

PARASITIC PROFILE MEASUREMENT OF 1 MW NEUTRON PRODUCTION BEAM AT SNS SUPERCONDUCTING LINAC

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Abstract

A laser wire system has been developed in the Spallation Neutron Source (SNS) superconducting linac (SCL). The SNS laser wire system has a capability of measuring profiles of an operational hydrogen ion beam at 9 cryomodule stations along the SCL by using a single light source. This talk reports our recent study of the laser wire profile measurement performance. Parasitic profile measurements have been conducted at multiple locations of SCL on an operational 1-MW neutron production beam that SNS recently achieved as a new world record. We will also discuss novel beam diagnostics capabilities at the SNS SCL by using the laser wire system.

INTRODUCTION

The Spallation Neutron Source (SNS) at Oak Ridge National Laboratory is an accelerator-based neutron-scattering facility. SNS uses a large-scale, high energy superconducting linac (SCL) to provide high beam power utilizing hydrogen ion (H^+) beams. For the diagnostics of high-brightness H^+ beams in the SCL, nonintrusive methods are preferred. Recently, a profile monitor system based on photodetachment, also known as laser wire, was installed in the SNS SCL. The SNS laser wire system is the world largest of its kind with a capability of measuring horizontal and vertical profiles of an operational H^+ beam at each of the 23 cryomodule stations along the SCL beam line by employing a single light source. Presently 9 laser wire stations have been commissioned.

This paper reports out recent measurement of 1 MW neutron production H^+ beam profiles. The measured profiles show how the H^+ beam evolves while being accelerated along the SCL. The measurement has been conducted in a parasitic manner. The laser wire system also offers a unique and useful tool for the ion beam diagnostics in a superconducting linac. With this setup, it became possible to separately measure the beam size of individual minipulses or even different segments within a single minipulse.

SYSTEM CONFIGURATION

Figure 1 shows an outline of the entire laser wire system. The first four LW stations are installed after the first four cryomodules (each cryomodule drives three medium-beta cavities), the next four LW stations are located after cryomodules 12-15 (each drives four high-beta cavities), and the last LW station is placed at the end of the SCL. The LW stations are arranged so that the H^+ beam at different energy levels (200 MeV – 1 GeV) can be

measured. A Q-switched Nd:YAG laser (~8 ns pulse width at a wavelength of 1064 nm and a repetition rate of 30 Hz) is used as the light source. The laser is located outside the linac tunnel the laser beam is delivered to each of the 9 laser wire stations through a free-space light transport line. An active steering mirror is installed in the laser room to stabilize the beam within $\pm 10 \mu\text{rad}$. Details of the system can be found in Ref. 1.

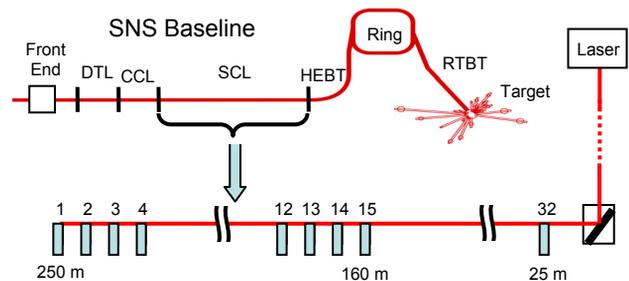


Figure 1: Outline of the SNS SCL laser wire system. Laser is installed in the HEBT service building. Numbers indicate the cryomodule stations where the laser wire profile scanner is commissioned. Distances are from the laser room.

PROFILE MEASUREMENT

Photodetachment Signal

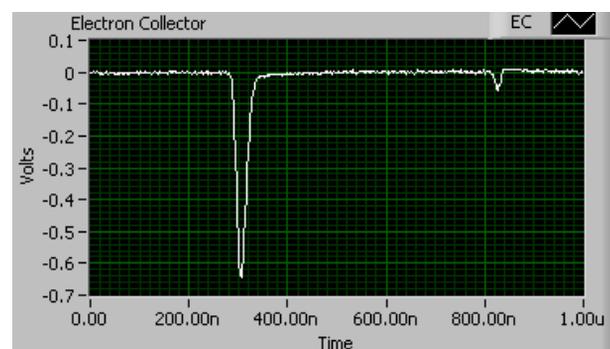


Figure 2: Photodetachment signal from the electron detector. The amplitude is proportional to the number of the detached electrons with a coefficient of $\sim 30 \text{ pC/V}$.

The principle of the laser wire profile measurement is based on the photodetachment of the electrons from the ion beam. When the H^+ beam interacts with a photon beam with photon energies above 0.75 eV, a certain number of electrons are detached from the ion beam by the photons. The detached electrons are bent in the

vertical direction by a magnetic field and collected by an electron detector placed downstream of the laser-ion interaction section. Figure 2 shows an example of the detached electron signal. The amplitude corresponds to the number of the photo-detached electrons with a coefficient of about 30 pC/V. The profile of the ion beam was obtained by scanning the laser beam across the ion beam and recording the amplitude as a function of the laser beam position.

Profile Measurement of 1 MW H Beam

The profile of the H⁺ beam in the SCL has been measured at all 9 stations (serially). The measurement was conducted on a 60-Hz, neutron production beam with an average power of 1 MW. Figure 3 is a snapshot recorded from the SNS beam status broadcast channel (available at <http://neutrons.ornl.gov/diagnostics/channel13/Ch13.html>) on the day when the laser wire measurement was performed. The neutron production H⁺ beam shows a very steady output power within the measurement time window, which clearly verified the parasitic nature of the laser wire diagnostics.

Figure 4 shows the horizontal and vertical profiles measured at all 9 laser wire stations in the SCL. Here, the marks are the measured values and the lines are the Gaussian fitting curves. 15 samples were taken at each position and the average was taken as the measurement result.

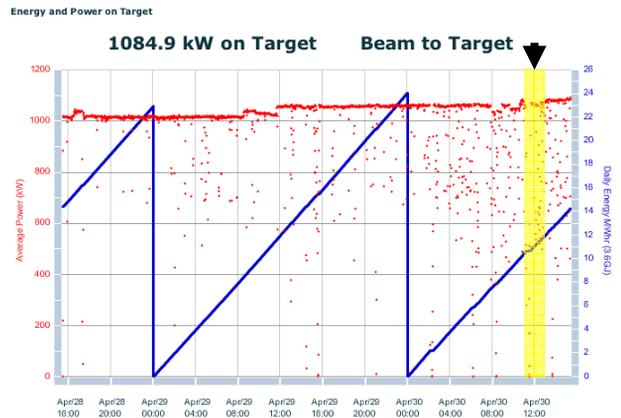


Figure 3: A snapshot of SNS beam status on April 30, 2010. Laser wire measurement time window is indicated by the shadowed region.

Beam parameters are estimated from the Gaussian fitted function. The beam sizes measured at each station are summarized in Table 1 together with the beam energy. Our measurement shows that the beam size before exiting the SCL is less than half of that at the entry of the SCL, while showing quite large variations during the acceleration path. Beam halos were observed in both horizontal and vertical H⁺ beam profiles at some stations. In this case, the measured H⁺ beam profiles were better fitted with a linear combination of two Gaussian functions sharing the same beam center position, but with different beam sizes and amplitudes, as shown in Ref. 1.

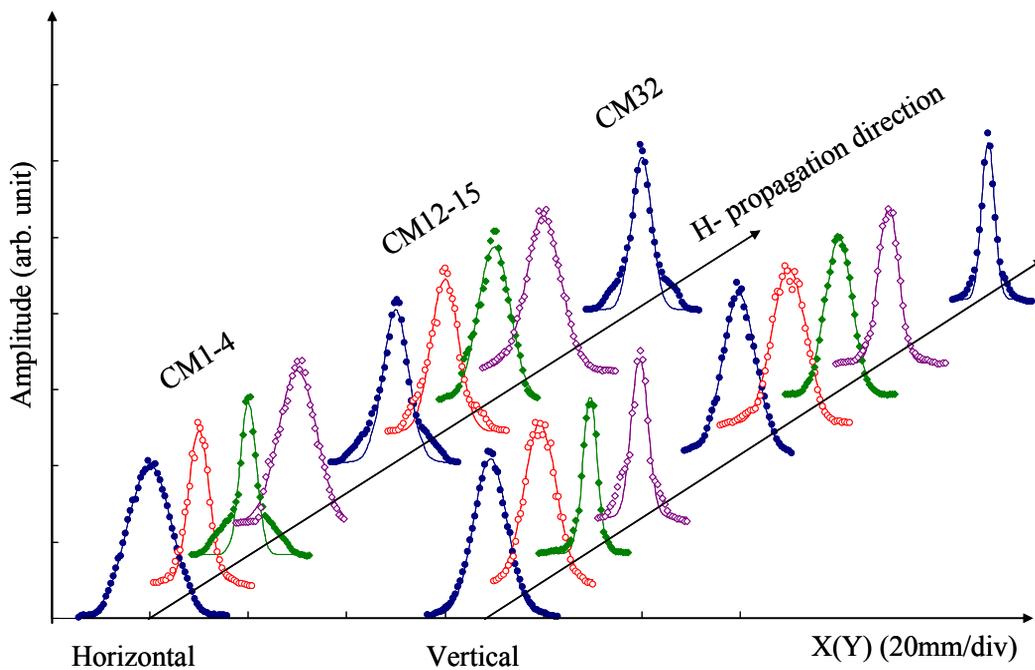


Figure 4: Profiles of 1 MW neutron production beam along the SCL measured on April 30, 2010. Marks are measured data and solid lines are Gaussian fitting curves.

Table 1: Measured Beam Sizes and Energies at Each Laser Wire Station of Scl.

Cryomodule #	H ⁻ Energy (MeV)	σ_x (mm)	σ_y (mm)
1	206	4.5	3.4
2	224	2.1	3.2
3	250	1.7	1.4
4	276	3.9	1.7
12	472	2.6	3.3
13	507	2.8	3.4
14	550	3.2	2.7
15	593	3.4	2.0
32	932	2.1	1.3

NOVEL CAPABILITIES

The laser wire system not only has advantages of reducing the risk of cavity contamination, being able to run at a parasitic manner on the production beam, it also offers novel capability over the conventional wire scanner. One of them is to measure the variation of the profile along the mini-pulse of the ion beam.

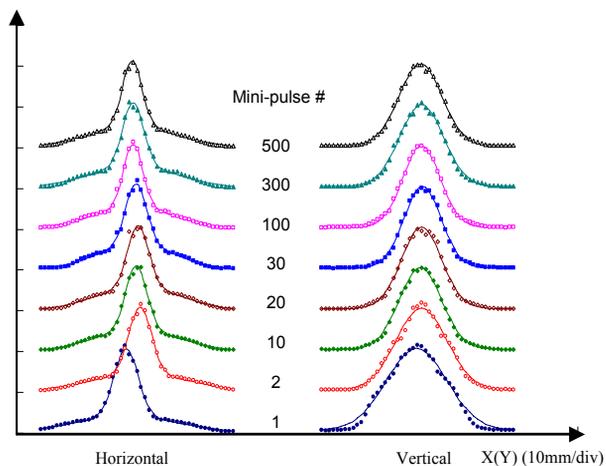


Figure 5: Profiles measured over different mini-pulses within one macro-pulse.

At SNS, the H⁻ beam consists of approximately 50-ps long micropulses separated by ~2.5 ns and gated into minipulses of 650 ns long. The period of minipulses, or a turn, is determined by the SNS accumulation ring beam path length and the beam energy. The minipulses are bunched into macropulses with a length of 1 ms and a repetition rate of 60 Hz. In the laser wire system, the firing of the laser flash lamps is locked to a precursor signal (timing signal) for the macropulse with a certain time delay that determines the phase relationship between the laser and ion pulses, i.e., the turn number of the minipulse within a macropulse. Since the time delay between laser pulses and the macropulse of the H⁻ beam is user adjustable, it is possible to measure beam profiles at different minipulses or even different segments within a single minipulse. This provides a unique profile study that

is unavailable with the technology of conventional wire scanners.

Figure 5 shows the measured profile parameters over different mini-pulses within one macro-pulse. We found that the beam size measured at the center minipulses is slightly smaller than those at the end minipulses. Meanwhile, changes in the peak height and beam center position are only within a few percent, which means the beam current and position changes very little along a macropulse. We can further look into details within a single mini-pulse by narrowing the tuning range of the delay time. An example is given in Fig. 6 which shows how the profile builds up at the edge of a mini-pulse at a beam energy of 930 MeV.

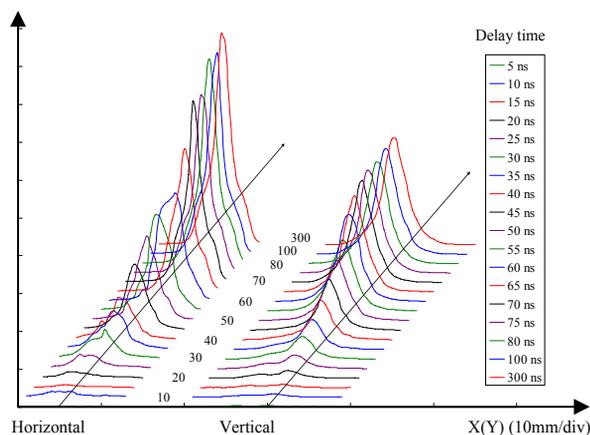


Figure 6: Measured profiles along the edge of a mini-pulse.

CONCLUSIONS

We have described a laser wire beam profile diagnostics system implemented in the SNS superconducting linear accelerator. The system measures 1-MW neutron-production hydrogen ion beam profiles at 9 locations corresponding to energy levels from 200 MeV to 1 GeV by using a single laser source. With this setup, it became possible to parasitically measure the size of an individual minipulse or different segments within one minipulse.

The ongoing work includes the enhancement of laser pulse temporal stability, reduction of the background noise level, simultaneous scan of profiles at multiple stations to increase the yield, and the transition to the operational use of the laser wire system.

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REFERENCES

[1] Y. Liu et al., *Nuclear Instruments and Methods in Physics Research A* 612 (2010) 241–253.