SLAC A-LINE UPGRADE TO 50 GeV*

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Abstract

The SLAC A-Line, originally developed to transport electron beams to experiments in End Station A at energies up to 25 GeV, is being upgraded to support a revived fixed target program. In this paper we discuss a proposed new configuration that will transport beams at energies up to 50 GeV. Implementation of this configuration will require the addition of several magnets, the replacement of power supplies, and modifications to the instrumentation. Also discussed are the energy resolving capabilities of the new transport line and design options for minimizing emittance growth.

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 the End Station A experimental hall [1]. As originally configured, the A-Line could transport beams at energies up to approximately 25 GeV, which was slightly above the peak energy capability of the linac at that time. This beam line proved to be an essential component of a spectacularly successful series of experiments. Beginning in the late 1960's, deep-inelastic scattering experiments provided the first conclusive evidence of substructures within the proton, and in the 1970's, a polarized beam was used to demonstrate parity violation in electron scattering, a direct manifestation of the weak nuclear force in electromagnetic interactions.

Now, after a decade of infrequent use, the A-Line is taking on renewed importance. The development of higher-power klystrons and RF pulse compression techniques, and various other improvements 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. Long-pulse beams (1.6 μsec) of up to 32 GeV could be produced, but this has not yet been attempted because of the limitations of the existing transport lines. Such beams could 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. The level of interest and variety of ideas expressed by participants at a SLAC-sponsored workshop [2] earlier this year have led to a series of projects to upgrade the A-Line to support this renewed program.

The Original Design

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 is provided by a set of five pulsed magnets which offer the option of directing beam pulses down any one of several beam lines on a pulse-by-pulse switching basis. The next 24 degrees are provided by two sets of four identical dipole magnets powered in series to bend the beam by 3 degrees each. A quadrupole doublet at the front of the first set of dipoles brings 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 is then used to define the desired energy spread. A symmetry quadrupole near the slit restores the dispersion to zero at the end of the second set of dipoles, which are followed by another doublet to vary the spot size and angular divergence at the target. A third doublet is available for added flexibility in manipulating the beam characteristics at the target.

With this configuration, long-pulse beams (up to 2.1 μsec) have been delivered over an energy range of about 1 to 22 GeV. An energy spread as small as ±0.06 % has been achieved, although ±0.5 % has typically been used when high currents have been desired. The maximum beam energy that could be delivered with the existing hardware is 25.7 GeV, a value limited by the power supply on the 24 degree bend magnet circuit.

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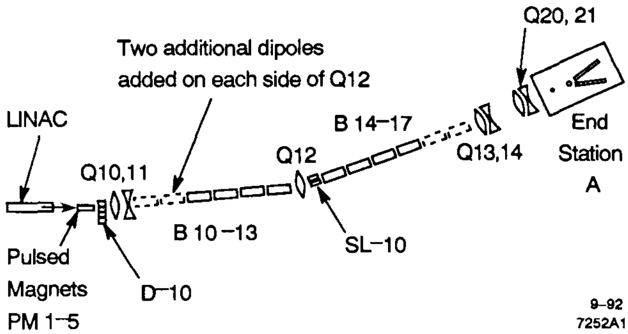

Figure 1. Schematic layout of the A-Line. The additional dipoles required for 50 GeV operation are shown in dashed lines.

The Upgraded A-Line

The new design is based on the same design concept as the original beam line, using as many of the existing components as possible, but constrained by the tunnel and experimental hall layouts to the same 24.5 degree total bend.

The factors considered in choosing a maximum design energy included both the linac capabilities and the space available for additional dipole magnets. In the limit of zero beam current and with all linac klystrons optimally phased, a peak energy of perhaps 56 GeV could be reached. In practice, beam loading effects, imperfect phase control, and the failure rate of klystrons impose a somewhat lower limit. A useful short-pulse energy of about 48 GeV can be delivered at 120 pulses/second at moderate currents, and an energy of about 52 GeV could be expected when all klystrons are operable or when low currents are acceptable.

Also considered were the properties of polarized electrons as they are transported through the 24.5 degree bend. 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. Of particular interest are those energies that correspond to spin orientations parallel to the momentum vector at the target. In transporting through a total angle of 24.5 degrees, the polarization will precess by 180 degrees for each energy increase of 3.237 GeV. Thus, beam energies of special interest are 45.32, 48.55, 51.79, 55.03 GeV, and so forth.

On the basis of on these considerations, a maximum design energy of 51.8 GeV was chosen for the A-Line. This also corresponds to the maximum practical magnetic field that can be reached with the existing magnet design.

Phase I: Power Supplies and Controls

Upgrading of the A-Line will be done in two phases, plus a possible third, interspersed with production runs for several experiments. In the first phase, the power supplies for the magnets will be replaced, and the control system will be upgraded. The new power supplies will be capable of driving the magnets to a point where their field quality becomes degraded by saturation effects. The control system upgrade, which involves replacing the original hard-wired controls and diagnostic equipment with new interface electronics, will put the A-Line under the control of the computer-based system developed for the SLC. In addition, the vacuum pumps and valves will be reconditioned, and new gauges and monitoring facilities will be added.

Following the first phase, the A-Line will be capable of transporting beams with energies up to about 34 GeV. The maximum energy of the transport system will be limited by the saturation of the bend magnets, but it will be sufficient for the highest linac energy available in the long-pulse mode. Energies of particular interest in this range are 25.9, 29.1, and 32.4 GeV, corresponding to longitudinal polarization at the target.

Phase II: Reconfiguration of Magnets

In the proposed second phase, most of the A-Line magnets and other devices will be repositioned along the beam line to make room for four additional dipoles. The four additional dipoles were manufactured along with the original set and are nominally identical to them. Two have been in storage and the other two will be salvaged from the B-Line. With a total of twelve dipoles along the beam line, each will be required to bend the beam through an angle of 2 degrees. Reaching 51.8 GeV, however, will still require about twice the current now needed for 25 GeV, because of the significant magnetic saturation at that excitation.

The positions and angles of the incoming and outgoing beams remain the same as the 25 GeV configuration, and the two massive high-power collimators will be left in their present positions. The first of these is D-10, a water-cooled collimator which follows the pulsed magnets and includes several fixed apertures to define and separate the various beam lines in the beam switchyard, plus a dump to absorb the beam during tune-up procedures. The second is SL-10, the high-power adjustable collimator referred to above, which defines the energy aperture of the A-Line system.

A possible third phase would be a project to upgrade the existing bremsstrahlung photon beam. Dipole magnets and a high-power dump downstream of the bremsstrahlung target can be used to deflect and absorb the electron beam just before it exits the beam switchyard. This project would require reconditioning of the dump dipoles and adding new power supplies to handle the higher beam energy.

Synchrotron Radiation Effects

Synchrotron radiation emitted by the beam in passing through the bend magnets has three effects that must be considered as the beam energy is raised: the energy lost to radiation increases as the fourth power of the beam energy, the emittance grows (and with it the spot size at the target), and the critical energy of the background radiation at the experiment increases.

Power loss (per electron) due to synchrotron radiation in the bend magnets is given by:

$$P = \frac{2}{3}\frac{r_e c}{\left(mc^2\right)^3}\frac{E^4}{\rho}$$

For a total bend angle of 24.5 degrees, the energy loss is:

$$\delta E = 6.02\times10^{-6}\,\frac{E^4}{\rho}$$

where E is the beam energy in GeV, and ρ is the bending radius in meters.

ρ = 57.285 m in the original 8-dipole configuration.

ρ = 85.927 m in the proposed 12-dipole configuration.

For beam energies below 25 GeV, the energy loss is negligible, but at 32 GeV (with the original magnet configuration), the loss is 0.11 GeV, which is comparable to the energy spread of the beam. At 50 GeV (with the proposed new configuration), the energy loss is 0.44 GeV, which is high enough to require special design modifications in order to keep the beam on the nominal trajectory.

Keeping the beam centered through the transport line at high energy can be done by setting the power supplies for the bend magnets and the downstream quadrupoles to the desired final beam energy, but setting the strengths of the quadrupoles upstream of the bends to the appropriate incoming beam energy. The strengths of the dipoles upstream of the slits will be boosted with additional power supplies to supplement the main excitation current.

At 32 GeV, the total power radiated in the dipoles by 5×10^{11} e^-/pulse at 120 pulses/second will be 0.69 kW (19 watts/m). At 51.8 GeV, with 1×10^{11} e^-/pulse at 120 pulses/sec, the total radiated power in the dipoles is 0.95 kW (26 watts/m). Thus, water-cooling will be needed for the vacuum chambers before the full energy and current capabilities can be exploited.

Calculations have shown that horizontal emittance growth is substantial and leads to a beam width at the target that is roughly five times larger at 50 GeV than at 25 GeV. This emittance growth could be suppressed by adding four additional quadrupoles, two on each side of SL-10, interspersed with the dipoles. With the addition of these quadrupoles, the dispersion function becomes smaller by about a factor of two in the region either side of SL-10. This has the effect of reducing the emittance growth at the expense of energy resolution.

The critical energy of the radiation from the last bend magnet is 3.3 MeV for a 50 GeV beam (c.f. 0.4 MeV at 25 GeV). If this poses a problem for future experiments, a "soft bend" magnet could be added. For example, a 3m dipole excited to 0.5 kG could be inserted just downstream of the second quadrupole doublet to provide the last 1 mrad of bend, thereby reducing the critical energy to 82 keV. The radiation from the last of the main bend magnets can then be blocked from reaching End Station A by a collimator in the switchyard.

Acknowledgments

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References

[1] *The Stanford Two-Mile Accelerator*, R.B. Neal, Editor (1968).

[2] *SLAC Workshop on High Energy Electroproduction and Spin Physics*, February 5–8, 1992, SLAC–392 (1992).