

LASER WIRE BASED TRANSVERSE EMITTANCE MEASUREMENT OF H⁻ BEAM AT SPALLATION NEUTRON SOURCE*

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Abstract

A laser wire based transverse emittance measurement system has been developed at the Spallation Neutron Source (SNS). The system enables a nonintrusive measurement of the transverse emittance in both directions on a 925 MeV/1 MW hydrogen ion (H⁻) beam at the high energy beam transport (HEBT) beam line.

INTRODUCTION

Conventional particle beam emittance measurement techniques such as the slit-and-collector or pepper-pot methods are generally intrusive and cannot be applied to full spec high-brightness particle beams [1, 2]. At the Spallation Neutron Source (SNS), we have developed a laser based, nonintrusive emittance measurement system at the high energy beam transport (HEBT) beam line [3].

The SNS laser emittance measurement setup consists of a laser wire scanner in the HEBT beam line and a metallic wire scanner in the linac dump beam line. The laser light slices out a narrow neutralized hydrogen beam (H⁰) through the photodetachment process. The H⁰ beam is transmitted through a downstream dipole and separated from the rest of the beam. The titanium wires measure the distribution of the H⁰ beam released from the laser slit. The system has been applied to the emittance

measurement of a 925 MeV/1 MW neutron production H⁻ beam.

SYSTEM DESCRIPTION

A schematic of the laser based emittance measurement system is shown in Fig. 1. The emittance measurement setup is located about 40 meters away from the beginning of the SNS HEBT beam line. The expected beam emittance at this location is about 0.5 mm-mrad. The setup consists of two parts: a laser wire scanner (laser slit) and a conventional metallic wire scanner. The laser wire scanner is installed right before the first of eight 11.25° C-type dipoles which turn the H⁻ beam to the accumulator ring. These dipoles also separate the neutralized hydrogen beam (H⁰) from the main beam trajectory and direct the H⁰ beam to the linac dump beam line. A metallic wire scanner is installed in the linac dump beam line, about 11.6 meters downstream of the laser wire station. The wire scanner measures the distribution of the H⁰ beam released from the laser slit. Since the laser wire only interacts with a very tiny portion (~10⁻⁷) of the ion beam and the wire scanner is interacting with an off-line H⁰ beam, the entire measurement is effectively nonintrusive and can be conducted parasitically on a neutron production H⁻ beam.

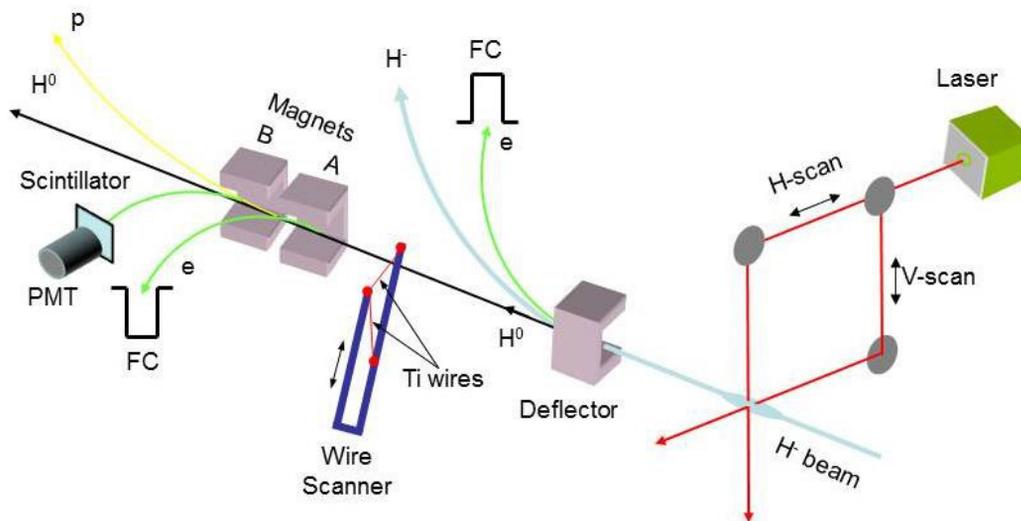


Figure 1: Schematic of laser wire based H⁻ beam emittance measurement system. FC: Faraday cup, PMT: photomultiplier tube, Magnets A and B deflects electrons for FC and scintillator detection schemes, respectively.

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The neutralized H^0 beam travels along a 11.6-m path before being intercepted by the wire scanner. The thickness of the wire is chosen to effectively detach the electrons but leave their energy and direction of flight almost unaffected. Our numerical simulation indicated that a 50- μm titanium (Ti) wire results in an excellent electron transmission and consequently higher detection efficiency [3]. Instead of the single-string wire scanner, a flat bundle of 10 Ti wires (Fig. 2) were assembled to increase the number of detached electrons from the wire scanner.

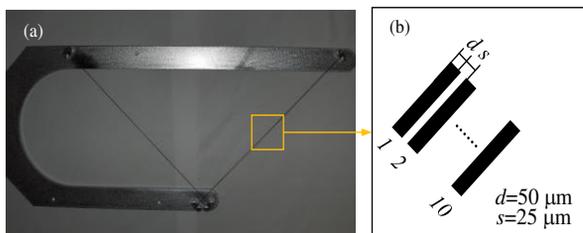


Figure 2: (a) Photo and (b) schematic diagram of the 10-string titanium wire scanner.

The detached electrons from both laser wire and wire scanner are detected with Faraday cups. The electrons are deflected in the vertical direction by two C-shaped dipole magnets with 5-inch gap. Since the electron collecting magnets also induce a minor deflection of the ion beam, a specially designed dipole correcting magnet with the same magnetic field but in the opposite polarity is installed in the proximity of the electron collecting magnets to compensate the ion beam trajectory. The laser wire Faraday Cup output is amplified with a low noise 26 dB gain amplifier and passes through a filter with a bandwidth of about 8 KHz – 40 MHz. The detection of the photodetachment signal from the wire scanner requires about 100 times higher sensitivity. The wire scanner output is amplified with an extremely high gain (~ 66 dB) amplifier over a frequency range of 2 – 40 MHz. The amplified electric signal is finally sent to an analog-digital-converter (ADC) for data analysis and emittance measurement. Details of signal processing can be found in Ref. [3].

MEASUREMENT PERFORMANCE

The initial commissioning of the system was conducted by using 30-Hz, 150-mJ laser pulses and a single 50- μm titanium wire which was later replaced by a 10-string bundle. Figure 3 shows a typical emittance graph measured on the neutron production H^0 beam. The measured emittance of 0.46 $\text{mm}\cdot\text{mrad}$ is close to the design value.

A self-consistency check has been conducted by summing the output of the emittance measurement over the angle and comparing it with the beam profile measured directly from the laser wire. It is expected that the integration of the emittance distribution over the divergence angle should reconstruct the original beam

profile. Figure 4 shows the results for both horizontal and vertical directions. The fitting errors between the directly measured profile and the integration from the emittance are only 2.2% (horizontal) and 5.9% (vertical).

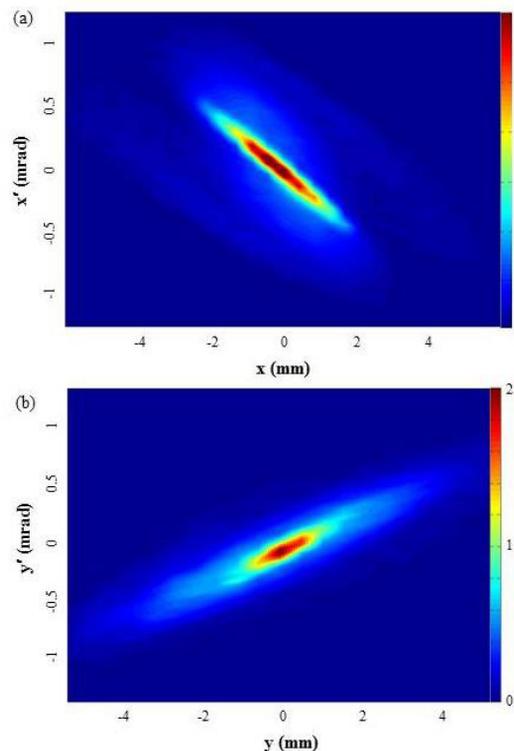


Figure 3: Emittance measured using the 10-string wire scanner and the Faraday cup electron collector scheme.

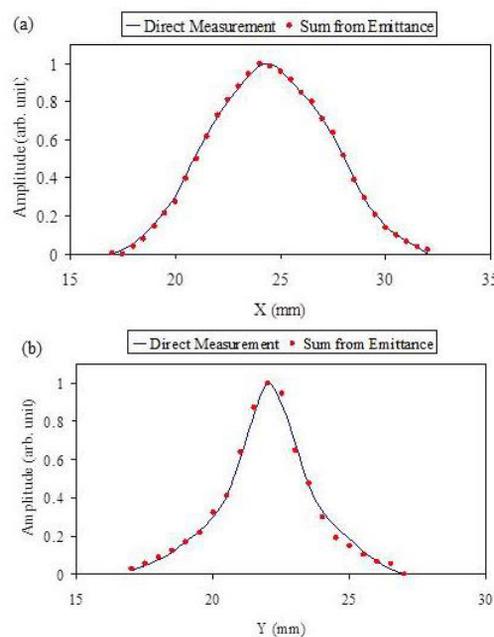


Figure 4: Comparison of directly measured profiles (blue lines) and profiles integrated from the emittance distributions (red dots). (a) Horizontal and (b) vertical profiles.

DETECTION SCHEME UPGRADES

The signal noise ratio of the measurement and the emittance resolution are mainly limited by the dynamic range of the detection. In particular, the weak signal of the wire scanner output requires a high sensitivity, low noise detection. In the original detection scheme, the Faraday cup output signal was sent to a high gain amplifier located in the klystron gallery through a long cable (over 100 meters) which picks up substantial noise. The dynamic range was below 10 for the single-string wire scanner and about 30 for the 10-string wire scanner. We have upgraded the detection system in recent years. We first improved the signal noise ratio by installing the amplifier next to the beam line. This enhanced the dynamic range to over 70. Recently, we installed a new detection scheme consisting of a scintillator inside the vacuum and a Hamamatsu H6559 photomultiplier tube next to the vacuum window (Fig. 1). Figure 5 shows typical detected waveforms from 4 generations of signal detection schemes. The corresponding dynamic ranges are 4, 28, 78, and 375, respectively. The measured emittance graph (Fig. 6) revealed a much better resolution especially around the edge.

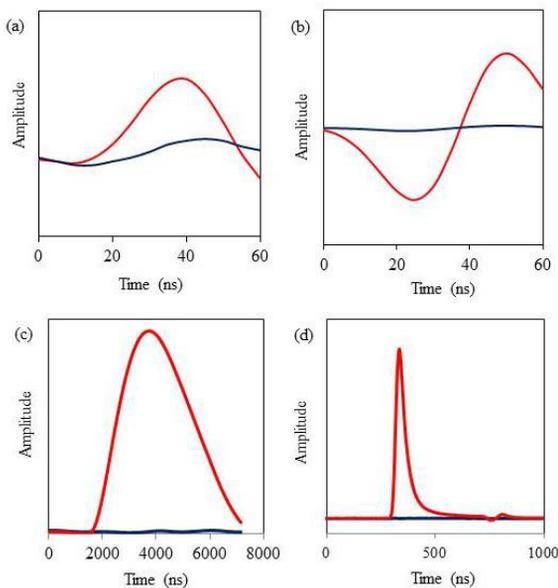


Figure 5: Output waveforms from the titanium wire scanner. Red and blue lines correspond to signals at the center and edge of the emittance plot. (a) single-string wire scanner output, (b)-(d) 10-string wire scanner outputs at different detection schemes.

CONCLUSION

We have described the system configuration, commissioning results, and present status of the laser

based H⁻ beam phase space measurement system implemented at the SNS high energy beam transport line. Emittance in both transverse directions can be directly measured with no requirement for additional beam parameters. The measurement time is comparable to that of the conventional emittance measurement instruments. However, since the laser based measurement method can be conducted in a parasitic manner, the measurement time does not impose any practical restriction on its operation.

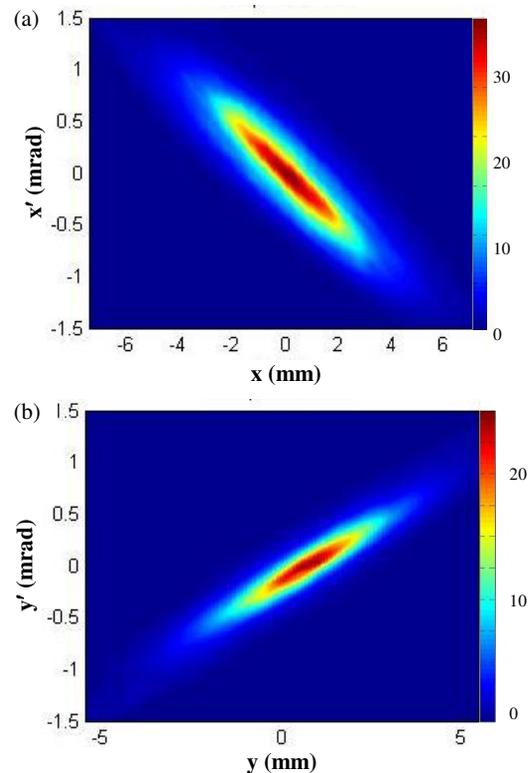


Figure 6: Emittance measured using the scintillator-PMT detection scheme.

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