SNS PROJECT-WIDE BEAM CURRENT MONITORS*

M. Kesselman, BNL, Upton, NY11973, USA; R. Witkover, TechSource Inc., Santa Fe, NM87594, USA;L. Doolittle, LBNL, Berkeley, CA94720, USA; J. Power, LANL, Los Alamos, NM87545, USA

Abstract

The Spallation Neutron Source[1] (SNS) to be constructed at ORNL is a collaboration of six US National Laboratories. Beam current monitors for SNS will be used to monitor H-minus and H-plus beams ranging from 10mA (tune-up in the Front End, Linac and HEBT) to over 60 A fully accumulated in the Ring and RTBT. The time structure of the beams to be measured range from 645nsec "mini" bunches, at the 1.05MHz Ring revolution rate, to an overall 1ms long macro pulse. While the beam current monitors for the SNS have requirements depending upon their location within the system, the development of a unified approach to satisfy requirements of the various locations with common components is a major design objective. This paper will describe the development of the beam current monitors. Various approaches considered for the detectors and signal conditioning will be presented.

1 BACKGROUND & REQUIREMENTS

The SNS will consist of:

- An H^- Ion Source, RFQ and MEBT (The Front End) provided by LBNL,
- The Linac, consisting of a warm section up to 186 MeV and a superconducting section up to a nominal 1 GeV, provided by LANL and TJNAL,
- The HEBT, Accumulator Ring and RTBT, provided by BNL

The Linac and HEBT design current will be a 57mA peak pulse of about 1 ms duration (macro-pulse) chopped at the Ring revolution frequency of 1.05MHz at a repetition rate of 60 Hz. The chopped "mini-pulses" will consist of a 645nS long bunch and a 300nS gap. The micro-pulse structure of 402.5MHz, which exists in the Front End, Linac, HEBT and shortly after injection into the Ring, will not be observed with the beam current monitors (BCMs). The Ring will accumulate this current over 1mS, about 1000 mini-pulses, resulting in an average of about 57 amps at the end of the cycle and a total charge of 2×10^{14} per pulse. The RTBT will carry the current of the last turn in the Ring to the target. The electronics in the Ring and RTBT must operate over a signal range of 1000 to 1 (60dB), however, the Ring gain must change to accommodate the wide variation. The basic circuitry used in the Front End, Linac and HEBT could be used with the addition of gain switching. To observe the details of the mini-pulse, a fast response (1nS rise time with a droop rate of about 0.1%/µS) is required. For the macro-pulse current, a rise time of about 50nS and a droop of 0.1%/mS would be sufficient.

2 DISCUSSION

2.1 BCM Sensor

There is an estimated requirement of a total of 25 transformers[2]. The transformers[3] considered were passive, active-passive[4], and fast current transformers (FCT), but each had limitations. Instead of utilizing two different transformers to observe the lower bandwidth macro-pulse separately from the wide bandwidth mini-pulse, it was decided to use an FCT with baseline restoration to compensate for the droop and use a single transformer. An FCT produced by Bergoz Instrumentation[5] is being tested for use in the HEBT, Ring, and RTBT. Similar units are under consideration in the Front End and Linac.

2.2 Signal Processing

The data required from the BCMs is current, wave shape, and mini- and macro-pulse charge. A comfort display indicating the typical macro-pulse wave shape and the integral of the current per micro-pulse will also be needed. In addition, there is a requirement to provide a circular buffer holding data from a number of past pulses for fault diagnostic purposes. An interesting solution to these requirements would be to convert to digital form as soon as possible, and to use digital signal processing to accomplish much of the signal manipulation. A general block is presented in Figure1.

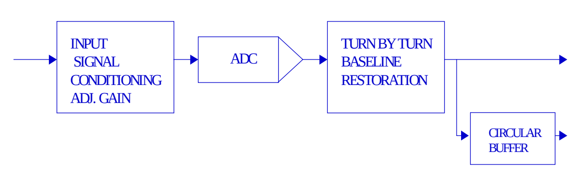

Figure 1. General Block Diagram

* Work performed under the auspices of the U.S. Department of Energy.

As is evident from the block diagram, the turn-by-turn baseline restoration will be done digitally. This drastically reduces the analog signal processing and eliminates the accompanying DC drift, offset, and non-linearities.

2.3 Input Signal Conditioning

In an attempt to minimize noise pickup, the prototype FCT was designed with a differential output at 78 Ohms. Initial testing indicate that the long (100 m) twisted pair cables required will cause significant distortion due to dispersion even for the highest quality cable. It is likely that the production units will have single ended output and use semi-rigid cabling to the remote electronics.

The large dynamic range expected in the Ring will require gain switching, but switchable gain amplifiers will not settle to the required precision in the 300 nsec between turns. One approach being considered would use two amplifiers preset to different gains and switch between them either at their input or output. Input switching requires a fast switch with low on-resistance, capable of withholding at least 15V, and switching at the output will still be required. It should be possible to switch only at the output if the amplifier is able to withstand the peak input voltage without failing or saturating from an over-voltage.

The Analog Devices AD600 has a gain range of 0 to 40 dB and a 35 MHz bandwidth. It is rated at ± 2V DC at the inputs, but can sustain ± the supply voltage (7.5V max) for 10 msec. A suitable fixed attenuator must precede the amplifier to match it to the expected peak current. As the charge in the Ring accumulates the higher gain amplifier nears the top of its range and the signal from the lower gain amplifier is used. After switching there would be no problem changing the higher gain amplifier to a lower gain to avoid saturation. This can be repeated again if a third gain range is desired. Fast post amplifier switching might be done digitally if an ADC is used for each amplifier. An Analog Devices AD6644 ADC is being tested at BNL for use as the digitizer. This device can provide 14bit conversion at up to 65MSa/S.

The BCMs in the RTBT must handle the range from a single injected turn to the full accumulation of 1000 turns and thus require settable gain. However, since the charge will be transferred in a single mini-pulse, more than 15 msec would be available to switch gains. The same amplifiers used for the Ring could be applied to the RTBT.

The Front End, Linac and HEBT BCMs do not require gain switching but could use the same amplifier and digitizer circuit.Turn-by-turn baseline restoration is required in all cases. There are several approaches under consideration, but digital processing is especially interesting. Baseline restoration can be implemented in conventional software at a high level in one of the various servers or workstations that make up a networked control system, or more intimately tied to the acquisition hardware, with embedded processing using a dedicated FPGA, DSP, or microprocessor. One technique would acquire multiple samples during the 300 nsec gap to form an average value which is subtracted from the mini-pulse to restore the baseline to zero. This can be done on a pulse-to-pulse basis using standard timing pulses during the interpulse period. Since the Ring, HEBT and RTBT transformers will droop less than 0.1% during the mini-pulse, they will require no low frequency compensation. Droop of the Front End and Linac BCMs will likely be greater since they are restricted in size, but are not expected to be more than a few percent during the mini-pulse. Software compensation for these units may be provided if deemed necessary.

Other required processing includes calculation of the charge in each mini-pulse. This will be necessary in the HEBT line as well as the Ring to calculate injection efficiency. It will also be needed to compute the turn-to-turn circulating charge in the Ring and the final charge delivered to the RTBT line. With a 60 MSa/S, 14bit digitizer, sufficient samples will be available to perform a good integration of the current to obtain the charge per mini-pulse. The charge per macro-pulse will also be computed.

For wideband viewing a 1GSa/s, 8bit digitizer will be used to observe the 695 nsec mini-pulse. The SNS instrumentation includes provision for an array of such digitizers, preceded by a wideband multiplexer, which would be used for acquiring other fast mini-pulse signals (Fast Loss Monitors, Wall Current Monitors) as well. These digitizers will be commercial VME or VXI units, which are essentially the electronics of fast digital sampling scopes. For precise measurements of mini-pulse and macro-pulse charge, a higher resolution (14 bit) 40MSa/s to 60MSa/s digitizer would be used.

2.4 Subsystem Configuration

A control system interface is being developed at LANL for the Linac Beam Position Monitor (BPM) system, which will be based on a conventional Personal Computer using the PCI standard. It offers a low cost housing with a standard high speed bus and a very fast, easily programmed local processor. Many commercial acquisition and control boards are available in PCI format. The practicality of this approach as opposed to a VME or DIN-rail environment will be evaluated.

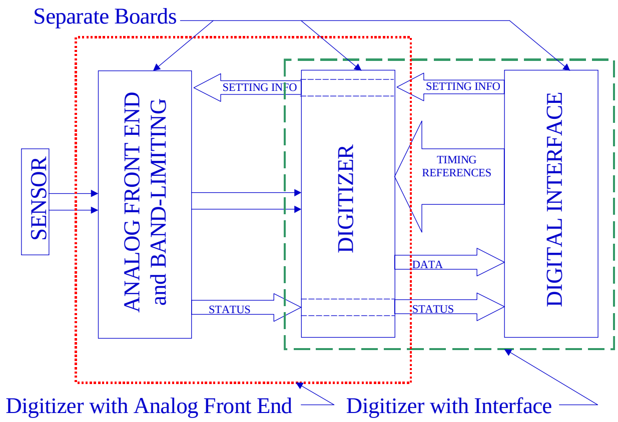

Figure 2: Subsystem partitioning

The general BCM electronics may be configured as shown in Figure 2, with three possible partitions depicted. The digitizer can be included with the digital interface, or with the analog front end electronics, or as a separate board. The advantages and disadvantages of each approach are being evaluated.

3 SUMMARY

The SNS beam current monitor system under development is focusing on a signal processing system that converts data to digital representation as soon as practical. Signal manipulation, calibration, filtering and noise reduction, baseline restoration, and droop compensation will be done digitally, as will calculation of the charge per mini-pulse and per macro-pulse. Commercial passive wideband current transformers will act as the basic current sensors, and the electronics will provide the appropriate filtering to tailor the signal for digitization.

REFERENCES

[1] See website; http://www.sns.gov

[2] M.Kesselman, et-al, “SNS Project-Wide Beam Current Monitors”, to be published in the Proceedings of the Beam Instrumentation Workshop 2000 (BIW00), May 8-11,2000, Cambridge MA.

[3] Bergoz Instrumentation, Espace Allondon Ouest, 01630 Saint Genis Pouilly, France.

[4] K. B. Unser, “Atomkernenergie”, Kerntechnik, Vol.47 (1985) No.1 (pg48)

[5] See ref. (3) and website; http://www.bergoz.com