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DC SEPTUM MAGNETS FOR THE DAMPING RINGS OF THE SLC SLAC LINEAR COLLIDER*

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ABSTRACT

The injection/extraction systems of the 1.21 GeV SLC damping rings[1,2] uses four pairs of water cooled septum magnets. Each pair consists of a thin-septum, low-field (3 mm, 3 kilogauss) magnet plus a thick-septum, high-field (12 mm, 8 kilogauss) model. In the latest design cooling reliability was improved by using stainless-steel tubing imbedded in the copper. The operating current in each is 2,600 amperes, at a density of up to 120 amperes per mm^2. Plasma-sprayed alumina is used to provide electrical insulation. The magnet system is compatible with 10^{-9} torr ultra-high vacuum. The magnet design, fabrication, and measurements are described. The principal parameters are:

Magnet	Septum mm	B kG	GAP mm	L Arc M	⊖ Bend O	I KA	V
S-1	3	3.1	10	0.39	1.7	2.6	2.3
S-2	12	7.7	7.88	0.751	8.4	2.6	2.3

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INTRODUCTION

The two injection systems and the two extraction systems of both damping rings in the Stanford Linear Collider complex use virtually identical beam trajectories, and all operate at the same beam energy. Thus the four systems can use identical components. Each utilizes two d.c. septum magnets in tandem in a ~ two meter straight section (Fig. 1).

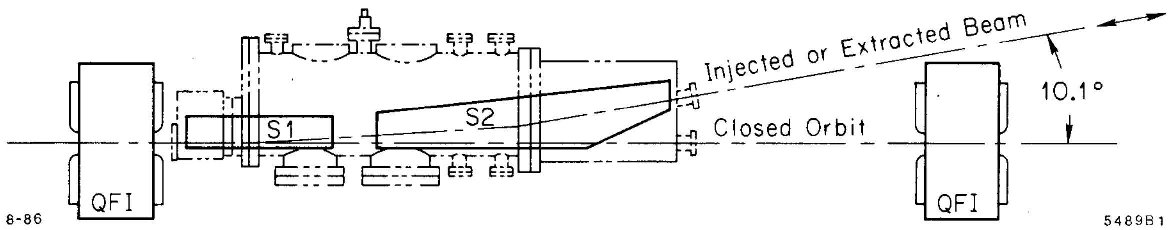

Fig. 1.

DC septum magnets were chosen, rather than pulsed septum magnets for stability reasons. It was judged to be easier to cool a dc magnet then to produce a pulsed power supply regulated to 10^{-5}. The required pulse-to-pulse reproducibility in total deflection angle of the extracted beam to be better than 10^{-5}. Each extracted beam is deflected about 7 milliradions by a kicker magnet into the thin-septum, low-field (0.3 cm, 3 kilogauss) magnet (S-1), which deflects the beam another 1.7 degrees so that it enters the second septum magnet (S-2). S-2 is a thick-septum, high-field (12 mm, 7.7 kilogauss) magnet which deflects the beam another 8.4°, which is sufficient to allow the extracted beam to clear the downstream quadrupole. This trajectory is illustrated in Fig. 2.

This paper describes the final design of the two septum magnets. The initial design gave the required field levels, but was plagued with frequent clogging of the water-cooling tubes. An improved design has been developed, built, and installed in the two damping rings.

The four injection/extraction systems are identical, except for mirror symmetry. Each magnet assembly was built so that it could be conveniently rolled by 180°, thus reversing its symmetry and allowing each to function in any of the four systems.

THE SLC DAMPING RING EXTRACTION GEOMETRY

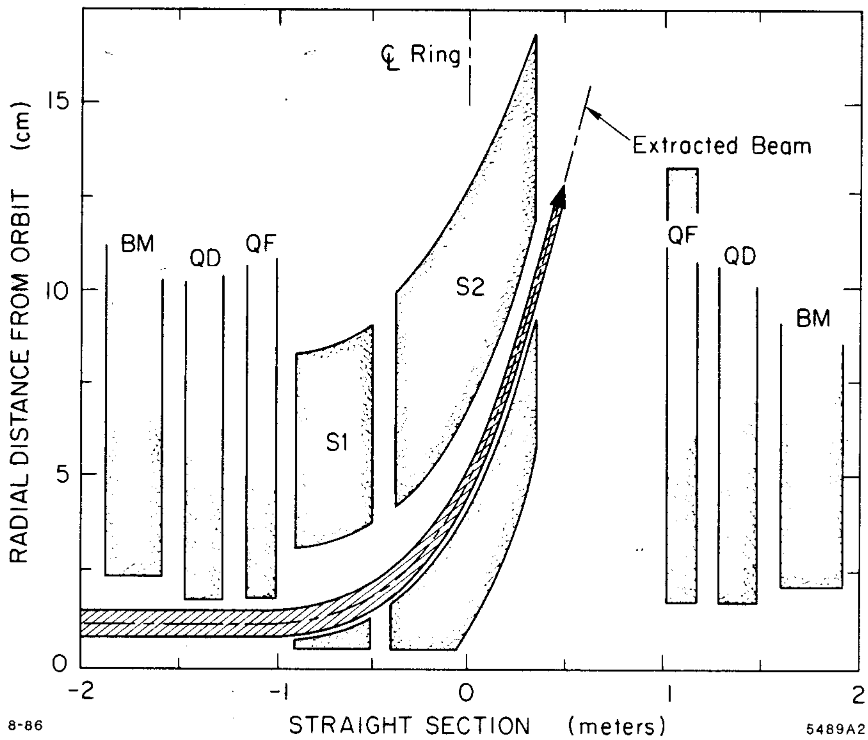

Fig. 2.

GENERAL MAGNET CONSTRUCTION

Each C shaped magnet consists of two 10–15 micron halves of solid 1010 type steel bolted together. The surface of the steel is plated with electroless Nickel to make the surface corrosion resistant. The two magnets S1 and S2 are kept together with solid stainless steel bridges.

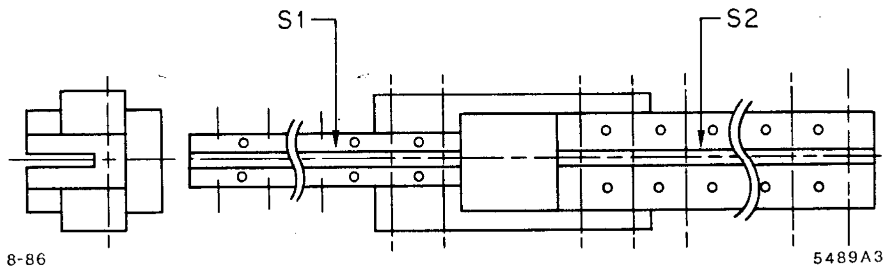

Fig. 3.

Septum S1 contains one copper coil which is cooled by two parallel cooling tubes (Fig. 4).

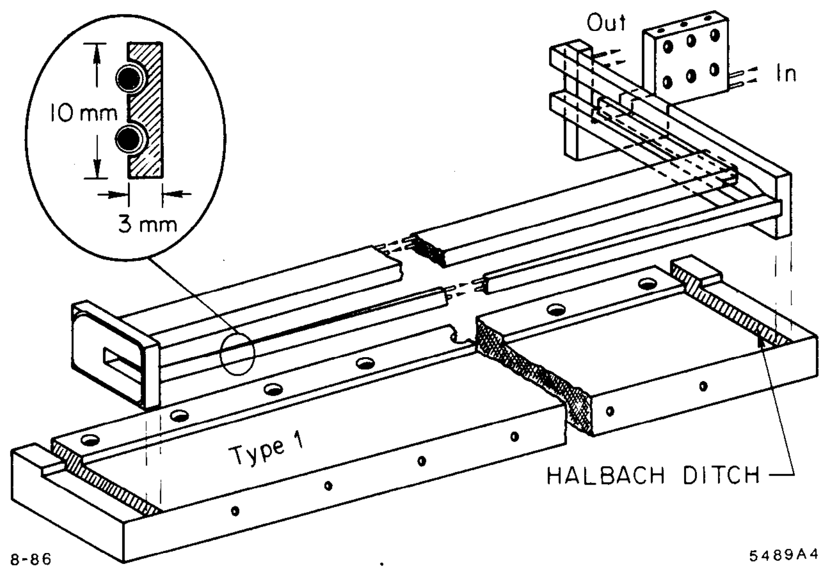

Fig. 4.

The Halbach Ditches reduced the stray field in longitudinal direction. Figure 8 illustrates that the maximum field in longitudinal direction at a given value is reached after 3 inches from the pole tip.

Magnet S2 carries two coils. Each coil is cooled by one cooling tube (Photograph). In every case, the cooling tube has no joints within the vacuum envelope. The photograph shows two magnet halves and the coils just before the assembly.

Magnets S1 and S2 are electrically connected in series, but the cooling is arranged in four parallel circuits, two in each magnet.

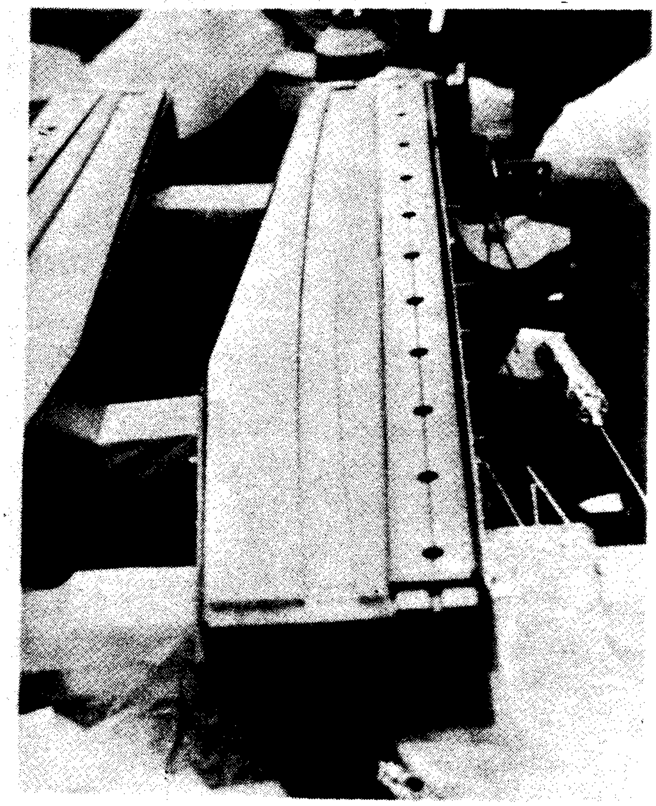

Fig. 5.

COOLING

The OFHC copper conductors have a non-uniform cross-section, so where possible a large cross-section was obtained to reduce the total coil resistance. The individual parts are brazed together, along with the embedded cooling tubes. The OD of the stainless steel cooling tubes is copper plated prior to the brazing. Special care was taken to avoid nicks or dents in the cooling tubes throughout the sequence of fabrication and final assembly. After the coils were brazed together the voltage drop across each braze joint was measured to detect possible imperfect braze joints. The cross-section of the current sheet allows for two cooling tubes, size 3/32 OD .015 wall thickness. Stainless steel tubes were choosen because the buildup of copper oxide is far less likely to happen, then in the prototype used copper tubing. To determine the real limits of the Septum cooling ability, a test was performed under similar working conditions as in the Septum operation. The results of the test indicates that a heat transfer density of 300 w/cm^2 is possible in the coils. The real limit is reached when the outlet temperature reaches the boiling temperature at the pressure of the return line. The maximum current density in septum #1, which occurs in the current sheet, is calculated as 100 w/cm^2 and well below 300 w/cm^2. Under working conditions typical values for pressure, temperature, and flow rates are:

	S1 and S2	S1	S2
Inlet Pressure	16 ATM		
Outlet Pressure	3 ATM		
Inlet Temperature	25°C		
Outlet Temperature		44°	50°
*Flow Rate L/Minute		0.8	0.7

Flow rates may vary a little for each septum cooling circuit depending on the resistance of each circuit. Full-flow deionizers and 1 micron filters have been installed to minimize contamination of the narrow cooling tubes. To minimize the amount of water which could enter the vacuum system in the case of a water leak, solenoid valves are installed in the water supply and return. They will close within 10 milliseconds when triggered by a vacuum switch in the case of a water leak inside the vacuum enclosure.

ELECTRICAL INSULATION OF THE CONDUCTOR

Various inorganic insulation techniques have been reviewed and tested. Amongst them Ceramic Enamel, a well known process, showed promising results on test samples. But during the process of enamelling the real size sample, the variable cross-section caused non-uniform temperatures along the sample and thus a non-consistent coating. For the right application the process of Ceramic Enamel is certainly worthwhile to be looked at! A technique called "plasma spray" was selected. Aluminum oxide powder, injected under high pressure in a plasma of nearly 10000°C will fuse onto the copper surface. To improve the bonding, beat blast to enlarge the surface and a so called ground coating of Copper-Aluminum alloy plasma sprayed first to the surface (thickness ~50 micron). Hereafter the $AL_2 0_3$ coating was sprayed on. Each step in the process was carefully monitored to ensure an evenly thick coating. After a functional test, the conductor + coating was baked in a hydrogen furnace at 600°C to ensure the vacuum integrity. One can imagine that any imperfections in the coating will be visible after this process! The quality of the electrical insulation was constantly followed through the whole process of fabrication. The magnets S1 and S2 (tandem) are adjustable supported in x and y direction inside the vacuum tank.

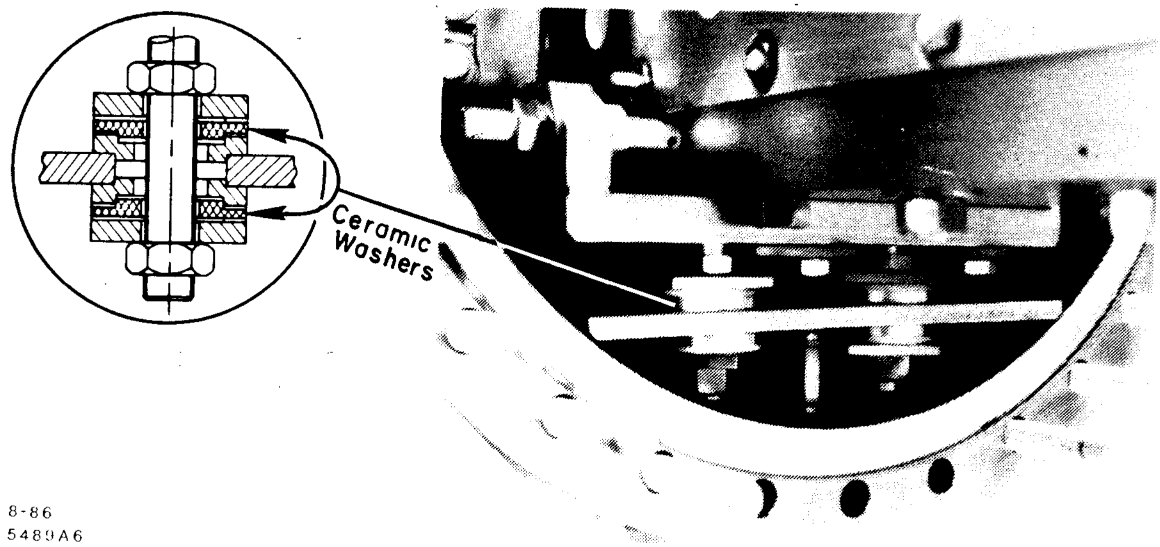

Fig. 6.

Ceramic washers provide electrical insulation between the magnets and the vacuum tank, for additional ground fault protection. A smooth transition, between the ring vacuum system and the septum magnets was implemented, to lower the impedance to the circulating beam.

Two water-cooled feedthroughs conduct the current of 2600 Amps inside the vacuum envelope. Since the supports allow for x and y adjustments, the connection between the high current water cooled-feedthroughs, and the magnet coils, must allow for the same adjustments in x and y direction.

The connection consists of two slotted square blocks and two clamping plates. The clamping plates consist of two parts, one the copper part to conduct the current and a stainless steel part, to provide sufficient stiffness for the clamping. Within limits of ±6 mm the clamp will find the ideal position. Figure 7 is showing a possible offset.

MAGNETIC MEASUREMENTS (David Jensen)

The magnetic measurements were made in two separate setups. The first was a hall probe (F.W. Bell 811A high linearity probe) measurement along the deflected beam line inside both of the magnets that make up the septum. These measurements consisted of the vertical component of B measured at many points along the beam line, and were numerically summed to find the integral of B.dL at a particular excitation current, I main. In this measurement, the trim current, I trim, was set to zero.

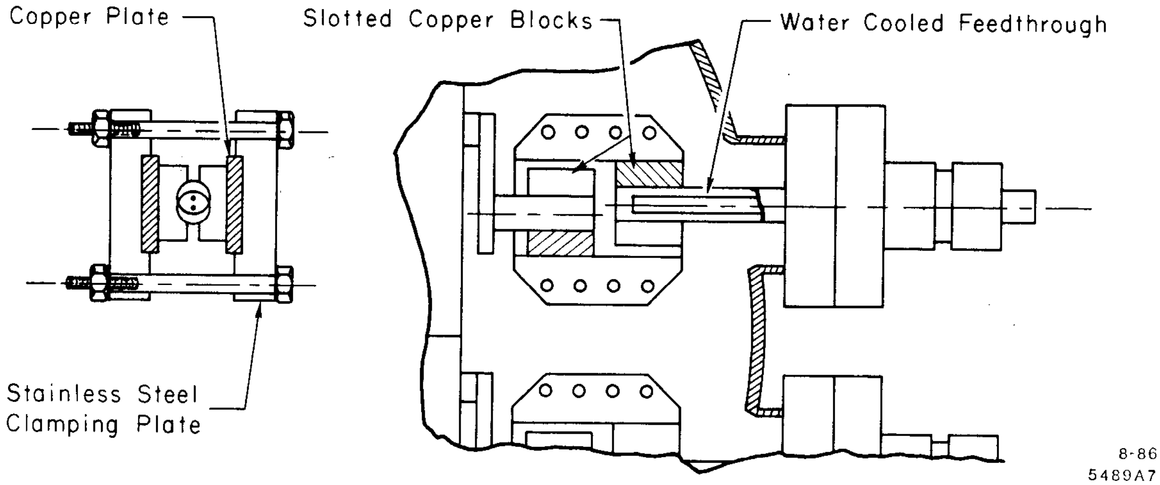

Fig. 7.

The second measurement setup consisted of a long stretched wire centered on the undeflected beam line, which runs along the outside of the septum. The Itrim setting necessary to reduce the integral of B.dL to zero along the undeflected beam line was determined. Since current in the trim windings increases the induction in the deflected beam channel, an iterative process of measurements was used to determine the correct settings of Imain and Itrim to produce the correct integral of induction over length in the deflected beam channel while at the same time reducing the induction in the undeflected beam line to a negligible value.

Figure 8 Halbach Ditches reduced the stray field in longitudinal direction.

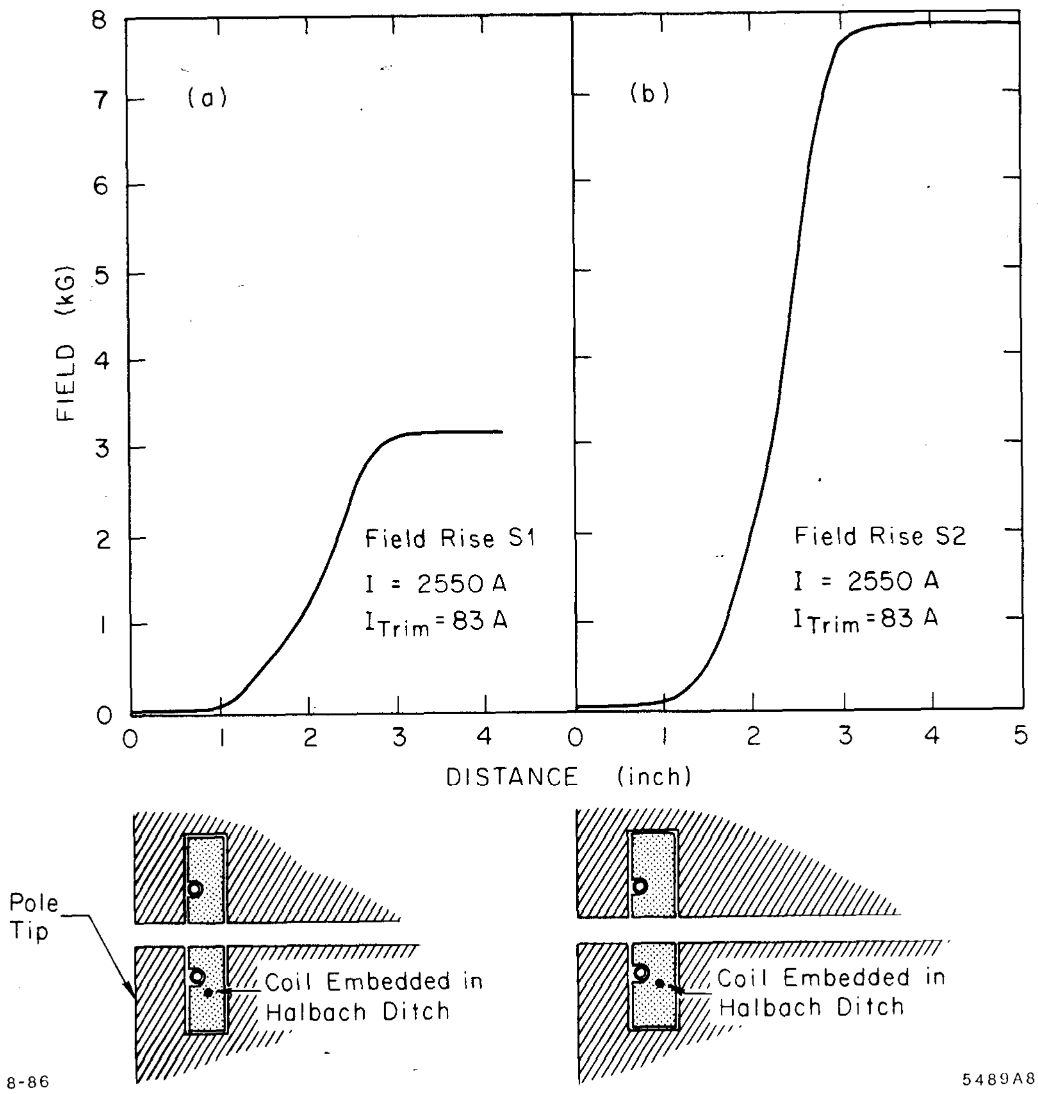

Fig. 8.

VACUUM REQUIREMENTS

Since the septum vacuum has to be comparable with the ring vacuum system 10^{-9} torr, parts were fabricated according to SLAC specs FP-202-631-14. Cleaning and assembly according to SLAC specs TN-73-13.

A 250°C bake of the pre-assembled septum in the tank was performed. The entire tank was wrapped with heater tape and thermal insulation blankets. After the pressure reached equilibrium, the bake out was terminated and after a cool-down time of $\sim$ 2 days a pressure of $5 - 10^{-9}$ torr was reached. Then, the tank was filled with nitrogen and opened to connect power, water, and trim coils. After this operation, a mild bake-out of 100°C was necessary to obtain the required pressure.

ACKNOWLEDGEMENTS

The preliminary design was done by Egon Hoyer at Lawrence Berkeley Laboratory. Under direction of Lawrence Karvonen two prototype septa were designed and built at SLAC.

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Excellent skills were demonstrated during the mechanical assembly by Ralph Thomson, Light Assembly Shop.

Special thanks for Artem Kulikov for invaluable help to overcome critical areas, concerning cooling and electrical insulation of the septa.

REFERENCES

1. G.E. Fischer and J.M. Peterson, SLAC Collider Note CN-125, "Specifications for Septum Magnets S-1 and S-2 in SLC Damping Ring," October 1981, unpublished.
2. J.M. Peterson, SLAC Collider Note CN-126, R-1 "The Injection and Extraction Systems of the Damping Ring," March 1981, unpublished.