Laser Based Beam Instrumentation

Yun Liu
Beam Instrumentation Team

Accelerator Advisory Committee

January 10 – 12, 2012
Laser Based Beam Instrumentation at the SNS Accelerator Complex

1. MEBT Laser Bunch Shape Monitor
2. SCL Laser Wire Profile Monitor
3. HEBT Laser Emittance Scanner
4. Laser Assisted H- Stripping
SCL Laser Wire Profile Monitors

Total of 9 laser wire stations commissioned

- 4 LWs from 200 MeV
- 4 LWs from 450 MeV
- 1 LW at 1 GeV

Q-switched Nd:YAG Laser

- $\lambda = 1.06 \ \mu m$
- $f_{rep} = 30 \ Hz,$
- $T_w = 7 \ ns$
- $E_p = 1 \ J$
Laser Wire Measurement Performance

10th mini-pulse
Beam profiles along the SCL

- Laser wire can measure profiles of

Measurements can be conducted parasitically during neutron production

Laser beam interaction location (unit: sub-rev turn, ~30 ns)
Recent Progress

- Simultaneous profile scans can be performed at multiple stations
- EPICS software developed to make laser wire measurement operation more convenient
- User can measure profiles at any single or a group of locations by simple clicks
HEBT Laser Emittance Scanner

- Laser wire scanner converts a narrow channel of $H^-$ beam into $H^0$ beam
- Titanium wire scanner measures divergence of the $H^0$ beam released from laser slit
- Measurement is nonintrusive.
Emittance Measurement Results

Self-consistency check – comparison between the integration of the emittance (over the angle) with the directly measured profiles

Fitting error: 2.2%

Fitting error: 5.9%

Measured emittance: ~ 0.5 mm·mrad
Event of Laser Induced Vacuum Failure

- On Nov. 18, 2011, a laser beam induced vacuum failure occurred during laser emittance measurement.
- Cracks on the vacuum window were caused by the over focusing of the laser beam by the telescope in the measurement station.
- Vendor specified threshold of optical breakdown has been re-confirmed in the lab.
- Optical design has been modified to ensure optical fluence on the vacuum window below 10% of the optical breakdown threshold.

Maximum optical fluence on vacuum windows

![Graph showing fluence (J/cm^2) vs. LW Station]

- Fluxes at LW32, LE, LW15, LW14, LW13, LW12, LW04, LW03, LW02, LW01
- Details of window damage and coating burning

Cracks on the vacuum window

![Image of a vacuum window with cracks]

- 20 mm, 15 mm, 1.5 mm, 2 mm dimensions
- Telescope, H-scan, V-scan, Ion Beam labels
Laser Based Bunch Shape Monitor

Pico-second laser pulses

H⁻ bunches

Measurement

| Laser source: Ti:Sapphire mode-locked laser |
| Externally locked to accelerator clock |
| Pulse width: 2.5 ps |
| Repetition rate: 80.5 MHz (5th subharmonic of RF frequency) |
Longitudinal Bunch Size Measured at MEBT (2005)

-40 deg

-20 deg

+20 deg

$y = 0.0025x^2 - 0.064x + 18$
Laser Bunch Shape Monitor at MEBT

- Picosecond pulse transmission through fiber has been studied
- Fiber transmission line has been installed
- Measurement station has been modified and tested
- Detection part is being designed and will be installed in the summer
Laser Assisted $H^-$ Beam Stripping

- Our team has developed a novel approach of “foil-less” stripping for charge-exchange injection in high intensity proton facilities
- The approach uses a three-step method employing a narrowband laser beam
- Proof-of-principle experiment demonstrated a stripping efficiency of 90%

Three-step laser stripping scheme

Step 1: Lorentz Stripping
$$H^- \rightarrow H^0 + e^-$$

Step 2: Laser Excitation
$$H^0 (n=1) + \gamma \rightarrow H^0^* (n=3)$$

Step 3: Lorentz Stripping
$$H^0^* \rightarrow p + e^-$$
Next Stage Laser Stripping Experiment Plan

New experiment site

Macro-pulse laser system

- Optimization of beam parameters has been investigated to minimize the laser power requirement
- Macro-pulse laser system has been designed, fabricated and tuned
- The laser can deliver 1 MW / 50 ps / 402.5 MHz micro-pulses at 355 nm. Micro-pulses are bunched to 10 us macro-pulses at 10 Hz.
- Laser is ready for experiment on actual SNS H⁻ beam
- Vacuum vessel and stripping magnets have to be designed and manufactured
Laser Optics Capabilities at SNS

• Laser Rooms
  • HEBT laser room – light source for SCL laser wire scanner and HEBT laser emittance scanner
  • Mezzanine laser room – light source for MEBT laser bunch shape monitor
  • Front end laser room – light source and optical cavity R&D development for laser assisted H\(^+\) beam stripping

• Lasers
  • Nd:YAG Q-switched lasers with pulse widths of 7-10 ns and peak powers of 100 MW
  • Ti-Sapphire mode locked laser with pulse width of 2.5 ps and rep. rate of 80.5 MHz
  • Master oscillator power amplifier (MOPA) system providing macro-pulses with 1MW/50ps/402.5MHz at 355 nm

• Expertise
  • High sensitivity high dynamical range signal detection
  • Motion control and optical sensing with high radiation resistance
  • Laser beam pointing stabilization

• Collaboration with DOE SBIR funded project is vital for supporting a PostDoc and R&D activity
R&D: Fiber Transmission of ps Laser Pulses

- Optical fiber transmission has advantages of stability, easy maintenance, and safety
- A 100-ft large mode area (LMA) fiber was used to transmit picosecond KW laser pulses
- Beam profiles and pulse width variation are studied as a function of launching optics, fiber length, and transmission power
R&D: Beam Recycling Optical Cavity

**Dual color optical cavity**

- Laser
- UV beam
- IR beam
- Feedback loop
- PZT mirror
- Error signal

- Beam recycling is possible due to very small photon loss during the photon-ion interaction
- A dual color optical cavity is being developed to enhance the power of macro-pulsed UV laser beam
- Successful cavity locking/re-locking has been achieved
Summary

• World-first large scale, operational laser wire system has been implemented at SNS-SCL. Profile measurement has been conducted on 1 MW, neutron production beam.

• Laser emittance scanner has been commissioned at SNS HEBT.

• Laser based bunch shape monitor is being developed at SNS MEBT using optical fiber transmission.

• Laser assisted H⁻ beam stripping – proof of principle experiment was demonstrated. Next stage experiment using macro-pulsed laser is being developed.

• Significant infrastructure and expertise on laser based beam instrumentation have been acquired at SNS