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LASER TRANSPORT AND STABILIZATION FOR THE CSNS LASER WIRE PROFILE MONITOR PROTOTYPE*

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Abstract

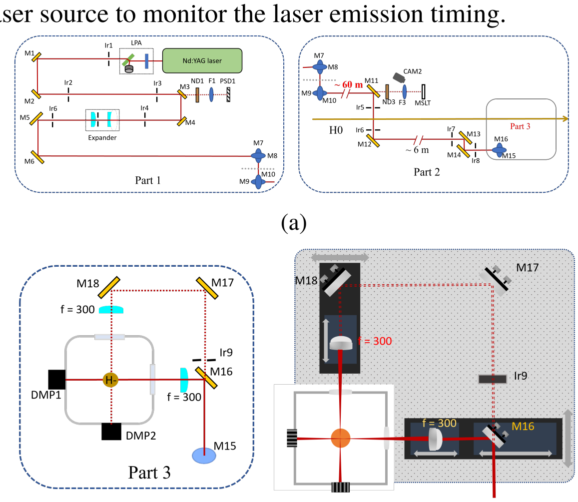
A laser wire monitor prototype has bean developed at the China Spallation Neutron Source (CSNS).The monitor utilizes a 1064 nm laser source to measure the horizontal and vertical profiles of a negative hydrogen ion (H^-) beam with an energy of 80 MeV in the injection zone. This paper describes the design of the laser optical path layout and the laser transmission performance of the system. The experiment focuses on the laser system's quality factor M^2 of the laser after more than 60 meters of transmission as well as the beam pointing stability. In this experiment, the laser quality factor M^2 after transmission is better than 4, and the beam pointing stability after focus is less than ± 2.5 μm, which is able to satisfy the required specifications for the first CSNS laser wire monitor.

INTRODUCTION

The China Spallation Neutron Source (CSNS) complex is designed as a multidisciplinary platform to support scientific research and applications for national institutions, universities, and industries [1]. The CSNS accelerator complex consists of a low-energy linear accelerator (linac), a Rapid Cycling Synchrotron (RCS), and two beam transport lines. For the CSNS-II upgrade, the beam power will be increased to 500 kW, maintaining a beam energy of 1.6 GeV. This upgrade involves increasing the linac beam energy from 80 MeV to 300 MeV by incorporating a new superconducting accelerating section [2]. Consequently, the use of physical wire scanners for beam profile monitoring is impractical in much of the linac due to the risk of wire breakage, which could contaminate the superconducting (SC) cavities. Therefore, a laser wire system has been adopted as a non-invasive alternative [3–5]. Given the challenging tunnel environment, this paper details the commissioning of the laser optical path layout and presents experimental results on laser transmission performance and beam spot stability monitoring.

LASER OPTICAL PATH SETUP

Figure 1 illustrates the schematic of the complete laser optical path. To mitigate the radiation environment, the laser source and expander system (Part 1) are situated in a sub-tunnel. A Q-switched Nd:YAG laser, operating at a wavelength of 1064 nm, serves as the light source [6]. The laser operates at a repetition rate of 1 Hz with a pulse width of 9 ns. Synchronization between the laser and the beam is achieved by precisely controlling the trigger timing of the laser flash lamp. Additionally, the laser energy can be adjusted by varying the timing between the Q-switch and the flash lamp. However, this method may compromise laser stability. To address this, the laser pulse energy is regulated using a set of polarization optics. The maximum laser output energy is approximately 800 mJ, sufficient to detach an adequate number of electrons [7]. To ensure high transmission efficiency and maintain beam quality, the laser spot size is expanded from approximately 9 mm to 27 mm using a threefold beam expander. A photodiode (PD) is positioned adjacent to the laser source to monitor the laser emission timing.



(b)

Figure 1: Outline of the laser optical path installed in the CSNS linac.

The laser beam is guided from the sub-tunnel to the main tunnel using mirrors and then propagates along the beam direction toward the laser wire station. Mirrors 7 and 8 are employed to adjust for variations in laser beam height during transmission. A laser position monitor, located 60 m downstream from the laser source, is used to track jitter and drift in the laser position caused by temperature, humidity, and mechanical instabilities. To ensure precise horizontal and vertical alignment of the incident light at the laser station, two additional mirrors (13 and 14) have been incorporated to enable fine adjustments. Additionally, for safety considerations, fire-resistant materials were employed for the laser beam tubes along the transmission path.

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Figure 1(b) illustrates the schematic of the laser wire station, which includes a flip-mirror (mirror 16) that can be moved into or out of the optical path to switch the laser beam between horizontal and vertical scans. For each scan direction, two motorized linear stages are employed: the first stage performs the scan of the laser beam across the ion beam, while the second adjusts the position of the focusing lens. The laser beam enters the vacuum chamber through a vacuum window and interacts with the ion beam at the laser beam's focal plane. Following the interaction, the laser beam is absorbed by a beam dump. A photodiode, positioned after mirror 15, provides an indication signal to confirm the presence of the laser beam during operation.

LASER BEAM TRANSPORT RESULTS

To characterize the laser transport system, a laser transmission experiment was initially conducted and completed in the laboratory. To achieve efficient laser propagation, both threefold and fourfold beam expansion systems were utilized to transform the laser beam, which has an initial divergence of 0.5 mrad, into a nearly collimated beam. Each expanded beam was transmitted over a distance of 40 m, and the beam quality was subsequently evaluated. The transmission efficiency was comparable for both the threefold and fourfold beam expansion systems, reaching approximately 80 %, with both systems yielding a beam quality factor of about 8. However, the asymmetry in the beam profile before and after focusing was more pronounced with the fourfold beam expansion system. Consequently, the threefold beam expander was selected.

Following the installation of the optical path in the tunnel, the laser beam energy and quality were measured at the detection location. The laser energy at the output of the laser generator is 780 mJ. After beam expansion, the energy measured by the power meter decreases to 590 mJ due to the enlarged spot size. After approximately 70 m of transmission, the laser energy reaching the detection position is approximately 500 mJ.

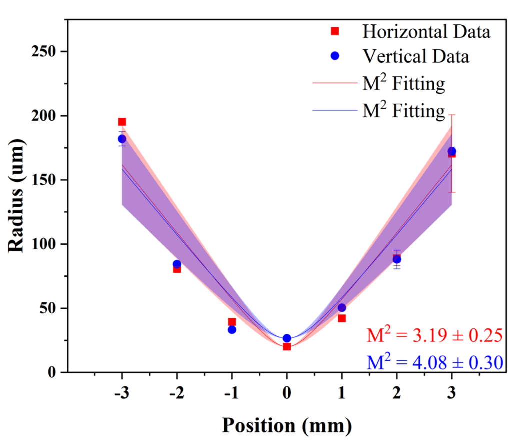

Figure 2: Fitting result of laser beam quality at the laser wire station location.

Figure 3: The laser beam spot at (a) 4 mm before the focus, (b) the focal point, and (c) 4 mm after the focus.

The laser beam radius at various positions on both sides of the focal point was measured using a beam profiler, and the data were fitted according to Eq. (1). Here, $W(x)$ represents the laser beam radius, defined as the distance from the center of the distribution to the point where the intensity decreases by a factor of e^2. The parameter W_0 denotes the laser beam waist radius, M^2 is the beam quality factor, λ_L is the laser wavelength, and x is the distance from the waist location along the optical axis [8]. The fitting results yield an M^2 value of 3.19 in the horizontal direction and 4.08 in the vertical direction, as shown in Fig. 2. Figure 3 illustrates the laser beam spot at different positions, with the minimum beam radius measured at 35.75 µm.

$$W(x) = W_0\sqrt{1+\left(x\frac{\lambda_L M^2}{\pi W_0^2}\right)^2} \tag{1}$$

LASER POINTING STABILITY MONITORING

A laser pointing monitor is positioned near the laser wire station, as shown in Fig. 4. By focusing the transmitted light from the mirror onto a screen, the laser position variation can be monitored in real time using a camera. Although the energy of the transmitted light is only 0.1 % of the original laser energy, the intensity after focusing may still be sufficient to damage the camera. Consequently, an attenuator is employed to reduce the light intensity to one-tenth of its original value.

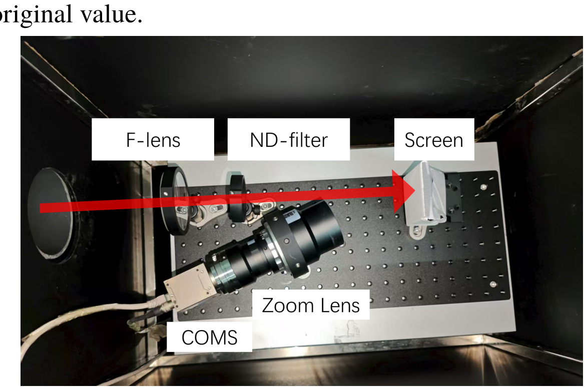

Figure 4: The laser pointing monitor.

The laser wire system exhibits two types of pointing instabilities. The first is position jitter resulting from inherent shot-to-shot variations in the laser pulses. The second is drift of the entire structure, induced by environmental factors such as groundwater flow and temperature variations.

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The spot position in the vertical and horizontal directions is determined by integrating the pixel values of the laser spot image captured by the camera along each respective axis and identifying the maximum integration value, as shown in Fig. 5. The laser system was reactivated every other day, and the position jitter of the detector was measured. Repeatedly switching the laser on and off induces greater jitter compared to continuous operation, likely due to instabilities in the water circulation system. Nevertheless, the total position jitter is less than 10 µm, which is negligible for the profile measurement.

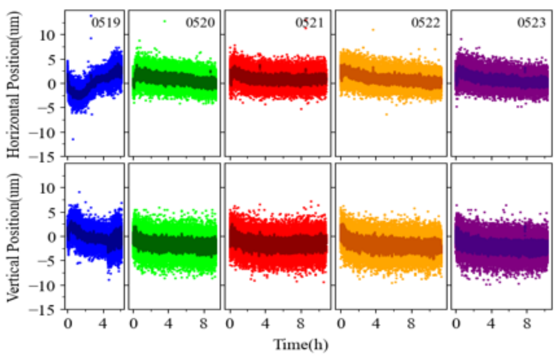

Figure 5: The laser position jitter over several days.

Figure 6 illustrates the cumulative laser drift observed over a two-week period. The horizontal axis corresponds to the monitoring date, while the vertical axis represents the mean coordinate position of the spot center, measured over a period exceeding five hours on each given day. Due to the limited duration of the monitoring period, no significant variation in the spot position was observed. The spot position drift over the two-week period remained within 2.5 µm. Further experimental investigation is required to determine whether noticeable positional drift occurs over longer timescales.

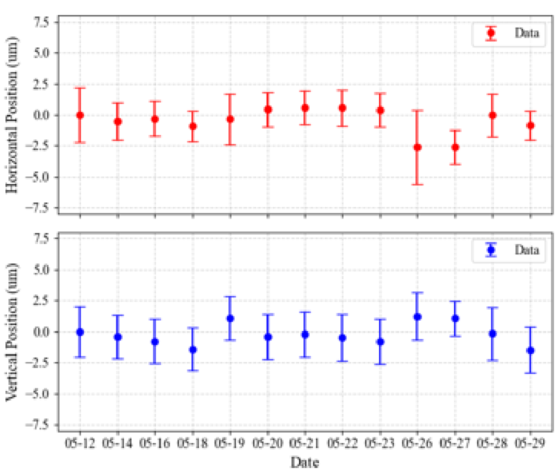

Figure 6: The laser position drift in two weeks.

CONCLUSION

A laser wire system has been successfully commissioned at the China Spallation Neutron Source (CSNS). After transmission over 70 m to the laser wire station, the system achieved a beam quality factor of 4 and a transmission efficiency of 83.8 %. A laser pointing monitor was established to track laser position jitter and drift. The results indicate that the jitter remains below 10 µm over several hours, and the drift is less than 2.5 µm over a two-week period. However, additional data are required to further analyze the laser drift. To enhance the system, the optical path will be upgraded by incorporating a remotely controlled mirror for feedback-based alignment correction. Additionally, a beam splitter combined with an optical delay line will be employed to sequentially direct the laser beam into the vacuum window along the horizontal and vertical directions, enabling simultaneous measurement of both the X and Y beam profiles.

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