A COAXIAL CABLE BEAM LOSS MONITOR ION CHAMBER SYSTEM FOR HIGH POWER MULTI-BUNCH BEAMS*

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Abstract

Gas filled coaxial cable beam loss monitors are a proven diagnostic in short pulse linacs and transport lines. At the SLAC linear collider (SLC), where the bunch length (σ_z) is ~ 1 mm, monitor cables with lengths ranging from 100 m to 3 km are used to locate beam losses of 5 x10^8 particles (1.5% of the nominal intensity) with a resolution of +/- 1 m. The monitor is effective because of the simplicity of its installation and signal interpretation. Future linear colliders (LC) will use beams made up of trains of many closely spaced bunches and will therefore require more careful signal processing in order to locate losses. Typical collider operation will involve the use of pilot pulses, made up of only one bunch, to test subsystem performance prior to full power operation. A simple signal processor will be able to locate losses by comparing the evolution of the loss monitor signal as the number of bunches is increased. The monitor must have 10 times greater sensitivity than the SLC monitors in order to provide a prediction of the expected beam loss at full power using only the signal from the pilot pulse. This paper describes the proposed linear collider loss monitor system.

1 INTRODUCTION

Future LC differ from the SLC in that they will use multi-bunch, very high power beams. The machine protection system (MPS) role is therefore more critical than in older, lower power machines [1] and the consequences of its failure are more severe.

The MPS for LC consists of two primary sensors: a device controller monitor and an errant beam detector (EBD). The purpose of the device controller monitor is to query the state of all appropriate devices before allowing the system to produce beam pulses. The monitor can be as simple as an analog comparison of magnet currents and will be queried and tested before each pulse. The EBD is typically comprised of loss monitors, such as gas filled ion chambers, current monitor toroid comparators and solid state radiation detectors as well as simpler devices such as thermal sensors. In an ideal system, the device controllers would be adequate to ensure that the machine is not in danger of damage from simple failures.

Some failures, such as instabilities in upstream systems, will not be identified by the device controllers. In this case, it may not be possible to recover stable operation without a diagnostic process that includes the generation of a sequence of beam pulses that may then be analyzed in order to determine the underlying cause of the fault. An essential aspect of the EBD system operation is to allow the generation of the diagnostic pulses and eventually to allow the recovery of full power operation.

2 MACHINE PROTECTION SYSTEM

The linear collider MPS will control both the termination of operation in the case of a device controller signal or an EBD signal and the restoration of full power operation. The system must at the same time protect the accelerator structure from possible single pulse induced failure (SPIF), i.e. failure that results from a single errant pulse without any warning. SPIF is a concern in future LC because the charge density, and therefore the power density, is high enough to cause substantial material damage.

Restoration of full power operation proceeds in 5 stages as outlined in table 2; 1) generation of a low repetition rate benign, low intensity, high emittance single bunch pulse which cannot cause SPIF, 2) generation of the same pulse at high repetition rate, 3) at full repetition rate, increase the single bunch intensity, 4) reduce the emittance to the nominal value, and finally, 5) raise the number of bunches (n_b) to the nominal.

The purpose of the coaxial cable loss monitor (CCLM) system is to aid in predicting what the beam loss profiles will be in order to allow the steps listed above to proceed. We will focus only on the last step, increasing n_b, since it involves the highest power beams. Collider systems are designed such that the difference between the trajectory and phase space volume of a single bunch and the projected volume of the entire train is small. However, following a system failure or an interruption, this cannot be guaranteed, so the response of the loss monitor must be checked and evaluated as full power operation is restored.

Typical Next Linear Collider (NLC) parameters are listed in table 1. Table 2 shows a typical full power recovery sequence from a ‘benign’ pilot beam at low repetition rate to full power operation.

* Work supported by the Department of Energy, contract DE-AC03-76SF00515

Table 1: NLC beam parameters [2]

Bunch intensity (I_b)	1×10^{10} e+/e-
Number of bunches (n_b)	90
Bunch spacing (τ_b)	2.8 ns (total Δz=77m)
$\gamma\varepsilon_x$(horizontal invariant emittance)	100×10^{-8} m-rad
$\gamma\varepsilon_y$	10×10^{-8} m-rad
Energy	500 GeV
Repetition rate	120 Hz
Typ. linac beam size (σ_x)	10 μm
σ_y	1 μm

Table 2: Five step full power operation start sequence for NLC. Note that beam power increases by 10^5. The multi-step sequence is required in order to use the benign pilot beam as a diagnostic and smoothly make the transition to full power operation.

Step	Parameters n_b, I_b, typ. $\sigma_{x,y}$	Charge density (C/m^2)	Average beam power
Pilot beam	1, 1×10^9, 30μm(1Hz)	.04	80
Full rate	120 Hz	.04	10KW
Nominal I	1, 1×10^{10}, 30μm	.3	100KW
Nominal ε and I	1, 1×10^{10}, 3μm	23	100 KW
Nominal	90, 1×10^{10}, 3μm	2100	8MW

The rate at which the sequence proceeds depends on the characteristic stabilization times of systems used to control the beam parameters such as the emittance controller and beam energy loading compensation. Typically, the transition between steps may require 10 or more machine pulses or sub-steps so that, for example, n_b might follow a 1,5,10,20,40,60,80,90 progression.

Table 3: Loss monitor sensitivity requirements and test results using SLC beam (see figure 3).

Trip threshold energy(V_{thres})	2 J (corresponds to 240W at full rate)
Required sensitivity	250 mV/J (5mV/(V_{thres}/n_b))
Nominal SLC system sensitivity [3]	60 mV/J
Fast gas –Ar CF_4	150 mV/J – test result
Ar CF_4, larger cable, HV gradient doubled	450 mV/J – test result

The threshold used in the MPS is determined using an estimate of the average power that can cause damage in a given mechanical subsystem (typically a few hundred watts). Operation with CCLM signals greater than the threshold voltage is not permitted. Since the nominal pulse rate is 120 Hz, the threshold against which each pulse will be compared is about 2 J (V_{thres}). An electronic sensitivity of 5mV/(V_{thres}/n_b) is required so that an estimate the losses at full n_b is possible. Table 3 summarizes the threshold and CCLM sensitivity requirements.

3 LOSS MONITOR SYSTEM

Gas-filled coaxial cable loss monitors have been used at SLC and other accelerators for the last few decades [3, 4, 5]. They offer excellent position resolution (1m) and good sensitivity for short bunches. As the gas in the cable is ionized, a signal propagates in both directions along the cable. In the direction opposite that of the beam, the signal carries position dependent loss information. For multi-bunch trains, the signal from losses of a small portion of each bunch in the entire train at a single location and that from a few bunches at more than one location can be similar. One way to resolve the ambiguity is by monitoring the evolution of the signal during the n_b progression. Figure 1 shows the expected waveform from a single point loss and illustrates how the signal evolves through the power up sequence.

The complete MPS will also rely on discrete loss monitor EBDs. These devices indicate the local energy deposition less ambiguously but do not have the comprehensive geometric coverage of a CCLM.

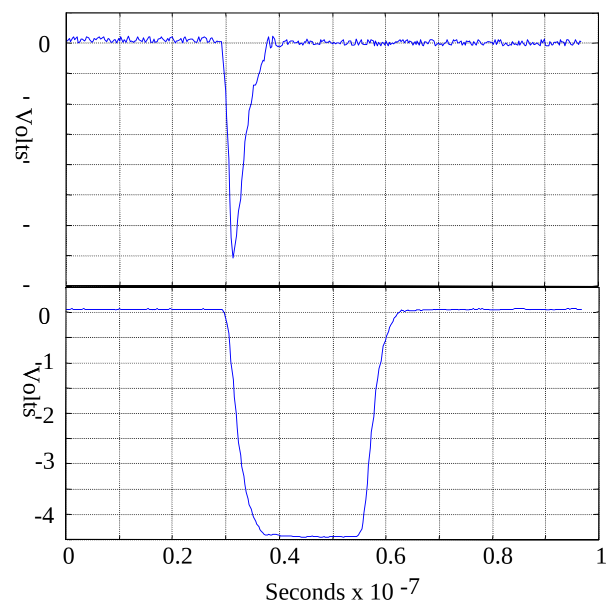

Figure 1: Simulation showing the expected CCLM performance as n_b is increased from 1 (top half of figure) to 90 (bottom half). The top half of the figure was recorded during SLC operation and illustrates a beam loss of 0.2J.

The loss monitor MPS signal processing schematic is illustrated in figure 2. Because the bunch train is long compared to the rise and fall time of signals in the cable, a simple V_{thres} comparator does not provide an accurate estimate of the local power deposition and an integrator with a time constant of $n_b\tau_b$ must be used.

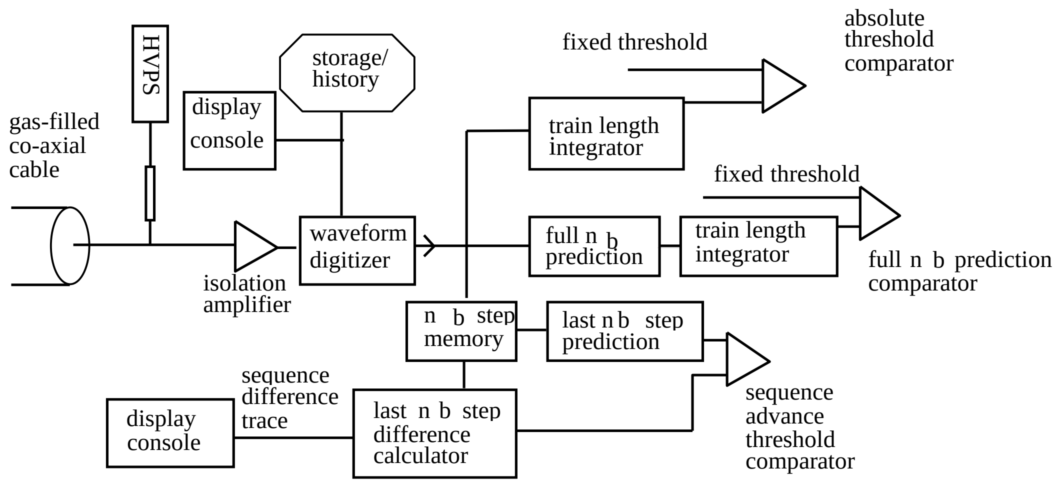

Figure 2: Signal processing schematic for CCLM MPS. The loss monitor signal emerges from the cable at the left side of the figure, is separated from the DC HV, and is amplified and digitized on each 120/s pulse. The signal is then processed and checked using the 3 comparators shown at right. If any threshold is exceeded, the sequence is terminated and a diagnostic process begins.

The electronics will use three comparators: 1) a local power threshold (V_{thres}), 2) anticipated V_{thres} for full n_b, and 3) a comparison of the observed vs. expected difference between the latest steps in the n_b sequence. It will analyze the signal evolution and abort the sequence, if necessary, before actually producing the pulse that exceeds the threshold.

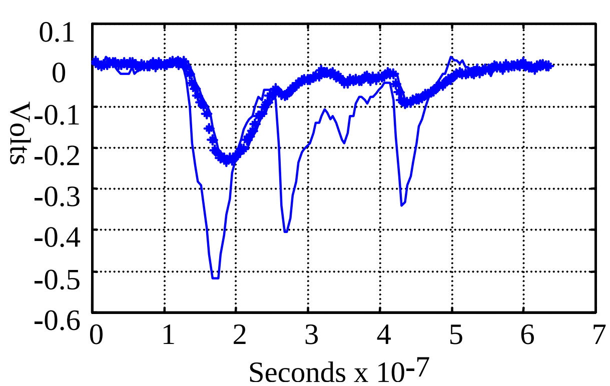

Figure 3: Loss monitor signals, (recorded during 1.2 GeV SLC beam operation), showing the difference between the Ar/CO_2 (95/5%) gas mixture (*) and the Ar/CF_4 (90/10%) gas mixture (-)[6]. The figure shows CCLM signals from a beam loss of about 4 x 10^9 particles distributed over three locations (0.8J total). The CCLM was mounted 0.3 m from the beamline.

Figure 3 illustrates results of tests aimed at increasing the sensitivity of the CCLM. As indicated in Table 3, the cable gas volume and the high voltage gradient were increased and a 2 x higher drift velocity gas was used. The combination of the three improvements provided adequate sensitivity.

4 CONCLUSION

The purpose of the pilot project is to develop a system for use of CCLM and determine its role in the LC MPS. While the CCLM does not replace discrete loss monitors, it has several advantages and will be used at future LC.

5 REFERENCES

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