

FIRST OPERATION OF THE UPGRADED SLAC A-LINE*

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ABSTRACT

The SLAC A-Line has been upgraded to transport electrons to fixed target experiments in End Station A (ESA) with energies up to 50 GeV. From September through November, 1995, this beam line was commissioned and used to deliver 48.36 GeV polarized electrons to Experiment E-154 at 120 pulses/sec and up to 10^{11} e⁻/pulse. The beam had a full width momentum spread of less than 0.5 percent, and was focused to a small spot ($\sigma = 0.7$ mm) at the target. In this paper we describe the first operational experience with this new beam line.

1 INTRODUCTION

The A-Line, one of the two original beam transport systems at SLAC, was designed some thirty years ago to deliver electron beams from the linac to fixed target experiments in End Station A [1]. As originally configured, the A-Line could transport beams up to a maximum energy of approximately 25 GeV, which was slightly beyond the capability of the linac at that time.

The development of higher-power klystrons and RF pulse compression techniques have more than doubled the beam energy available from the linac. Short-pulse beams of 47 GeV are routinely and reliably produced for colliding beam experiments, and energies up to about 52 GeV are within reach. These beams significantly expand the kinematic region open to exploration in fixed-target experiments. In addition, new techniques for producing polarized beams and polarized targets have opened new possibilities for exploring the spin structure of both protons and neutrons. Experiment E-154, designed to measure the neutron spin structure function, required a longitudinally polarized electron beam with as high an energy as could be reliably delivered.

2 THE ORIGINAL A-LINE

The A-Line, which was designed to function as a first-order energy-defining spectrometer as well as a transport system, guides the beam through a total bend angle of 24.5 degrees. The first 0.5 degree bend was originally provided by a set of five pulsed magnets which offered the option of directing beam pulses down any one of four beam lines on a pulse-by-pulse switching basis. The next 24 degrees were provided by eight large conventional dipole magnets, each three meters long, consisting of

water-cooled copper coils on solid iron cores [1]. A quadrupole doublet upstream of the dipoles brought the beam approximately to a focus at a high-dispersion point midway along the string of bend magnets and 180 degrees in betatron phase from the pulsed magnets. A high-power adjustable slit at this position was then used to define the desired energy spread. A symmetry quadrupole near the slit restored the dispersion to zero following the last dipole, which was followed by another doublet to vary the spot size and angular divergence at the target. A third doublet was available for added flexibility in manipulating the beam characteristics at the target.

The A-Line upgrade began in 1993 with the replacement of the power supplies and the modernization of the control system. The new power supplies had sufficient capacity to drive the magnets that were anticipated for the 50 GeV design. The control system upgrade involved replacing the original hard-wired controls and diagnostic equipment with new interface electronics for the power supplies, adjustable collimators, and beam position monitors (BPMs). With this new hardware, the powerful control system software developed for the SLC could be used for A-Line running.

Experiment E-154 was successfully carried out between November, 1993, and February, 1994, with a long-pulse (unSLEDed) beam at 29.1 GeV. This was the highest energy that could be transported through the A-Line, as limited by the temperature rise in the bend magnets.

3 THE 50 GEV UPGRADE

The original A-Line was dismantled and removed from the Beam Switchyard in February and March, 1994. Over the course of the following year, the magnets were modified and tested, and new vacuum chambers and special instruments, including a synchrotron light monitor, were fabricated. Many of the original components, including the BPMs, profile monitors, and nearly all the mechanical support structures, were refurbished and incorporated into the new system. Installation of the upgraded beamline was completed during the following year's shutdown period from April through August, 1995.

The positions and angles of the incoming and outgoing beams are the same as in the original 25 GeV configuration, and the two massive high-power collimators, D-10 and SL-10, were left in their original positions. A pair of DC magnets was added to provide the first 0.5 degree bend.

The eight original dipole magnets, along with five identical magnets, were modified to increase their

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strengths by reducing their pole-to-pole gaps from 60 mm to 46 mm. This was done by installing steel shim plates under the pole pieces [2]. This gap was chosen to provide the necessary magnetic strength while maintaining a beam stay-clear of at least three sigma for a 5 GeV beam. One magnet, with characteristics that most closely matched the average of the other twelve, was designated as the reference magnet, and was equipped with a flip coil and powered in series with the beam line magnets.

The magnet coils were originally cooled with low conductivity water (LCW) from a system capable of supplying approximately 12 gallons/minute to each magnet. As part of this project, the plumbing system was upgraded to provide LCW at nearly twice the original pressure, resulting in a pressure drop of approximately 210 psi and a flow of about 20 gallons/minute in each magnet. At 48.36 GeV, the magnet current was 966.7 amps, and the temperature rise was approximately 16° C.

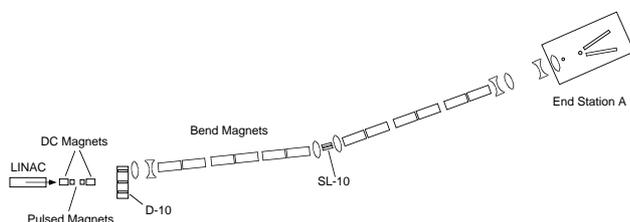


Figure 1. Schematic layout of the upgraded A-Line.

Electrons that are longitudinally polarized in the linac will precess to an orientation at the target that depends on their energy and the total bend angle through the transport line [3]. Synchrotron radiation losses, which are negligible below 30 GeV, result in an energy loss of about one percent at 50 GeV. The energy corresponding to a total spin precession of 15π rotations was achieved with 48.75 GeV at the end of the linac and 48.36 GeV in End Station A. To keep the beam properly steered through the A-Line, it was necessary to adjust the magnet strengths according to a "synchrotron taper" scheme using individual trim windings on each dipole. Computer simulations showed that grouping the magnets in pairs for this purpose gives a smooth enough taper; therefore, the trim windings of each pair of consecutive magnets are powered together in series.

In addition to lowering the average beam energy, the synchrotron radiation enlarges the horizontal beam emittance by a large factor. Calculations had shown that the original optical configuration, which was based on a 2π betatron phase advance, would produce a horizontal spot size several mm wide at the target. Instead, a new configuration was developed using stronger focusing and a second symmetry quadrupole downstream of SL-10 to provide 3π phase advance in the horizontal plane, while retaining 2π phase advance in the vertical. In addition, the last two quadrupoles were moved closer to the target

to provide stronger demagnification in the horizontal plane.

The BPMs in the linac, which provide the signals needed for the steering feedback systems, were designed for very short high-intensity SLC pulses. These BPMs were insensitive to the long pulse beam for this experiment, because the charge is distributed among more than 600 S-band buckets. In order to provide a suitable signal for the BPMs, one short pulse, designated the "diagnostic" or "witness" pulse, was accelerated each second. These witness pulses were produced using a separate laser to illuminate the gun cathode and carried a charge of about 5×10^9 electrons each in about 2 to 5 nsec (about ten S-band buckets). These pulses were unsuitable for the E-154 apparatus because of their high charge density, and so were deflected from the main beam trajectory and dumped at the D-10 dump. This deflection was accomplished using two of the original pulsed magnets, which were upgraded with new pulsed power supplies.

The synchrotron light monitor consisted of a video camera and telescope set to observe light emitted tangentially to the beam at the center of the fifth bending magnet. This apparatus provided the control room staff a non-interfering real-time view of the beam, which proved to be particularly valuable for guiding adjustments of the energy and energy spread.

4 E-154 OPERATIONAL EXPERIENCE

A 45.6 GeV linac beam was delivered to the A-Line (with SL-10 closed) on September 15, 1995, and appeared immediately on a profile monitor screen upstream of the slit. The beam energy was initially set at this reduced energy to allow an assessment of the linac klystron requirements and to check the temperature rise in the magnets. The pulse rate was set to 30 Hz to limit the total beam power and to conserve electric power during the commissioning period. Following a program of tests to verify the proper operation of the safety systems, steering correctors, and diagnostic instruments, and to confirm the adequacy of the radiation shielding, the SL-10 slit was opened and the beam was transported cleanly through the second half of the beamline, through End Station A, and on to Beam Dump East. The instrumentation downstream of SL-10 was checked and calibrated, and the steering feedback loops were commissioned. On September 25, the linac energy was raised to 48.75 GeV, and the program shifted from a machine development effort to E-154 pre-run checkout. On October 4, the pulse rate was raised to 120 Hz for production running.

The beam polarization was measured in End Station A using a Møller polarimeter while the energy was varied over a range of several hundred MeV. The optimum longitudinal polarization was found by lowering the energy about 200 MeV below the original setpoint.

Three factors were found to explain this energy shift. The reference magnet equipped with the flip coil was mechanically supported on a stand different from those of the identical magnets on the beam line. Calculations showed that the steel in the support stands under the beam line magnets increased their field strengths as they became saturated at high energies. This required a correction of 0.45 percent compared to the reference magnet at 48.36 GeV. In addition, corrections were needed for the field that extends beyond the end of the flip coil (0.06%), and for a bias in the flip coil readout electronics. When these effects were included, the flip coil measurements and the polarization measurements gave the same results to within about 40 MeV at the nominal 48.36 GeV.

The SL-10 slit was set for a 1.0 percent full-width energy spread, although the value measured with the synchrotron light monitor was typically less than 0.5 percent full-width, and beam losses on SL-10 were negligible. Other adjustable collimators, which had been provided to remove off-axis particles, proved to be unnecessary and were left fully open.

Table 1. Summary of beam parameters.

Linac:		
Beam energy	48.75	GeV
Pulse rate	120	Hz
Emittance (normalized)	2×10^{-4}	m•rad
Beam to E-154:		
Energy	48.362	GeV
Pulse rate	119	Hz
Charge (typical)	$3 \text{ to } 5 \times 10^{10}$	e ⁻ /pulse
Pulse length	210 to 240	nsec
Polarization	80 to 82	%
Horiz. emittance (norm.)	6×10^{-3}	m•rad
Vert. emittance (norm.)	2×10^{-4}	m•rad
Spot size at target (σ)	0.7×0.7	mm
Witness pulse:		
Pulse rate	1	Hz
Charge (typical)	5×10^9	e ⁻ /pulse
Pulse length (typical)	3	nsec

Lengthening the time distribution of each pulse as much as possible was desirable to maximize the efficiency of the experiment. A beam pulse up to 240 nsec was achieved with a total energy spread $\Delta E/E < 0.5\%$ through the use of a new SLED timing technique [4].

The focused beam size at the target could be estimated by observing the apparent size at a profile monitor screen located 2.1 m upstream of the target. Based on this screen

the final spot size could be adjusted for a minimum of approximately 0.5 mm ($= \sigma_x = \sigma_y$). This is consistent with a (normalized) vertical emittance ϵ_y of 2×10^{-4} m•rad and a horizontal emittance of $\epsilon_x = 6 \times 10^{-3}$ m•rad. Part way through E-154, the spot size was increased to approximately $\sigma_x = \sigma_y = 0.8$ mm, and the charge per pulse was decreased to about 3×10^{10} e⁻/pulse to prolong the life of the polarized helium targets. This spot size change was accomplished simply by changing the magnification with the last four quadrupoles. The beam parameters are summarized in Table 1, and the operational statistics are summarized in Table 2.

Table 2. Operations statistics: 1 Oct - 30 Nov, 1995.

	Hours	Percent
A-Line beam to E-154	1017	69
PEP-II development	56	4
Schedule off	97	7
A-Line tests and tuning	151	10
Unscheduled down	144	10

5 ACKNOWLEDGMENTS

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