

LIONS at the Stanford Linear Accelerator Center

T. N. Constant, R.W. Zdarko, R.H. Simmons, B.M. Bennett
Stanford Linear Accelerator Center, 2575 Sand Hill Road, CA 94025, USA

Abstract

The term LION is an acronym for Long Ionization Chamber. This is a distributed ion chamber which is used to monitor secondary ionization along the shield walls of a beam line resulting from incorrectly steered charged particle beams in lieu of the use of many discrete ion chambers. A cone of ionizing radiation emanating from a point source as a result of incorrect steering intercepts a portion of 1-5/8" Heliac cable (about 100 meters in length) filled with Argon gas at 20 psi and induces a pulsed current which is proportional to the ionizing charge. This signal is transmitted via the cable to an integrator circuit whose output is directed to an electronic comparator, which in turn is used to turn off the accelerated primary beam when preset limits are exceeded. This device is used in the Stanford Linear Accelerator Center (SLAC) Beam Containment System (BCS) to prevent potentially hazardous ionizing radiation resulting from incorrectly steered beams in areas that might be occupied by people. This paper describes the design parameters and experience in use in the Final Focus Test Beam (FFTB) area of the Stanford Linear Accelerator Center.

1 Introduction

SLAC Long Ion Chambers have been standing guard as faithful watchdogs protecting the SLAC LINAC and beam transport lines from potentially dangerous and damaging errant beam power since the inception of SLAC. Because of their keen sense of detection they have been used extensively throughout all of the SLAC beamlines to track wayward and missteered beam particles and alarm the Machine Protection System (MPS) instantly when errant beam power strays from its prescribed flight path along the transport system.

The term LION is an acronym for "Long Ion Chamber". The LION at SLAC is a long single length of gas filled Heliac cable used as an ion chamber for the detection of

ionizing radiation. Because SLAC beams are pulsed in nature, errant beam particles produce pulsed ionization fields, which in turn induce pulses of current within the coax cable structure. These pulses are applied to peak detection discriminators to generate shut-off commands for the MPS, thereby turning off potentially damaging beam power when pulse heights exceed a preset threshold. These LIONS, more commonly known as PLICs (Panofsky Long Ion Chamber) [1,2,3], named after the person who proposed the initial system, have also proved to be a very sensitive diagnostic tool to indicate where along the beam path problems arise, and thereby aid in beam tuneup and guidance.

With the installation of the FFTB (Final Focus Test Beam) line in the SLAC Research Yard, a new role was proposed for the LION, that of protecting SLAC personnel from dangerous radiation resulting from missteered beams in the Research Yard area. It was at this juncture that the term "LION" was coined. This new role introduced the concept of integrating the pulsed response from ionizing radiation. The varying D.C. output level produced when applied to a comparator circuit could develop a shut-off command to the Beam Containment System (BCS) for turning off SLAC beams to remove the source of radiation. The conventional beam containment systems at SLAC use discrete Ion Chambers (ICs) for the detection of ionizing radiation. Protecting the exterior environment outside the long shield walls of the FFTB beam line in the Research Yard area would require a prohibitively large number of such discrete ICs and was not economically viable. It was decided to use a long length of gasfilled 1-5/8" Heliac cable at beam height to do the job of providing continuous coverage along the walls; by segmenting the cable along the length of the beam line, different sensitivities could be used for each region along the beam line. The final arrangement called for three lengths of cable along each side of the tunnel walls, resulting in six LIONS for the FFTB (see Figure 1).

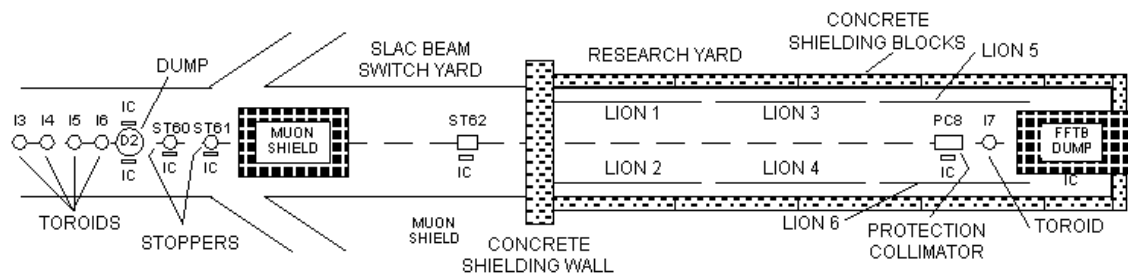


Figure 1 Diagram of Beam Containment devices installed in the SLAC FFTB showing the location of the six LIONS.

2 Sensitivity

It was estimated that point source beam losses greater than 1 watt in the FFTB shield block tunnel section would produce ionizing radiation levels of the order of 1R/hr distributed in a small cone along the inside of the tunnel shield walls. This would correspond to about 1mR/hr at the outside of the shield wall in the Research Yard area (assuming a worst case minimum shielding attenuation of 1000). It was further estimated that 1 meter of 1-5/8" gas filled Heliac cable would have the equivalent volume of a standard discrete Ion Chamber used at SLAC. The length of the FFTB external tunnel is about 100 meters, and therefore three 30-meter lengths of Heliac could be used to provide coverage along the entire length of the FFTB tunnel. This would correspond to the equivalent of three groups of 30 discrete ICs each, thereby providing distributed IC coverage equivalent to 90 ICs at considerably lower cost. Background levels of radiation were estimated to be in the 20-30 mR/hr range (perhaps as much as 50 mR/hr) during normal FFTB operation. This corresponds to a background threshold current in the cable of about 400 picoamps (pA). A rate of 1 R/hr of radiation induces about 270 pA in a standard IC, and therefore in 1 meter of cable; thus 50 mR/hr of radiation induces $0.05(270)(30)$ or about 405 pA in 30 m of cable.

D.C. housekeeping currents are used to verify the integrity of the Ion Chamber cable plant and, therefore, using a 50% margin of safety, a housekeeping level of 250 pA was first used with a low threshold trip setting of 120 pA. This requires that leakage currents in the Heliac cable be less than 0.1 of the set point, or 12 pA. In actual practice, leakage currents have been maintained below 25 pA. It was decided to set the housekeeping level at 2500 pA (or 2.5 nanoamps [nA]). Adding all of these factors together yields a resulting background current of approximately 2.9 nA in the LION segments. This allows high trip point settings as low as 10 to 15 nA to detect a 1 R/hr radiation field. It has been determined experimentally that a 10-15 nA level will result from a 1 R/hr flux in the typical LION cable in the FFTB.

In order to establish a D.C. housekeeping level of 2.5 nA, a 100 G-ohm (10^{11}) resistor is used as a load at the far end of the cable in conjunction with a 250 volt isolated power supply (see Figure 2). Care must be exercised in the assembly of this system to maintain low leakage currents. For a schematic drawing of a single LION detector as used for LIONS 5 and 6 see Figure 2.

3 Leakage

Cable leakage was addressed by measuring the leakage current on long cable samples (60' and 270') at the FFTB tunnel site. Initial tests using a Keithley meter, chart recorder, and a 1KV isolated power supply showed leakage currents of from 3 to 70 nA for unpurged cable. After purging (i.e., allowing argon gas to flow through the cable samples for about 1 week) the measured leakage

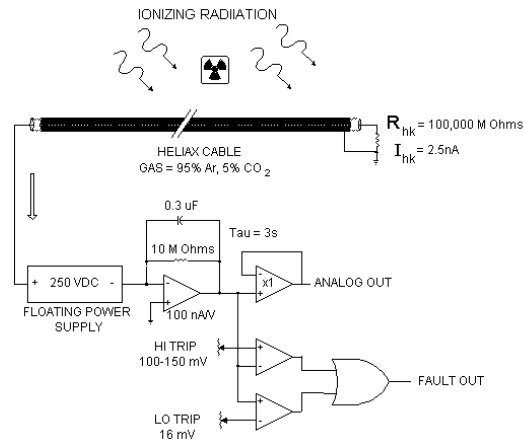


Figure 2 Schematic drawing of a single LION detector as used for LIONS 5 and 6.

currents stabilized to values below 50 pA.

Tests with a 500 volt P.S. resulted in leakage currents less than 20 pA. Normal operation involves the use of 250 volt power supplies, resulting in leakage of about 10 pA. Maintaining pressure in the cables has kept the leakage well within specifications and by monitoring gas pressure with an alarm circuit, system performance is safeguarded.

4 Gas pressure

A one foot section of a 60' length of cable was exposed to a radiation source set to 1 R/hr to determine the effect of gas pressure on sensitivity. After purging with argon and stabilization of the 60' length of cable, the test results obtained are shown in Table 1.

Table 1 Test results of 1' of cable exposed to 1R/hr of radiation as a function of voltage and gas pressure.

VOLTAGE	ARGON PRESSURE	INDUCED CURRENT
250 V	10 psi	53 pA
250 V	20 psi	72 pA
500 V	20 psi	79 pA

Leakage current was less than 20 pA with P.S. voltages from 250V to 500V. Doubling the gas pressure increased the induced current by about 35%. Doubling the voltage had less than 3% effect on the induced current. With leakage currents of about 20 pA, the net induced current at 20 psi was about 50 pA (72 pA-20pA) for a 1' length of exposed cable sample at 250 volts, or about 150 pA per meter. It was suggested by David Burke that the shallow solid angle of incidence would increase sensitivity by a factor of π in the FFTB tunnel to an estimated integrated result of about 500 pA per meter for 1 R/hr of ionizing radiation, as compared to the IC model of 270 pA. This provides a further margin of safety. Actual experience

bears this out as is depicted by the results plotted in Figure 3. Using an Integrator op-Amp with a throughput gain of 100 nA/volt resulted in 100-150 mv output for a 1 R/hr radiation field. This corresponds to an input of 10-15 nA respectively which agrees with the predicted value [(30)(500)=15000 pA].

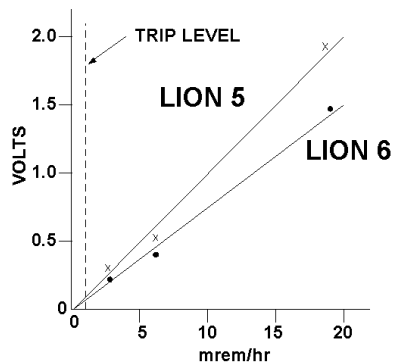


Figure 3 Calibration data for 2 LION detectors. Radiation was measured outside the concrete shielding walls adjacent to the LIONS with neutron & gamma detectors. The beam was steered around the Protection Collimator (PC8) to achieve different levels of secondary radiation.

5 Integrator

The standard PC card integrator used at SLAC has a gain of 1 μ A per volt with a time constant of 0.1s, utilizing a 1 M Ω resistor shunted by a 0.1 μ F capacitor. Changing the op-amp shunt resistor to a value of 10 M Ω in parallel with a 0.01 μ F capacitor to increase the gain to 100 nA per volt with a time constant of 0.1s resulting in a system which trips within one pulse at beam rates down to 1 pps. By increasing the time constant to 1.0s, the system response time is slowed, allowing an operating margin for 1 pps faults, thereby providing beam tune-up capability without continual beam shut-off. In the case of LIONS 5 & 6 the time constant was increased to 3.0s (response time \cong 10s) because of the proximity to the beam dump. The larger capacitance also provides better filtering for the repetition rate related ripple in the integrator output, reducing this ripple by a factor of 10 or more. This ripple is a critical parameter in this circuit arrangement, especially in view of the low trip threshold of 1.6 nA (corresponding to a 16 mv output level). A low bias current FET op-amp is used to provide the stability and high sensitivity required for this application.

6 Packaging

It has been estimated that a two channel chassis can be fabricated with power supplies, integrator electronics, metering, signal distribution, and alarms for about \$2500

US and a total system cost, including Heliac cables, gas-tight connectors, high resistance terminators, and Keithley calibration source for under \$5000 US per channel.

7 Conclusions

After over four years of operational experience with LIONS at the FFTB, it has been clearly demonstrated that they provide an effective "early warning system" to potentially hazardous radiation levels in the SLAC Research Yard, and have greatly minimized the likelihood of BSOIC (Beam ShutOff Ion Chamber) hard trips. BSOICs are the last line of defense in the event of excessive external radiation, and when tripped, they shut down the SLAC LINAC in a way that results in longer recovery times and a lot of administrative overhead. This early warning has been a real plus in providing sensitivity to low beam power losses (of the order of 1 watt) within the FFTB environment.

In addition, initial concerns of deteriorating cable leakage levels over extended periods of time have proven to be without foundation. Careful consideration of system design, isolation and continuous low-level gas purging have maintained stable low-level cable leakage currents well within tolerable limits.

SLACs LIONS are cost effective, reliable, and trustworthy, and they continue to act as tireless sentinels, ready to "roar" at the slightest provocation from threatening secondary ionization.

Acknowledgments

Credits to Dave Burke who originated the concept for use of D.C. LIONS in the FFTB tunnels for the detection of lowpower beam losses, and to Rick Iverson for his enthusiastic support during the initial feasibility studies. Also our thanks to the SLAC safety office (ADSO), in particular Bill Kroutil, for his assistance in obtaining the calibration data with beam.

References

- [1] W.K.H. Panofsky, "The Use of a Long Coaxial Ion Chamber Along the Accelerator", SLAC TN-73-57 (1963);
H. de Staebler, "Note on Panofsky's Long Ion Chamber", SLAC TN-63-63 (1963).
- [2] M. Fishman and D. Reagan, "The SLAC Long Ion Chamber for Machine Protection", IEEE Transactions on Nuclear Science (June 1967).
- [3] J. Rolfe, R. Gearhart, R. Jacobsen, T. Jenkins, D. McComick, R. Nelson, D. Reagan, and M. Ross, "Long Ion Chambers for the SLC", IEEE Particle Accelerator Conference (1989: 1531-1533).