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LONG ION CHAMBER SYSTEMS FOR THE SLC*

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ABSTRACT

A Panofsky Long Ion Chamber (PLIC) is essentially a gas-filled coaxial cable, and has been used to protect the Stanford Linear Accelerator from damage caused by its electron beam, and as a sensitive diagnostic tool. This old technology has been updated and has found renewed use in the SLC. PLIC systems have been installed as beam steering aids in most parts of the SLC and are a part of the system that protects the SLC from damage by errant beams in several places.

1. INTRODUCTION

The use of a single coaxial cable as a long ion chamber was initially proposed by Panofsky in 1963.[1] A PLIC is a gas-filled coaxial cable supplied with high voltage, which detects beam losses along a beam line. It is useful as both a beam diagnostic device and as a machine protection element. The PLIC in the Linear Accelerator (linac) is made from 1.63-inch (4.1-cm) diameter RG-319/U coaxial cable. In the accelerator housing, this original PLIC system has protected the disc-loaded waveguide and beam profile monitors from catastrophic beam damage for more than 20 years.[2] Within the past 10 years, stripline beam position monitors were installed and the trip threshold of the PLIC system was reduced and has successfully protected them. Pulses produced by radiation incident to the PLIC cable propagate along the cable, thus providing a time-resolved indication of the location of beam losses and are particularly helpful in establishing and tuning beams. The PLIC is a relatively simple system that provides a real time, easy to interpret, display of beam losses induced by mis-steering and mis-focusing.

2. PLIC IN THE SLC ARCS

It was easy to make the linac system useful for both protection and diagnostics, in that the structures along the linear accelerator housing are nearly uniform in their effects on PLIC sensitivity. A joule of beam dumped in any manner over any short region along the linac will produce nearly the same PLIC signal (roughly 0.06 V). In tests, the signals have been observed to vary by perhaps ±20%, except in a few special places.

In the SLC Arcs, radiation from the thin beam pipes is alternately shadowed to left and right by 8-foot magnets. The back legs of the magnets are effective radiation shields. When electrons strike the beam pipe, most of the resulting electromagnetic shower directed toward the back leg is absorbed. However, the other side of the beam pipe is clearly seen by one PLIC cable. Additionally, since the shower is directed strongly forward, most of the shower will be absorbed in the next magnet downstream. The resulting PLIC sensitivity is not obvious.

Shower calculations were performed[3] using the EGS4 Monte Carlo program[4] to demonstrate how radiation reaches the PLIC detectors. A semi-infinite slab geometry was used for the SLC Arcs, as depicted by the center sketch in Fig. 1. The beam pipe is represented by the dark curved lines that extend from left to right along the general direction of the beam. The figure is purposely distorted so that the total horizontal distance represents 12.5 m, whereas the vertical distance covers about 16 cm on either side of the beam pipe. The curvature corresponds to that of the SLC arcs. The cross-hatched areas represent magnet iron; beam pipe material is aluminum (1-cm diameter, 1-mm thick), and all the other regions are vacuum.

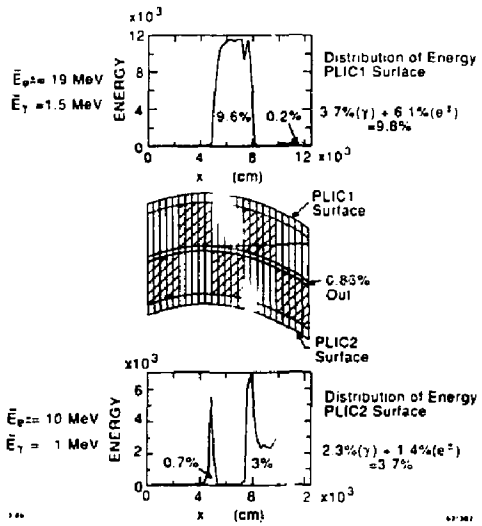

Fig. 1: Energy reaching PLIC surfaces in SLC Arcs.

The circle and ray indicate the location and direction, respectively, of a typical electron beam hitting the SLC beam pipe at an angle of 1 mrad. As stated, most of the energy gets deposited in the magnet iron. However, a small fraction does reach the two PLIC surfaces as indicated in the plots surrounding the geometry sketch—*i.e.*, 9.8% at PLIC1 and 3.7% at PLIC2—and this can provide a reasonable PLIC signal. To determine if there are times when the shower leakage is effectively hidden from either or both PLICs, the incident beam position was varied over the lattice. We found that the energy percentage seen by an individual PLIC ranges from 2–20%.

Fortunately, when one PLIC becomes hidden from the shower, the other becomes visible. Numerical calculations showed that if the signals from the two PLIC cables on both sides of the beam pipe are added, the variation in sensitivity is only 30% for events originating at different points along the beam path through most of the Arcs. The system is thus satisfactory for both beam diagnostic and machine protection purposes in the SLC Arcs. Figure 2 shows the installation of the PLIC cables in the SLC Arcs.

3. DECREASING PLIC SENSITIVITY TO AVOID SATURATION PROBLEMS

PLIC saturation is a problem at several places in the SLC because of high radiation, and desensitized PLICS have been installed in the Beam Switch Yard (BSY) and the extraction line. Initial tests of desensitized PLICs were done in the BSY.

The geometry is more complicated in the BSY than in the linac, as the structures are nonuniform. The beam pipe is only a fraction of a radiation length thick. For perhaps half its length, the pipe is covered by very thick radiation absorbers, such as magnets and collimators; some of them are many radiation lengths thick. In other places, the beam pipes are surrounded with shielding of intermediate thickness. As a result,

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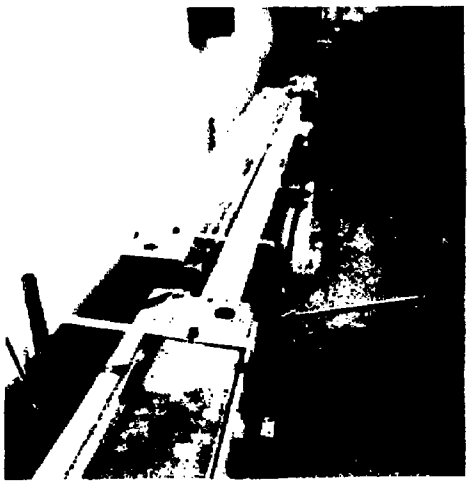

Fig. 2: PLIC cables in SLC Arcs.

a joule of beam loss might produce a PLIC signal of 1 V when dumped in one place and 10 mV when dumped in another place. To help make PLIC sensitivity more uniform, two PLIC cables were used, mounted on either side about 4 feet away from the beam pipe.

Maximum signal amplitudes obtained depend mainly upon saturation effects, which occur at about 6 V with the gas mixture of 95% argon and 5% carbon dioxide used for most PLIC systems (with 250 V on the PLIC cable). The PLIC sensitivity can be reduced in areas of high-incident radiation by adding freon to the filling gas. Freon absorbs electrons and thereby reduces sensitivity and extends saturation limits on signals.

The BSY system has separate filling-gas plumbing, so that the sensitivity and saturation levels for the BSY PLIC cables can be adjusted by changing the percentage of freon in them.

Measurements were made with a 1E10 particle electron beam (75 J at the end of the linac) dumped near a large bending magnet, since consistent and large PLIC signals could be obtained there. Three different gas mixtures were tested, with the beam resteered for maximum PLIC signal near this same large bending magnet each time. Results were as follows:

Table 1.

Freon %	CO_2 %	PLIC volts out	mV/joule	Sensitivity as ratio
3.0	3.0	0.26	3.47	1.0
0.3	4.7	2.0	26.7	7.7
0.0	5.0	6.0 (saturated)	—	
		10.0 (extrapolated)	133	38.3

The remaining gas is argon in each case.

Although deposited PLIC charge/joule is the correct measure of PLIC sensitivity, the output voltage is proportional to charge, and therefore may be used to compare sensitivities.

Because of the uncertainties in the relationship between energy loss and PLIC amplitude, the use of the PLIC for machine protection in the BSY is not considered practical. However, the BSY PLIC is extremely useful for beam steering. Signals originating in the BSY substantially exceed the signals in the Arcs which appear on the same oscilloscope display. The 95% argon, 4.7% carbon dioxide and 0.3% freon gas mixture makes BSY and Arc signal levels nearly equal on the oscilloscope display, and works well as far as diagnostic use of the BSY PLIC system is concerned.

4. OTHER PLICS IN THE SLC

Figure 3 is a map of the SLC showing all of the places that PLICs have been installed, with each PLIC described briefly. The timing and operation of the SLC have been discussed in the *SLC Design Handbook*.[5] The following are some general comments concerning the PLIC system.

All the SLC PLIC systems have been made with 1/2-inch coaxial cable (Andrew Corp HJ4-50). Electron collection times increase, but propagated pulse rise time decreases with increasing cable diameter. For the length of PLIC cables in the SLC Arcs—about 4000 feet—the two effects produce a broad minimum in signal rise time, and therefore best spatial resolution, for a cable diameter near 1/2 inch. Since a standard cable for all PLIC systems is desirable, this cable was used in all of the PLIC systems built for the SLC. This also happens to be the least expensive cable suitable for a PLIC system.

Fiducial cables have been added to clearly mark particular places along the PLIC system. These are coiled, 50-ns-delay sections of nonsensitive cable (RG-214) inserted to provide a zero-response baseline at known places. Additionally, the use of 1/2-inch cable has made it possible to thread the PLIC cables through beamline components, such as magnets, that otherwise would shield the PLIC.

5. CONCLUSION

We have described a number of PLIC systems installed in the SLC. They are continuing to be extremely valuable tools for beam diagnostics, and also to protect the SLC from damage by its own beams in several places.

ACKNOWLEDGMENTS

We acknowledge the help of all the people who worked on these systems. In particular, we thank the following for their contributions: the cable hangers in the Arcs were fabricated and installed by Z. Vassilian; PLIC cables were installed by M. Baldoza, M. diSalvo, B. Limones, P. Sandhu, and L. Soria; electronic packaging design was performed by S. Billitzer and J. Cabading; and electronic assembly and testing by D. Cha, J. Rock, and R. H. Simmons.

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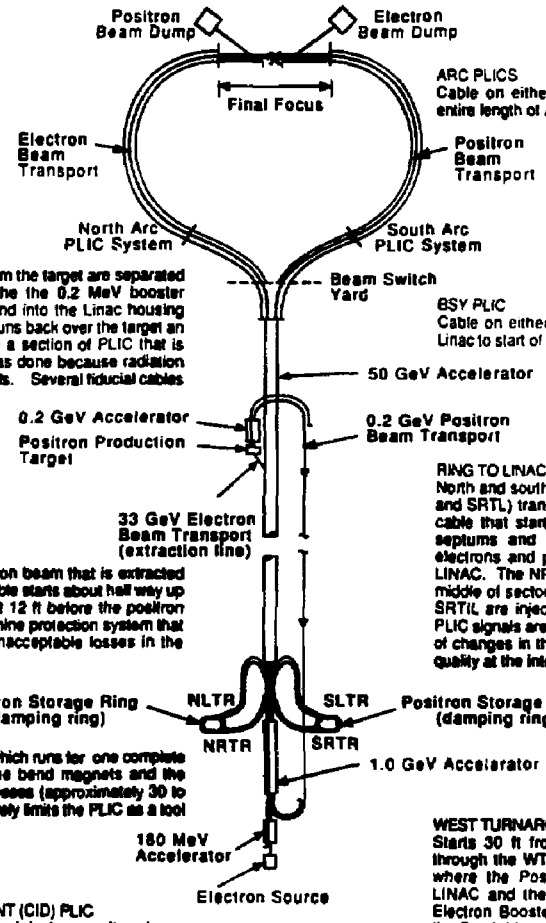
PLIC installed in both the North and South SLC Final Focus Region. Cable is run aproximately 36 inches above beam pipe to avoid interfering with optical alignment. Normal viewing at up beam end of the cable, gives spatial resolution of about 5 feet. Two fiducial cables in each system help localize beam losses. However, shielding by magnets, etc, makes sensitivity marginal. Sensitivity to total beam loss is improved by viewing at the downstream end of the cable where signals arrive essentially simultaneously and the sum of losses is seen.



ARC PLICS
Cable on either side of beam pipe along the entire length of Arc Magnets (approx 4200 ft)

EAST TURNAROUND (ETA) PLIC
Starts after the positrons produced from the target are separated from the electrons, runs throught the the 0.2 MeV booster section, continues around the turn and into the Linac housing where it ends. Where the beam pipe runs back over the target an ordinary coaxial cable is used obtain a section of PLIC that is insensitive to the beam loss. This was done because radiation from the target causes confusing signals. Several fiducial cables are used.

BSY PLIC
Cable on either side of beam pipe from end of Linac to start of Arc Magnets.

RING TO LINAC (RTL) PLICs
North and south Damping Rings to Linac (NRTL and SRTL) transition regions each have a PLIC cable that starts at their respective extraction septums and runs to the point where the electrons and positrons are injected into the LINAC. The NRTL PLIC cable continues to the middle of sector 2 of the Linac. The NRTL and SRTIL are injection lines for the Linac and the PLIC signals are particularly sensitive indications of changes in the beams which decrease beam quality at the interaction point.

EXTRACTION LINE PLIC
Monitors losses of the 33 GeV electron beam that is extracted from the LINAC to make positrons. Cable starts about half way up the extraction line and runs to about 12 ft before the positron target. This PLIC is a part of the machine protection system that limits beam power in the event of unacceptable losses in the extraction line.

DAMPING RING PLICs
Each damping ring has a PLIC cable which runs for one complete turn. Due to the tight packing of the bend magnets and the quadrapoles in the rings only large losses (approximately 30 to 40 % or more) can be seen. This severely limits the PLIC as a tool for fine tuning of ring beams.

WEST TURNAROUNG (WTA) PLIC
Starts 30 ft from the turnaround itself, runs through the WTA and along the beam pipe to where the Positrons are reinjected into the LINAC and then accelerated in the 1.0 GeV Electron Booster section. Continues through the South Linac to Damping Ring (SLTR) to the entrance of the South Damping Ring. Numerous fiducial cables are used to obtain display markers in this region of complicated beam guidance.

COLLIDER INJECTOR DEVELOPMENT (CID) PLIC
Starts at the 20 MeV point inside the Injectors vault and runs through 180 MeV booster section, the 1.0 GeV booster section, and the North Linac to Ring (NLTR) transition region to the injection point into the North Damping Ring. Numerous fiducial cables are used to provide display markers.

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Fig. 3: Overall SLC layout, showing PLIC installations.

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