SPALLATION NEUTRON SOURCE BEAM LOSS MONITOR SYSTEM*

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Abstract
The Spallation Neutron Source (SNS) [1] being built at Oak Ridge National Laboratory (ORNL) is designed to deliver 1.5 x10^{14} protons at 1.0 GeV in one bunch at 60 Hz to a liquid mercury target. To achieve this without excessive activation, an uncontrolled loss criteria of 1 part in 10^4 (~1 W/m) has been specified. Measured losses will provide machine tuning data, a beam abort trigger, and logging of loss history. The design of the distributed loss monitor system utilizing argon-filled ionization chambers and photomultipliers will be presented, as well as data from tests with beam.

BACKGROUND

The SNS is being built at ORNL by a collaboration of 6 laboratories, each responsible for specific sections of the accelerator. However, for efficiency and uniformity, controls and some beam instrumentation were handled globally. BNL has responsibility for the beam loss monitoring system for all of SNS. An H-minus ion source injects into a 2.5 MeV RFQ, followed by a Drift Tube Linac (DTL) which accelerates the beam to 87 MeV. The beam then enters a Cavity Coupled Linac (CCL), exiting at 186 MeV. A Superconducting RF Linac (SRF) brings the beam energy to 1 GeV. The High Energy Beam Transport (HEBT) carries the beam to the Ring where it is stripped to protons and accumulated in a single 695 nsec bunch over the 1 msec injection pulse. The bunch is transported via the Ring-to-Beam-Target (RTBT) line to the target. The design pulse beam current in the Linac and HEBT is 38 mA. In the Ring it will increase to more than 40 A at the end of the pulse, for a total of 1.5 x 10^{14} protons. This high average beam power makes it crucial that uncontrolled losses be minimized through careful design with beam dumps and collimators handling losses in a controlled manner. It is the job of the BLM system to provide data to minimize uncontrolled losses and inhibit the beam when excessive losses occur.

SYSTEM PHILOSOPHY AND DESIGN

Sufficient detector coverage is required to accomplish this goal. To provide full coverage the BNL Linac and AGS Ring uses long argon-filled ion chambers made from hollow, large diameter coaxial cables[2]. The same type of detectors have been used at ISIS, a machine similar to SNS [3]. A long detector can provide continuous coverage but its length often prevents close coupling to the beam line, lowering response. Since most losses will occur at the beta-max most of the detector receives a much lower exposure, reducing the benefit of the greater length. These cables cannot support high bias voltage, limiting them to low dose rates. For these reasons, smaller, sealed glass ion chambers were designed for the FNAL Tevatron [4] and also used in RHIC [5]. In the SNS HEBT, Ring and RTBT, detectors will be placed at essentially every quadrupole and at other key points. In addition a number of movable BLMs have also been included. Table I shows the distribution of BLMs.

DTL	CCL	SRF
12	28	86
HEBT	**Ring**	**RTBT**
59	70	40

Table I. Distribution of BLMs. Total = 295

Ion chambers will be used as the primary detector. Commercial pin-diode BLM [6] are not well suited to the 1 msec beam pulse. PMTs require excessive recalibration and are not practical for a high count distributed system. However, some will be installed to view losses within the bunch. These will be used for only relative time history.

SYSTEM REQUIREMENTS

The SRF cavities can quench if hit by large beam losses over several pulses. At the other end of the scale, even low level losses over extended periods can prevent “hands-on” maintenance. Experience at LAMPF and the PSR, and studies for APT at LANL [7] indicate that a loss of 1 W/m corresponds to about 100 mR/hr. This would be equivalent to a loss of about 0.01% uniformly around the Ring. The system should be able to detect this level with a resolution of 1%. The BLM system must have sufficient dynamic range to detect long-term low level losses, but not saturate during short duration, high level losses.

Experience has shown that the beam-on dose rate can be estimated from the beam-off dose rate by a “rule-of-thumb” multiplier of 1000. Thus 100 mR/hr at 1 foot would imply a beam-on dose rate of 100 R/hr, or, 0.46 R/sec during the 1 msec, 60 Hz beam. This is taken as the 1 W/m low end loss. The upper end limit (1% local loss) is based on the expected losses in the Ring collimators

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[8]. This represents a 6-decade range but linearity at the high end is not critical.

The BLM system must generate a beam abort signal for the Machine Protect System (MPS) in less than 10 µsec. Long term low level losses can activate and damage beamline components. Channels exceeding the 1 W/m loss level for extended periods will be monitored in software resulting in a warning alarm to operations. Losses which exceed the programmable threshold will trigger an inhibit signal sent through the IOC hardware to the MPS.

DETECTOR

SNS will use 295 argon-filled ion chambers as the primary detectors for monitoring beam losses. Argon has the advantage of fast electron transit time compared to slower air filled detectors [9]. The initial choice was an ion chamber designed for the Tevatron, but concerns about saturation at high dose rate and long ion transit time (~ 700 µsec at 2 kV bias) led to the development of a new ion chamber designed to overcome these limitations [10.] It utilizes a larger inner diameter electrode to significantly decrease the ion transit time and raise the collection efficiency for a 1% local loss.

BLMs mounted near RF cavities may detect X-rays. Measurements at RHIC indicate that this may reach 50 R/hr for a 1 MV gap voltage. This would be at a level comparable to the 1 W/m losses. It is estimated that 3/8-inch of lead would provide sufficient shielding but a study will be done using the SRF cavities to determine if this would reduce the X-rays to an acceptable level. It will also be necessary to determine the effect on the beam loss measurement.

CABLING

Experience with the RHIC loss monitor system has shown that nano-ampere measurements require low tribo-electric cable. Tribo-electric noise comes from friction between the conductors and insulation due to movement, such as vibration, but a low friction coating between insulator and conductors will reduce this significantly. Special cable such as Belden 9054 or 9224 will be used for the signals. Two HV cables (Times Microwave 91421), from separate HV power supplies will connect to alternate BLM's from each rack to provide some coverage in the event of a high voltage short or power supply failure.

ELECTRONICS

The interface to the Controls system will be in VME, with analog signal electronics housed separately in the same rack. Figure 1 shows the system block diagram.

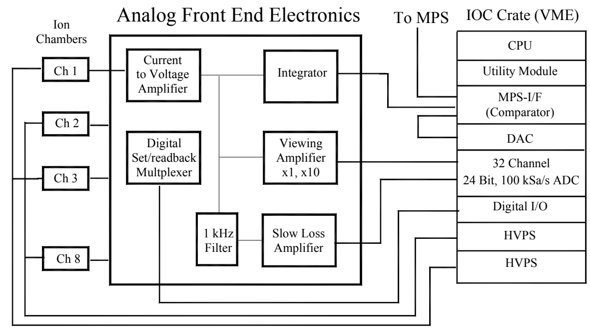

Figure 1. BLM System Block Diagram

ANALOG FRONT END ELECTRONICS

The BLM System must measure beam losses from a 1% local loss (15 kW) down to 1% resolution of a 1 W/m (~0.01%) loss, a dynamic range of over 120dB , or at least 21 bits. In terms of signal current, this corresponds to a range from 324 pA to 486 µA. Fortunately there is a large difference in bandwidth between the requirements (0.1 Hz to 35 kHz), which can be exploited. The circuit (Figure 2) provides 3 outputs to meet the wideband-wide range data, fast trip, and 1 W/m sensing requirements.

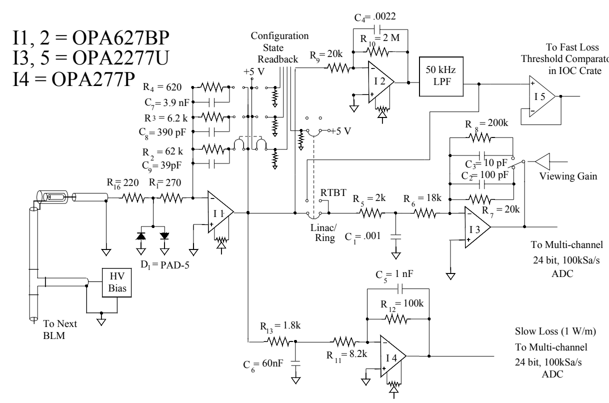

Figure 2. Analog Front End Electronics Schematic

Since the ion chamber is a current source, the transfer gain is set by the feedback resistor while the input resistor only determines the voltage noise gain and input signal risetime. For a typical 100 m cable the 470 Ω input resistor gives about a 5 µsec risetime. Three jumper selectable gains are provided to allow for lower losses in the linac or higher losses near dumps or collimators. "Viewing Gain" can be set and read back remotely without affecting the beam interrupt or 1 W/m outputs. A 6.2 kΩ feedback resistor puts the signal mid-range for 5 V ADC for a 1% beam loss. For the 35 kHz SNS BW, the 10 pA equivalent noise observed in RHIC with a 10 Hz BW would correspond to 3.7 µV.

A 1 W/m loss will produce about 200 μV out of the input stage, roughly an LSB for a 5V, 16-bit (15-bit plus sign) ADC. Another 6 to 7-bits would be needed for 1 % resolution of the 1 W/m loss. The first stage signal is split and passed through a 1 kHz low pass filter, reducing the noise and lowering the peak of fast losses, allowing an additional gain of 10. While a lower cut-off would further reduce the noise it might not allow measurement of the baseline for offset subtraction. The output is applied to a 24 bit, 100 kSa/sec ICS-110B ADC. Testing has shown that it can achieve 18-19 bit resolution but taking over 600 samples provides the required sensitivity.

Experience at LANSCE [11] has shown that integrated dose rather than dose rate should be used for the beam inhibit. The output of the first stage is split again and sent to an integrator. The integrator output is fed to a comparator module in the VME which generates an inhibit for the MPS when the programmable reference is exceeded. The circuit is a "leaky integrator", with a large value resistor to bleed the charge. It is simple and provides a good representation of the pulse dose. Simulations indicate that for the 1 msec pulse the output will reach equilibrium in 3 beam pulses with an error of less than 10% while decaying to under 5% by the next beam pulse. For the RTBT channels the integrator serves a dual purpose. Since impulse losses from the 695 nsec wide RTBT beam pulse would be too narrow for the 100 kSa/s ADCs to acquire through the wideband output, the signal from this integrator will be jumper selected for input to the Viewing Gain stage.

MPS INTERFACE CIRCUIT

The output of the leaky integrator is compared to a computer settable reference voltage to sense excessive loss. The comparator output is applied to an open-collector TTL driver which is used to signal the MPS that the beam should be inhibited. The circuit also passes through a continuity line from the MPS through the AFE module which will alert the MPS if either the MPS interface or AFE module is removed or powered down.

PACKAGING

The 8 channel AFE boards are packaged in 6U, 6hp wide eurocard modules. Four modules are mounted horizontally in a 4U high cardcage. A custom backplane provides a common bus to allow multiplexed readback of the more than 220 digital states by the IOC, using 8 bits. Linear supplies provide clean power. The HV power supplies, ADCs, DACs for the MPS references, Digital I/O modules, and the MPS-I/F modules are located in the VME crates with the control system IOC CPU and support modules.

STATUS

A prototype AFE crate has been fabricated with a hand-wired backplane and tested with an IOC. One 8-channel AFE module has been fully tested. The AFE crate 8-channel AFE module, IOC and 2 detectors have been delivered to the ORNL site for commissioning of the DTL linac section. Another four AFE modules have been built and are being testing. Seven more detectors are being prepared for shipment. An AFE crate is being prepared to accept the PCB backplane when it is completed shortly. This preproduction crate with the 4 AFE modules will be sent to ORNL following testing.

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REFERENCES

[1] J. Alonso, "The Spallation Neutron Source Project," Proceedings of the 1999 PAC, NY, p. 574 (1999). For current status see http://www.sns.gov.

[2] R.L. Witkover, "Microprocessor Based Beam Loss Monitor System for the AGS," IEEE Trans. Nucl. Sci **26** 3313 (1979).

[3] M. A. Clarke-Gayther et al., "Global Beam loss Monitoring Using Long Ionisation Chambers at ISIS," 4th European Particle Accelerator Conference, London, England, p. 1634 (1994).

[4] R.E. Shafer et al., "The Tevatron Beam Position and Beam Loss Monitoring Systems," Proc. The 12th Int'l Conf. High Energy Accel., p. 609 (1983).

[5] R.L. Witkover, R.J. Michnoff and J.M. Geller, "RHIC Beam Loss Monitor System Initial Operation," Proceedings of the 1999 PAC, NY, 1999, 2247 (1999).

[6] Bergoz Inc, http://www.bergoz.com.

[7] R.A. Hardekopf, "Beam Loss and Activation at LANSCE and SNS," LA-UR-99-6825, Los Alamos National Laboratory, Los Alamos, NM. Sept. 1999.

[8] Y.Y. Lee, BNL, Private Communication, Oct 2001.

[9] M. Plum and D. Brown, "Response of Air-Filled Ion Chambers to High Intensity Radiation Pulses," Proceeding of the 1993 PAC, p. 2181 (1994).

[10] R.L. Witkover and D. Gassner, "Design and Testing of the New Ion Chamber Loss Monitor for SNS," these proceedings

[11] M. Plum and R. Shafer, Private communications.