THE SNS LASER PROFILE MONITOR DESIGN AND IMPLEMENTATION*

S.Assadi, A. Aleksandrov, W.Blokland, A. DeCarlo, C. Deibele, P. Gibson, W. Grice, M. Hechler, T. Hunter, J. Kelly, P. Ladd, G. Murdoch, M. Plum, J. Pogge, K. Potter, D. Purcell, T. Shea, D. Stout
ORNL, Oak Ridge, TN 37830 USA

Abstract

After a successful demonstration of a non-intercepting beam profile monitor for the H^- beams at the 750 KeV and the 200 MeV LINAC at Brookhaven National Laboratory, the SNS project approved using a Nd:YAG laser rather than the traditional carbon wire for transverse profile monitors in the SNS super-conducting LINAC. Experiments have also been performed on SNS 2.5 MeV medium energy beam transport line at LBNL. The design and the implementation of a multi-station profile monitoring system using a single laser will be presented. The laser beam is scanned across the H^- beam to photo-neutralize narrow slices. The liberated electrons are collected to provide a measurement of the transverse beam profile. The prototype system has been tested; the measurement and performance results will be presented.

INTRODUCTION

The SNS accelerator systems are described in details elsewhere [1]. 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 super-conducting RF cavities. These eleven medium beta (β=.61) and twelve (β=.81) cavities are separated by warm sections (Fig.1). 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 super-conducting cavities and cause them to fail. The SNS based-line carbon profile monitors developed [2] at Los Alamos National Laboratory in conjunction with search for alternatives such as laser profile monitors to minimize the above risks. Experiments at Brookhaven National Laboratory (BNL) using Nd-Yag laser to measure profiles of H^- beams proved to be promising. Once the laser profile monitor concept was proven by experiments at BNL, and subsequently on the SNS MEBT at Lawrence Berkeley National Laboratory [3,4], the decision was made to replace the carbon wire scanner system with the laser profile measurement system in the Super-Conducting LINAC (SCL). The 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

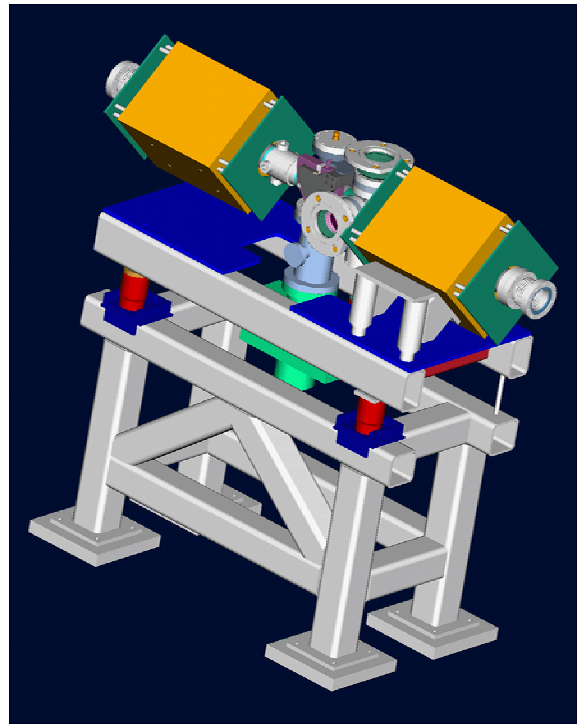

Fig.1. SNS "warm section" is a two quadrupole and diagnostic beam-box located between two super-conducting cavity modules.

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 radiation hardens as a wire scanner actuator, but we have overcome this issue by placing the laser far away from the beam line in the Klystron Gallery and use optical transport line to transfer the laser beam to each station.

Dynamic range

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 3D drawing of the concept is shown in Fig. 2.

0-7803-7739-9 ©2003 IEEE

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 super -conducting LINAC.

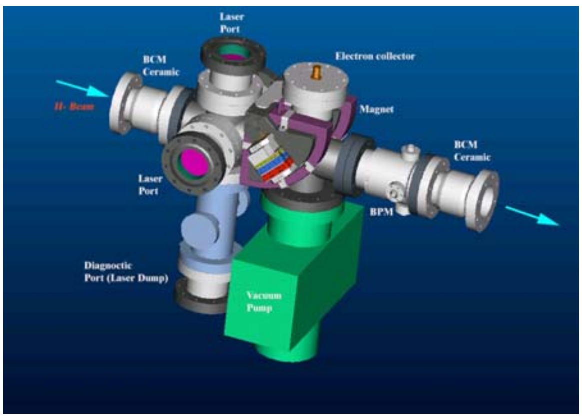

Fig. 2. Stripped electrons are bent into the collector via the dipole magnet (magenta color).

LASER AND OPTICS CONSIDERATIONS

General

A number of considerations guided the design of the optical system for the SNS laser profile monitor. First and foremost, the system must be capable of delivering high peak-power optical pulses to the ion beam. In order to provide adequate spatial resolution, the laser beam must be brought to a focus smaller than the ion beam and must be scanned in both transverse directions across the ion beam. Finally, the design must include a distribution system to accommodate multiple diagnostic stations.

The pulses are provided by a Q-switched Nd:YAG laser that runs at a repetition rate of 60 Hz and emits 9-ns pulses with energies up to 650 mW. The laser operates at a wavelength of 1064 nm, which is near the peak of the photo-neutralization response for H^-. Because the 9-ns laser pulses are significantly longer than the ion pulses, a narrowband injection seeder is also included in the system to provide a smoother temporal profile. The prototype experiments were performed in low radiation areas and so the laser could be placed in close proximity to the diagnostic station. In the final implementation, however, the radiation levels will be much higher, thus necessitating removal of the laser to a remote location. The proposed location for the laser is in an adjacent building near the end of the LINAC tunnel and over 200 meters from the diagnostic stations. For propagation over a distance this large, the beam must be expanded to a size of one inch or more. After being directed to the tunnel by a series of mirrors, the beam will travel down the tunnel in a beam tube mounted near the tunnel ceiling. Removable mirrors will be placed at each diagnostic station to direct the laser beam to the focusing and scanning optics. A second removable mirror switches the beam between the horizontal and vertical scans.

Because the laser beam must propagate so far from source to target, and because the source and target are in different buildings, mechanical vibrations are a concern. Of course, it is difficult to estimate the magnitude of these vibrations until the full system is implemented. A number of measures have been taken, however, to minimize and control beam jitter. The first comes in the optical design, itself. As described below, a lens is used to focus the laser beam onto the target. Mechanical vibrations in any of the upstream optics are expected to result in variations in both the position and incidence angle of the incoming beam. Because a lens maps the direction of an incoming beam to a single position in the focal plane, changes in the beam position alone have no effect on the focal position. Thus, it is only the angle of incidence that is of concern. The geometry of the system helps here. Nearly all of the downstream optics for each diagnostic station are mounted on a custom optical table. Most of the mechanical instabilities, then, are expected in the upstream optics where the beam is sent from one building to another. Because the upstream optics are over 200 meters from the target, large angular deviations in the beam will cause it to miss the downstream optics altogether. If the beam pointing is stable enough to keep the laser beam on the downstream optics, therefore, the angular variations from the upstream optics will be too small to significantly affect the profile measurement.

The challenge, then, is to keep the beam jitter small enough so that the beam is not steered off the downstream mirrors. The current design includes active stabilization to help in this regard. A beam position sensor will be placed near the diagnostic stations and will provide an error signal to piezo-electric actuators controlling one of the upstream mirrors. The feedback will be used to lock an auxiliary beam, rather than the primary beam, since it pulses at a rate of only 60 Hz. This method should make it possible to correct for much of the mechanical instability in the system.

The laser pulses arrive at each diagnostic station in the form of a one-inch beam and are then focused into the ion beam by a single lens. The lens is located approximately 20 cm from the beam center and is placed as close as possible to the vacuum windows. This design serves a number of purposes. First, it ensures that the beam is large when it passes through the vacuum window, thus reducing the chances of laser damage. Second, the relatively short focal length yields a convergent beam. By changing the position of the focusing lens, it is possible to change by a small amount the size of the laser beam as it crosses the ion beam. This function is accommodated in our set-up by a translation stage that moves the lens parallel to the laser beam. For the ion beam profile, itself, the laser beam is translated across the ion beam. This is accomplished by translating the final steering mirror. Since the light passes through the focusing lens after striking the mirror, the two are mounted and translated together. Thus, the effect of the lens upon the beam is unchanged throughout the scan.

An additional benefit afforded by the optical design described above is that it minimizes the effects of unwanted reflections. As the beam exits the vacuum chamber, a small fraction of the light is reflected back toward the ion beam. Even with uncoated windows, the amount reflected is only a few percent of the primary beam. But the signal level from this unwanted reflection can be significant if the light is concentrated near the center of the ion beam. Using a lens to couple the light into the vacuum chamber ensures that the beam is diverging as it leaves the target. It continues to diverge as it is reflected back toward the ion beam so that the reflected energy is spread out over an area much larger than that occupied by the ion beam. Thus, the signal contribution from unwanted reflections is quite small and is fairly constant throughout the scan.

Data acquisition system

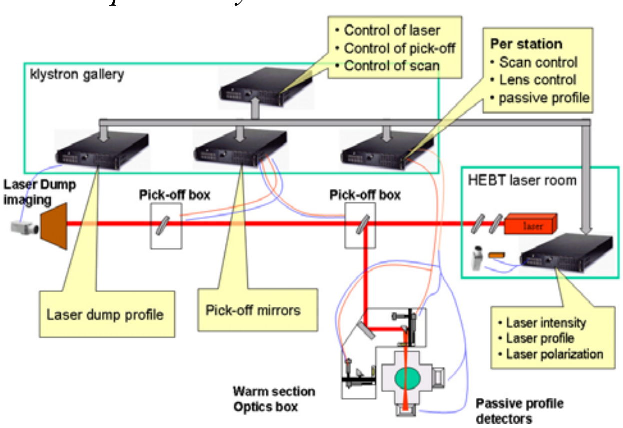

Fig. 3. Distributed PC systems and LabView data acquisition is used to collect and analyze data.

EXPERIMENTAL RESULTS AND CONCLUSION

We have successfully tested the SNS laser profile monitor. Figure (4) shows the completely stripped off electrons from the portion of the H^- beam intercepted by the laser.

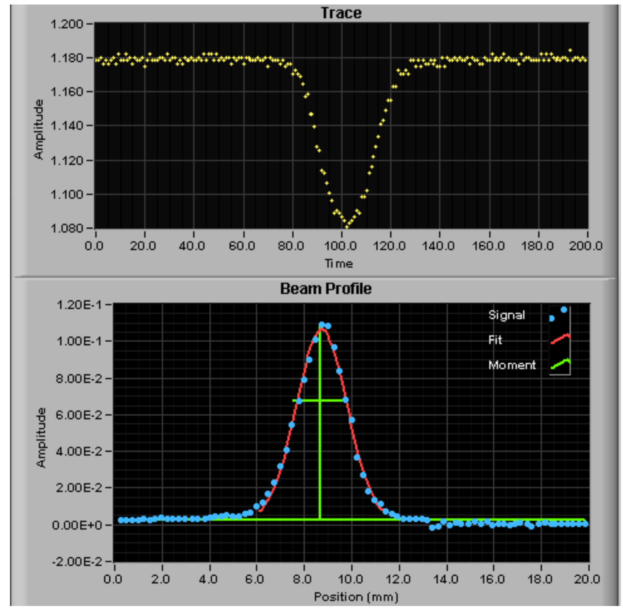

Fig.4. Horizontal beam profile in the SNS MEBT, measured in January 2003. Top: The electron collector signal at the center of the H-minus beam. Bottom: the results of the measurement, with a Gaussian fit plotted out to 2.5 σ.

REFERENCES

[1] N. Holtkamp,'', these conference proceedings, PAC2003, Portland

[2] R. Hardekopf et al, "Wire Scanner Design for the SNS Superconducting-RF Linac," proceedings of the 2001 Particle Accelerator Conference, Chicago, Ill, USA, June 18 – 22, 2001.

[3] R. Connolly et al., "Laser Profile Measurements of an H- Beam," proceedings of the 2001 Particle Accelerator Conference, Chicago, Ill, USA, June 18 – 22, 2001.

[4] R. Connolly et al., "Laser Beam-Profile Monitor Development at BNL for SNS," proceedings of the 2002 Beam Instrumentation Workshop, Upton, NY, USA, 6 – 9 May 2002.

[5] A. Aleksandrov, SNS-NOTE-AP-44

* SNS is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy. SNS is a partnership of six national laboratories: Argonne, Brookhaven, Jefferson, Lawrence Berkeley, Los Alamos and Oak Ridge.