DIAGNOSTIC CHALLENGES AT SNS*

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Abstract

The Spallation Neutron Source now being built in Oak Ridge, Tennessee, USA, accelerates an H^- ion beam to 1000 MeV with an average power of 1.4 MW. The H^- beam is then stripped to H^+, compressed in a storage ring to a pulse length of 695 ns, and then directed onto a liquid-mercury neutron spallation target. Most of the acceleration in the linac is accomplished with superconducting rf cavities. The presence of these cavities, the high average beam power, and the potential for the e-p instability in the storage ring, provide unique challenges to the beam diagnostics systems. In this talk we will discuss these challenges and some of our solutions, including the laser profile monitor system, the residual gas ionization profile monitors, and network attached devices. Measurements performed using prototype instrumentation will also be presented.

INTRODUCTION

Most of the beam diagnostics [1] at the Spallation Neutron Source (SNS) are fairly standard: beam position monitors, beam loss monitors, wire scanners, beam current monitors, slit and collector emittance stations, Faraday Cups, etc. However, there are several aspects about the SNS that create some special challenges, such as the superconducting rf cavities, the high beam power, and the potential for the e-p instability in the ring. The high beam power and the superconducting rf cavity challenges have led to the development of a laser profile monitor system that replaces the originally-envisioned wire scanner system in the superconducting linac (SCL). The challenges associated with the e-p instability and the expected beam loss in the ring have led to improvements in the gas ionization profile monitor design. We have also taken advantage of technology developments by basing many of our diagnostics instrumentation designs on the personal computer (PC) platform. A layout of the various diagnostics systems is shown in Fig. 1.

LASER PROFILE MONITOR SYSTEM

The profile monitor system for the SCL was originally envisioned to be a carbon wire scanner system. However, linac designers were concerned about the possibility that carbon wire ablation, or broken wire fragments, could find their way into the superconducting cavities and cause them to fail. A high reliability wire scanner actuator was

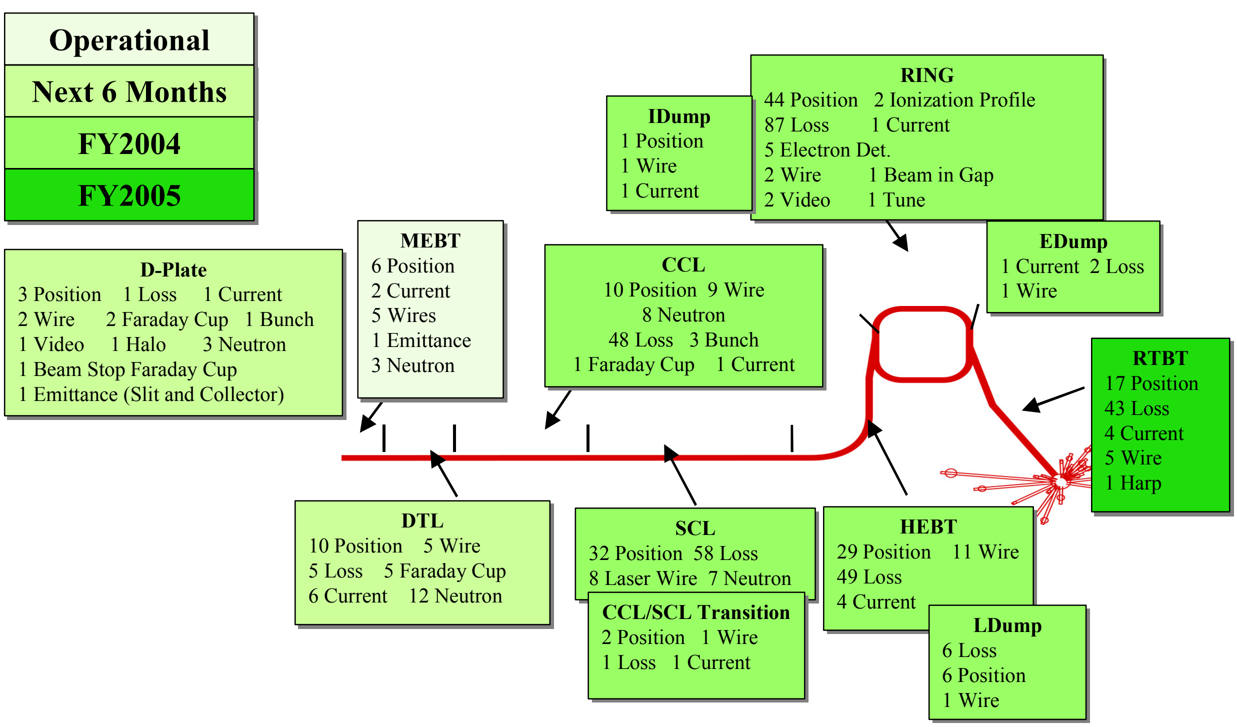

Fig. 1. (color) Layout of the diagnostics in the SNS facility, color-coded to indicate the staged installation dates.

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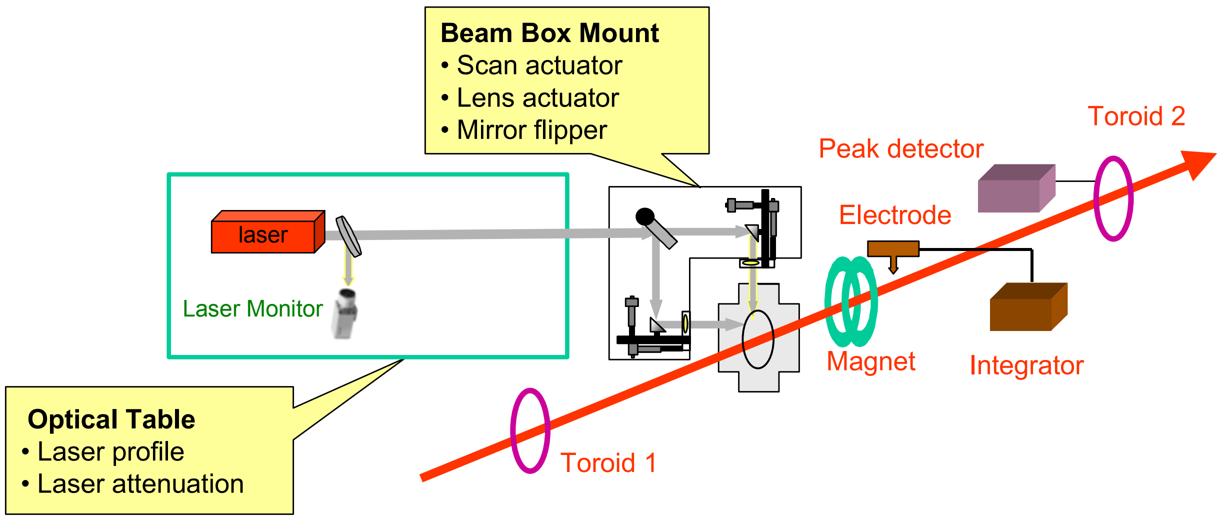

Fig. 2. (color) Schematic layout of a laser beam profile monitor.

developed [2] at Los Alamos National Laboratory (LANL) in tandem with experiments [3,4] using a laser to measure profiles of H^{-} beams at Brookhaven National Laboratory (BNL).

Once the laser profile monitor concept was proven by experiments at BNL, and subsequently on the SNS MEBT at Lawrence Berkeley National Laboratory, the decision was made to replace the carbon wire scanner system with the laser profile measurement system in the SCL. The

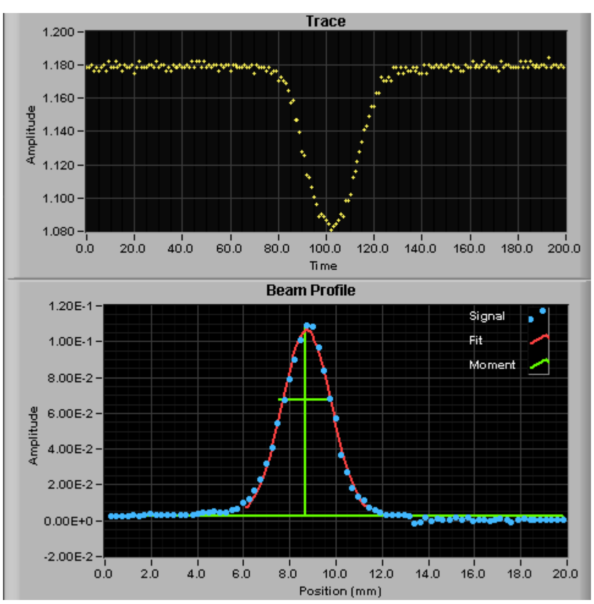

Fig. 3. (color) Horizontal beam profile in the SNS MEBT, measured January 2003. Top: an example of the electron collector signal. Bottom: the results of the measurement, with a Gaussian fit plotted out to 2.5 σ.

advantages that the laser profile monitor system has over the wire scanner system are: 1) profiles can be measured during normal operations, as opposed to the 100 µs, 10 Hz duty factor restriction needed to prevent damage to carbon wires; and 2) there are no moving parts inside the vacuum system, thus reducing the possibility of a vacuum system failure. A disadvantage is that the laser is not as rad hard as a wire scanner actuator, but we have overcome this issue by placing the laser far away from the beam line.

The laser profile monitor concept is straightforward: a tightly focused laser beam is directed transversely through the H^{-} beam, causing photo-neutralization. The released electrons are either swept away by magnetic fields normally present in the linac lattice, or directed by a special dipole magnet to an electron collector that may or may not be part of the laser profile monitor system. The beam profile is measured by scanning the laser beam across the H^{-} beam and measuring the resultant deficit in the H^{-} beam current and/or, if the released electrons are collected, by measuring their current. A simple schematic of the concept is shown in Fig. 2.

The advantage of collecting electrons vs. measuring the deficit in beam current are: 1) the signal to noise ratio is better because of the large numbers of released electrons; and 2) the simplicity of the electron collector, since the electron energy is well defined and the electrons are well collimated. The disadvantages are: 1) an external magnetic field is required, 2) an in-vacuum electron collector is required, and 3) the electron collector signal may suffer from interference caused by beam loss. At the SNS linac we will use both methods. Every laser station will have an electron collector, and there will be beam current measurements at the entrance and exit of the superconducting linac.

Recent developments in laser technology have raised laser powers to the point where a low-cost laser that can be easily carried by a person is now powerful enough to

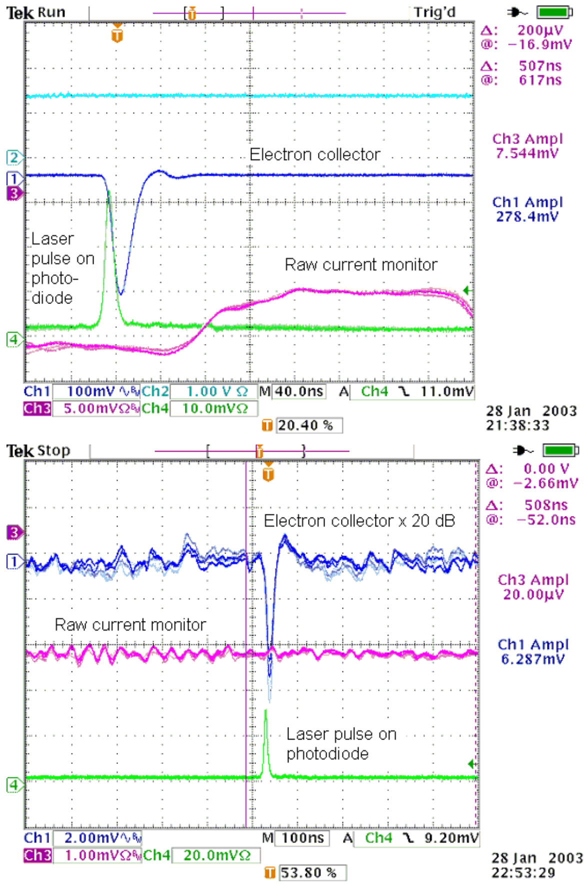

Fig. 4. (color) Some waveforms from the laser profile monitor tests in the SNS MEBT. Top: The laser is fired near the center of the 32 mA peak current beam bunch. Bottom: the laser is fired during the 310-ns gap between the 690-ns minipulses.

almost completely strip all the electrons from the portion of the H$^-$ beam intercepted by the laser. The laser can be mounted directly to actuators on the beam line, and this was in fact the method used for some of the earlier work. However, concerns about long-term radiation damage have led us to install a single laser in a room above the SNS linac, and to transport the laser beam to the profile monitor stations using a system of mirrors.

The laser chosen for the SNS system is the Continuum Powerlite Precision II, 600 mJ, 10 nsec, 1064 nm, 30 Hz ND-YAG laser. The laser beam is transported down through a hole in the ceiling of the beam tunnel at the downstream end of the linac, and then along the length of the linac to the various beam profile measurement stations. Each of the 32 warm inter-segment regions will contain a beam box with fused-silica view ports and an electron collector. However, to contain costs, only the first four inter-segment regions in the medium-beta portion of the SCL and the first four inter-segment regions in the high-beta portion of the SCL will be instrumented with the actuators, the electron deflection magnet, and the electronics needed to make a profile

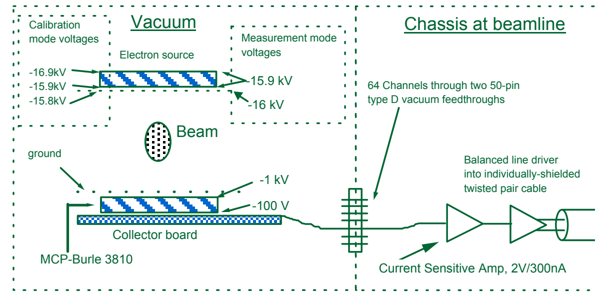

Fig. 5. (color) Schematic of the IPM.

measurement. With this setup, a laser station can be moved or added in an 8-hour shift.

Proof of principle tests were conducted at BNL and on the SNS MEBT at LBNL. The most recent and most complete tests were conducted last January on the SNS MEBT at ORNL. Shown in Fig. 3 is an example of this latest test, where a prototype system was installed at the end of the MEBT using the final-design beam box, dipole magnet, and mirror actuators.

The laser profile monitor can also be used to measure any beam that might be in the gap between the 690-ns long mini pulses. This gap is ideally void of any beam. By adjusting the laser firing time to occur within the gap, any signal on the electron collector must be due to beam in the gap. As shown in Fig. 4, this concept was also tested last January during the MEBT commissioning, and some beam in the gap was in fact detected, with a magnitude of about 2 parts in 1000. We eventually expect to achieve an accuracy of about 1 part in 10,000. We expect to complete the installation of the laser profile system by September 2004.

IONIZATION PROFILE MONITOR

The SNS ionization profile monitor (IPM), to be installed in two (one horizontal, one vertical) locations in the ring, will be based on an improved version of the IPMs installed [5] in the RHIC ring. In fact, some of the improvements have already been tested on the RHIC IPMs.

The SNS (and RHIC) IPMs are based on electron collection in parallel electric and magnetic fields. The electrons are amplified by a microchannel plate and collected on a 64-channel gold-plated printed circuit board. The resultant signals are then transported through the vacuum chamber on 50-pin D-connectors to charge-sensitive amplifiers mounted near the beam line. The signal from each channel is transported to the equipment building using balanced line drivers and individually-shielded twisted pair cables. An electron source has also been added to calibrate the instrument. Some specifications are shown in Table 1, and a schematic is shown in Fig. 5.

The modifications to the RHIC IPM were necessary due to rf coupling to the beam, susceptibility to beam loss, and possible interference from the e-p beam

Table 1. Some specifications of the SNS IPM.

Peak beam current range	15 mA to 60 A
Bandwidth	5 MHz
Profile monitor resolution	±2.8 mm
Profile measurement accuracy	±2.5% of nominal beam width
Aperture radius	100 mm
Micro channel plate	Burle 3810
Electron source	Burle electron generator array
Magnetic field	2 kG
Electric field	75 kV/m
Pre amp	Current sensitive, 2 V / 300 nA

instability. Beam loss in the vicinity of the IPM can cause the primary beam and secondary particle showers to pass through the micro-channel plate and the collector board, thus causing large background signals. Also, as demonstrated in the LANL Proton Storage Ring, the e-p instability can create huge amounts of electrons that could be collected by the IPM and possibly swamp the beam profile signal.

To alleviate these concerns the detector components were moved outside the beam aperture by moving the

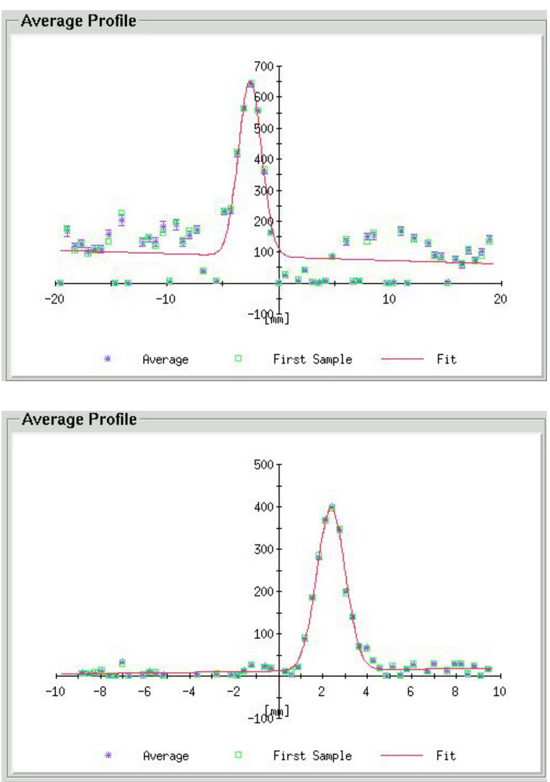

Fig. 6. (color) The RHIC ionization profile monitor measurement before (top) and after (bottom) the modifications.

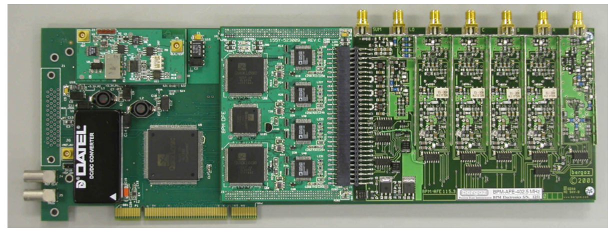

Fig. 7. (color) Photograph of the custom-designed PCI card and Digital Front End for the BPM system. The Analog Front End was designed and fabricated by Bergoz, Inc.

electron sweep electrode and the microchannel plate (MCP) away from the beam centerline and shielding the MCP with a grounded wire grid. The beam pipe in the vicinity of the IPM (in fact all the beam pipes in the SNS ring) will also be coated with TiN to suppress secondary electron creation. Additionally, the IPM's electric and magnetic fields will now extend upstream and downstream of the active volume to prevent electrons created outside the IPM from entering the active volume. Finally, the IPM's strong electric field will prevent electron multipacting within the active volume. To counteract the influence of the IPM's fields on the ring orbit, three electromagnetic dipole magnets will be added to the ring lattice.

The SNS beam intensity will be high enough that it will not be necessary to inject any gas into the IPM. This will make the system simpler, more robust, and will reduce the costs. A 10^{-8} Torr vacuum is expected in the ring, which corresponds to an expected signal level of about 150 electrons collected per turn injected into the ring (a total of 1000 turns will be injected during normal operations). For example, to obtain 5 to 7 profiles along the length of the beam bunch, and to collect at least 200 electrons per profile, we must average over about 10 machine cycles (at 60 Hz during normal operations) to get the profile information for turns 1 – 10. For turns 11 – 1000 no averaging will be required.

The new RHIC IPM, which incorporates many of these design changes, was tested by purposely causing a substantial amount of beam loss by bumping the beam into the beam pipe wall. The test was conducted using gold beam in the yellow ring in March 2003. As shown in Fig. 6, the profile using the improved IPM is much better than the profile measurement using the unmodified unit. The SNS IPMs are scheduled be delivered to ORNL by May 2004.

NETWORK ATTACHED DEVICES

At the SNS we have chosen to base many of our diagnostics on the rack-mounted personal computer (PC) platform, rather than the more typical VXI, VME, or CAMAC platforms. Instead of implementing many BPMs within, e.g. one VME crate, the Networked Attached Device concept implements each BPM with its own independent resources such as a processor, a timing decoder, and a network interface. The overall costs stay the same using the cost-effective PC platform but the software is simplified and common failure points are reduced. The standard software suite [6] includes Windows 2000 or XP embedded for the operating system, LabVIEW for the signal acquisition and signal processing software, Input-Output Controller (IOC) core software to communicate with the EPICS-based control system, and a Shared Memory Interface to connect LabVIEW to the IOC. Bench tests on a prototype network attached device demonstrated a 100-element (with 4 bytes /element) waveform update rate of 1000 Hz generated by LabVIEW and communicated over the network to a remote EPICS Channel Access client. The 800-MHz Pentium CPU was less than 5% busy. In some cases (e.g. the beam position monitor (BPM) and the beam current monitor (BCM) systems), custom PCI cards have been designed and fabricated, so that the signal cables are connected directly to connectors on the rear panel of the PC. In other cases (e.g. the wire scanner and the energy degrader / Faraday Cup systems) we use off-the-shelf PCI cards to control actuators and acquire data. For example, shown in Fig. 7 is the PCI card for the BPM system [7], and Fig. 8 shows how the PCI card fits into a rack-mounted PC.

The Network Attached Device concept was first tested with the prototype BPM, BCM, and wire scanner systems on the SNS MEBT at LBNL in February 2002. All these systems were brought on line in one short week, and performed well during this initial commissioning period. We did however have some difficulties interfacing to the EPICS control system because we did not at this time have the IOC core software installed on the PCs. We plan to have this software ready for the upcoming DTL commissioning.

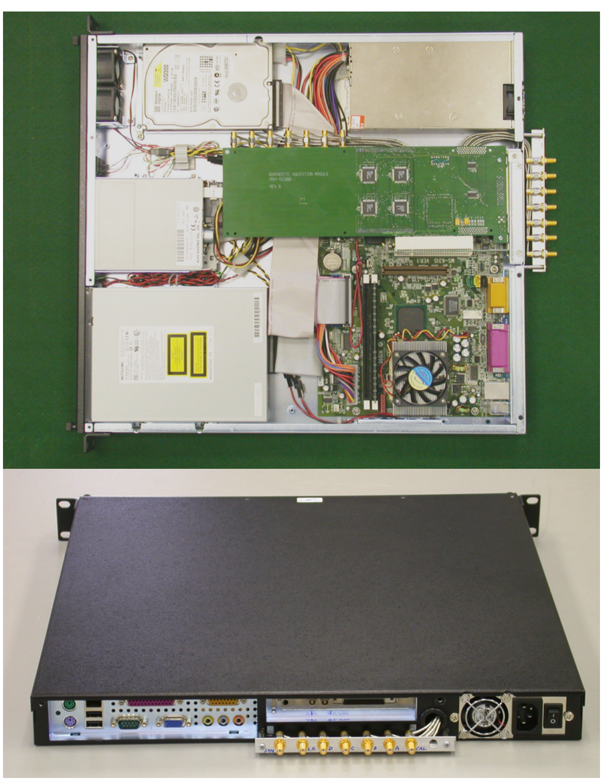

Fig. 8. (color) Photos of the BPM system in a 1U rack-mount PC.

SUMMARY

A suite of diagnostics instrumentation has been designed to meet the challenges offered by the SNS project. Interesting developments include the laser profile monitor for H^- beams, the improvements to the RHIC ionization profile monitor, and the network attached devices based on the PC platform.

To date the SNS facility has been commissioned up through the end of the MEBT at 2.5 MeV using prototype BPM, BCM, wire scanner, and slit and collector emittance systems. All of these systems have performed well, although a few bugs remain to be worked out, like the IOC core software for the PC systems. The laser profile monitor concept was also tested on the MEBT, as well as at a couple different beam lines at RHIC.

The next stage of diagnostics installation is now in progress to prepare for DTL commissioning later this year, followed by CCL commissioning in 2004. The SNS is expected to be fully commissioned by early 2006.

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