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A PROGRESS REPORT ON THE SLAC LINEAR COLLIDER*

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1. Introduction

The SLAC Linear Collider project (SLC) which began formally in October 1983 is nearing completion. Some systems of the collider have been completed and brought into service, some are being completed this month, and the last systems are scheduled to be finished by the end of November. The project is slightly behind schedule, having originally been scheduled to be complete by the end of September, but progress has been good and no major obstacles now appear to stand in the way of completion.

The main performance specifications of the SLC are shown in Table 1. The second column, labeled "First Year", gives the performance we hope to attain with the collider in its initial form, and the third column, labeled "Nominal" gives our eventual goals — goals which exceed those set forth originally.[1] The principal differences in the physical machine between the two columns are in the repetition rate and the final demagnification. The collider will operate initially at repetition rates up to 120 Hz rather than 180 Hz and the final demagnifying lens system uses iron magnets instead of superconducting magnets

Table 1. Luminosity Specifications
The performance specifications of the SLAC Linear Collider. The second column shows the performance expected from the machine as it is being built, and the third column shows the performance goals eventually sought as the machine is improved.

	First Year	Nominal	Units
Beam Energy	50	50	E(GeV)
Repetition Rate	120$^{(a)}$	180	$f(\mathrm{sec}^{-1})$
Interaction Flux	5×10^{10}	7.2×10^{10}	$N^{\pm}\left(\frac{e^{\pm}}{\mathrm{bunch}}\right)$
Normalized Emittance (at RTL)	3×10^{-5}	3×10^{-5}	$\gamma\epsilon$ (m-rad)
Effective Emittance (at FF)	4.2×10^{-10}	4.2×10^{-10}	$\epsilon_{x,y}$ (m-rad)
Momentum Spread	± 0.2	± 0.2	$\frac{\Delta P}{P}$ (%)
Bunch length (linac)	1.5	1.5	σ_z(mm)
Bunch length (IP)	1.0$^{(b)}$	1.0$^{(b)}$	σ_z(mm)
Final Demagnification	$\times 4^{(c)}$	$\times 5$	
Spot Size (IP)	2.07	1.65	$\sigma_{x,y}$ (μm)
Disruption Parameter	0.34	0.76	D
Pinch Factor	1.14	2.2	H
Luminosity	6.4×10^{29}	6.0×10^{30}	$\mathrm{cm}^{-2}\,\mathrm{sec}^{-1}$

$^{(a)}$Assumes technical contingency exercised initially.
$^{(b)}$Assumes σ_z compression in arcs due to p/z correlation.
$^{(c)}$Assumes conventional iron quadrupoles initially.

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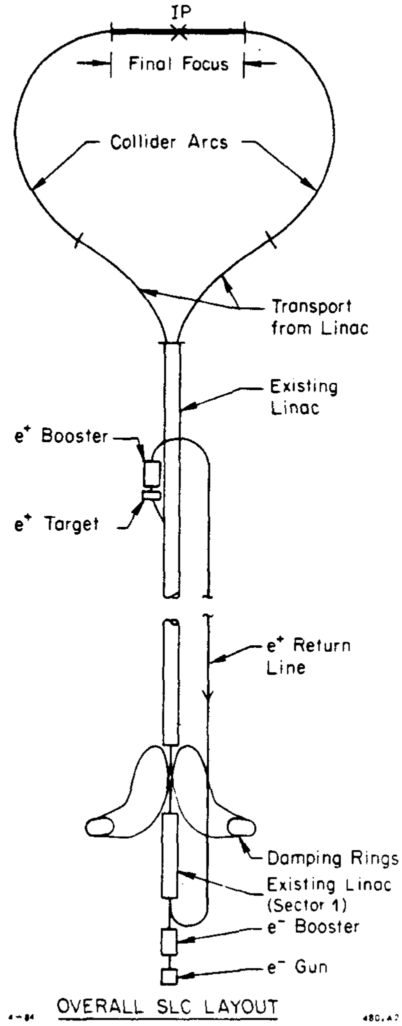

Fig. 1. Schematic layout of the SLC.

with the consequence that the demagnification is less. Even with these reductions in performance, the expected luminosity will yield about 60 Z^0's per hour — a sound basis for a vigorous and fruitful experimental program.

A schematic drawing of the SLC is shown in Fig. 1, which identifies the major systems of the collider, and in the following sections, we shall discuss the status of each system.

2. The Front End

The SLC front end comprises the electron gun and booster and the first sector of the linac. (The linac is organized into 30 sectors.) The purpose of this part of the collider is to produce a pair of electron bunches, spaced apart by about 60 ns; to boost these bunches to an energy of about 200 MeV at the beginning of Sector 1, where a single bunch of 200-MeV positrons (which has been transported from the positron source) is injected about 60 ns behind the trailing electron bunch; and to

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accelerate all three bunches through Sector 1 to an energy of 1.21 GeV. At the end of Sector 1, the three bunches are deflected into the north and south transport lines that lead to the damping rings. At the output of the electron booster, the electrons have an energy of about 50 MeV, a bunchlength of about 2 mm and a normalized emittance $\gamma\epsilon = 15 \times 10^{-5}$ m-rad. (Emittances in this report are areas in phase space divided by π.) In April, 1986, the thermionic gun was displaced 38 deg off the linac axis to permit installation of a polarized photoemitter, also displaced by the same angle in the opposite direction. The gun area is shown in Fig. 2. Testing of the polarized source is planned for later in the year.

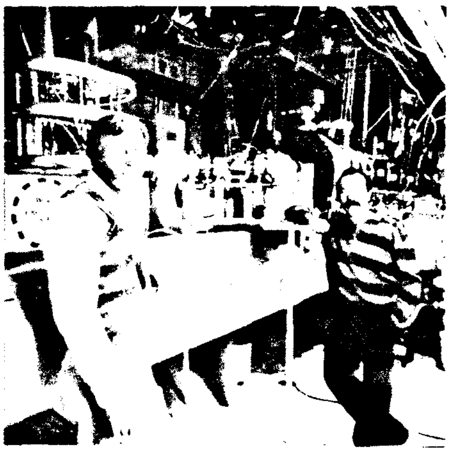

Fig. 2. The SLC gun area. The thermionic emitter is inside the corrugated ceramic bushing to the left of center.

In order to transmit the positrons with their large emittance ($\gamma\epsilon = 1000 \times 10^{-5}$ m-rad) through the front end, a very strong external focusing system, shown in Fig. 3, is required. As early as October 1984, a pair of electron bunches was accelerated through the front end to full energy with bunch populations of 6×10^{10} electrons each and within specified emittance, and the front end has been in regular use since Autumn 1985.

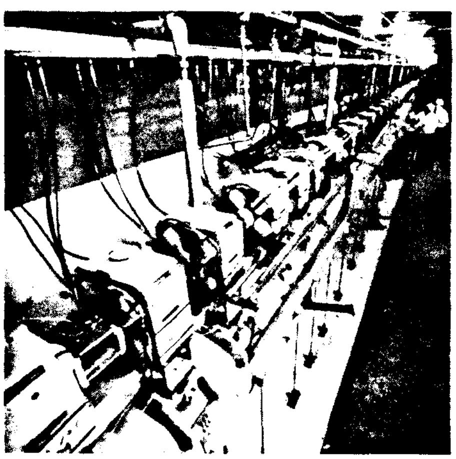

Fig. 3. Focusing system on Sector 1.

3. The Linac

The linac downstream of the damping rings (Sectors 2–30) has a length of 2900 meters and is powered by 229 50–MW klystron tubes. A strong-focusing FODO lattice of 282 quadrupoles, together with beam position monitors and pairs of steering dipoles associated with each quadrupole, constitute the SLC beam focusing and guidance system. This system is needed to prevent emittance growth due to wake field effects. More details of this will be presented by the next speaker.[2] Figure 4 shows one station of the system. At this time all of the magnets have been constructed as have the beam position monitors. All of the dipoles have been installed, and 235 of the quadrupoles have been installed. All of the dipoles are operational and the quadrupoles are being commissioned now.

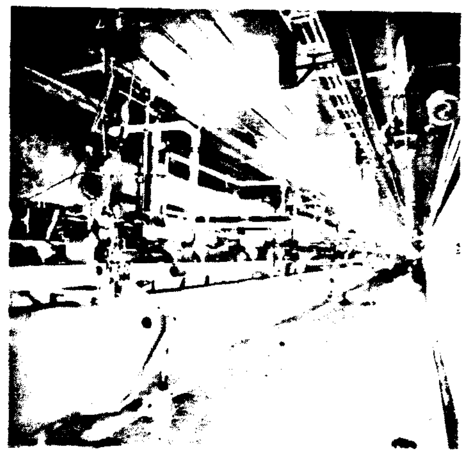

Fig. 4. The linac beam focusing and guidance system. At the left of the photograph is a quadrupole magnet and the associated horizontal and vertical steering dipoles. A beam position monitor is imbedded in the bore of the quadrupole. The positron return line can be seen at the upper right.

The accelerating gradient of the linac has had to be raised to accelerate SLC beams to 50 GeV. This is being accomplished by replacing the klystrons with new 50-MW (nominal) klystrons of SLAC design and manufacture. They are shown in Fig. 5. We have found that these klystrons operate better at 60 MW to 70 MW with a shorter pulse (3.6 μsec) than they do at their original design power of 50 MW with a longer pulse. There are about 150 of these new tubes in service now on the linac, and they are being manufactured at the rate of 11 starts per month with a yield of between 70% to 80%.

For these more powerful tubes, the SLAC modulators and their associated systems are being rebuilt. More details on this program are reported to the Conference in another paper.[3]

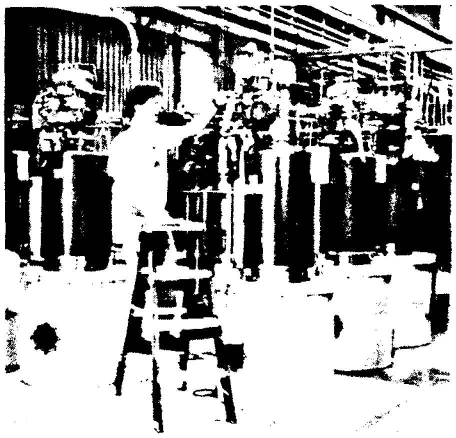

Fig. 5. SLC 50-MW klystrons mounted in their oil-filled pulse-transformer tanks and surrounded by their focusing electromagnets. The collector is upright and shielded in lead and the double-window output circuit is next to it.

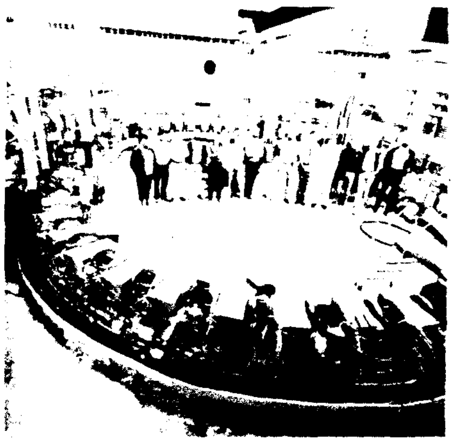

Fig. 6. The north damping ring in its underground vault.

4. Damping Rings

The damping rings are located 1/30th of the way down the linac at the end of Sector 1. The north damping ring (to the left in Fig. 1) is being commissioned now. A photograph of it is shown in Fig. 6. The south damping ring has been rebuilt in part and will be commissioned later this month. It was originally built as a research and development vehicle, and it was operated in 1984 and 1985.[4] Its performance revealed several weaknesses in the original design that have been corrected in the present design. For example, chromaticity correction to combat the head-tail instability was implemented in the original design by shaping the ends of the poles of the dipole magnets to produce local sextupole fields. Since the dipoles are operated at a field of almost 2 Tesla, the pole pieces are somewhat saturated, and the precise field shape desired is difficult to achieve in practice. Unwanted higher-order fields tend to arise. In the present design, the poles are optimized to produce the highest dipole field — and with it the smallest bending radius and the fastest damping time — and the sextupole fields are produced by compact permanent-magnet sextupoles.

5. Positron Source[5]

The positron source system is shown schematically in Fig. 7. When a positron bunch and an electron bunch are launched into the linac from the damping rings to be accelerated and collided at the final focus, a third bunch (electrons) is also launched, trailing them. When the third bunch reaches the two-thirds point of the linac, a fast kicker magnet deflects it out of the linac into a 33-GeV extraction line which transports it to a heavy metal target where it produces an electromagnetic shower. Positrons are collected from the shower by solenoids and a high-gradient accelerator.[6] They are accelerated to about 200 MeV by a short linac and sent *via* an isochronous beam transport line in the main linac housing back to Sector 1 of the linac. The extraction line and a portion of the positron return line are shown in Fig. 8. The last parts of this system are being installed now, and commissioning has started.

6. The SLC Arcs

The SLC arcs are composed, for the most part, of very-strong-focusing alternating gradient magnets with an aperture of only about a centimeter. In 50-GeV operation, these magnets produce a bending field of about 0.6 Tesla and a gradient of 0.7 Tesla/cm ($n \approx 33{,}000$). The strength of focusing

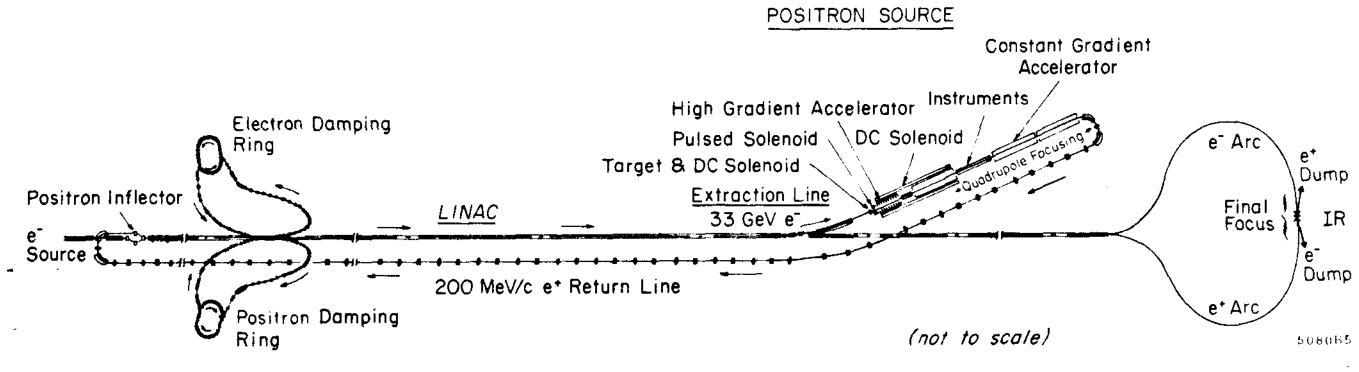

Fig. 7. Schematic diagram of the positron source system.

Fig. 8. Photograph showing the 33-GeV extraction line and, above it, a portion of the 200-MeV positron return line.

is dictated by the need to suppress, as much as possible, the growth of beam emittance due to quantum fluctuations in the synchrotron radiation. Each individual magnet core is about 2.5 m long, and all of the cores of an arc are excited by a single turn of conductor above and a single turn below the gap. The turns are formed by square aluminum bars measuring about 5 cm on a side. There are, in addition, trim windings on each core. Figure 9 is a photograph of a portion of the south arc in an early stage of alignment. The cores are mounted with their back legs alternately on the inside and the outside of the orbit. A pair of the aluminum bus bars can be seen in the center; the opposing pair is hidden.

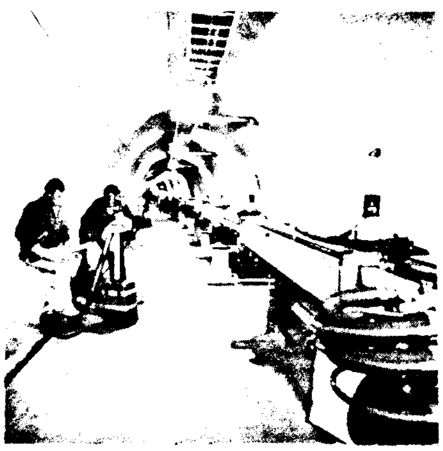

Fig. 9. A portion of the south arc in the process of alignment.

7. Final Focus

All of the 905 alternating gradient magnets have been built, measured, fitted with their vacuum chambers and assigned to their locations in the ring. The AG magnets for the south arc are all installed and 50% of those for the north arc are installed. Beam position monitors, which span between the AG magnets, have all been fabricated and are being installed now. The arcs are scheduled to be ready for beam tests by October.

The final focus system, filling the last 500 feet of tunnel on either side of the interaction point, contains the elements that demagnify the beams to a final spot size of about 2 μm, steer them into collision, and transport the disrupted outgoing beams to beam dumps. This system of the SLC, being the last to receive beams, has been the last to reach the fabrication stage. At this time, most of the shop facilities at SLAC — mechanical, electronics and vacuum — are busy making parts for the final focus system. Most of the magnets and other major components are finished and are awaiting final calibration and mounting on their support girders. The final mounting of magnets with vacuum chambers and diagnostic instruments is expected to get under way in about three weeks. As each girder is finished, it will be transported to the tunnel and installed.

In the tunnels and the experimental hall, preparations are being made now to facilitate the installation of the girder assemblies. The cable trays and plumbing in the tunnels are finished, and the installation of cables is proceeding. The first racks of control electronics, fully wired and tested, will be installed in the experimental hall in about two weeks.

In parallel with the construction activities, the final focus group has been developing instruments and procedures for measuring the emittance and dispersion of the beams, guiding them into collision, and diagnosing problems. Of particular interest are devices to detect the beamstrahlung radiation emitted by each bunch as it passes the opposing bunch. This previously unobserved phenomenon is expected to provide a powerful diagnostic signal to guide us in tuning the machine for maximum luminosity.

Looking ahead, design work has already started on high-gradient superconducting quadrupole magnets to replace the final triplet lens. Prototype superconducting quadrupoles, built at Fermilab specifically for this application, have been successfully tested and shown to meet the strength and field-quality requirements of the SLC.

8. Conventional Facilities

Figure 10 shows the SLC site in an aerial photograph taken during the underground portion of the construction of the Collider Experimental Hall (CEH) which is the only manifestation of the SLC readily visible from the air. The status

Fig. 10. Aerial photograph of the SLC site taken during the early construction of the Collider Experimental Hall.

of construction of the CEH in May is shown in Fig. 11. The near side of the building houses the counting house, and the concrete pad for the utilities can be seen in the foreground. The first detector to use the SLC will be the venerable but improved Mark II which had seen service at both SPEAR and PEP. It is being installed in the SLC experimental pit now for use next Spring, and Fig. 12 shows the first of its parts being lowered into the pit.

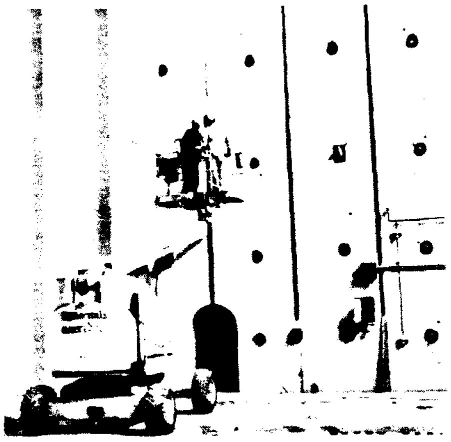

Fig. 11. The Collider Experimental Hall in May 1986.

Acknowledgments

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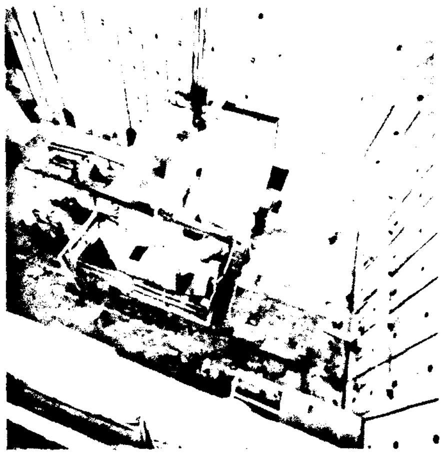

Fig. 12. The first part of the Mark II detector being lowered into the experimental pit.

References

1. B. Richter *et al.*, 11th International Conference on High–Energy Accelerators, Geneva, 1980, p.168, CERN (1980).
2. J. Seeman, these Proceedings.
3. M. Allen *et al.*, these Proceedings.
4. A. Hutton *et al.*, IEEE Trans. Nucl. Sci., NS-32, p.1659 (1985), and L. Rivkin *et al.*, same Transactions, p.2626.
5. H. Hoag, these Proceedings.