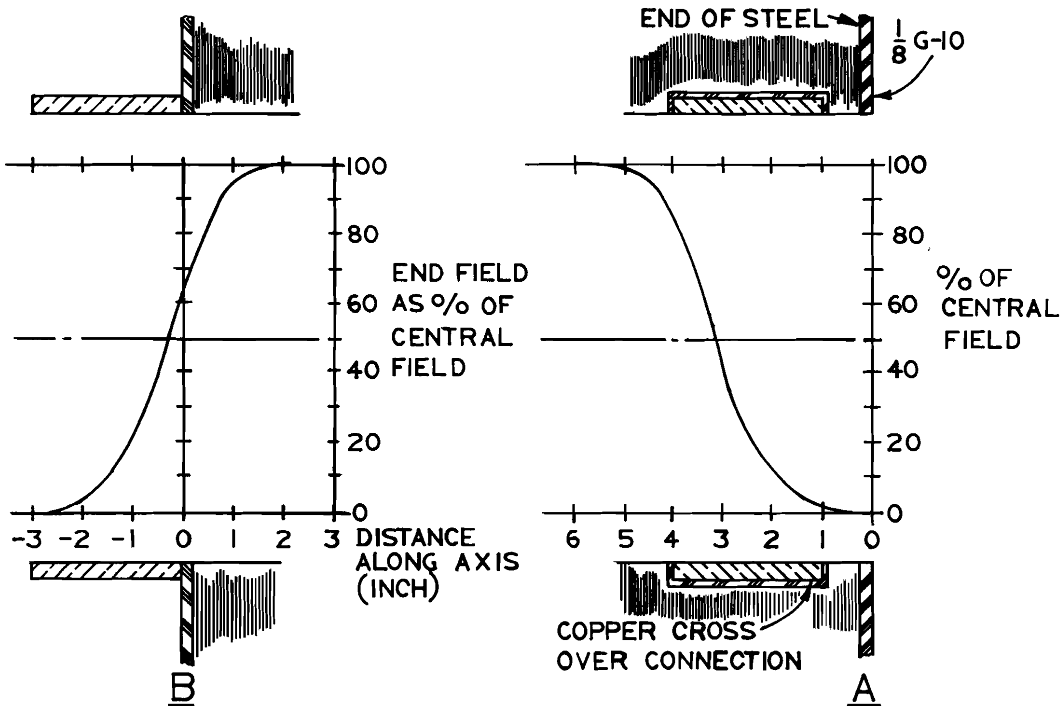

FIGURE-4

A-THE FRINGE FIELD TAKEN ALONG THE CENTER OF THE APERTURE AT THE END OPPOSITE THE LEAD END.
B THE FRINGE FIELD AT THE LEAD END OF THE MAGNET.

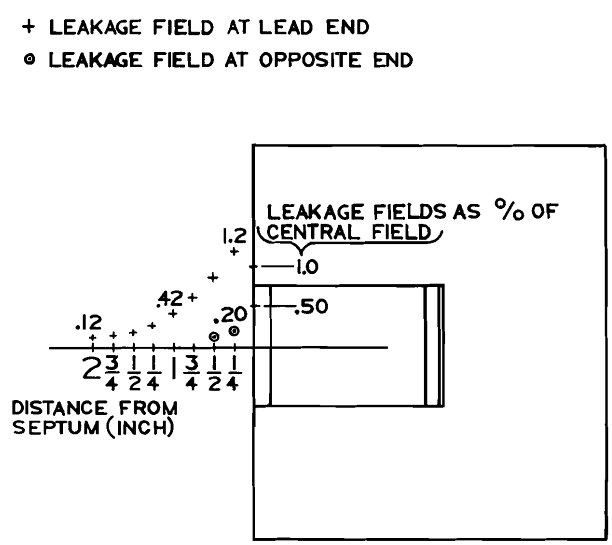

FIGURE-5
LEAKAGE FIELDS OUTSIDE THE SEPTUM