EXPERIENCE WITH PHOTOMULTIPLIER BASE BEAM LOSS MONITORS (PMBLM) AT THE LOW ENERGY DEMONSTRATION ACCELERATOR (LEDA) *

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Abstract

LEDA is presently configured for investigating space charge induce halo formation[3]. A total of seven PMBLM units are placed along the transport between the RFQ and the beam dump. Each PMBLM consist of a 5 cm diameter by 1.25 cm thick CsI(Tl) scintillation crystals attached to 5 cm diameter 10 or 11 stage photomultiplier (PM). The voltages to the PM's are adjustable thus giving the system a wide dynamic range. Approximately 200 ft. of cable caries the output current to a transimpedance amplifier outside the high radiation area. The system bandwidth is about 170 kHz thus allowing the observation of 1 μs rise time constant signals. After further processing the PMBLM signals are presented to A/D's in a VXI crate for data acquisition by the EPICS control system. Beam loss fast protect signals are also generated. This paper will discuss the motivation, design and operational experience with this PMBLM system.

1 MOTIVATION

The use of Ionization Chamber based beam loss monitors in LEDA was described earlier[1]. Despite the use of components with low temperature related drift, unacceptably large offsets drifts were observed. The drifts were an order of magnitude larger than would have been expected from temperature related gain changes. They were probably due to thermoelectric effects arising from temperature gradients induced by changing ambient temperature. Additionally, sudden offset changes were occasionally observed, possibly indicating radiation effects on the preamplifiers located adjacent to the detectors.

In the present (Halo) mode of operation the beam pulse length is about 30 μs. Future operation may involve 100 mA CW beams and a few μA of loss detection may be required. The fast protect feature[1] needs to be implemented. The system should be designed to last several years in the expected radiation environment. A photomultiplier plus scintillator system was chosen as a system that would meet these requirements. This system needed to be completed in a few months thus limiting component selection to items that could be procured in time.

2 SYSTEM HARDWARE DESCRIPTION

Bicron Inc. manufactured 8 detectors. The PM is either a ETI9202QB or ETI9266QB. The scintillators and (quartz window) PM's are expected to last 10 years or more in the radiation environment of LEDA. High voltage is supplied by a LeCroy model 1454 mainframe, containing a 1461N 12 output high voltage module. The PM anode is directly connected to a 50 Ω cable that takes the output current to a transimpedance amplifier located outside the radiation area.

The signal processing is done by the same electronics as was used previously[1] except that the differential input circuitry was modified to be a transimpedance amplifier with a 170 kHz bandwidth. An active low pass filter that can be switched between a bandwidth of 33 Hz and 1 kHz presents the loss signal to an ADC located in a VXI crate. This filter can also be operated in a charge mode by temporarily shorting across the feedback capacitors and than letting the charge build up before sampling by the ADC. The output of the transimpedance amplifier also goes to the accelerator fast protect circuit[1].

The LeCroy high voltage supply is connected to the LEDA EPICS control system by a serial port. The rest of the interface to the control system is done through Green Springs ADC, D/A and binary I/O modules on cards that plug into a VXI crate.

3 DETECTOR CALIBRATION

Each PM plus scintillator assembly was calibrated with a 6.03 mCi Cs^{137} source and a calibrated ionization chamber detector (Eberline model RO-2). The source was placed at the bottom of a shielded 5X5 cm box and the ionization chamber detector was placed at the open top end about 2 in. away. Typically the reading was 190 mR/hr. The PM detector was than placed in the same place as the Eberline. The PM detector output current was measured over a range of high voltage until the output current exceeded 10 μA DC. The results for the 8 detectors are shown in figure 1 all normalized to 190 mR/hr.

To extend the gain curve, the data was plotted as shown in figure 2 (diamonds). The manufacturers typical gain curve is a straight line when plotted as shown (squares). The slope of the typical gain curve was kept unchanged but the line was moved so it coincides with the last data point. This combined data set was fitted with a fourth order polynomial P(x) to complete the extension. Given a desired output current i_0 for a specified dose rate r in R/hr a current in nA is calculated: $i=.19i_0/r$. Than $x=\log(i)/10$ and the tube voltage is $10^{P(x)}$.

The worst error in output current resulting from slope mismatch between the measured data and the extrapolated

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points is estimated to be about a factor of 2.5 at the highest gain setting. Current errors in the region of the measured data are about 10%. Fast protect is normally operated in this low error region.

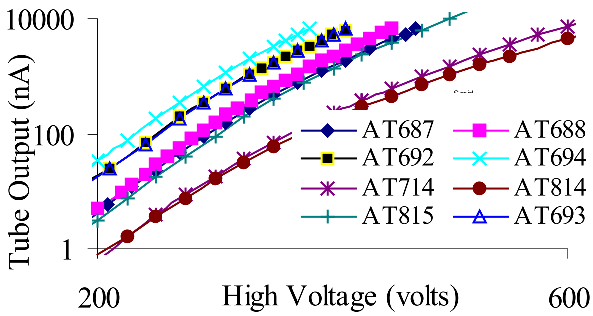

Figure 1. Gain Data For All Detectors

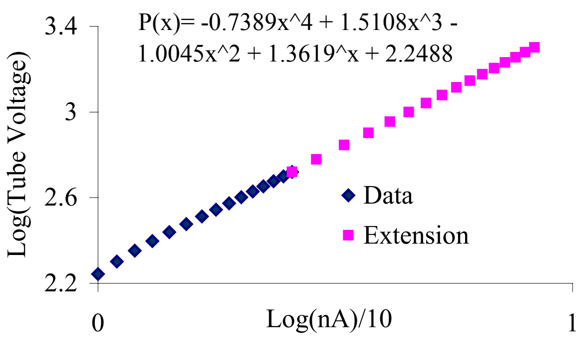

Figure 2. Extension of Gain Curve AT815

1 mA loss on the stainless steel beam tube is calculated to produce 10 R/hr at 1 m from the loss point[1]. A nominal X1 gain is defined as producing 1 µA output from the PM tube for a 1 mA beam loss. All the detectors using ETI9202QB were placed 1 m above the beam line. The operating voltage for an X1 gain is obtained by letting i=.19/10. The detectors containing ETI9266QB tubes were placed 2 m from the beam tube and the voltage for an X1 gain is obtained by letting i=.19/2.5. Higher tube gains were defined: X10 will produce 10 µA output from the detector; X100 will produce 100 µA etc.

Dark current was measured on each detector. It is typically equivalent to .2 nA of beam loss.

4 SYSTEM SOFTWARE DESCRIPTION

Below is a brief and partial description of the operations software running under EPICS.

There are an extensive set of EPICS screens for controlling and monitoring the high voltage on the PM's. These were obtained from TJNAF Lab[2]. A screen was produced for loading all the voltages to obtain a gain of Xn on all the tubes where n=0.1, 1,…,1000000.

There are five operating modes controlled from the main operator screen: 1) Pulsed Current, 2) Pulsed Charge, 3) CW current, 4) CW Charge, 5) Calibration. In pulsed mode the loss signal can be sampled and digitized before the beam comes on. This is used to correct for offset drift. For CW operation, the only way to correct for offset drift is to run a Calibration (5). For this the beam needs to be off and the offset voltages from all detectors is measured and stored. These offset voltages can than be used either in the pulsed or CW modes. In the charge modes, the feedback capacitor in the low pass active filter is discharged by switch across it. The output voltage is sampled a fixed time later and lost charge and current are calculated. Results are displayed and archived.

The main operation screen also provides for entering set points for the fast protect system and monitoring fast protect status.

5 CALIBRATION CHECK WITH BEAM

In order to check the adequacy of the beam loss calibration a 1.6 mA, 10 µs beam was sent through the RFQ and all but the first 12 quads were turned off. On the scale shown on figure 3, beam confinement stopped at 157 cm. Figure 3 shows the output voltage of the first five detectors (referred to as 1 through 5 from left to right) measured using the output of the transimpedance amplifiers. If all the loss were 1 m from one of the detectors, that detector should have read 37 mV for X1 high voltage settings used for this measurement. The largest reading is 77.6 mV, which is twice as high as the predicted highest value.

Before the quads were turned off, the reading on all the detectors was zero when the beam was on. In figure 3, the first detector (at 0 cm) read 2.72 mV and the third (at 397 cm) read 69.6 mV. Assuming $1/r^2$ decrease in signal, using the observed values on detector 1 and 3 and a point source loss, the loss could be explained as at a point just below detector 3. The emitted radiation is expected to be isotropic and thus if the loss were at this point, detector 1 and 5 should have read the same and also 2 and 4. This is clearly not the case. In fact there appears to be no point about which the losses are symmetric. A reasonable interpretation of the graph is that much of the beam is lost between detectors 2 and 3, and some of it is lost as far down as detector 5. Therefore the loss reported by the detectors is at least two, and possibly four time higher than what is actually lost.

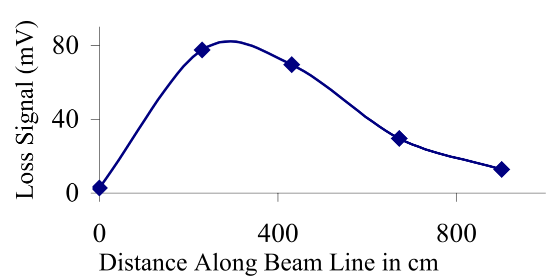

Figure 3. Observed Lost Current

6 MEASUREMENT OF OFFSET DRIFT

The EPICS archive system saves the ADC readings for each beam loss monitor channel about every 30 seconds. If the accelerator is off, this record can be used to check for drift of the processing electronics. Figure 4 shows this type of data in histogram form for three days for one of the ADC's. The average channel number is 2.90 and the rms deviation from this is 0.31 channels. Each channel is 5 mV and for an X1 PM gain setting each 100 mV corresponds to 1 lost mA. Thus the rms drift is less than the signal that would be measured for .016 lost mA with an X1 gain setting. With a gain of X10, the drift is equivalent to less than .0016 mA, and decreases in inverse proportion to the PM gain setting.

The results in figure 4 were obtained with the 33 Hz low pass filter. The rms deviations discussed above are a result of noise and drift combined. Therefore the statements about drift in the previous paragraph also apply to the maximum rms noise with the 33 Hz filter.

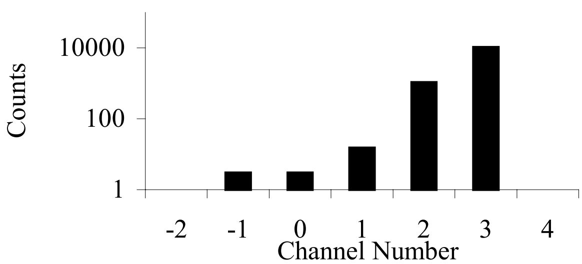

Figure 4. ADC Channel Number Distribution

5 PC SATURATION + DYNAMIC RANGE

The time it takes to produce a fast protect signal depends on the PM output current. If this current is lower than it should be, the fast protect signal will not be produced in time, and accelerator damage can result.

To test for photocathode (PC) saturation, one of the ETI9202QB based detectors was moved next to the beam tube so it was about 15 cm from a collimator. The beam was steered into this collimator. A second detector one meter away was used to determine the actual beam hitting the collimator.

Figure 5 shows the results. The saturation of the photocathode (PC) on the tube near the beam line is clearly illustrated. Besides the data, a straight line extrapolation of the first five points is also shown and it can be seen that deviations from linearity start at about 30 mA loss. No correction for the calibration error investigated in section 5 was made to the data of figure 5. Thus saturation occurs at around 10 mA loss and this is the upper limit of the loss measurement range. Problems with the fast protect can be eliminated by moving one or two of the ETI9202QB based detectors to a distance of about five meters or more from the beamline.

The .2 nA loss equivalent dark current is .07 nA with the recalibration of section 5. Processing electronics drift is equivalent to 5 μA at 1X gain. These produce the same reported loss with a 10000X gain. Therefore the lowest stable reported loss is about 0.1 nA and the dynamic range is 10^8:1. In practice it is difficult to observe losses of less that 3 μA because of radiation from the beam dump and RFQ.

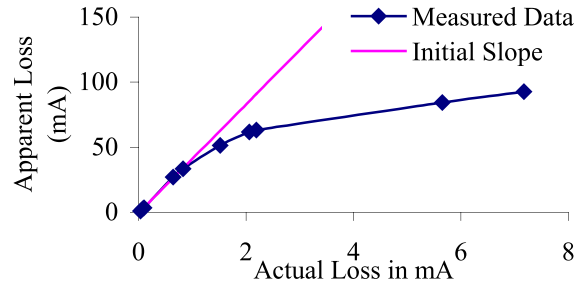

Figure 5. Data and Extrapolation

6 SIGNAL RISE TIME

A qualitative inspection of most scope traces generated when displaying waveforms from the transimpedance amplifier outputs indicate the presence of a time constant much longer than can be readily explained. Figure 6 shows a scope trace using an X1000 gain setting with nothing inserted into the beam path to cause radiation. The beam pulse is about 30 μs with rise and fall times of about 5 and 20 μs. The beam and the amp output start at 180 μs from the left. The trace leaves the display for about 50 μs. It returns at about 260 μs from the left with the trace very jagged. When this signal is averaged over many beam pulses, most of the jaggedness goes away, and the trailing edge becomes a smooth exponential looking rise with a time constant of 150 μs (+/-25%). An expansion and examination of one of the trailing spikes of figure 6 results in a decay time constant of 1.8 μs (+/-25%). The time constant of the amplifier was designed to be 1μs, and is measured as 2.2 μs with a signal generator.

The cause of the spikes and tail when averaged is unknown at present. It may be due to slow neutrons from the beam dump or a 150 μs level in the stainless steel beam tube.

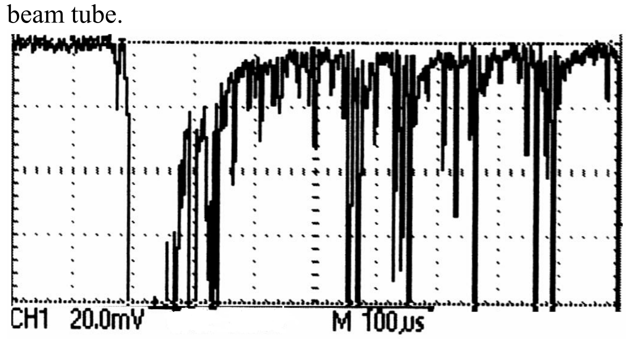

Figure 6. Scope Trace of a Transimpedance Amp Output

7 REFERENCES

[1] W. C. Sellyey, J. D. Gilpatrick, D. Barr, J. F. O'Hara "Experience With Beam Loss Monitors In The Low Enegy Demonstration Accelerator (LEDA)", Beam Instrumentation Workshop 2000, AIP Conference Proceedings 546, p585.

[2] J. Coleman, TJNAF, Private Communication.

[3]J. D. Gilpatrick, et al., "Experience with The Low Energy Demonstration Accelerator (LEDA) Halo Experiment Beam Instrumentation", this conference.