A LARGE APERTURE PULSED SEPTUM MAGNET FOR ANTIPROTON INJECTION INTO THE CERN AC RING

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Summary

A new collector ring (AC) is being built around the existing Antiproton Accumulator (AA) machine in order to increase the accumulation rate of antiprotons [1]. A much larger fraction of the particles produced at an improved target station will be transported to AC with a new 3.5 GeV/c beam line. This increased flux will be injected using a large aperture pulsed septum magnet capable of handling the 240 π.mm.mrad transverse emittances. Because the antiproton beam traverses the septum gap in air no vacuum problems arise and consequently the magnet can be of simple, glued construction. The beam requirements together with some of the unusual engineering design features of the 1.6 m long, 1 Tesla curved septum magnet are discussed.

Introduction

The optics of the injection scheme require that the septum magnet deflects the incoming antiproton beam by 140 mrad onto the injection orbit. This requires a bending strength of 1.67 T.m. Although the straight section length in the machine is 2.5 m the useful physical length for the magnet is only 1.7 m.

A separation of 30 mm between the edges of the circulating and injected beams has been set. This value is a compromise. On the one hand a large separation allows a thick septum blade capable of withstanding the pulsed magnetic pressure to be used. It also gives sufficient clearance to reduce the time varying stray field seen by antiprotons with large betatron oscillation amplitudes. On the other hand this large separation is costly on injection kicker strength and horizontal aperture of the quadrupole immediately downstream of the septum.

Measurements [2] in the AA, extrapolated to conditions with the momentum defining collimator in the new injection line indicate that dose rates at the septum will be less than 10^4 rad/h. Therefore radiation resistant, epoxy thermosetting resin can be used in the magnet manufacture.

Because of foreseeable access difficulties in this area of the machine an easily maintainable magnet is required. With these constraints in mind a simple, classical design has been adopted that is both easy to make and will be reliable in operation.

Magnet Design

Initially a dc septum magnet was considered but quickly abandoned for the present pulsed magnet design [3]. This decision was taken because of both the cooling problems anticipated with a calculated 300 kW power dissipation and the high running costs.

The basic pulsed magnet specification (Table 1) evolves from the antiproton beam requirements at injection. The position of the magnet within the 2.5 m section length is influenced by the need to have sufficient separation from the adjacent quadrupoles to avoid magnetic interference.

Table 1
Septum Magnet Parameters

Peak magnetic induction	1.0022	T
Bending angle	8°	
Magnet radius of curvature	11.892	m
Overall magnet length	1.7	m
Vertical aperture between poles	90	mm
Horizontal aperture between coils	111-119	mm
Apparent septum width	23-15	mm
Number of turns	2	
Coil resistance at 20°C	0.165	mΩ
Magnet inductance	11	μH
Peak pulse current	36	kA
Pulse repetition interval	2.4	s
Pulse duration	5	ms

The design includes laminated shims to enclose the end conductors so that the overall physical length of the magnet becomes 1.7 m. With this technique a measured magnetic length of 1.675 m along the radius of curvature is obtained.

The gap dimensions are taken from the beam size curves of Figure 1. These design curves, derived from computer generated plots of the injected beam [4], give the beam size in both transverse planes relative to the magnet position.

The horizontal aperture is varied over the total length and the magnet curved so as to follow the beam on the injection trajectory. In using this approach the magnet inductance is kept to a minimum and at the same time the tapered septum blade has minimum width where the injected and circulating beams are closest.

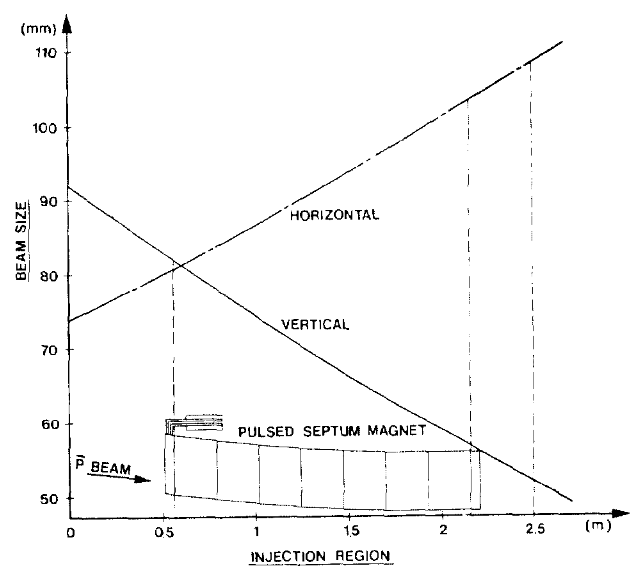

FIG. 1 Beam size in the injection region.

The magnet is powered through a 10:1 stepdown pulse transformer and is connected by a stripline to minimize the inductance. Using a standard pulse power supply of 1200 μF capacitance, the required charging voltage is 3.6 kV at the nominal peak current.

A very low resistance is obtained for the two turn coil by using 10 mm wide massive copper conductors. At the nominal operating conditions the mean power dissipation is only 200 W. A simple edge conduction cooling technique via the coil insulation to the core can be used for a magnet operating in air with such a low dissipation. The magnet core has a large surface area with a total steel volume of about 0.4 cubic metres. A small bore cooling tube attached to the underside of the core with a flow of 1 l/min is sufficient to stabilise the copper temperature at 40°C.

Magnet Construction

The magnet follows the design philosophy that it should be robust, of straightforward construction and have the possibility of coil removal for repair in the laboratory. The laminated curved steel core is glued to avoid using tie bolts so reducing mechanical wear. Glass fibre wedges, Figure 2, are employed to retain the coil in the magnet gap.

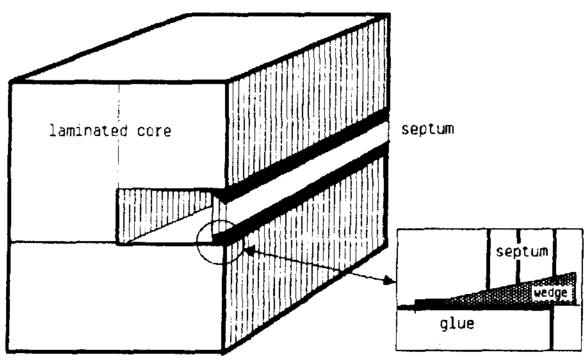

FIG. 2 Glass fibre wedges to retain coil in gap.

Laminated Core

Standard 0.5 mm silicon grade transformer steel strip is used for the lamination manufacture. This has a 5 μm layer of synthetic resin on one side. The strip is cut to form laminations out of three rectangular pieces, Figure 3, and then positioned by butt jointing using the special stacking tool in Figure 4.

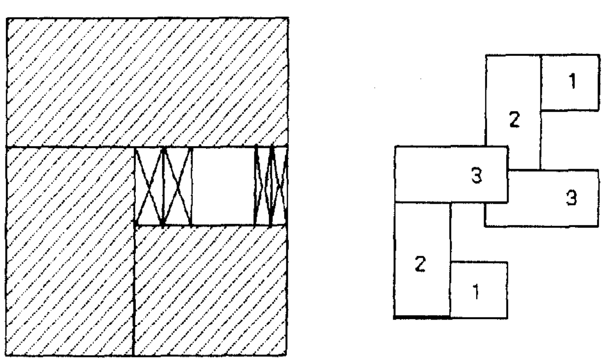

FIG. 3 Magnet lamination construction.

This tool allows the laminations to be stacked so that blocks of approximately 23 cm length are made. Each block is formed at a different angle to the stacking direction, so approximating the arc of a curved magnet (see Figure 1). During this process the lamination pieces are held onto the tool by an electromagnet inside the gap former and a final gap tolerance of 0.1 mm is obtained.

The assembled block is then clamped at a pressure of 30 kg/cm² by large bolts and placed in an oven and baked for 8 hours at 200°C. The seven blocks that make up the core are then aligned on the final assembly jig (0.1 mm) and glued using a cold setting araldite.

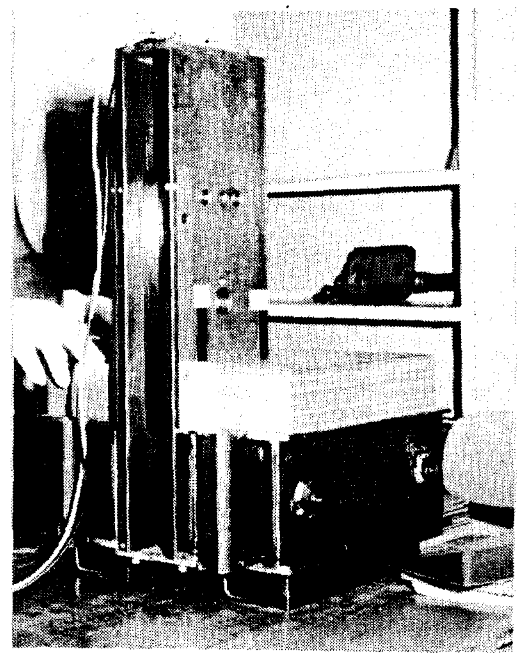

FIG. 4 Lamination stacking tool.

Coil

A two turn coil is chosen to keep the peak current below 40 kA. The 10 mm thick by 1.7 m long OFHC copper conductors with 1 mm of fibre glass insulation and Redox 213 resin between them, are placed, sandwich fashion, into a coil forming tool. The tool, Figure 5, is heated electrically with a water jacket to 120°C whilst applying an even pressure of 6 kg/cm². After curing, the septum blade is tapered down to 12 mm at one end. The conductor pair is then curved in a bending tool to the radius of the magnet core. Finally, the 20 mm return conductors are completely insulated in a similar way and curved to match the septum blade.

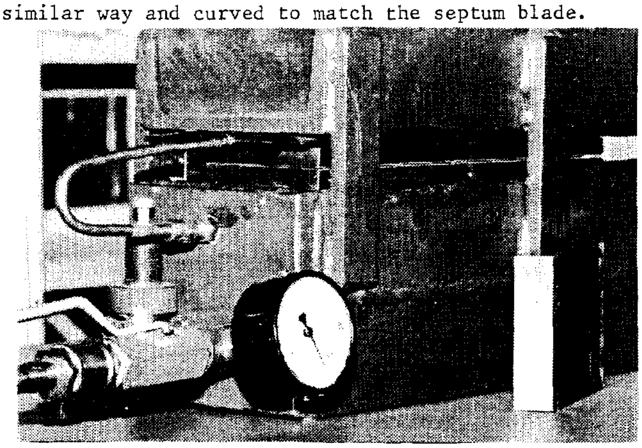

FIG. 5 Coil forming tool.

At the working field of 1 T, a total magnetic force of about 6 tons is exerted on the septum blade. The coil is held in position by the combined action of tapered septum conductor edges and tapered 0.5 mm glass fibre wedges. These wedges, placed along the magnet length, are held by friction between the conductors and the pole faces and prevent the septum from blowing out. They also provide the coil to core insulation along the septum length and transfer heat between the coil and the cooled core.

To help to prevent these wedges from moving out under extreme conditions an insulated 2 mm thick mumetal screen is placed in front of the septum blade. At the same time this reduces the stray field.

The return conductors are glued directly to the rear face of the core gap. The electrical end connections between septum and return conductors use copper bridging pieces with provision for a low inductance stripline connection on the magnet rear side.

Final Assembly

The final assembly of the septum into the magnet gap requires the pole pieces to be moved apart slightly, using a stainless steel envelope pressurised from a 40 bars water system. The septum and the fibre glass wedges are then inserted. When the pressure is released a compressive force of >2000 N/cm is present on the fibre glass wedges. The pulsed magnetic force during operation is about 400 N/cm, hence a friction coefficient >0.18 is sufficient to retain the blade under normal conditions. The septum blade can be easily removed by applying a small inward force at its centre.

The completely assembled magnet with its lifting frame attached is shown in Figure 6.

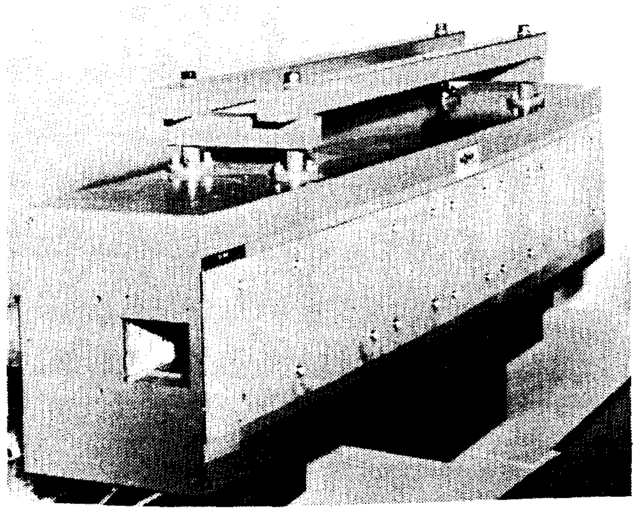

FIG. 6 Completely assembled septum magnet.

Measurements

A prototype magnet has been constructed and tested in the laboratory for about 10^5 pulses with peak currents up to 34 kA. When the final power supply is completed the magnet will be tested with pulses of 40 kA.

Preliminary magnetic measurements have been made and compared, where possible, with the computer field calculations using MAGNET and TOSCA codes.

The magnet has an ideal geometry with very small clearance between the coil and pole faces. The use of a high permiability steel, the absence of cooling channels inside the conductors and a mumetal screen minimise the stray field [5]. The good agreement between measured and calculated fields is summarised in Table 2 as percentages of the central field.

Table 2
Magnet Measurements

Parameter	Measured Values	MAGNET Values	TOSCA Values
Stray Field at 10 mm from septum with no screen	0.89 %	0.35 %	-
Stray Field at 10 mm with 2 mm screen	0.1 %	-	0.089 %
End Field at 20 mm from magnet	0.063 %	-	0.076%
Variation over gap (x) dBy/B	0.25 %	0.35 %	0.18%
Longitudinal Variation (z) dBy/B	1.0 %	-	-
Magnetic Length	1.675 m	-	1.654 m

All measurements have been made on the median plane using calibrated coils connected, directly to a computer controlled digital measuring system [6].

Because the magnet is curved the effective stray field has to be integrated over the magnet length, along the circulating beam path.

The magnetic length has been determined from two integrated field measurements in the gap using a 1.3 m long coil on the central axis. Since the magnet is 1.7 m long the coil had to be accurately positioned from the physical centre to extend outwards successively at each end. The two values were summed and knowing the centre gap field value the magnetic length was then obtained within an accuracy of 1%.

Conclusion

With the limited pulse testing of the magnet to date, the performance comes up to expectations, with no major problems. The electrical and magnetic measurements are to continue at currents up to 40 kAmps so that the reliability and performance can be further assessed and a final magnet constructed for the machine.

Acknowledgement

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References

[1] "Design Study of an Antiproton Collector for the Antiproton Accumulator (ACOL)", CERN 83-10.
[2] A.H. Sullivan, "Shielding for Acol", CERN PS/AA/ACOL 84-23.
[3] P. Pearce, "Calculations on Injection and Ejection Septa for ACOL", CERN/PS/BT 84-1.
[4] C.D. Johnson, S. Maury, T.R. Sherwood, A. Sullivan, "Injection into the new CERN antiproton ring". These proceedings.
[5] A.J.T. Holmes, "Calculation and Optimization of Stray Fields of Septum Dipole Magnets", CERN 75-17.
[6] H. Dose, "Integrated Measuring System", CERN/PS/BT 83-4.