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W. Kroutil, G. Nelson, A. Fasso, W. R. Nelson

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94309

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Comparison of Experimental Data Versus Computer Modeling of a Radiation Detecting Personnel Safety System Ion Chamber.

William R. Kroutil
Industrial Engineer
Stanford Linear Accelerator Center
Stanford University, CA 94309

Gerard Nelson
Accelerator Department Safety Officer
Stanford Linear Accelerator Center
Stanford University, CA 94309

Dr. Alberto Fasso
Radiation Health Physicist
Stanford Linear Accelerator Center
Stanford University, CA 94309

Dr. W. R. Nelson
Radiation Health Physicist
Stanford Linear Accelerator Center
Stanford University, CA 94309

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ABSTRACT

The purpose of this paper is to present experimental data to demonstrate the validity of a computer-designed safety system, based on an ionization chamber, used in the detection of electron beams. The first section of the paper describes the safety system, from the radiation producing beam line to the electronic safety system monitoring modules. The second section of the paper describes the radiation simulation modeling program, EGS4. This computer code predicts where the beam-generated radiation, commonly known as a "shower," deposits its energy after colliding with beam line devices (e.g., collimators, stoppers, etc.). This allows for the best placement of safety devices to protect these beam line devices.

INTRODUCTION

The Stanford Linear Accelerator Center (SLAC) is a multipurpose physics laboratory operated by Stanford University. SLAC operates under contract of the Department of Energy conducting high-energy physics using electron and positron beams for basic research, and synchrotron light physics using photon beams investigating general sciences for the National Science Foundation. This paper describes one part of the radiation safety system used in the high-energy physics laboratory.

Beams are created in the SLAC Two-Mile Accelerator by capturing electrons from a cathode and accelerating them down a 10,000 foot copper waveguide to energies as high as 50 Giga Volt potential. When high-energy electrons strike a device, such as a beam stopper that is intended to prevent the beam from going any farther for people protection reasons, high-energy x-rays are produced. These x-rays commonly referred to as bremsstrahlung, in turn produce more electrons, which produce more x-rays. The final result is what we call a *radiation shower* — namely, a single high-energy electron produces hundreds to millions of electrons and photons, albeit at much lower energies (100 keV to several MeV) — that sprays out of the stopper.

SLAC uses beam stoppers to contain the primary electron beam at shielded locations where people are not permitted to enter. However, these stoppers can be compromised when beams of high intensity impinge upon them and produce showers. That is, the energy deposited in the stopper can lead to melt down and subsequent beam pulses may no longer be "contained". To prevent destruction of the beam stoppers, the incident beam intensity is limited by using both current toroids and ionization chambers, the latter being the subject of this paper.

THE HARDWARE CONFIGURATION

The beam stopper in the present study is made of copper. It has a cross sectional area of 3.5 x 4 square inches, and is 8 inches in length (along the direction of the beam). It is situated in a stainless-steel vacuum chamber can to make it easier to place in and out of the beam. On the outside of the can a pair (for purposes of redundancy) of protection ionization chambers (PICs) are located to sense the radiation shower that will take place when a beam strikes the stopper.

Ion chambers are simply devices that collect charge released by the passage and interaction of radiation in the chamber gas. The PICs that are used at SLAC contain a stack of 32 thin-aluminum plates in a cylindrical containment vessel filled with about one liter of air at atmospheric pressure. A voltage of about 200 Volts is applied across every other plate and collected charge is summed to give an average current for a pulsed electron beam (*e.g.*, at 10 Hz).

To facilitate the measurement of the current, Beam Containment System (BCS) circuit boards (cards) have been designed. These cards serves three (3) functions: (1) to stretch the short beam pulses (<3 nano-seconds) to 100 milli-second pulses, thus creating an average pulse, (2) provide an interface with the PIC tester for calibration and high trip set point adjustment, and (3) to send the PIC output first through CAMAC then digitized to a real-time computer display. The PIC tester is the source for the calibration signal and PIC output current read back.

When an excessive amount of radiation is produced at the stopper, then the ion chamber current will increase above a pre-determined high-trip set point and the beam will be turned off. Thus an accurate ion chamber calibration and computer modeling must be done in order to protect the stoppers themselves, and therefore personnel downstream in the experimental area. Computer modeling is used to determine the optimum location for the ion chambers relative to the radiation shower that emanates from the stopper. The purpose of the computer modeling is to study the feasibility of reducing the number of ion chambers from four (4) protecting two (2) stoppers, to a single pair protecting two (2) stoppers. The stopper and ion chamber configuration is shown in Figure 1.

Currently the components used are engineered and assembled at SLAC. This is an expensive way to operate, in the case where multiple stoppers are required for redundancy. Future trends are to obtain commercial off-the-shelf equipment, if available, for use at SLAC.

THE COMPUTER MODELING

The important aspects of the computer modeling are (1) simulating the radiation that escapes a stopper, and deposits energy in an ion chamber, as a function of electron beam current, and (2) including other factors involved in the ion chamber response, such as recombination of ions in the chamber.

The electron beam is made up of pulses. Each pulse contains about thirty billion (3×10^{10}) electrons. The pulse length is about three billionths (3×10^{-9}) of a second and there are 10 pulses per second evenly separated in time by 100 milliseconds.

In the ion chamber, the shower-produced charge (ions) appears with each beam pulse. The transit time for the ions to reach the PIC collector plates is about two millionths (2×10^{-6}) of a second. Because the ion transit time is so much longer than the length of the beam pulse, and so much shorter than the time between pulses, simple theory would predict that the average current from the ion chamber should be linearly proportional to the beam intensity (electrons/pulse). However, the measurements presented in Table 1 show the ion chamber current rolling-off as beam intensity is increased. This can be explained as follows.

In the case of air ion chambers, both positive and negative ions are created. That is, positive ions are created by the removal of orbital electrons (called ionization), and there is a high probability for these free electrons to be captured by a neutral atom, which leads to a negative ion. As the ions of both signs pass through each other to their respective collection plates, they have a tendency to recombine. This recombination increases strongly (and non-linearly) with the ionization density (ion pairs/cm^3), and the latter increases linearly with beam intensity.

SUMMARY

The recombination effect observed in Table 1 must be taken into account when setting trip levels. That is, a single measurement made at low beam intensity cannot be easily scaled up to a high beam intensity, for purposes of setting the high-trip set point, unless there is a full understanding of the recombination that takes place. In this paper we have studied this condition both theoretically and experimentally.

The following graphs (Figure 2) show the result for three test conditions: (1) stopper #1 in the beam only, (2) stopper #2 in the beam only, and (3) stoppers 1 and 2 both in the beam. In these figures, I_O curve is the ion chamber current if recombination is not taken into account. The I curve is the ion chamber current with recombination included, which clearly agrees better with the experimental data.

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Table 1. Measurement of the average current $I(\mu\text{A})$ vs. electron beam intensity $I_{beam}(e^-/p)$ for various stopper configurations, at 10 GeV and 10 Hz (DC offset not subtracted).

I_{beam}	ST-1 Only		ST-2 Only		ST-1 and ST-2	
($\times 10^{10}$ e^-/p)	IC-4047	IC 4048	IC-4047	IC-4048	IC-4047	IC-4048
0.0	0.21[a)]	0.19[a)]	0.21[a)]	0.19[a)]	0.21[a)]	0.19[a)]
0.5	0.6061	0.6261	0.3601	0.3134	0.6303	0.6706
1.0	0.9804	0.9760	0.4873	0.4189	0.9648	0.8130
1.5	1.569	1.413	0.6813	0.6012	1.451	1.261
2.0	1.490	1.322	0.7539	0.5995	1.666	1.337
2.5	1.897	1.872	0.9364	0.7516	1.615	1.445
3.0	2.145	1.800	1.084	0.7712	2.119	1.719
3.5	2.308	2.294	1.189	0.7659	2.442	1.991

a) DC offset

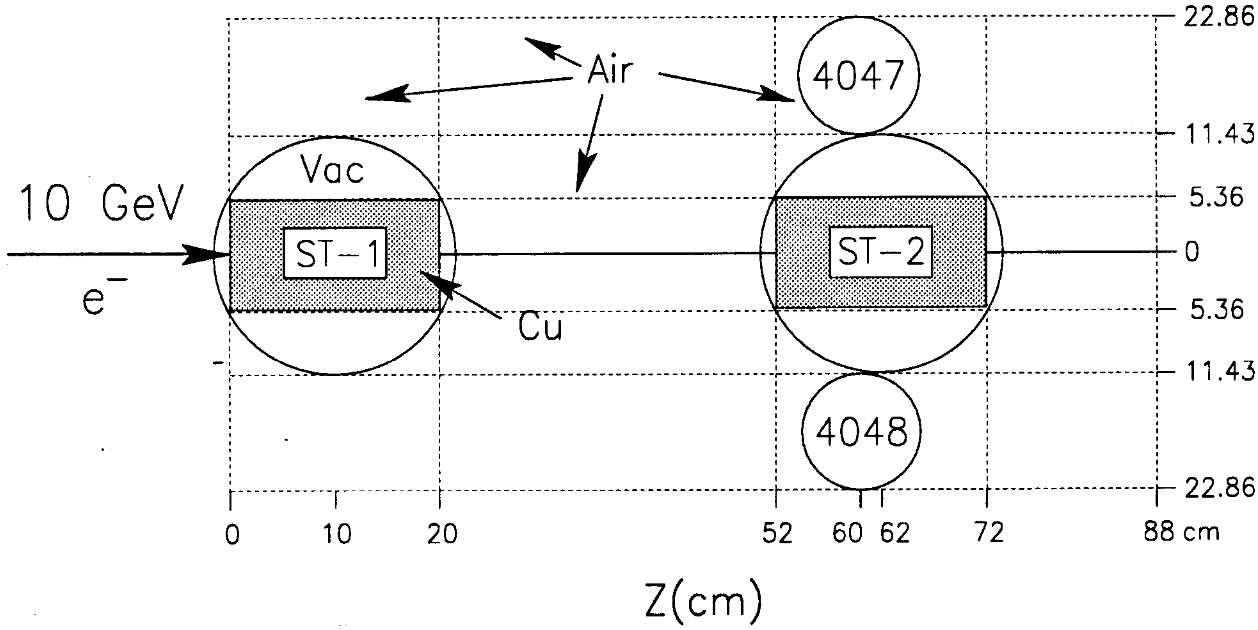

Fig 1 Stopper 1 (ST-1) and Stopper 2 (ST-2) with ion chambers 4047 and 4048.

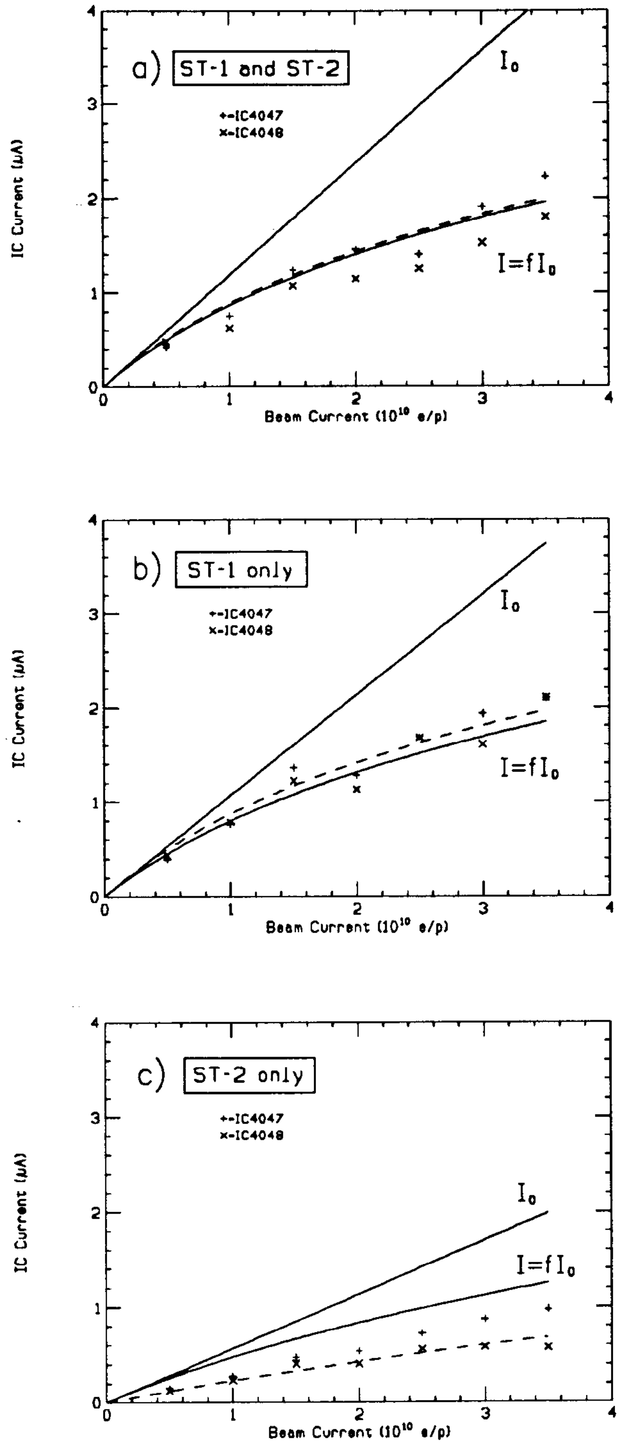

Fig 2 Average currents for three stopper configurations.
Experiment (dc offset subtracted): + and x.
Calculation: solid line (Z=60 cm) and dashed line (Z=52 cm).