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# THE AGS BOOSTER BEAM LOSS MONITOR SYSTEM*

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## ABSTRACT

A beam loss monitor system has been developed for the Brookhaven National Laboratory Booster accelerator, and is designed for use with intensities of up to $1.5 \times 10^{13}$ protons and carbon to gold ions at 50-3 x $10^9$ ions per pulse. This system is a significant advance over the present AGS system by improving the sensitivity, dynamic range, and data acquisition. In addition to the large dynamic range achievable, it is adaptively shifted when high losses are detected. The system uses up to 80 argon filled ion chambers as detectors, as well as newly designed electronics for processing and digitizing detector outputs. The hardware simultaneously integrates each detector output, interfaces to the beam interrupt systems, and digitizes all 80 channels to 12 bits at 170 KHz. This paper discusses the design, construction, and operation of the system.

## ARCHITECTURE

The AGS Booster Radiation Loss Monitor (BRLM) system incorporates several features of the AGS radiation loss monitor system and provides new capabilities.[1][2] The most unique feature of the BRLM is the adaptive dynamic range limit, where the upper limit of the measurement range is increased with the lower limit and resolution fixed. Therefore, high loss levels that would otherwise saturate the processing electronics are tracked. This system also supports multiple users, each with multiple data windows per Booster cycle.

The hardware block diagram is shown in Figure 1. The detectors are biased at 200 VDC. The bias is developed using a dc/dc conversion circuit that directly couples the detector to the measurement electronics. The cables connecting the bias supplies to the detectors are triple-shielded coax (Belden 9054) and provide a shielding effectiveness of 110 db. The analog integrators accumulate the charge generated in the detector. The integrator circuit input resistance, in parallel with the signal cable capacitance, impacts the response time for the system. Therefore, the input resistance of channels in the injection and extraction locations has been selected to be compatible with use in the beam interlock functions. The integrators have two gain settings and the full-scale output at low gain measures a 10% localized beam loss at full energy without saturating the integrator.

Following the integrators is a commercial VME bus based data acquisition system (Datel, Inc.) consisting of several multiplexing S/H cards (Datel DVME 645) and an intelligent A/D board (Datel DVME 601). The system is configured for 80 channels and is expandable to 256 channels. The A/D card locally controls the entire acquisition process using preprogrammed firmware and the analog expansion bus. The channels are simultaneously held, sequentially digitized and written to the onboard dual port memory coded as bipolar 2's compliment. Additionally, the system accepts the circulating beam monitor which provides a measure of the beam intensity when the loss data is acquired.

A communications link (Bit 3 Corporation) transparently transfers the data between the Multibus instrument controller and the VME bus data acquisition hardware and provides the bus arbitration logic for the VME system. The translator presents the dual ported VME memory as local memory to the Multibus processor.

The comparator block provides threshold detection for the integrator outputs. The comparator outputs are used by the channel mask and interlocking functions. The threshold levels for each channel are individually adjustable. For transfer line channels, the thresholds will be set by operational requirements and other channels have their threshold nominally set at 80% of the ADC full-scale input.

The channel mask allows selected channels to be inhibited from requesting scan triggers. This is useful for disabling malfunctioning channels which may continually request the ADC to scan the system or to inhibit high loss channels from generating scan requests, allowing "zooming" to view low loss channels. Any or all of the channels can be disabled in software. The injection channels are not part of the mask because multiple ADC scans cannot be performed on the time scale of injection.

The beam interlock functions primarily include channels located in the transfer lines, although any other

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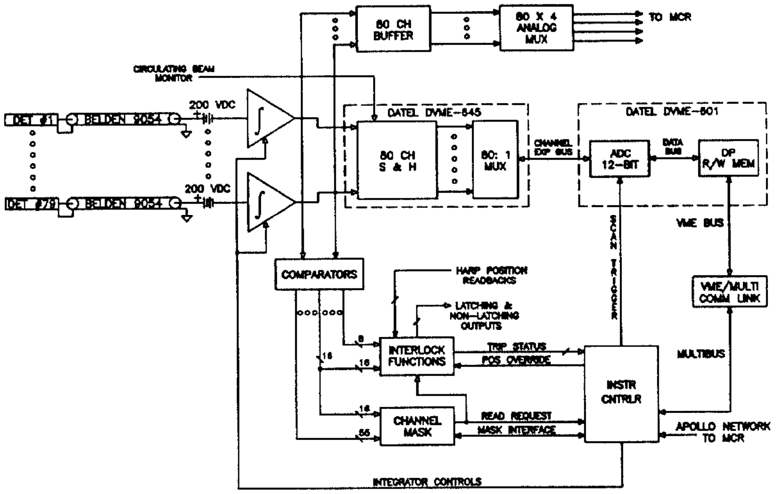

Figure 1. BRLM system block diagram.

channel may be "patched" into these systems. The interlocks are intended to prevent damage to the accelerator from a poorly steered or focused beam. There are two systems: the non-latching and latching beam interlock systems. The non-latching system causes the Linac injection pulse, 200 $\mu$s nominal, to be shut off at the ion source within 10 $\mu$s of detecting a high loss. The non-latching output is active only during injection and is formed by ORing the injection line detectors and the channel mask output. This system is automatically reset by the Booster timing system at the start of a new cycle. The latching system trips an external hardware latch, inhibiting injection into the Booster until a manual key switch is cleared. In this system, extraction line detectors are used, although provision for monitoring the ring channels via the channel mask output during extraction is included. There has also been provision made for sensing conditions when losses may be high such as those caused by beam invasive measurements. The BRLM system monitors the position of these devices and can selectively disable the interlocks until the measurement is complete.

## ADAPTIVE DYNAMIC RANGE

The combination software and hardware generated read requests are used to implement an adaptive dynamic range. The system is adaptive in the sense that it responds to changing or unexpected loss patterns without losing data. If only software control was used, one or more channels might exceed the ADC full-scale limit between requests and some data would be lost. The comparators flag the condition that at least one channel is approaching the ADC full scale and the flag is processed by the channel mask to establish that it originates from a detector designated to generate read requests. If so, the flag is forwarded to the instrument controller as a read request. The controller then arbitrates, if necessary, between software and hardware sources before producing a scan trigger. In either case, the acquisition process is triggered, the integrators are reset to zero and continue to accumulate data. It is possible to have multiple hardware-generated triggers bracketed by software requests. The number will depend on the spatial and temporal loss character. However, the time required between scans is approximately 2 ms. This includes the ADC scan time and overhead in the controller. Each scan is stored as a table and sent to host. When the Booster cycle is complete, the host software assembles the individual scans into the time intervals requested by the users. Although the ADC limits the instantaneous dynamic range and resolution on each scan, the total dynamic range is bounded by the word size of the processor summing the individual scans. The dynamic range on each scan is the ratio of the data accumulated in the highest channel to one count. The single count represents the converter resolution. However, for channels with low count totals, the relative accuracy of the measurement decreases as the number of scans increases.

## DETECTOR DESIGN AND MOUNTING

The detector is a coaxial ionization chamber made with an Andrews Corporation RG318 style Heliax cable pressurized with Argon to 10 psig. Most of the detectors are 5 meters long, although other lengths are also used. The detector is capped on one end with a standard bicycle valve as a pressure fitting. On the other end is a rexolite

UHF connector for the signal output and bias input. Rexolite is used because of its radiation resistance. The detectors are mounted close to the median plane on the inside tunnel wall cable tray approximately 30" radially inside the reference orbit. Median plane mounting maximizes the detector sensitivity and the cable tray provides constant geometry with respect to the central orbit while not blocking access to the magnets and beam pipe. In locations where the tunnel walls fall away from the beam pipe, special mounting stands are used to maintain the detector geometry. In the ring, there are 48 detectors, each spanning one half-cell with the ends of the chambers overlapping slightly at the middle of each dipole magnet reference location. In addition, there are 16 more detectors, 8 in each transfer line. These detectors are positioned below the beam line on the support girder, resulting in potentially less sensitivity than on the beam plane, but experience with similar devices shows the sensitivity is still adequate. There is also provision for mounting up to 15 auxiliary detectors to be located at arbitrary locations in the Booster and transfer lines as required.

## CONTROLS INTERFACE AND SOFTWARE

The control for the system is provided by the instrument controller. It is a dual processor system, with one processor for I/O and the other for communications. The communication processor has a DMA channel between the controller and network station. The station connects to host computers using a token-ring LAN[4].

The software provides the user with control over the programmable scan times, display of data, channel mask, and overrides. Several graphical and numerical displays are available to the user, with the ability to overlay one cycle atop the other. The software also assembles the time sampled detector data for each user and schedules the programmed resets to avoid conflicts. There is also a standard user called the background logging task. This task runs continually to maintain a record of the machine operation. As an addition to this task, the ability to generate and display the mean and standard deviation for losses both spatially and in time are being considered. These parameters can be used to inhibit the machine when loss conditions deviate from acceptable limits. In addition, recent data is stored providing diagnostic aspects similar to an aircraft flight recorder. Several acceleration cycles of loss data will be buffered in a FIFO. At any time, the data can be "played back" to look for indicators of poor performance, or as diagnostic information for checking other systems.

## COMMISSIONING

The BRLM hardware, detectors, and software were initially tested during Booster commissioning. The LTB detectors displayed a higher than expected sensitivity. As commissioning continues, the sensitivity will be quantified. Figure 2 shows the output of a single detector as monitored in the AGS Main Control Room. The detector is measuring a small loss at approximately 5% of the nominal Linac current. The loss correlates to the measured beam position errors. The non-latching interlock system was tested and functioned properly by promptly turning off the beam. The mask was successfully used to prevent hardware trips from triggering data acquisition. Hardware and software triggered ADC scans were observed in the same machine cycle. The software has allowed control of the functions to operate the system and has tabulated multiple scans correctly.

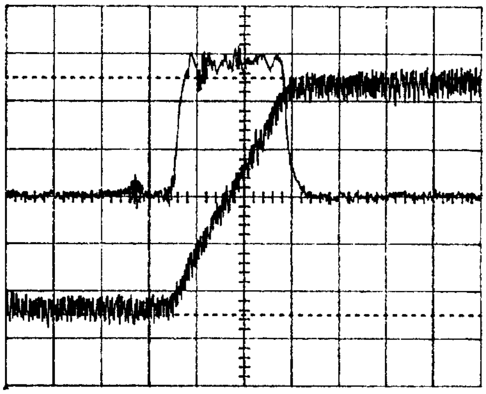

Figure 2. Detector output. Top: Linac output 0.5 mA/div. Bottom: Detector output 50 mV/div. Time scale: 10 $\mu$s/div.

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