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THE ELECTRON DAMPING RING FOR THE SLAC LINEAR COLLIDER*

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Abstract

A second damping ring to store and damp two electron bunches for the SLC project was constructed in 1985 and brought into operation early in 1986. Although generally similar to the damping ring (now used for positrons) constructed earlier[1], there are a number of design improvements and changes.

- The dipole magnetic field was raised to 2.1 T to improve damping.
- Sextupole fields were provided by separate permanent magnets, rather than being incorporated in the dipoles.
- The vacuum chambers, including the beam position monitors, were re-designed for lower longitudinal impedance.
- A new kicker was developed by Fermilab to handle the two electron bunches.
- Improvements were made to the dc septum magnet design.

Several of the features are described in detail elsewhere. Where possible, the improvements were incorporated in an upgrade of the earlier damping ring.

Introduction

The proposal to build the SLAC Linear Collider (SLC), published in 1984,[2] envisaged two damping rings near the injector end of the 2-mile-long accelerator. In normal SLC operation, both rings (Fig. 1) store two bunches—positrons in the south damping ring (SDR) and electrons in the north damping ring (NDR). For each SLC pulse, one positron bunch and two electron bunches are extracted and accelerated and then are replaced from the positron source return line and the injector, respectively. The storage times, at 180 pps, are then 11.11 ms for positrons and 5.56 ms for electrons in a ring of 35.27-m circumference. The damping time is 3.06 ms, and the output emittance for both 1.21-GeV electrons and positrons is 2.9×10^{-5} m-rad, with a design intensity of 5×10^{10} particles per bunch. For a comprehensive report on the damping rings, see Ref. [3].

Magnet Design

The original bending magnets were wedge-shaped, and had sextupoles designed into the pole

ends[2]. To increase the sextupole strength to give a higher natural chromaticity, separate permanent magnet sextupoles were designed, built, and measured at SLAC [4][5]. The dipoles, still providing 9° bend each, were re-designed to increase the maximum field from 19.7 to 20.6 kG (which decreases the damping time proportionally to the field, B⁻²). The pole configuration is rectangular, with an integral of 0.65 m at the operating current. A comparison of measured fringe field with TOSCA calculation is given in Ref [6]. The dipole characteristics are listed in Table 1. The arrangement of the dipole, with a permanent magnet sextupole shown at only one end, can be seen in Fig. 2. The dipoles are trimmed to give the same field integral $\pm 0.08\%$ using shims behind the pole ends; trim coils provide for finer tuning and horizontal steering. Figure 2 also shows a section of one of the steel-topped concrete girders on which the damping rings and their beam lines were preassembled. This allowed components to be aligned and connected—including their vacuum systems—while construction of the vaults and installation of services were going on simultaneously.

The original positron SDR dipoles were modified to achieve the same characteristics. The sextupole pole-ends were removable, making the retrofit relatively straightforward.

Quadrupoles

The damping ring lattice is FODO; the focusing (QF) and defocusing (QD) quadrupoles are of different strengths (see Table 2); therefore, the magnets are made as shown in Fig. 3—stacks of laminations 0.635 cm thick are welded together into pole blocks that, in turn, are bolted and doweled into an assembly with the coils. The outside notches behind each pole allow for support (at the bottom) and the setting of an alignment fixture (on the top). Figure 4 shows a focusing quadrupole (split) with the permanent magnet sextupole at the end of the adjacent dipole, the beam position monitor (BPM) inside the quadrupole, and the water-cooling system to remove synchrotron radiation heat from the vacuum enclosure.

All QF's are powered by one power supply and all QD's by another. The "trim" windings in the quadrupoles are connected to provide vertical steering correction; there are some auxiliary windings in independently powered quadrupoles in the injection and extraction straight sections that provide horizontal steering.

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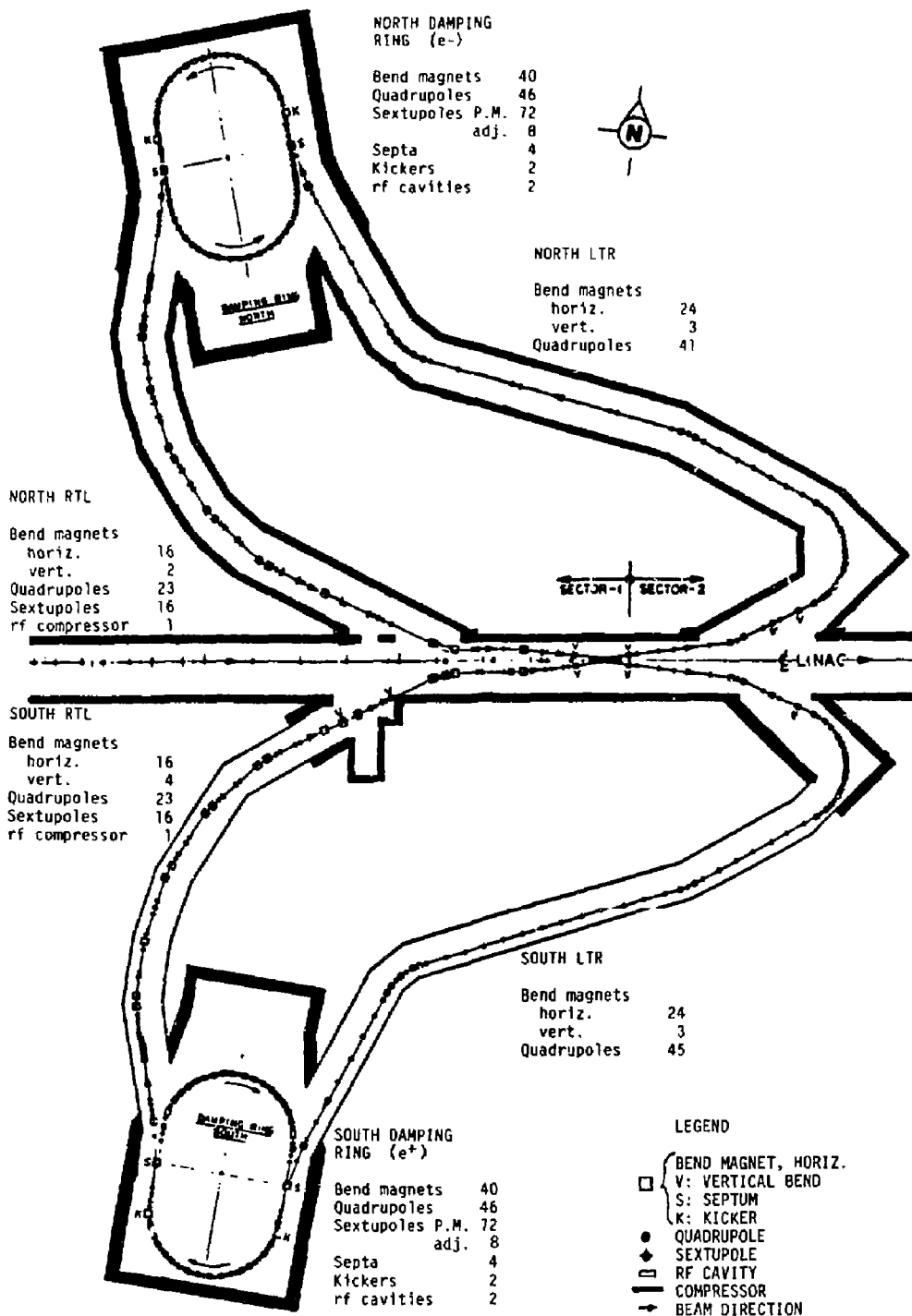
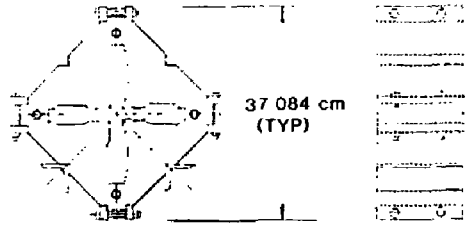


Fig. 1. Layout of north (e-) and south (e+) damping rings.

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TABLE 1 Damping Ring Dipole Magnet	
Maximum field	20.6 kG
Integral field	0.65 T-m
Effective length	30.8 cm
Pole length	29.21 cm
Overall length	40.64 cm
Gap	2.0 cm
Turns per pole	48 T
Design excitation	481 A
Trim coil	82 T
Bend angle	9°



Bore: 2.576 cm

DAMPING RING QUADRUPOLES

Length: "A": QF (focusing) 15.113 cm

Length: "A": QD (defocusing) 8.573 cm

Fig. 3. Quadrupole magnet core construction.



Fig. 2. Damping ring dipole magnet showing vacuum chamber incorporating distributed ion pump and one of two permanent magnet sextupoles.

TABLE 2
Quadrupoles

Focusing (QF)		Defocusing (QD)	
Bore	2.57 cm	Bore	2.57 cm
Core length cm	15.113	Core length cm	8.575 cm
Overall length	19 cm	Overall length	12.55 cm
Turns per pole	34T	Turns per pole	34 T
Operating current	148 T	Operating current	143 A
Gradient	73.8 T/m	Gradient	72.2 T/m
Eff. length	16.56 cm	Eff. length	9.86
Trim turns per pole	76 T	Trim turns per pole	76 T

Vacuum Chamber and BPM

The vacuum system of the damping rings is entirely inorganic and made to standards developed at SLAC for the SPEAR and PEP storage rings—operation is in the 10^{-8} to 10^{-10} torr range. Vacuum chambers in the curved bending magnet sections are subjected to synchrotron radiation and, therefore, are made of low- z aluminum;



Fig. 4. Focusing quadrupole (split) showing BPM and vacuum pipe cooling.

they also incorporate SLAC-built distributed ion pumps[7]. There is an aluminum-to-stainless steel transition at the end of each of these pumps (visible in Fig. 4).

Excessive beam power loss could result from the longitudinal parasitic loss caused by the discontinuities at the ends of the BPM electrodes. A combination of calculation and modeling yielded a design with acceptably low loss [8]. A sketch of the resulting ring BPM, showing the 0.1-mm gap at the free end of the electrode, is given in Fig. 5.

Kickers

While the requirements of the south (positron) ring kickers are to provide a jitter-free pulse with fast rise and fall times (the bunch rotation period is 116 ns) to inject or extract single bunches [9], the requirement in the north (electron) ring is to handle two bunches. To meet this need for a relatively long-pulse, fast-rising and fast-falling magnetic kick of 5 mrad, the Fermilab team headed by Quentin Kearns uses a travelling-wave ferrite

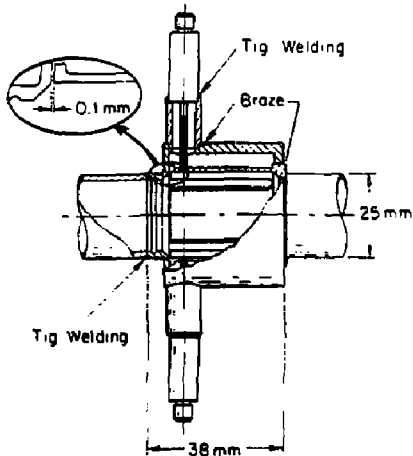


Fig. 5. Low-loss BPM for the damping rings.

magnet of 12.5- Ω characteristic impedance. A pulse-forming line of 70 kV polyethylene cable is pulse-charged and switched by a pair of deuterium thyratrons[10]. A more complete description of the equipment is given in Ref. [11].

Septa

The other injection-extraction components are pairs of dc septum magnets, sharing a common vacuum enclosure and powered in series. Table 3 gives the general parameters of the septa.

TABLE 3
Septum Magnet Data

Bend angle degrees	Septum Width mm	Gap mm	Field kG
1.7	3	10	3.1
8.4	12	7.88	7.7

Both magnets are energized at 2600 A; the power is about 6 kW each. Construction is of OFHC copper, with embedded stainless steel water-cooling tubes. The coil assembly is double-brazed, then insulated with plasma-sprayed alumina. With a maximum current density of 120 A/mm², particular attention is paid to the protection system. Further details are found in Ref. [12].

Acknowledgment

The successful construction and operation of the second Damping Ring at SLAC is a result of the efforts of a great many people, inside and outside SLAC. Some of them can be seen in the photograph of the completed electron ring (Fig. 6).



Fig. 6. Electron damping ring, February 1986.

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