STATUS OF LASER STRIPPING AT THE SNS*

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Abstract

This paper presents an overview of experimental and theoretical studies on laser stripping that have been conducted up to the present time in the SNS project. The goal of this work is to develop techniques to achieve the experimental preconditions necessary for the successful realization of a future intermediate experiment on laser stripping. The experimental work consists of the tuning and measurement of H^- beam parameters in readiness for the intermediate experiment, and also takes into account the features and possibilities of the SNS accelerator.

INTRODUCTION

The laser-assisted charge exchange injection of H^- beams is of great interest for a future power upgrade of the SNS project. In fact, the method ensures injection without hazardous carbon foils. This automatically eliminates problems of their activation and destruction at high power operation. More details about laser stripping (LS) development can be found in [1-5]. By now, the theory of the process is more or less completely understood for application purposes, and a computer program for numerical calculation and optimization has been created [6].

At present, the next reasonable step for LS development is for an intermediate experiment to be planned at the SNS. The experiment must demonstrate stripping a 1-10 us beam instead of the 10 ns achieved in the proof-of-principle experiment [3]. For realization of this experiment, SNS has a powerful laser with the required parameters. Preliminary calculations predict more than 90% stripping efficiency to be achieved in the experiment [4] using measured micro-pulse laser parameters. However, from SNS operational experience, calculated Twiss parameters of H^- beams used for the estimation differ significantly from experimentally achievable parameters of the accelerator at the IP (interaction point). Success of the intermediate experiment will depend on H^- beam parameters that can be achieved in reality. The content of this paper focuses mainly on an experimental routine of appropriate beam tailoring for the intermediate experiment.

Beam tuning is a very delicate process because of the specific physics of laser interaction requiring the simultaneous adjustment of about 5 independent parameters. A micro-pulse laser has a very small transverse size and longitudinal duration. For this reason, the H^- beam must be strongly focused in both transverse and longitudinal directions to overlap with the laser beam for better laser-beam interaction. This approach is opposite to the foil injection condition that requires the foil beam spot not to be too small (so as to prevent overheating of the foil). Another parameter that must be adjusted simultaneously is an appropriate dispersion function of the H^- beam. The dispersion derivative

$$D' = -\frac{\beta + \cos\alpha}{\sin\alpha} \quad (1)$$

(which depends on the relativistic factor β, and the incidence angle α between the H^- and laser beams), significantly compensates for the negative effect of beam energy spread at the IP, and thus increases the efficiency of LS [2]. The dispersion function D must be zero for a smaller transverse beam size and for the stability of the beam position, in spite of beam energy instability taking place at the SNS accelerator. Another important parameter is the maximum transverse size of the beam being limited by the aperture of the transport beam line. There is also limited magnetic power supply capability for tuning the beam, and this must be taken into account.

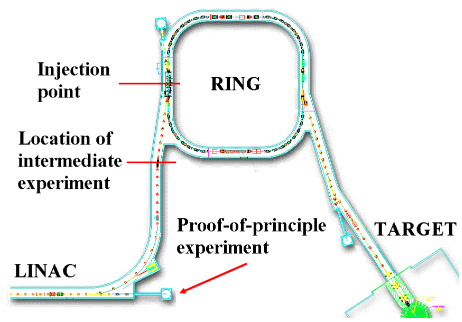

Figure 1: Location of intermediate experiment at the SNS.

Experimental tuning of the beam parameters listed below is impossible without an online model, which will consume substantial computational resources because of the complicated optimization problem. In this paper we will mention an online application that has been developed for this purpose. At the end of the paper we will present experimental results on beam tuning. Finally, some conclusions and future plans will be listed.

STATUS OF LASER STRIPPING

At present, the SNS laser stripping team is preparing for an intermediate experiment that intends to improve H^- conversion to protons. For this experiment, we will use the three-step scheme for laser stripping [2] because of its verification [3] and relatively low cost. It is proposed to demonstrate the stripping of one or more mini-pulses at the SNS facility. One mini-pulse has ~ 1 us length, and consists of a number of micro-pulses of 402.5 MHz frequency. For realization of stripping of the total mini-pulse, SNS has a powerful 355 nm laser with the same

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temporal structure as that of the H⁻ beam. Laser measurement specifications show that duration of one mini-pulse can be varied from 5 to 10 us. This opens the possibility for the stripping of 5…10 H⁻ mini-pulses correspondingly. Figure 2 shows the temporal structure of a laser pulse.

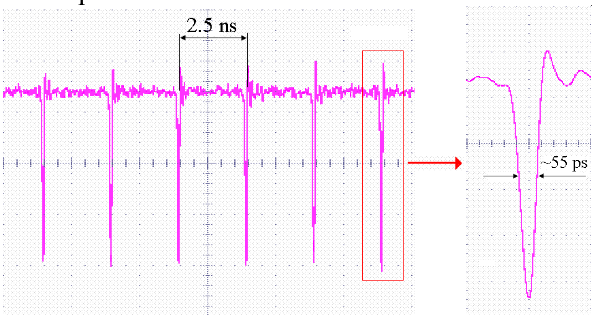

Figure 2: Micro-pulse train of UV laser measured with fast detector.

The amplitude of a micro-pulse depends on the mini-pulse duration: 5 and 10 us modes of mini-pulses correspond to 0.75 and 2.2 MW peak power of the laser micro-pulse. Full width at half maximum of a laser micro-pulse is approximately 55 ps. For a first intermediate experiment, we intend to use a single pass laser beam without amplification by optical cavities. For this scheme we need to develop laser beam optics to manipulate the size and divergence of the beam at the IP.

The manipulation of H⁻ bunch parameters (that define the efficiency of interaction with a laser pulse beam transport line) has many possibilities. Tuning of transverse size can be achieved with the help of 17 independent quadrupoles. Tuning of the dispersion function becomes possible using a large dipole magnet to provide transport of the beam from the linac to the ring (Fig. 1). In fact, even a best case calculation shows that it is impossible to achieve 90% LS efficiency without appropriate dispersion tuning.

The beam transport line has 10 wire scanners for measurement of transverse size, and 18 BPMs for measurement of dispersion function. Unfortunately, all the diagnostics are located near the IP excluding the point itself; however, we can measure parameters at the IP just by the measurement of nearby parameters, and then interpolate them to the IP with the help of a model. It is planned to install the necessary diagnostics at the IP in time for the experiment's final measurement. We plan to install an additional wire scanner, a BPM, and a longitudinal Beam Shape Monitor (BSM). In addition, to carry out the experiment, we will also need two stripping magnets, a dedicated vacuum chamber, and auxiliary equipment.

LONGITUDINAL BUNCH SHORTENING

The longitudinal length of H⁻ micro-pulses can be shortened by manipulating the superconducting linac (SCL) cavity phases. Numerical calculations show that the length of the ion bunch must be approximately half the length of the laser micro-pulse for optimal laser power usage. Preliminary experimental tests demonstrated positive results in the shortening of H⁻ bunch. Figure 3 shows the micro-pulse of an ion beam for both nominal and longitudinally-focusing cavity phase scenarios.

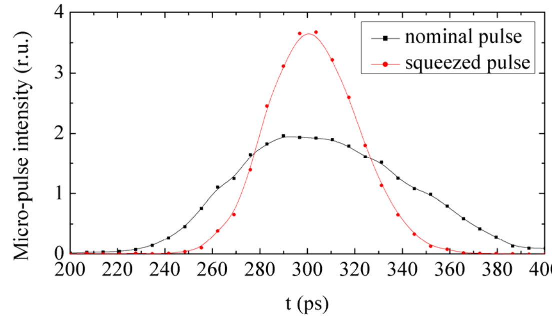

Figure 3: Nominal and squeezed H⁻ micro-pulse.

The longitudinal profiles were measured with the help of a BSM located at the end of the linac (Fig. 1). Estimations show that we need to provide bunch < 25 ps—which is smaller by a factor of 10 than the estimated default H⁻ pulse at the IP. Presently, SNS has a set of cavities, the last of which is located 200 m before the IP. In these conditions, and within this distance, it is very difficult to provide good longitudinal focusing without cavities. Moreover, the focusing mode is characterized by reduced output energy and a bigger D' parameter (1) complicating its experimental tuning. The power upgrade project [7] intends to install additional cavities to the available space of the linac in ensuing years. In this way, the situation will be simpler.

TRANSVERSE BEAM TUNING

For the successful realization of the intermediate experiment, we need to adjust 4 transverse parameters at the IP simultaneously. In this section, we will present experimental results for the beam presently available at the SNS. Formula (1) gives a dispersion derivative D' = -3.4 and an angle of incidence α = 30.5 degrees, for present operation energy T = 925 MeV. Dispersion D must be zero. Transverse vertical size must be as small as possible for better overlapping with the laser beam that irradiates the hydrogen beam in a horizontal plane. Estimations give a good result for σ_{rms} vertical < 0.5 mm. The beam is limited by the 76 mm diameter of the vacuum camera, hence σ_{rms} of the beam must be limited by 12–15 mm to avoid losses.

A simple linear model without space charge can be used for beam optimization at the interaction point for the intermediate experiment because of the high energy of the beam. A calculation of corrected beam optics satisfying all listed transverse parameters requires an optimization of 17 independent quadrupoles to be available between the last accelerating cavity and the experimental point. This leads to a big nonlinear optimization problem that can be calculated numerically. This problem has a huge number of solutions corresponding to different local minimums for the optimized beam parameters.

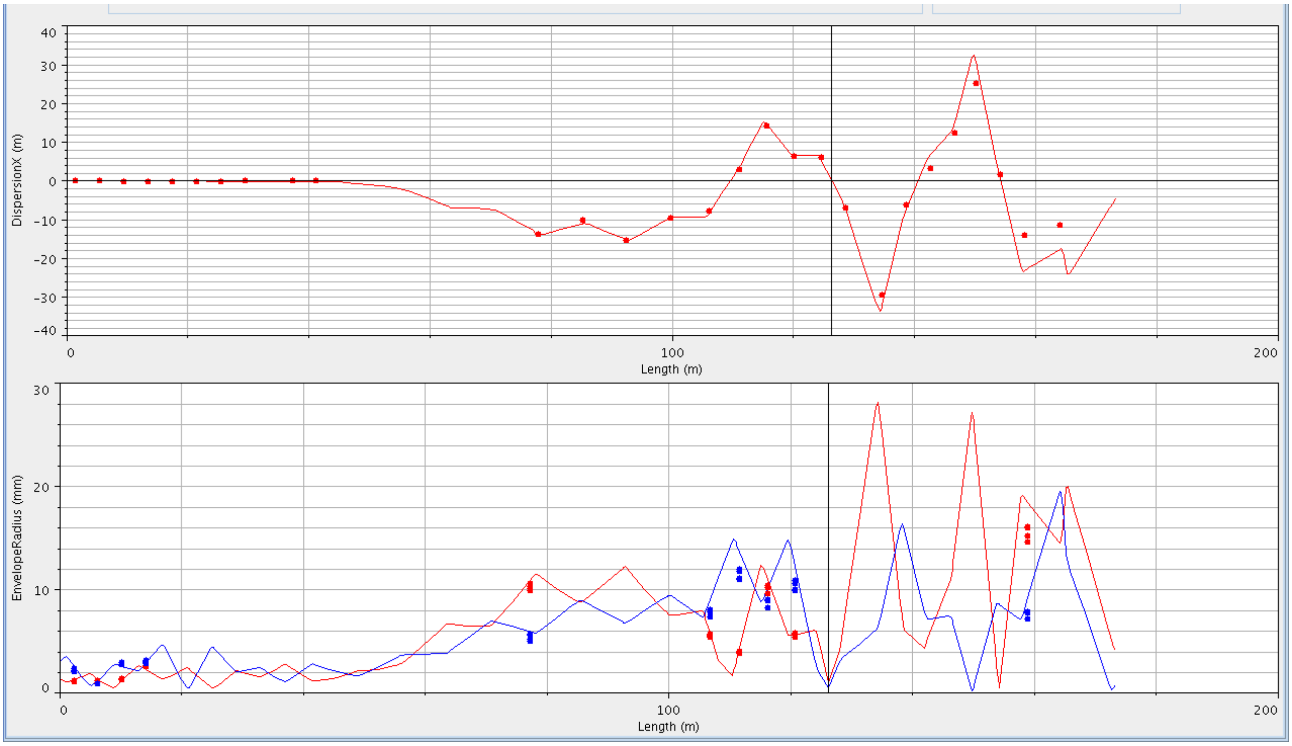

Figure 4: Example of H⁻ beam optics setup for laser stripping. The upper plot is a dispersion function. The lower plots are vertical (blue) and horizontal (red) rms transverse envelope radii.

The optimization code, which has been developed especially for this purpose within an XAL application, has a fast performance. The code simply generates thousands of solutions, and then selects the best of them without an analysis of mathematical equations. As a whole, beam tuning has the following scenario: measurement of input parameters at the beginning of the transport line; calculation of the most optimal optics for these initial parameters with the help of the online code; setup of the calculated power supply for quadrupoles; and the final measurement of achieved beam parameters.

Figure 4 presents an example of final optics tuning for LS. The vertical black lines in both plots mark the interaction point. The upper plot is a horizontal dispersion function where. The lower plot represents vertical (blue) and horizontal (red) rms transverse envelope radii. The solid lines and the points mark model prediction and measurements correspondingly. It should be said that it is possible to achieve perfect matching of model and experiment by calculating input parameters for every individual setup. However there is a small discrepancy between theory and measurement when using the same input parameters for the default optics and the LS optics as presented in Figure 4. This fact actually shows validity of the model when varying quadrupoles in a wide range. Summing up, the beam at the IP has the following parameters: D = 0 m, D' = -3.3, σ_{rms} (vertical) = 0.6 mm, σ_{rms} (horizontal) = 1.0 mm, $\beta_{horizontal}$ = 3.5 m. The small $\beta_{horizontal}$ in this experiment is correlated to a big horizontal angular betatron spread of the beam that impacts high efficiency stripping. However, calculations show that it will not be a problem to achieve bigger $\beta_{horizontal}$ = 25 m used in [4] and it will be studied theoretically and experimentally in the future.

CONCLUSIONS

The preliminary tuning of H⁻ beams and calculations indicate a successful realization in the next phase in laser stripping experiments at the SNS. For this experiment, we will need additional diagnostics and auxiliary equipment to continue our studies on beam manipulation, and to carry out the laser stripping experiment itself.

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