SNS TRANSVERSE AND LONGITUDINAL LASER PROFILE MONITORS DESIGN, IMPLEMENTATION AND RESULTS*

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Abstract

SNS is using a Nd:YAG laser to measure transverse profiles at nine-stations in the 186-1000 MeV Super-Conducting LINAC (SCL), and a Ti:Sapphire mode-locked laser to measure longitudinal profiles in the 2.5 MeV Medium Energy Beam Transport (MEBT). The laser beam is scanned across the H- beam to photo-neutralize narrow slices. The liberated electrons are directly collected to measure the transverse or longitudinal beam profiles. We have successfully measured the transverse and longitudinal profiles at all stations. The SCL laser system uses an optical transport line that is installed alongside the 300 meter super-conducting LINAC to deliver laser light at nine locations. Movement of the laser light in the optical transport system can lead to problems with profile measurements. We are using telescopes to minimize the oscillations and the active feedback system on mirrors to correct the drifts and movements. In this paper we present our implementation and beam profiles measured during SCL commissioning. We also discuss future improvements, the drift/vibration cancellation system, as well as our plan to automate subsystems for both the transverse and the longitudinal profiles.

INTRODUCTION

The SNS accelerator systems are described in details elsewhere [1]. The 1ms long H^- macro pulses are accelerated by the linac to 1GeV energy and injected into the accumulator ring. The electrons of this 1 ms H^- beam is stripped by a carbon foil. The accumulated proton beam (minipulse circulating for more than 1000 turns) with average power of 1.44MW is sent to the spallation target every 16 ms. Minimization of the beam loss is expected to be challenging for the SNS, and it will likely be a limiting factor during high power operations.

Conventional Carbon Wire scanners

The physics of secondary electron emission of the carbon/tungsten wire signal is not well understood, and the signal amplitude is not easily calculated. It depends on the velocity of the incident particle, the angle of the incidence, the condition of the wire surface, and the wire bias voltage. More importantly, the H- pulse length has to be less than ~100 micro-second at low repetition rate. Using the wire scanner during normal beam-on-target operation will damage the wire and possibly contaminate SRF cavity. This is a major impact on normal operation. Another important handicap is the ionizing radiation caused by the beam hitting the wire creates a large beam-loss signal. Roughly 2% of the beam will be stripped by the wire and hit the quadrupole doublet sections between the SRF cavities. This is roughly 70 nA average current (~ 70 watts) for 100-us pulses at 1 Hz which may be sufficient to quench the super-conduction cavities if *all* of the beam hitting the wire is stripped and lost locally. This beam loss signal is significant above 100 MeV: In this mode, overlapping (crossed) wires cannot be used. Ablation from the wire (carbon wire), caused by high beam currents, may contaminate the SRF cavity. Use of refractory metals i.e. tungsten wires seems to minimize these contaminations. The wire scanner actuator is a mechanical system with moving parts inside the vacuum chamber: dirt from moving parts such as bellows could migrate into the SRF cavities. Moreover, the measured profile represents the average profile during part or all of short (off-normal) macro-pulses, taken at 1 or 2 Hz maximum pulse rate.

Laser Profile Monitors

The photo-neutralization cross section varies with photon energy, and is known to about +/- 10%. The neutralization yield depends on the H- beam energy in a well-known way, and varies approximately as 1/□.

The most easily-detected signal is by separating the librated electrons from the H- beam and the neutralized beam, using a small dipole magnet, measure the electrons The only competing signal are the free electrons flux resulting from residual-gas stripping, which forms a baseline (offset) as the Q-switched laser is fired. Laser profile measurement can be performed for any pulse length and it does not affect the normal beam operation. There is virtually no impact on the SRF cavities or vacuum, unless ablation or out-gassing from an internal laser beam stop is significant. No beam box is required, only optical ports for the laser beam. Radiation from beam loss is roughly 1 nA of the beam current due to 8-10 nano-sec laser pulse. This one Watt loss cannot quench the cavities even localized.

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SNS LASER PROFILE STATIONS

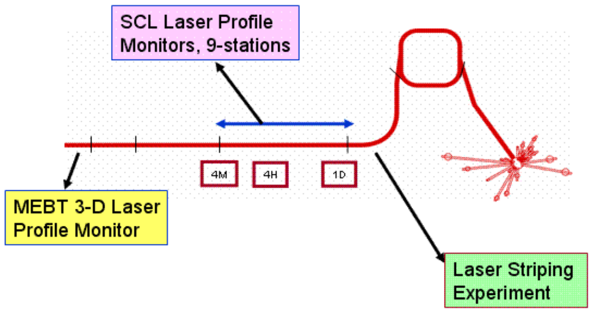

Figure 1. Longitudinal profile monitor located at 2.5 MeV MEBT uses a Ti-Sapphire laser phased locked at 1/5 RF bunching frequency [402.5 MHz]. Nine SCL profile monitors and the laser stripping stations use one Nd:YAG laser.

LONGITUDINAL BUNCH MEASUREMENTS

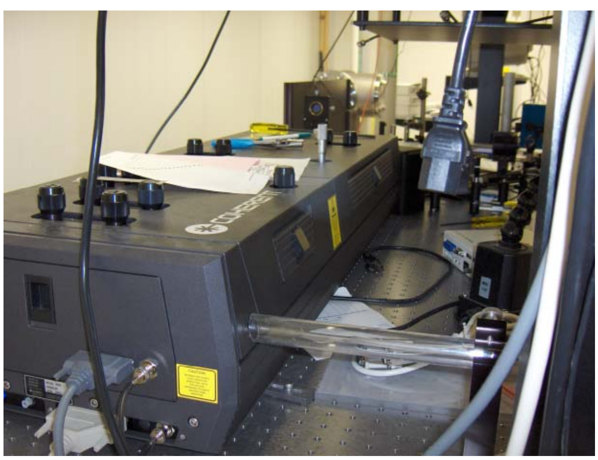

Figure 2. Ti-Sapphire mode-lock Laser with 2 Pico-second pulse length is used to measure the longitudinal bunch length at 2.5 MeV.

The longitudinal bunch profiles measured with the mode-locked laser system are shown in Figure 4. In order to scan the laser light along the H^- bunch, the laser has been modified so that it operates at a repetition rate of 1/5 the RF frequency, and is locked to the LINAC 402.5 MHz clock; adjusting the phase of the clock signal allows a longitudinal scan. The liberated electrons are few due to the laser pulse length with respect to the H^- bunch length. As such, we are using electrostatic deflectors at MCP to amplify the signal. Figure 3. shows the assembly of the deflector prior to installation on the MEBT.

When the rebuncher phase diverges from the nominal, asymmetry appears (top left and top right) Figure (5) in coordination with the simulation. The RMS bunch length vs. the rebuncher phase is shown at bottom right. The measured values [squares] are congruent with the PARMELA predicted [stars] This measurement confirms that longitudinal bunch parameters are similar to the design [2].

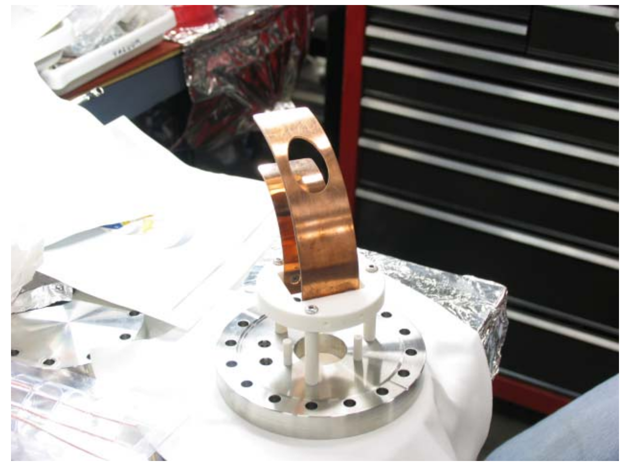

Figure 3. Copper electrostatic deflectors mounted on Al_2O_3 insulators are biased to ~+/-800 Volts on two plates. MCP is not shown in this picture.

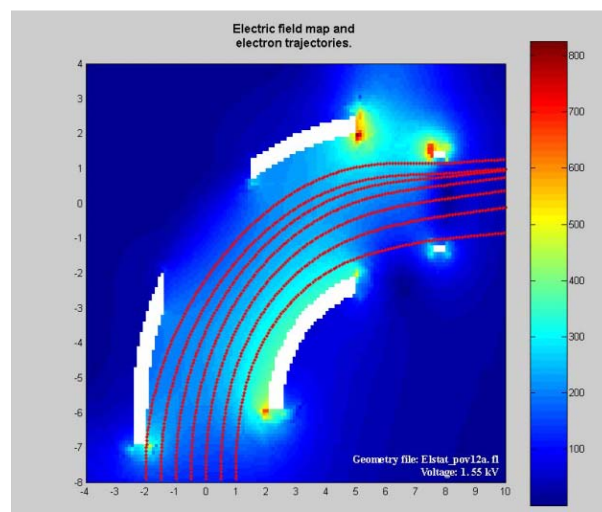

Figure 4. Trajectory of the liberated electrons into MCP is modeled by Victor Alexandrov from BNIP.

TRANSVERSE BUNCH MEASUREMENTS

The Installation and initial progress of the SNS laser system has been presented elsewhere [3,4,5]. Nine stations from 32 SCL transverse profile monitors are operational in expert mode. The laser pulses are created in a Q-switched Nd:YAG laser operating at 1064 nm. The pulses are then transported via a matched Gaussian special expanding mode lenses over a distance of ~380 meter the laser room via an access pipe into the tunnel housing the SCL LINAC. Entrance of the laser light is at 1. GeV and ends at 184 MeV [transition between CCL and super conducting LINAC.

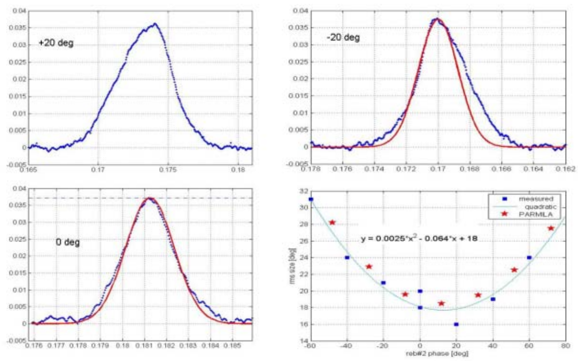

Figure 5. Longitudinal bunch profile measured with mode-locked laser in the MEBT (blue dots) and Gaussian fit (red line). RMS bunch-length vs. the rebuncher phase (measurements – squares, simulation – stars, solid line quadratic fit) are shown on bottom right figure.

OPTICS AND DATA ACQUISITION

The Transverse Profile Monitor DAQ system has five main components: (1) the hardware trigger which synchronizes the laser and DAQ components to the H^- beam,(2) the LabView software which controls the acquisition of data from multiple sensors [photo-diodes, cameras, laser position detectors] from each profile-station, (3) laser light drift compensation system, (4) laser light vibration correction and (5) the laser PPS (personal protection and safety system. We have tested individual components of the above during SCL commissioning. Integration of all systems under a finite state machine is underway.

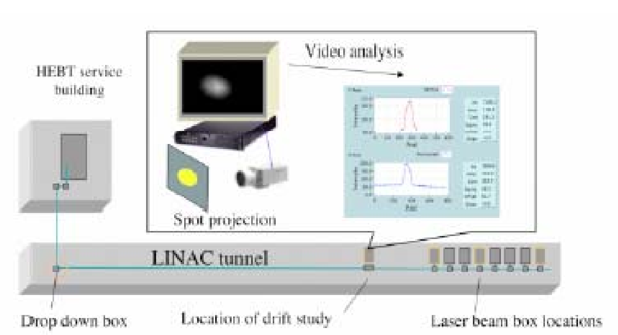

Figure 6. SCL schematic of profile stations and DAQ are shown.

The laser light is scanned across the H- beam by moving the mirror-lese actuator. Liberated electrons are bent via a small dipole magnet [B-field from 40 Gauss at 2.5 MeV to 180 Gauss at 1 GeV] into a high precision Faraday cup biased at 200 Volts. Signal from the Faraday cup is amplified in the tunnel and sent to the DAQ. The signal from the electron collector goes to peak-detector [software] and analog integrators [hardware] for comparison of profile reconstruction. Both methods have been used to generate transverse profiles.

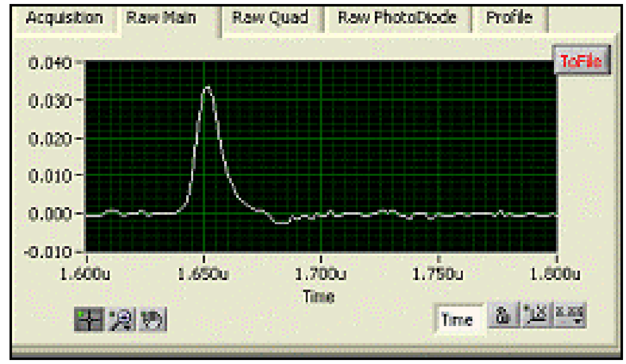

Figure 7. Liberated electrons are collected by the Faraday cup shows the direct measurement of signal at each step of generation the transverse profiles.

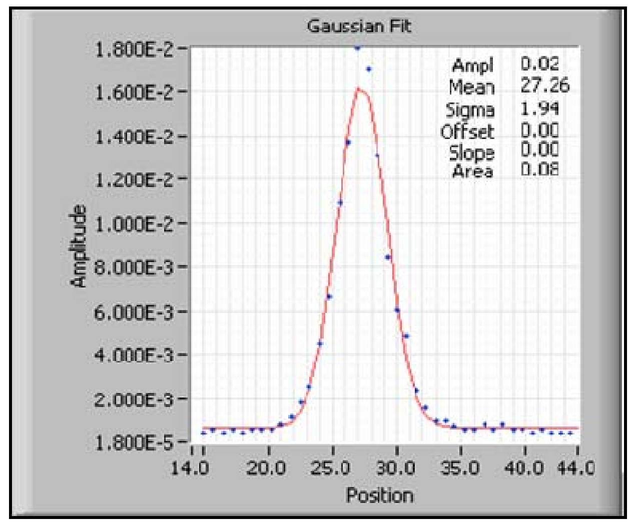

Figure 8. The blue dots are baseline subtracted integral of the figure (7) above. The Gaussian fit is shown in Red.

SUMMARY

Concept, implementation and commissioning of the multi-station transverse profile monitors with direct measurement of the liberated electrons at SNS has proven that a cost effective alternative to tradition wire scanners is possible. Performance of the laser based system is better than the traditional wire scanners. Automation and advancement of our system is underway.

LASER PROFILE MONITOR TEAM

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