15th International Particle Accelerator Conference,Nashville, TN JACoW Publishing
ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-TUPS85

RECENT PROGRESS IN LASER WIRE-BASED H- BEAM DIAGNOSTICS AT THE SNS LINAC*

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Abstract

Laser wire has been used for nonintrusive profile and emittance measurements of operational hydrogen ion (H-) beam at the Spallation Neutron Source (SNS) linac. In this paper, we will review the recently upgraded light source, laser transport line, and the improvement of the measurement dynamic range.

INTRODUCTION

Laser-wire-based H- beam diagnostics use a light-ion interaction process known as photo-detachment or photo-neutralization [1]. As schematically shown in Fig. 1, the irradiation of an ion beam with photons above a certain energy causes detachment of electrons from negative ions and the measurement of the resulting electron density leads to determination of the negative ion density. Compared to the conventional wire scanners, laser wire brought several notable advantages: 1) the measurement can be performed during normal operations; 2) there are no moving parts inside the vacuum system; 3) a longitudinal beam scan is conceivable; 4) a time-resolved measurement can reveal variations of the beam parameters within a very short time interval. On the other hand, the laser wire also has drawbacks including limited stability and measurement dynamic range.

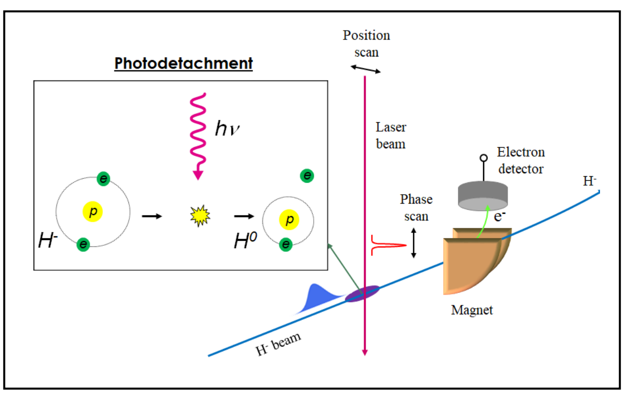

Figure 1: Schematic of laser wire-based H- beam diagnostics.

In this paper, we will describe our recent upgrade of the laser wire system. The previously used Q-switched laser was replaced by a customized laser system consisting of fiber-based seeders and diode-pumped solid-state amplifiers. The laser pulse width can be selected over a wide range from a few picoseconds to over 100 ps, which enables measurements in the longitudinal domain as well as time-resolved beam diagnostics. We have also implemented several modifications in the laser wire chamber and detection scheme to improve the measurement dynamic range.

LASER SYSTEM

The original light source for the laser wire measurements was a commercial flash-lamp pumped Q-switched laser with the pulse width of ~ 7 ns at 30 Hz. Such a laser system has high pulse energy, excellent reliability, reasonable beam quality, and is generally insensitive to the phase jitter since the pulse width is much wider than the H- beam bunch width (10 – 100 ps). A major drawback is its relatively long pulse width which produces excessive exposure on the vacuum window, causes background noise due to the reflection, and is unsuitable for beam diagnostics in the longitudinal domain.

Recently, we constructed a new light source based on a master oscillator power amplifier (MOPA) scheme. The master oscillator uses fiber-based mode-locked lasers which have pulse widths ranging from a few picoseconds to nearly 100 ps. The laser has a central wavelength at 1064.5 nm and a repetition rate that is equal to or a subharmonic of the RF frequency of the accelerator.

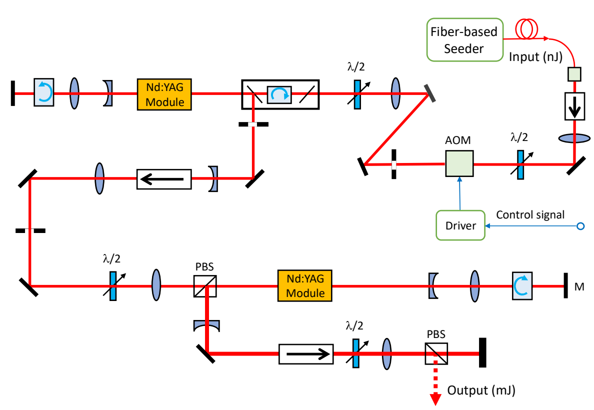

Figure 2: Macropulse laser amplifier.

The output power from the seed laser typically has pulse energies in the order of sub-nanojoule. Multiple stages of the amplifications are necessary to boost the pulse energy to the millijoule level for the measurement. Prior to the amplification, the macropulse structure of the laser pulses is

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formed by using an acousto-optical modulator. Currently, 2-3 stages of the diode-pumped Nd:YAG amplifier modules from Cutting Edge Optronics (CEO) are used to boost the laser power. The Nd:YAG gain medium was chosen for its excellent thermal characteristics and beam quality in the room temperature. The diode pumping scheme enables the generation of up to 1-ms macropulses with a repetitio rate of 60 Hz, identical to the macropulse structure of the H^- beam in the SNS linac. Figure 2 shows a schematical of one implementation example consisting of two stages of the amplifier modules. The first stage uses a 2-mm YAG rod and the second stage uses a 6-mm YAG rod. Both amplifiers are operated in the double-pass configuration. The optics between the YAG rod and reflector contains a Faraday rotator and a pair of relay lenses. The reflected laser beam has a perpendicular polarization direction with respect to the incoming laser beam and the lens pairs are designed so that the reflected laser beam will have a proper beam size and divergence when re-entering the rod, which is critical to compensate both the thermal-induced birefringence and focusing effects inside the gain medium.

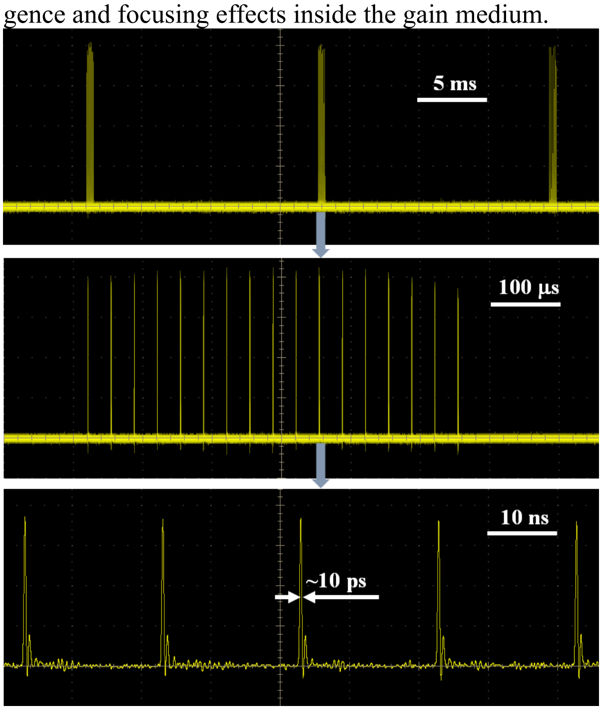

Figure 3: Waveforms of the amplifier output. The seed laser has a FWHM pulse width of about 10 ps.

An example of the laser pulse waveforms from the amplifier is shown in Fig. 3. The top plot shows the 60-Hz macropulses. Each macropulse contains ~20 sub-pulses with flexible repetition rates and pulse durations. Finally, each sub-pulse contains multiple micro-pulses whose repetition frequency and pulse width are determined by the seed laser. By optimizing the beam size and time delays between pumping and laser pulses, even a two-stage amplifier scheme can amplify the pulse energy from a sub-nanojoule level to a few millijoules. The beam quality was measured to be $M^2 \sim 1.15$. It worths noting that the above multi-layer temporal structure, also known as a laser comb, has been used to simultaneously measure profile or emittances of an operational beam at different portions of a macropulse or within a turn from a single scan [2].

There are 10 laser-based H^- beam diagnostic stations installed along the SNS linac. The laser beam is sent to the measurement locations through a free-space transport line. At each measurement station, a motorized pick-up mirror is used to redirect the laser beam to the measurement chamber. The furthest measurement station is about 250 meters away from the laser lab. To deliver the laser beam to all individual measurement stations with proper beam size, we introduced image relay lens pairs or telescopes in the transport line. Figure 4 shows the locations of the measurement stations and telescopes installed in the transport line. Three telescopes, each consisting of a pair of lenses with adjustable spacing, are installed in the laser lab and two locations (95 and 185 meters away from the laser, respectively) in the transport line. The image relay optics delivers laser beam with proper beam sizes at individual measurement stations. The laser beam spot on the view screen is monitored by a digital camera. The beam position is stabilized by an active feedback that steers the mirror based on the position of the laser beam monitored along the transport line.

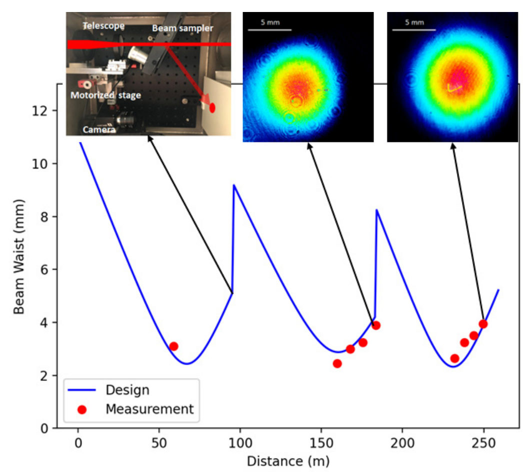

Figure 4: Designed values and actual measurement results of laser beam size along the optical transport line. Inset figures (from left to right) are a telescope installed in the transport line and laser beam profiles measured at two locations of the transport line.

HIGH DYNAMIC RANGE MEASUREMENT

A major challenge in the laser wire-based beam diagnostics is its dynamic range is limited by the level of the background noise. Main contributions of the background noise are gas tripping noise and unintended photodetachment caused by the optical reflections from the viewport and the surface of the vacuum chamber. While the gas stripping induced background can be removed by a gated detection, it is difficult to separate the background noise induced by the optical reflection from the laser itself. In particular, the reflected light is a diverging beam and can interact with the

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entire H- beam, which creates a photodetachment outcome that could be much higher than the reflection ratio. In general, the background level from a Q-switched laser is at the level of 1%, which restricted the capability of the laser wire in the measurement of beam tails or beam halo.

The optical reflection effect can be effectively mitigated by using sufficiently short laser pulses and a proper design of the measurement chamber so that the reflected light beam will miss the bunch of the ion beam. We modified the measurement chamber in the HEBT laser wire station so that the reflected laser beam falls exactly in the middle point between two consecutive ion bunches, which essentially eliminated the effect of the optical reflections to the photodetachment signal. We found out that such a modification can increase the dynamic range by an order of magnitude.

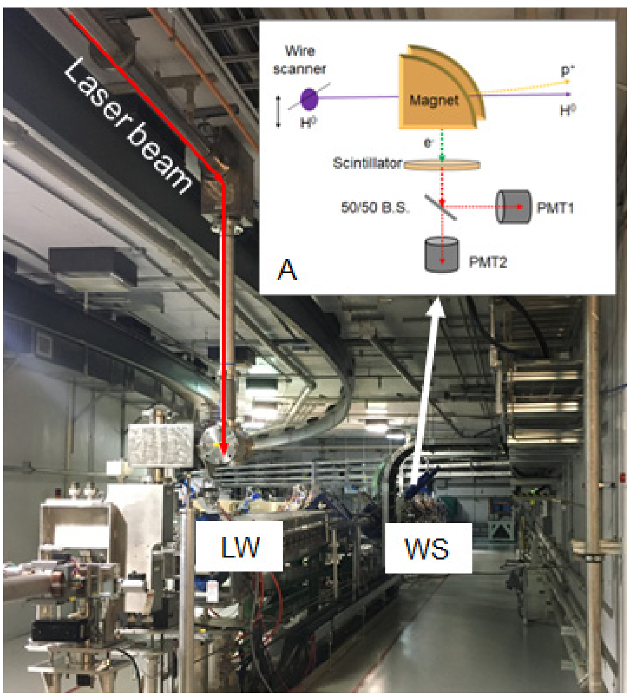

Figure 5: HEBT laser wire-based transverse phase space emittance measurement setup. LW: laser wire measurement station; WS: wire scanner; inset box A: detection scheme using dual-gain PMTs.

The dynamic range is vital in the measurement of phase space. At SNS, we applied the laser wire to measuring the transverse phase space (emittance) in the high energy transport line (HEBT). The setup is shown in Fig. 5. When the H- beam interacts with the laser light, some ions are neutralized and separated from the beam path. These hydrogen (H^0) atoms preserve the angular distribution of the original H- beam. Therefore, the measurement of the divergence of the narrow H^0 beam leads to the determination of the H- beam divergence. The measurement of the H^0 beam angular distribution is conducted through the measurement of its transverse profile by a titanium wire scanner after its propagation over a certain distance. The titanium wires in the wire scanner detach the electrons from the H^0 beam and the detached electrons are steered to a scintillator by a small magnet. Finally, photons emitted from the scintillator are detected by a photo-multiplier tube (PMT).

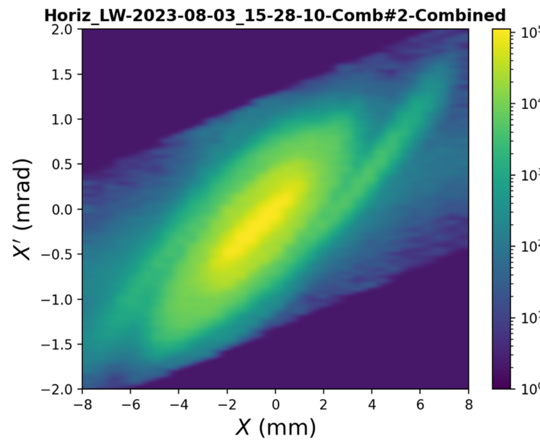

Figure 6: Measured emittance plot on the 1.7-MW neutron production H- beam based on dual-gain PMTs.

Recently, we implemented two PMTs with different gains to increase the dynamic range. By stitching the outputs with pre-evaluated gain coefficients, the dynamic range has been improved by an order of magnitude. An example of the measured emittances of the 1.7-MW neutron production beam is shown in Fig. 6. Details of the measurement setup and signal processing will be reported elsewhere.

CONCLUSION

We have described our recent upgrades on the light source and detection scheme in the laser wire-based H-beam instrumentation at the SNS linac. The upgraded system brought the measurement dynamic range by more than an order of magnitude.

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