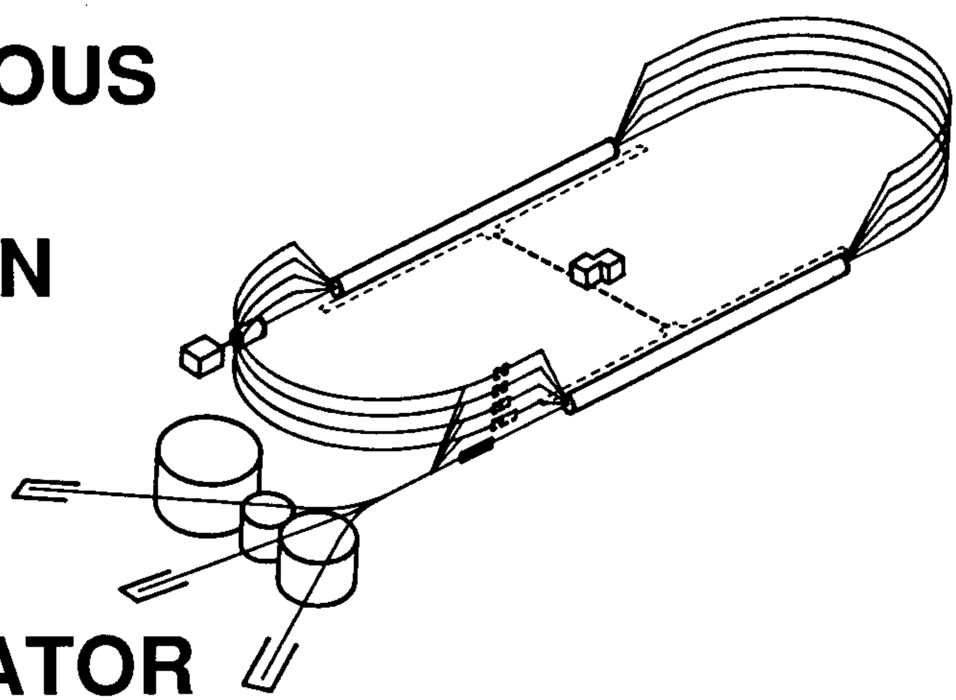
CEBAF PR-90-022
October 1990

The Beam Loss Monitors at CEBAF

John Perry
Continuous Electron Beam Accelerator Facility
12000 Jefferson Avenue
Newport News, VA 23606

CONTINUOUS
ELECTRON
BEAM
ACCELERATOR
FACILITY



SURA Southeastern Universities Research Association

Newport News, Virginia

THE BEAM LOSS MONITORS AT CEBAF*

John Perry
Continuous Electron Beam Accelerator Facility
12000 Jefferson Avenue, Newport News, VA 23606

REQUIREMENTS

The CEBAF beam will carry about 800 kW of power concentrated into a 200 μm diameter. Current estimates are that a stray beam will burn through the vacuum wall within 50–100 μsec. The CEBAF Fast Shutdown (FSD) system and the Beam Loss Monitor (BLM) system have been designed to prevent such an occurrence.

Initial estimates of the time constraints[1] dictated that FSD sensor functions would have about 10 μsec to detect and forward a fault to the FSD. The BLM is one of the sensor functions; therefore, we designed it to this specification. Reliability of the FSD was a critical concern that dictated a 5 MHz permission signal sent from the sensor function; permission exists when the signal is present, and is removed if the signal is not present for any reason, including system failure. A strong desire was expressed among the CEBAF design community for a short history of the radiation levels before a fault condition. All these considerations went into the design of the BLM system.

ARCHITECTURE

The BLM detects a beam loss fault by the radiation shower generated by the interactions between the beam electrons and surrounding matter. The critical time limit dictated by the vacuum wall burn through time placed strong constraints on the type of sensor used, on the signal conditioning method, and on the fault detect processing.

The BLM's fit into the FSD system as the leaves of the FSD tree (figure 1). This makes the fault trace fast and straightforward. Part of the FSD specification for permission inputs is that each input hold its fault state until queried by the FSD. The FSD only holds permission state information for the control system, and cannot distinguish among the various types of faults except as to their location on the tree.

Therefore, the BLM module must not only condition the sensor signal; it must also hold its own fault state, accept commands to set radiation trip levels, and provide this information to the control system upon command. We have successfully incorporated all these functions into a four channel CAMAC module which sends four independent FSD permission signals to the FSD interlock tree,

* This work was supported by the U.S. Department of Energy under contract DE-AC05-84ER40150.

accepts independent trip level commands for each channel, provides current radiation level for each channel, and keeps for access by the control system a −3 ms to +1 ms log of each channel's radiation level history around a fault.

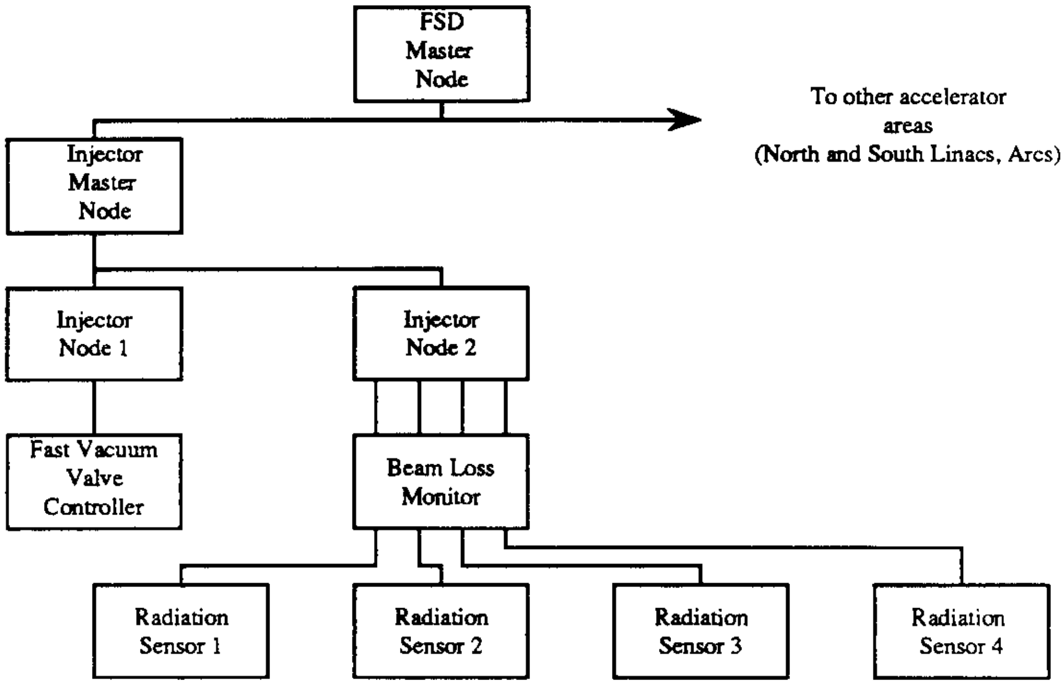


Figure 1. Beam Loss Monitors in Fast Shutdown system.

SENSORS

We investigated a number of types of radiation sensors for our use. Gas chambers were excluded quickly because they are mostly far too slow to satisfy the 10 μsec sense requirement. Some can react fast enough to remove permission within the limit, but they all require a high voltage power supply, and a great deal of manual intervention for construction and maintenance. We, therefore, investigated photoemissive and photoconductive devices for sensitivity and speed to see if their generally lower cost systems could satisfy our needs.

Preliminary research revealed[2,3] that photomultipliers would respond strongly to scintillation in their own envelopes, removing the need for scintillator material. Further, even the least expensive photomultipliers were sensitive enough to supply our needs. We looked at these as the first alternative to the very expensive Aluminum Cathode Electron Multipliers (ACEM's) used at CERN.[4] The question remaining was whether the envelope would darken during the life of the accelerator, making the photomultipliers blind to their own scintillation. The 10^5 rads of exposure required according to the literature to reduce their sensitivity to about half the initial value[5] will be sustained over a period of at least three years.[6] If the sensors respond well to visible wavelengths, that time will be stretched even further. The photomultipliers we are currently investigating are a factor of 10 less expensive than the ACEM's; hence, they are quite cost-effective. Furthermore, since the BLM was emphatically intended as an interlock system and not as a measurement system, we did not see gradual degradation in the response to fault level radiation as a handicap.

This still left us with the rather expensive high voltage power supply required for photomultipliers. We are presently investigating the use of vacuum photodiodes and silicon PIN diodes with scintillator material to eliminate the need for the high voltage. Preliminary results with vacuum photodiodes are very encouraging, and the lifetime considerations mentioned for photomultipliers apply equally to vacuum photodiodes.

NODE MODULE

The BLM module (figure 2) has been explicitly designed to permit a number of different signal conditioners to be used. This allowed us to design the fully specified control system interface immediately, leaving the less well defined analog system for further development. Since it was already established that the ACEM's and photomultipliers would fulfill our requirements at considerable cost, it was clear that the only questions lay in the kind of sensors we could use.

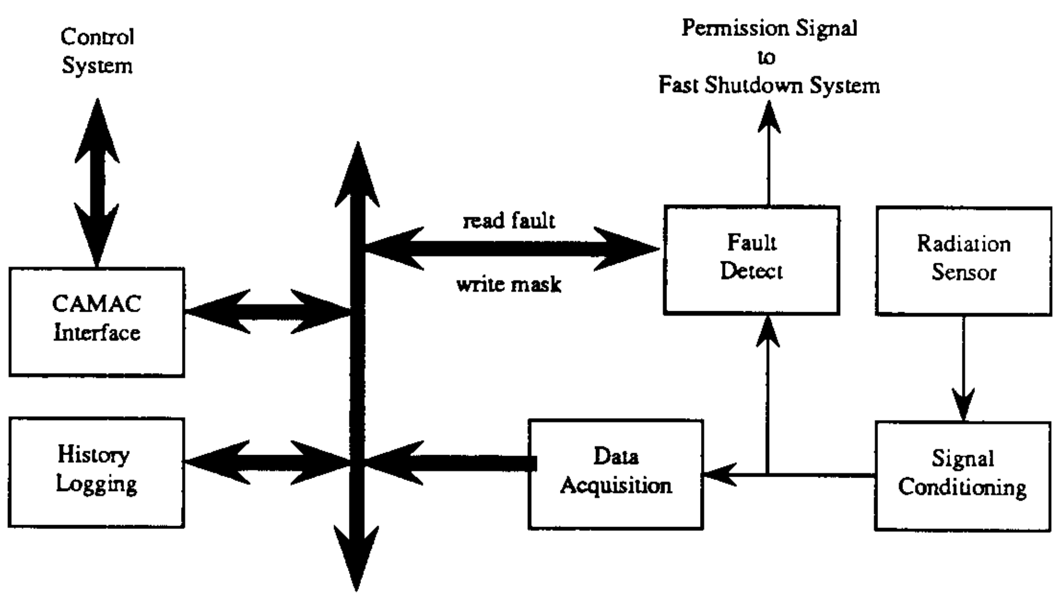


Figure 2. Beam Loss Monitor block diagram (one of four channels).

The module is therefore divided into a 3/4 CAMAC data acquisition board and a 1/4 replaceable analog signal conditioner. In principle, the BLM module could be used as a low resolution 8-bit data acquisition module with limited sequential storage.

The acquisition module interfaces the data acquisition blocks to the CAMAC bus, translating CAMAC function codes and addresses into command writes and data reads of the acquisition circuitry. The signal conditioner board allows us to continue to develop lower cost sensors, and fortuitously allows us to adapt a common interface to different sensors. This will permit us to back up whatever BLM sensors we choose with a slower gas-type detector. The present organization will allow us to use the same acquisition interface for both types of sensors, avoiding yet another software/hardware development cycle. The software interface provides the following functions:

- Function F0 (CAMAC read)
  - A0–A3: Read current ADC data (8 bits plus fault bit)
  - A4–A7: Read current mask and fault status
    - Bit 0: Mask status
      - 0 → channel may remove permission
      - 1 → channel may not remove permission
    - Bit 1: Fault status
      - 0 → channel has not tripped since last reset
      - 1 → channel is in tripped state
- Function F16 (CAMAC write)
  - A0–A3: Write current trip point (8 bit value for DAC)
  - A4–A7: Set mask and fault conditions
    - Bit 0: Mask command
      - 0 → allow channel to remove permission
      - 1 → prevent channel's removing permission
    - Bit 1: Fault command
      - 0 → clear any existing fault
      - 1 → generate a test fault

Setting both mask and fault in a command is not used (however, it results in safe operation if the module is tripped).

- Function F2 (CAMAC destructive read)
  - A0–A3: Read channel history (Q-stop block protocol)

The data acquisition circuitry consists of an inexpensive 8-bit analog-digital converter with sequencing circuits that control both the ADC and the history block, which is a first-in, first-out storage chip. All the sequence control is done by two other chips: a dual monostable and a 20-pin programmable logic chip. This arrangement keeps the acquisition running constantly, updating the FIFO at each ADC cycle. When the channel detects a fault and the control system must read the history, it sends an F2 read command. The acquisition system does not stop for an F2 command; the channel must be faulted to get intelligible data. A test fault suffices.

Finally, the fault circuitry runs in parallel with the other functions. The fault circuitry monitors the conditioned analog voltage coming from the signal conditioning block without disturbing it in any way, until a fault is detected. Then the fault signal removes the 5 MHz permission from the output to the FSD, sets the fault bit in the CAMAC status register, and stops the acquisition cycle after approximately 1 millisecond.

EXPERIENCE

Prototypes of the BLM module in the FSD system have been running and successfully shutting down the accelerator during our recently concluded injector tests. Both photomultiplier tubes and vacuum photodiodes have been incorporated into the system, and have given full scale signal levels (5 volts out of the signal conditioners) for stray beam radiation levels. Placement of the sensors has not usually been particularly critical; however, we have as yet made no effort to characterize response vs. placement. Neither have we as yet made any attempt to measure radiation levels vs. signal strength in the accelerator. We have attempted to make such measurements at the cancer treatment center of a local hospital; however, in the limited time available we were not able to reduce the radiation level at the sensor enough to get linear readings suitable for obtaining numeric relations. When our beam, whose intensity can be controlled, turns on again, we expect to be able to make such measurements.

The CEBAF beam loss monitor design has shown itself to be a highly effective tool in protection for and analysis of the operation of the CEBAF injector. Further development of sensor technique is required to optimize cost and response.

REFERENCES

1. The CEBAF Fast Shutdown System, CEBAF PR 90-015, given at the 1990 LINAC Conference, Albuquerque, New Mexico, September 1990.

2. Young, Andrew T., "Cosmic Ray Induced Dark Current in Photomultipliers", *Review of Scientific Instruments*, Vol. 37 no. 11 (Nov. 1966), p. 1472.

3. Makeev, S. N., Petrov, V. A. Smelyanskii, I. M., Trubitsyn, N. M., "Variation of Photomultiplier Anode Current for Continuous and Pulsed Gamma Radiation", Trans. in *Instr. and Exp. Techn.* (USA), vol. 29 no. 1, pt. 2, (Jan–Feb 1986), pp. 182–185.

4. Agoritsas, V., Beck, F., Benincasa, G. P., Bovigny, J. P., "A Microprocessor-Based System for Continuous Monitoring of Radiation Levels Around the

CERN PS and PSB Accelerators", presented at the 2nd International Workshop on Accelerator Control System, Los Alamos, New Mexico, October 7–10, 1985.

5. Takasaki, F., "A Note on Radiation Damage to Photomultiplier Tubes", Appendix 15, *Radiation Effects at the SSC*, SSC-SR-1035, M. G. D. Gilchriese, Ed., Publ. by SSC Central Design Group, Lawrence Berkeley Laboratory, June 1988.

6. Stapleton, Geoffrey, *Summary of Radiation Damage Problems in Beam Enclosures*, CEBAF TN-0069, Dec. 1987.