THE LASER EMITTANCE SCANNER FOR 1 GEV H^- BEAM*

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Abstract

A transverse phase space laser emittance scanner is proposed [1] and under development for the 1-GeV H^- SNS linac, using a laser beam as a slit. For a 1-GeV H^- beam, it is difficult to build a slit because the stopping distance is more than 50 cm in copper. We propose a Laser Emittance Scanner (LES) to use a laser beam as an effective slit by stripping off the outer electron of the H- (making it neutral) upstream of a bend magnet and measuring the stripped component downstream of the bend magnet. The design and modeling of the system will be discussed.

INTRODUCTION

Unlike wire-scanners that provide only beam profile data, emittance scanners provide direct information about beam quality and are essential for identifying the underlying mechanisms. Practically no emittance scanner is available for high energy beam only for low energy beam. For high energy beam, emittance is generally estimated from profile measurements.

The conventional slit has a few problems for a high energy high intensity beam. For instance, a 1-GeV H^- beam travels more than 50 cm in copper as shown in Fig. 1 and it is practically impossible to build an effective slit. Also thermal load can be an issue, because a 1-GeV 50-µs 38-mA beam dumps 1.9kW of beam power to the slit. And the conventional slit can operate only under limited operating conditions such as < 50 µs. Also there is scattering by the slit material.

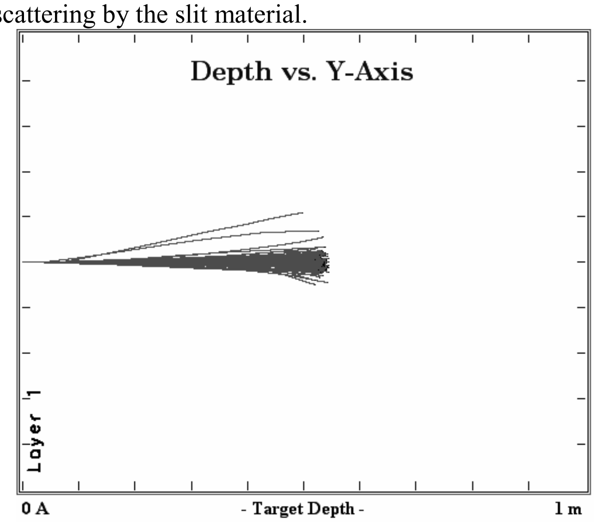

Figure 1: Plot of the stopping range of a 1-GeV beam in solid copper. The range of the horizontal axis is 1 m.

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LASER BEAM AS A SLIT

As an alternative, a slit using a laser beam was proposed [1] for the 1 GeV H^- beam of the SNS linac [2]. When the laser beam is shone to the 1-GeV H^- beam before the bending dipoles, the laser beam strips the outer electron and the stripped H^o beam goes straight while H^- beam travels along the bending dipole separating two species as shown in Fig. 2. As a pickup, single wire or a harp with multi-wires or scintillator can be used. At present single wire is planned to be used as a pickup device.

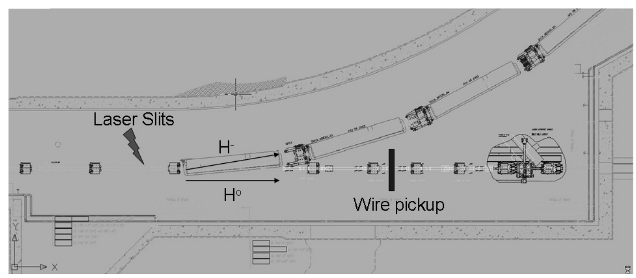

Figure 2: Schematic plot of the 1 GeV laser emittance scanner to be installed in HEBT of the SNS. Stripped H^o beam goes straight while H^- beam travels along the bending dipole separating two species.

There are a few advantages of the laser emittance scanner, listed as follows:

1. It is operable anytime even for production beam with a few mega watt beam power.
2. It can measure the beam emittance at any temporal part of the beam pulse.
3. The same laser slit can be used for a wide range of beam energy, even for 1.3 GeV proposed for the SNS power upgrade.
4. Laser slit can avoid scattering and thermal issues of conventional slits.
5. At most about 3 ~ 10 % of 7 ns H^- beam is stripped, posing minimal radiation issues.
6. For resolution, a sufficient distance between the slit and the pickup can be easily secured due to nature of neutral H° beam.

LASER EMITTANCE SCANNER SYSTEM

Since the outer electron of the H^- is bound by 0.75 eV, photons with an energy above this threshold level (corresponding to wavelengths <1.65 µm) can be used to detach electrons from H^- beam. In our system, a Q-switched 50-mJ Nd:YAG laser operating at 1.06 µm will used as the light source. The laser has a repetition rate of 20 Hz and a pulse width of about 7 ns.

The optical equipment for the laser emittance scanner (LES) is quite similar to the existing linac laser wire system. Since the laser will be installed close to the beam line, key components including YAG rod and prism are radiation resistant. Both the laser flashlamp and the Q-switching gate will be externally triggered by the H^- beam macro-pulse timing to ensure the laser pulse interacts with the same number and position of micropulses at each measurement cycle.

The laser beam can be focused to a diameter of about 20 µm leading to 100 % photo-neutralization. Only moderate laser pulse energies of 10 ~ 50 mJ are needed depending on the spot size on the H^- beam. Figure 3 shows the schematic of the laser emittance scanner under development at the SNS. The H^- beam is located where the yellow vertical arrow is. A mirror is positioned at the focal length of the focusing lens followed by a window. By rotating the mirror, scan is made.

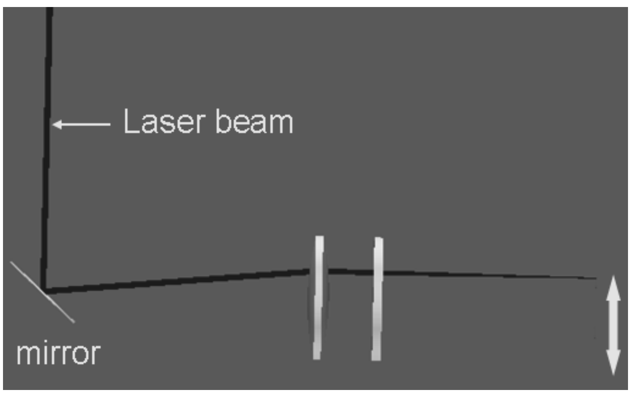

Figure 3: Schematic plot of the laser slit of the emittance scanner.

Extensive modeling of the optical system shows that the focal point of the laser beam, nominally 20µm - 40µm, stays well within desired size and intensity throughout the scanned region, with only small distortion at the outside edges of the proposed ± 35 mm scanning range.

Improved Optical Design

The prototype LES under construction at SNS uses an improved optical system to increase repeatability and accuracy of the scanning optics with a decrease in overall size as shown in Fig. 4.

The prototype LES also incorporates an embedded 50 mJ 1064 nm Nd:Yag pulsed laser. Located directly on the LES assembly, dramatically reducing the complexities of laser delivery to the optical scanning system. Stepper driven linear stages have been replaced with fixed angular scanning mirrors that have been precisely aligned and locked down prior to installation. A focusing singlet is placed at distance from the steering mirror equal to the lens focal point. The compact design in Fig. 4, allows the optical assembly to be easily removed and/or replaced under repair conditions leaving the magnet and vacuum assemblies untouched. The optical scan mechanism's fast settling time and high repeatability, ± 0.000025° with 80°/sec travel allows the system to collect data at a maximum rate of 30 Hz limited by the embedded laser pulse rate.

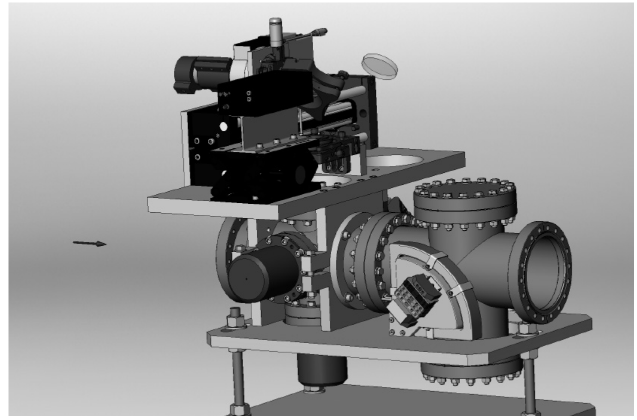

Figure 4: Assembly model showing the beam direction.

EMITTANCE MEASUREMENT

Initially a CsI Ti coated aluminum scintillator similar to other schemes [3] was considered as a pickup, located approximately 15 meters downstream of the laser beam slit.

Figure 5 shows a simulation of the H^o beam intensity profile stripped by the laser beam expected at the pickup location. Maximum 3 % of the beam is neutralized for a 0.02 mm wide laser beam, generating peak intensity at the detector location of ~ 0.1 % or less on a 1 mm x 1 mm spotsize. For a 0.2 mm wide laser beam, maximum 10 % of the beam is neutralized.

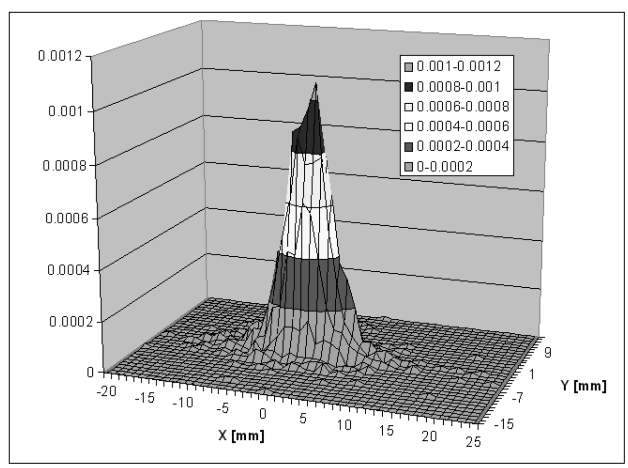

Figure 5: Plot of the beam intensity at the pickup 10 m downstream of the laser slit.

H^o Background

Recently a beam experiment was conducted to measure the intensity of H^o beam formed from other sources such as residual gas stripping, etc, which constitutes the constant background. According to the measurement, the ratio of the background H^o beam intensity to the H^- beam is $H^o/H^- = 1.1 \times 10^{-7}$. The level of background H^o seems to indicate that the emittance measurement of the stripped beam by the scintillator may be difficult. Unless a fast scintillator and fast camera are used, we will see the integrated background H^o from the beam pulse from the scintillator, which can be comparable to the signal from the photo-neutralized beam by the laser slit. Now we are considering to use single wire-scanner as a pickup device. A maximum 3% of proton beam is neutralized for a 0.02 mm-wide laser wire, indicating that 0.2~0.3% or less will be intercepted by a single wire. We modeled the expected SNS beam profile at the proposed pickup location using the Parmila code as shown in Fig. 6. The estimated total emittance scanning range is ± 3~ 4 cm.

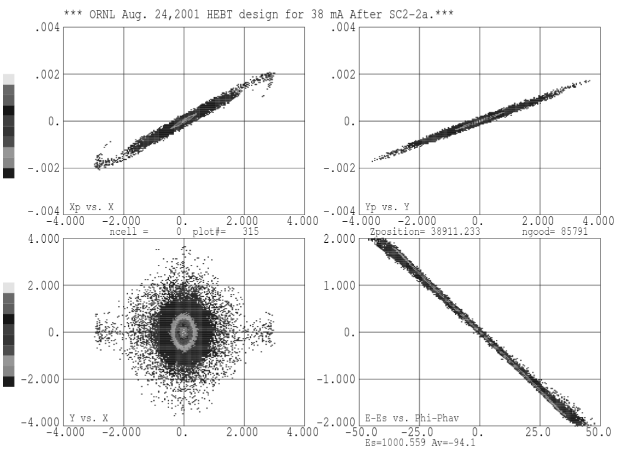

Figure 6: Plots of the beam distribution at the pickup 15 m downstream of the laser slit.

OUTLOOK

The laser emittance scanner for 1-GeV H^- beam is under development at the SNS and will be an important diagnostics in achieving 1.4 MW design beam power. It will be crucial to physics studies and will become a norm for a high power H^- beam linac.

REFERENCES

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