LASER WIRE BASED PARALLEL PROFILE SCAN OF H⁻ BEAM AT THE SUPERCONDUCTING LINAC OF SPALLATION NEUTRON SOURCE*

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Abstract

We report on the world's first experiment of a parallel profile scan of the hydrogen ion (H^-) beam using a laser wire system. The system was developed at the superconducting linac (SCL) of the Spallation Neutron Source (SNS) accelerator complex. The laser wire profile scanner is based on a photo-detachment process and therefore can be conducted on an operational H^- beam in a nonintrusive manner. The parallel profile scanning system makes it possible to simultaneously measure profiles of the 1-MW neutron production H^- beam at 9 different locations (corresponding to energy levels of 200 MeV – 1 GeV) of beamline using a single light source.

INTRODUCTION

In recent years, laser based nonintrusive H^- beam profile/emittance measurement systems have been developed at the SNS which is an accelerator based, world's most intense short-pulse neutron scattering facility [1,2]. Although laser wire profile monitors were installed at multiple locations along the SCL beamline, previously profile measurements have only been performed serially since a single light source is used. On the other hand, physics study such as the SCL modeling at SNS requires the measurement of H^- beam profiles at different locations along the acceleration path and usually such measurement needs to be conducted many times on different accelerator settings. A simultaneous profile measurement would be especially helpful to improve the efficiency and accuracy of the physics studies. We show that through a series of improvements on the optical transfer line, timing control and scanning software, it is possible to simultaneously measure H^- beam profiles at 9 different locations along the SCL. The measurement was conducted completely in a nonintrusive manner on the neutron production H^- beam. The entire measurement process takes less than 5 minutes to complete. Together with the hardware modification, we have also upgraded our user interface to provide a push-button style, informative platform to make the laser wire system a truly convenient and useful tool for the accelerator operators and physicists.

SYSTEM CONFIGURATION

Laser Wire System Layout

The 230-meter long SCL is the longest section of the SNS accelerator complex and it accelerates the H^- from ~ 200 MeV to 1 GeV. The SNS laser wire system consists of 9 profile monitors that cover from the beginning to the end of the SCL. Figure 1 shows a layout of the system.

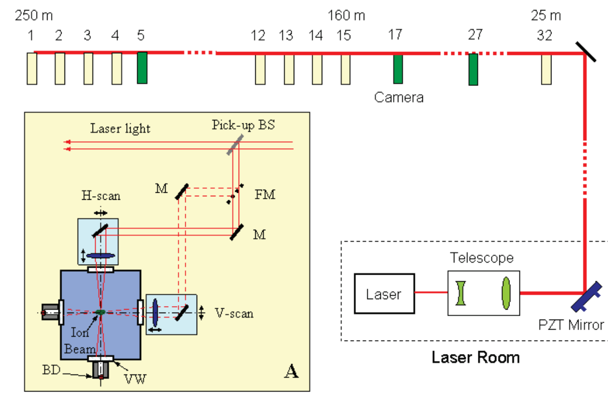

Figure 1: Outline of the SNS laser wire system. PZT Mirror: piezo-electric transducer driven mirror for beam position stabilization. The numbers in the figure indicate the SCL cryomodule and distances are from the laser source. Inset box A: diagram of an individual profile measurement station. BS: beam splitter, M: mirror, FM: flipper mirror, BD: beam dump, VM: vacuum window.

A schematic illustration of the laser wire measurement station is shown in the inset box A of Fig. 1. At each measurement station, a stepper motor driven pick-up mirror intercepts the free-space laser transport line (LTL) and redirects the laser light to the measurement box. Inside the measurement box, a motorized flip mirror switches the laser light between the horizontal and vertical scanning axes. The laser beam enters a vacuum chamber through a vacuum window (laser port) and is designed to interact with the ion beam close to the focal point of the laser beam.

When the H^- beam interacts with the laser light, a small portion of the ions illuminated by the laser pulse are neutralized and the liberated electrons are collected by an electron detector. The measurement of the resulting electron density leads to the determination of the negative ion density. By scanning the incident laser beam in horizontal or vertical directions, profiles of the ion beam along the correspondent axis can be obtained.

Optical System

All 9 SCL laser wire profile monitors use the same, single Q-switched Nd:YAG laser as light source. This laser is capable of producing a maximum pulse energy of 1.5 J with a 7 ns pulse width and a 30 Hz pulse rate. The firing of laser pulses is triggered by a clock signal from the accelerator baseline timing system. The laser is located outside the linac tunnel to avoid radiation damage

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and the laser beam is delivered to SCL through LTL. To facilitate parallel profile scan, all the pick-up mirrors except the last one in the transport line were switched from the original 5-cm diameter mirrors to 7.5-cm diameter and 5-mm thick beam splitters. For each beam splitter, the back surface is anti-reflection coated while the front surface is coated with appropriate reflection ratios. The reflection ratios are properly arranged so that each measurement station receives similar light power when all pick-up optics (mirrors/beam splitters) and beam samplers (for image monitoring) are in place.

Maintaining a high spatial (pointing) stability of the laser beam is critical to ensure the laser beam be intercepted by each pick-up optics and therefore to perform a valid profile scan. We have implemented an active stabilization scheme by steering the laser with an actuator-driven mirror installed in the laser room [3]. By using feedback, the achieved laser beam stability at low frequencies is better than 5 μrad. This corresponds to only ±1.25 mm of the beam position variation at the furthest measurement station, which guarantees the entire laser beam is well within the apertures of the pick-up and scanning optics.

Phase Tuning between Laser and Ion Pulses

The baseline H^- beam of the SNS accelerator has a 1 ms pulse length and a repetition rate of 60 Hz. To match the configuration of the SNS accumulation ring, the 1-ms long H^- macro-pulse is chopped into 'mini-pulses' of ~ 650-ns duration with a period of ~ 950 ns. Each of the above mini-pulses is further bunched into 402.5 MHz/50 ps 'micro-pulses' by the SNS RFQ before propagating to the linac. The firing of the laser is locked to a precursor signal (timing signal) for the macro-pulse. As the laser pulse width is about 7 ns, a single laser pulse will 'illuminate' 3 micro-pulses of the ion beam. The phase delay between laser and ion beam triggers needs to be properly adjusted so that the laser pulse will encounter the ion pulses at all measurement stations.

We analyzed the time-of-flight of the ion beam along the SCL based on the measured energies of the H^- beam. Figure 2 shows the propagation of both the light beam and the ion beam in a temporal-space domain. The space covers from the beginning to the end of the SCL. Each vertical bar represents a mini-pulse (~650 ns long) of the H^- beam at one measurement station. Three consecutive minipulses are shown in the figure with the spacing equal to the period (~950 ns) of the mini-pulse. The straight line represents the trajectory of the laser pulse propagating from the end to the beginning of the SCL. We found that there exists a small time window (~30 ns) within which the laser pulse encounters the H^- beam at all 9 measurement locations. Obviously, the laser pulse interacts at different segments, or even a completely different mini-pulse of the H^- beam at different locations. In the experiment, the phase delay is automatically calculated for all measurement stations once the mini-pulse number is decided.

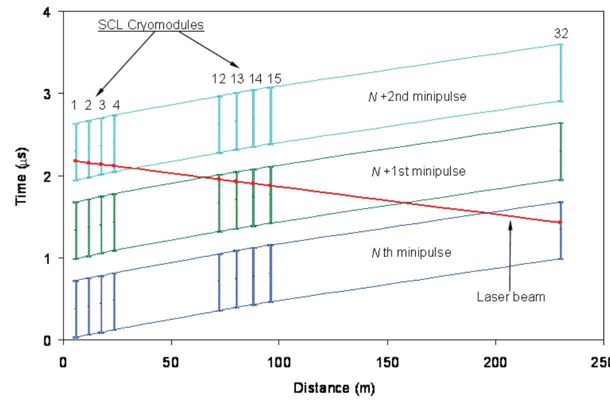

Figure 2: Temporal-space representation of the laser pulse and ion beam's mini-pulses along the SCL. Distance is from the beginning of SCL. Laser pulse and ion pulses are travelling in opposite directions.

MEASUREMENT RESULTS

The parallel profile scan system was commissioned in the spring run of 2012. The laser wire software was originally implemented on the LabVIEW platform. To facilitate its operational use at SNS, the laser wire user interface screens were changed to EDM for EPICS. This allowed them to be integrated into the standard operating platform of the SNS beam instruments. Figure 3 shows an EDM screen of the laser wire based parallel profile scan system. The program is written using Perl script for push-button commands. The program also calculates the correct timing to ensure that a single laser pulse to interact with a minipulse and acquire data at each laser wire station. The simultaneous profile scan is initiated by a single push-button 'Laser Wire Scan All!'. The platform also provides estimated parameter values, time needed to accomplish the scan, and the time stamp information for each measured profile. One can further zoom-in an individual measurement station and use an expert screen that allows experienced users the ability to perform advanced configuration and data analysis such as the adjustment of timing, moving stages manually, and investigating raw signals at different situations.

The user interface also offers a real-time visualization of the measured 9-pairs of H^- beam profiles, which presents a highly intuitive and informative picture of the H^- beam propagation along the acceleration path [4]. A full scan with an average of 25 measurements only takes about 2 minutes to finish. The entire measurement has little influence on the accelerator and therefore has been routinely applied to neutron production H^- beam. The system provides a powerful tool for accelerator operators and physicists to monitor and/or tune the beam parameters.

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Figure 3: EDM screen of the laser wire based parallel profile scan. The EDM screen provides the user with the ability to change settings for either all of the laser wire stations or individual stations. Prominently displays the horizontal and vertical profiles for each station on the same plot, which axis is selected, and the state of the scan. For convenience, toggle buttons along the side of the plot enable/disable the display of individual profiles.

CONCLUSION

The SNS laser wire system is among the very few operational laser based nonintrusive beam diagnostics systems implemented in accelerator facilities. The parallel scan allows a simultaneous profile measurement of the neutron production hydrogen ion beam at 9 different locations along the superconducting linac of SNS. The parallel profile scan system provides an unprecedented diagnostics tool for accelerator operators and physicists by measuring beam profiles and beam parameters with high speed, high accuracy, and in a nonintrusive manner.

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REFERENCES

[1] Y. Liu et al, “Laser wire beam profile monitor in the Spallation Neutron Source (SNS) superconducting linac,” Nucl. Instr. and Meth. A 612 (2010) 241.

[2] Y. Liu et al, “Nonintrusive emittance measurement of 1 GeV H^- beam,” Nucl. Instr. and Meth. A 675 (2012) 97.

[3] R. Hardin, Y. Liu, C. Long, A. Aleksandrov, “Active beam position control of high power pulsed laser for laser-based remote diagnostics,” Opt. Express 19 (2011) 2874.

[4] Y. Liu, C. Long, C. Huang, R. Dickson, A. Aleksandrov, “Simultaneous ion beam profile scan using a single laser source,” Phys. Rev. ST Accel. Beams 16 (2013) 012801.

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