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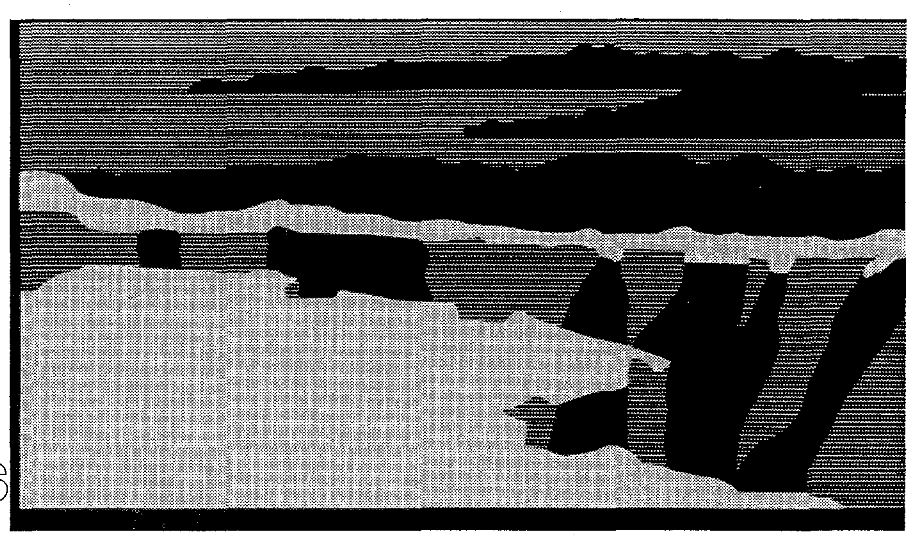

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Experience With Beam Loss Monitors In The Low Energy Demonstration Accelerator (LEDA)*

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Abstract. This paper will discuss the operational experience with the Ionization Chamber Beam Loss Monitors (ICBLM) in the Low Energy Demonstration Accelerator facility at LANL. LEDA is a test bed for a 6.7-MeV, cw, 100-mA proton radio frequency quadrupole (RFQ). There are three ICBLM's located in a short beam transport downstream of the RFQ. (This transport is called HEBT for High Energy Beam Transport.) Their function is to convey beam loss information to the operators and to protect the accelerator from being damaged by large beam spills. Signals from the ionization chambers are ten times less than expected. This results in a signal to drift ratio of 0.4 for a 1 ma beam loss and prevents protection of the machine below 2.5 ma loss. Since it is important to protect the machine down to 0.2 ma loss, improvements in and alternatives to the ICBLM are being investigated and will be implemented.

INTRODUCTION

A beam loss monitor system had been designed and largely constructed and implemented for the former Ground Test Accelerator (GTA) experiment [1,2]. The detectors and modified electronics of this system were used here with some modifications. The modifications are needed because GTA was a relatively high energy pulsed beam experiment, while LEDA is a high current relatively low energy cw machine. Thus DC coupling as well as higher gain and more stable electronics were needed in LEDA.

A BRIEF SYSTEM DESCRIPTION

The beam loss monitor system consists of the following:

Remote Sender Unit (RSU). This is the element placed about 1m from the beam line. It consists of an ionization chamber detector with DC/DC high voltage supply and a pre amplifier with DC/DC converter supply (figure 1). The ionization chamber of the RSU converts some of the ionizing radiation energy into a current proportional to the proton current hitting the beam tube. The pre-amplifier in the RSU amplifies this signal and sends it to the Differential Receiver Module. There are three RSU's

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along the HEBT in LEDA. The ion chambers were made by Far West Technology, Inc.

Differential Receiver Module (DRM). This is located outside the accelerator area and is connected to the RSU by about 170 ft. of cable. It receives the differential signal from the RSU and performs needed analogue processing (figure 2). A low pass active filter and comparator can produce a beam shutoff (Fail) signal. A second circuit is used to generate beam loss information for the operators.

Control System Interconnection. The DRM's are in a VME like crate and this allows them to be interconnected with the control system. The signals sent to/from a VXI control system crate include the warning and beam Fail signals, beam loss analog data and a fail set point.

Other components like power supplies and interconnecting cables as well as display and control software running under an EPICS operating system [3].

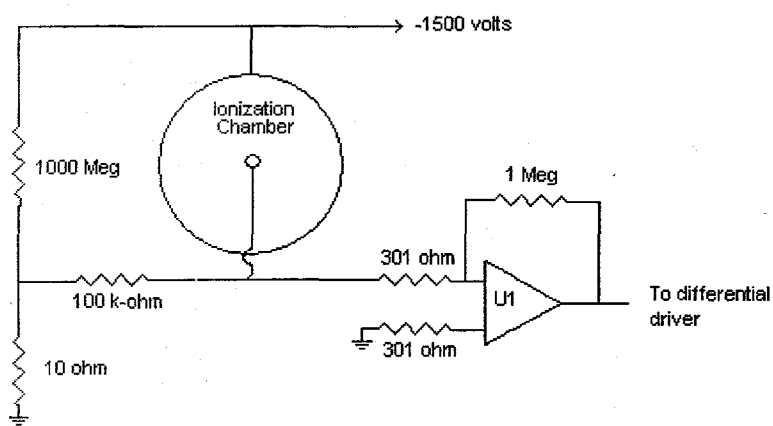

Figure 1. Ionization Chamber and first amplifier of the Remote Sender Unit.

MODIFICATION OF ELECTRONICS

The input amplifier (U1 in Figure 1) for the GTA experiment in the RSU was an HA-5160 in a transimpedance configuration. This was replaced by an OPA277P. The differential driver used a pair of OP37EZ's which were also replaced by OPA277P's Resistor values were optimized to minimize drift and noise.

An essential change in the DRU was to replace coupling capacitors with short circuits. Values of R3, R4 and C3 (figure 2) were chosen such that when a 100 mA spill is detected the comparator will generate a Fail (beam abort) signal in 200 μs if the comparator set point is at one volt. For the operator interface, C1, C2 and R2 were chosen so that the band width is 1 kHz when the CMOS Band Width switch is open and 33 Hz when this switch is closed. The reason for these choices are further explained below.

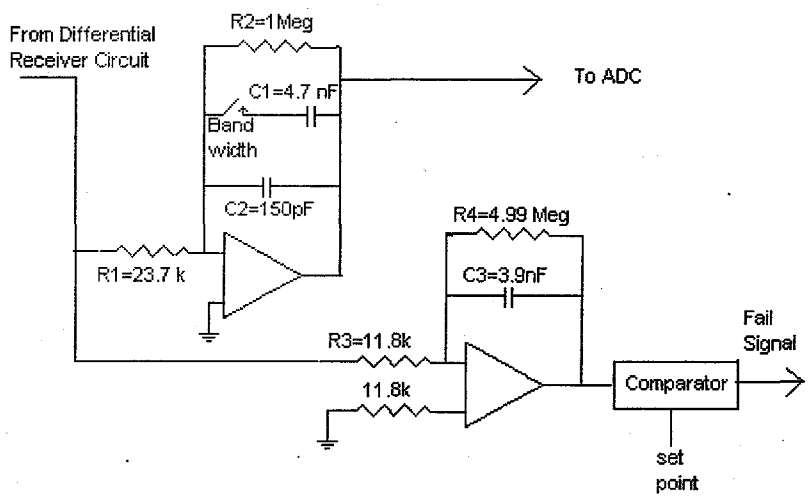

Figure 2. Part of the Differential Receiver Unit

BEAM LOSS MODEL

The worst beam loss situation would occur if the beam hit an object sticking into the beam pipe perpendicular to the beam direction. If the object were stainless steel, it could start to melt in 2 _s. The fast protect system is not intended to protect against this situation. The model described below [4] is intended to protect the beam tube under the worst realistic conditions which are likely to occur.

As the beam exits the RFQ it has an rms radius of about 1 mm. The strongest deflector available near the RFQ exit is a steering element. It can cause a maximum deflection of about .0125 radians. Thus the worst case situation would be a 6.7 MeV 100 mA gaussian distributed beam hitting the beam tube at an angel of 0.0125 radians. As the beam moves down the HEBT its rms radius grows to about 3 mm. Also, to simulate what might happen in a partial beam spill, fractions of the beam spill ellipse were used. To get a fractional beam spill, the incident angle would probably be greater than .0125 radias, and the beam would diverge to at least a 3 mm radius everywhere in the HEBT.

For beam loss greater than 0.93 mA, an rms beam radius of 1 mm, a .0125 radian angle of beam to beam pipe, and a 6.7 MeV beam energy was used. For losses below 5.5 mA, a beam rms radius of 3 mm was used with .0125 radian incident angle. The melting point of the beam tube is about 1423 °C. The fail point temperature is taken as 700 °K = 427 °C. In practice, this limit may be exceeded by several hundred degrees because of uncertainty in the temperature calculations. Thermal calculations were done using the finite element code COSMOS. The following were taken into account: (beam tube taken as 1/16 in. 304 stainless)

1)Power distribution due to a fraction of gaussian beam on the beam tube surface.
2)Specific heat and its variation with temperature.
3)Thermal conductivity and its variation with temperature.
4)Emissivity and its variation with temperature.

5)Convection cooling.

Time versus temperature graphs were generated for 13 different loss currents down to .053 mA. Below 0.225 mA loss the beam tube will never reach the melting point, but the fail point temperature of 427 °C is still exceeded. Figure 3 shows the data points with a quadratic fit to the natural log of the 427 °C points.

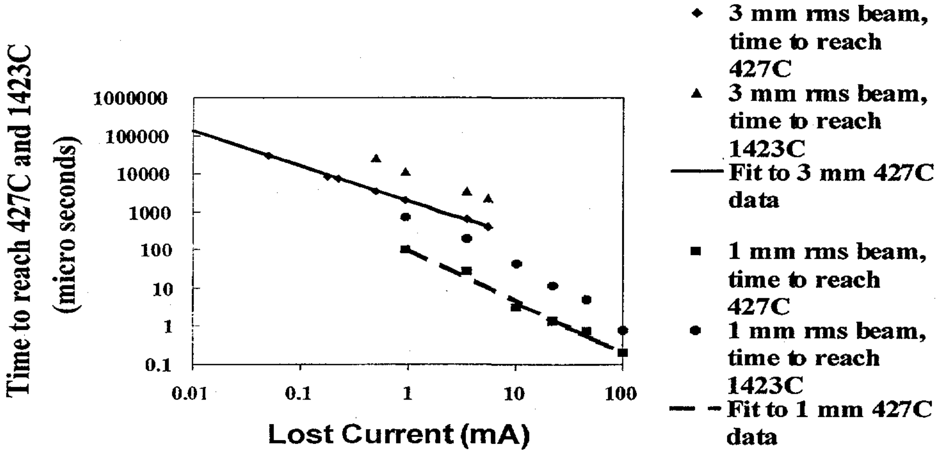

Figure 3. Time for 304 stainless to reach 427 °C and 1423 °C

SYSTEM SENSITIVITY

Radiation dose calculations were performed using the code MCNP[5] for 1 mA beam loss on stainless steel. These included attenuation due to steering and quadrupole elements. The beam loss monitors were located about 87 cm from the beam tube. There was one monitor at the start of the (3.5 m long) HEBT (HEBT_1_BLM), a second one was near the middle (HEBT_3_BLM) and third one was at the end (HEBT_3_BLM). A typical beam loss situation consisted of beam hitting the beam tube one meter from a detector, with the beam passing through part of a steering element and resulting in a dose rate at the detector location of 4 mRad/s for a 1 ma beam loss. The highest expected dose rate at a detector for a 1 ma beam loss was predicted as 10 mRad/s. The ionization tube sensitivity was measured to be 59 nC/Rad. Thus for a 4 mRad/s signal, the expected output would be 0.236 nA. To simplify discussion a nominal situation is here defined as an X mA beam loss producing X times 4 mRad at a detector.

CHOICE OF COMPONENTS

The transimpedance gain from the Ionization Chamber output (figure 1) to the input at figure 2 was adjusted to 10^7 ohms. In figure 2, R1 and R2 were chosen so that the ADC input would be 10 volts for a continuous 100 mA beam loss in a nominal

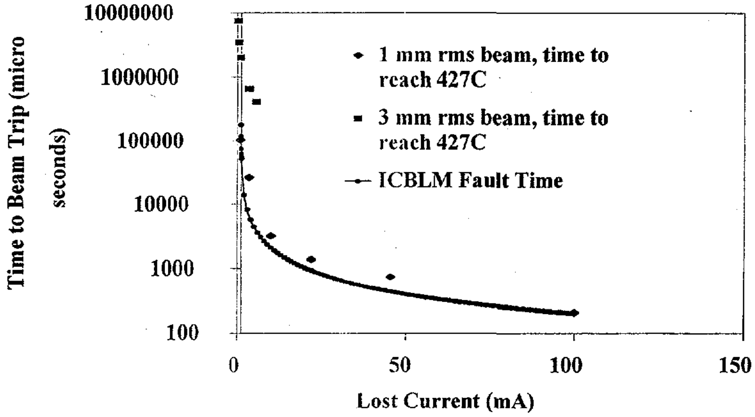

Figure 4. Ionization Chamber Beam Loss Monitor Fault Time.

situation. The ADC samples this beam loss signal up to 10 times a second and its digital output is used by EPICS software to display beam loss information for the operator.

Figure 3 shows the relation between time in which the beam needs to be turned off (taken as the time needed to reach 427 °C) after the onset of beam loss and the current being lost. It will be demonstrated below, that because of temperature induced offset drifts in the beam loss electronics, it would be counter productive to try to protect LEDA below 1 mA of beam loss with this system. Referring to Figure 2, the ratio of R4 to R3 was chosen so that for a Imin = 1 mA nominal continuous loss the comparator input will be 1 volt. Imin = 1 mA in a nominal situation was chosen as the highest loss at which no trip will occur. The largest expected loss is the design operating current of LEDA and is Imax = 100 mA. To a good approximation in the nominal situation Imin/Imax = τ/(R4*C3) where τ = time allowed to shut the beam down with Imax beam loss. From the data used to generate figure 3, τ = 200 µs. That is, for a 100 mA beam loss the beam will be shut off in 200 µs. This results in R4*C3 = 20 ms. Choosing R4 as 4.99 Meg results in the values shown on figure 2.

A good approximation for the time it will take to shut down the beam is given by:
T = -R4*C3*ln(1-(Imax/I)*(τ/(R4*C3))) where I = lost current. Inserting the numeric values gives
T= -.019461*ln(1-1.0277 / I).
This is plotted in µs as the solid line in figure 4. T approaches infinity at 1.0277 mA, the highest (nominal) beam loss for which there will be no Fail signal. Also plotted is the calculated time for the beam tube to reach 427 °C [4]. It can be seen that, in the nominal situation, for lost current greater than about 1.03 mA, the beam is shut down in time to prevent damage to the accelerator.

TEST RESULTS

After modification, each RSU and DRU were tested by placing their RSU in a temperature-controlled oven. Figure 4 shows one set of results. It shows the temperature and the comparator input (figure-2). The comparator input voltage is equal to the current in mA in the nominal loss situation. It can be seen that a sudden temperature change results in a transient voltage (or equivalent lost current) output lasting for about thirty minutes. It is believed that the transients are caused by a thermocouple effect in the circuit board, and is unrelated to the OPA277P op amp. However no experiments were done to confirm or deny this. The change from before to after the transient is about of 100 mV for the 20 °C change.

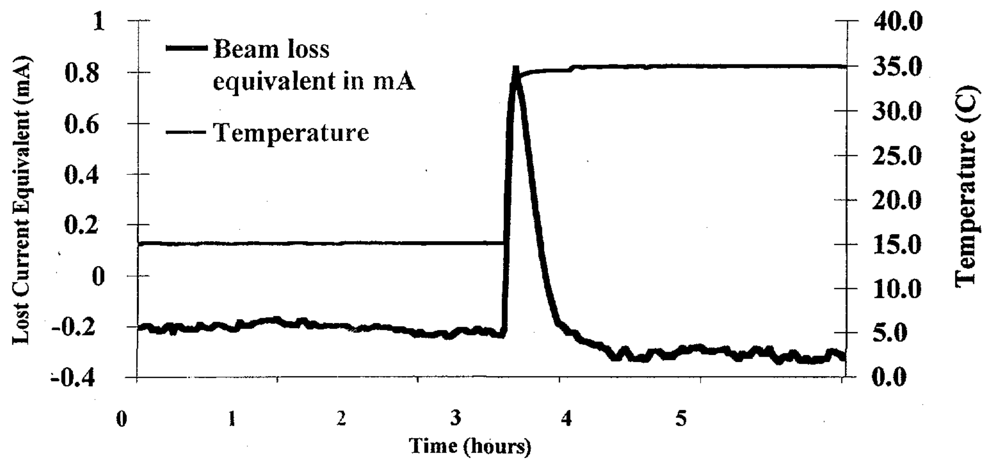

Figure 5. Apparent transient beam loss caused by a sudden temperature change.

The input offset voltage drift of the OPA277P used as the transimpedance amplifier in the RSU is typically 0.1 _ V/ ° C. For the 20 ° C change this would cause a 93 mV change at the comparator input. The input bias current drift is typically about 0.002 nA/ °C. This would result in a 170 mV change at the comparator input. These numbers are comparable to the 100 mV observed for the difference from before the transient to after the transient. This 100 mV corresponds to a 0.1 mA beam loss, and it sets the limit on to how low a loss current the machine could have been protected to in the absence of the transient observed in figure 5. Measured noise at the comparator input is 8 mV rms. Thus 10 X .008 or .08 mA is the minimum nominal current to which LEDA could be protected to by this method.

Figure 6 shows a 72 hour comparator input voltage history for the three RSU's installed in the LEDA HEBT. The largest change observed is about 250 mV which corresponds to .25 mA lost nominal current. This measurement is what dictated that the lowest current to which the machine will be protected for will be 1 mA loss without causing excessive (temperature change related) false trips. Additionally, a drift correction procedure has been implemented. In this, the apparent beam loss is measured every few hours with the actual beam off. The result is subtracted from loss data taken with beam.

A quantitative calibration of the beam loss system was performed. This was done by steering some of the beam onto a water cooled collimator, while observing the flow rate and the temperature difference between the water inlet and outlet. 0.3 kW of power was deposited by a 2% duty cycle 100 mA beam. The lost current while the beam was on was 2.24 mA. An ionization chamber detector was 1m from the beam loss point, and it reported a beam loss of .45 mA during the time the beam was on.

Thus the calculated response of the detectors over estimated the actual response by a factor of five. A similar measurement was performed using the Silicon Carbide 100 _m wire scanning profile monitor, discussed else where in these proceedings [6].

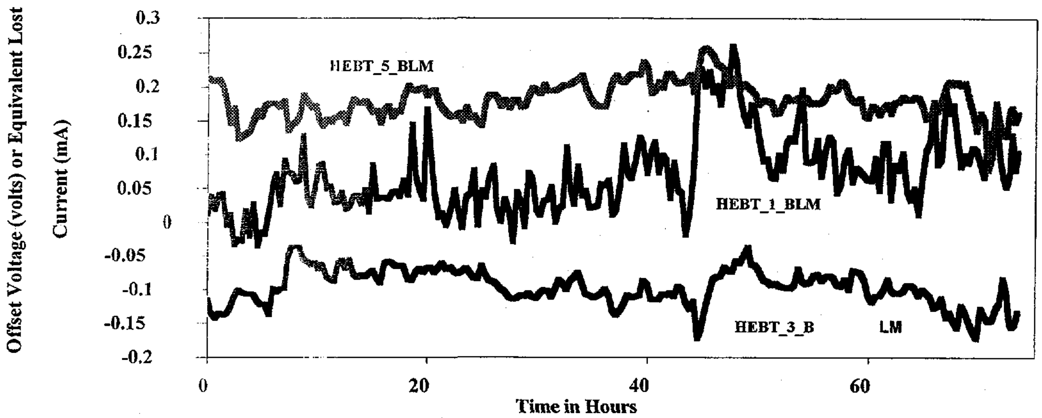

Figure 6. Drift of apparent lost current caused by temperature change for installed RSU's.

This requires the reevaluation of both the operator display part of the system, as well as the fast protect system. The operator display numbers need to be multiplied by a factor of five. What corresponded to a 0.25 mA loss is now a 1.25 mA loss and the lowest nominal beam loss for which the HEBT is protected has to be raised from 1 mA to 5 mA. Leaving the electronics as shown in figure 1 and 2, would result in a fail signal 1000 μs after the onset of a 100 mA loss. This is inadequate protection, because the beam tube may start to melt after 800 μs.

IMPROVEMENTS AND UPGRADES

In order to improve on this an LND, INC. 52102 proportional tube was tested. It was used to replace the ionization chamber in a spare remote sender unit and was connected to a spare DRU in the VME like crate. This RSU was placed near the first ionization chamber RSU along the beam line. The outputs of the two types of detectors were compared while varying the voltage to the proportional tube. The proportional tube voltage was finally set to 1800 volts where its output signal was 100 times that of the ionization chamber. This higher output signal permits a factor of 20 reduction in the system gain, which in turn reduces the effect of drift by a factor of 20. The bandwidth required for the fast abort system is 8 Hz. The rise time constant for the proportional tube is about 1.5 ms. This corresponds to a bandwidth of 100 Hz and satisfies fast protect speed requirements.

In upcoming experiments to be performed with a modified LEDA, 100 μs beam macro pulses will be used (The Halo Experiment will measure and try to control the evolution of beam halo for a 100 mA proton beam). It is also hoped that 100 mA 100% duty factor operation will continue in coming years. Thus a new set of requirements will be imposed on the beam loss monitor system:

1) Effect of drift and noise less than 0.1 ma beam loss equivalent at 8 Hz.
2) Signal rise/fall time constant about 1 _s (170 kHz).
3) All electronics will be DC coupled.
4) No active electronics near the beam line.

One way to achieve this is to use a scintillator like BGO attached to a photo multiplier tube. The tube gain will be adjusted so a 1 mA nominal DC beam loss will result in a 1 μA DC anode current. The concept has been tested using 1 cc of GSO attached to a Hamamatsu R2059 PM tube. The PM output was connected to 170 ft. of 50 ohm cable. The cable output was connected to a transimpedance amplifier using an OPA627 configured with a gain of 23600 ohms and band width of 170 kHz. The cable capacitance was about 4 nF. Calculated noise and drift due to a 10°C temperature change in the amplifier is less than the expected signal due to .025 ma nominal beam loss. With the full 170 kHz bandwidth, the main source of noise appeared to be from chopper power supplies associated with PM high voltage. With 1000 volts applied to the PM tube, there was a peak AC noise signal equivalent to 0.6 mA of lost current. This can probably be eliminated as a problem by using a larger scintillator. In addition, work will be done to try to eliminate most of the power supply noise. After the loss signal goes through the 8 Hz fail signal amplifier, the noise is reduced to less than 0.01 mA lost current equivalent.

In order to minimize development time and to utilize as much as possible of what already exist, the front end of the DRU boards will be modified. The differential receiver on this board will be reconfigured into a transimpedance amplifier. The rest of the board will not be changed, accept for some gain resistors. The interface to the control system will remain the same accept for increasing the number of units from three to seven.

The detectors being purchased for this system will consist of 2 in. diameter by 0.5 in thick BGO attached to a Hamamatsu R-375 PM tube. BGO was chosen because of its relatively good radiation resistancs, and the PM tube was chosen because of its high cathode current capability. The detectors will be mounted so it will be easy to move them perpendicular to the beam and to change the radiation levels they are exposed to over an order of magnitude.

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