CONCEPTUAL GAS JET AS A STRIPPING TARGET FOR CHARGE EXCHANGE INJECTION

Vadim Dudnikov# and Charles Ankenbrandt, Muons, Inc. Batavia, IL, 60510 USA

Abstract

As stripping targets for charge exchange injection now used thin carbon or Al_2O_3 foils. During long time injection for high intense beam accumulation by low current injection a foil life time can be compromised by overheating and alternative stripping targets need be developed. A laser stripping injection is now under development.

A pulsed supersonic gas jet was used as a stripping target in first realization of charge exchange injection with H- ion energy 1.5 MeV and stationary gas jets are used as internal targets in experiments with super high vacuum. A stripper target thickness is proportional to the injection energy and for energy ~1 GeV should be ~0.3 mg/cm^2 of carbon. The pulsed gas target with such thickness acceptable for long time charge exchange injection can be produced with using of heavy hydrocarbon molecules used in the diffusion or booster vacuum pumps. Formation of the pulsed gas jet stripping targets will be considered. Using of the nozzle with central body has advantages for low divergence supersonic jet production.

INTRODUCTION

The multi-turn charge-exchange injection developed in [1,2] is accomplished by stripping the electrons from the H^- ions at the injection point. A common technique is to pass the H^- to be injected through a thin stationary carbon or diamond foil to remove the electrons [3,4]. Since this process allows injection of additional beam into already-occupied portions of phase space, it can result in a circulating proton beam that has higher phase space density than that of the linac beam. That is a fundamental advantage over conventional transverse or longitudinal stacking methods, which are limited by Liouville's theorem. However, in many cases the desired resulting transverse emittances in the synchrotron are much larger than the emittances of the H^- ion beam to be injected. For example, larger transverse emittances are often necessary to mitigate space-charge effects. In those cases, a technique called transverse phase space painting is employed by varying the closed orbit in the synchrotron or the trajectory of the incoming beam during the injection process. Painting into the longitudinal phase space is also possible. Significantly higher brightness can be produced by means of the charge exchange injection with the space charge compensation [5,6].

For the practical application of charge exchange stripping, the lifetime of the carbon foil should be long, preferably at least thousands of hours. The lifetime of these foils under ion bombardment is determined by radiation damage (defect generation rate), peak temperatures, strength characteristics of the foil material, migration energy of the displaced atoms and its dependence on the crystalline size, the conditions of fastening the foil on the frame, and oscillation frequency of the atoms in a crystalline structure .

The experience at the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory has shown [7] stripper foils under ion bombardment surviving with accumulated charge of more than 7.5 kC, with estimated peak temperatures in the 1500^{o}K range. The integrity of the foil degrades rapidly if the temperature rises much higher. This practical experience gives us a benchmark on survivability of stripper foils. For Project X, the injected charge is 26 μC per injection at roughly a 1 Hz rate. Assuming a 100% duty factor and the parasitic hits/injected ion, h_{min} , to be 50 and keeping the peak foil temperature below 1500^{o}K, a foil should last on the order of 60 days. The conclusion to be drawn is that peak foil temperatures are a critical factor affecting the foil lifetimes.

To overcome a foil overheating problem at high beam intensity a laser stripping injection is under development [8]. However, the laser-assisted stripping technique imposes considerable demands on the laser system: large pulse energies, high pulse frequencies, large macropulse lengths, and large average powers. The wavelength of the required laser field is dependent on the energy of the H^- ion beam and the selected level of excitation of the neutral atom. For SNS the required laser wavelength is 355 nm, whereas for projects above 3.24 GeV the n=2 excited level may be reached using a more mature technology of lasers in the 1 μm range. Laser system requirements for laser stripping at SNS are very stringent due to the required laser wavelength, and a complete solution does not exist today, though significant effort is being deployed to solve these issues.

GAS JET AS A STRIPPING TARGET

As the stripping target for the beam with very high intensity and long time injection can be used a supersonic gas (vapour) jet. The main component of the charge-exchange injection system is the charge-exchange target installed at the proton orbit of accelerator. The main considerations for its choice of high energy injectors are given, in particular, in Ref. 3. Its thickness is determined by the cross section of electron detachment from the H- ion σ_{-10}, and from the H atom, σ_{01} . The proton yield from the primary beam of H- ions for a d thick target is

$\Phi^+=1-e^{-\sigma_{01}d}$ (1).

The required thickness of a target is $d\sim 4(\sigma_{01})^{-1}$.

#Vadim@muonsinc.com

A pulsed supersonic Hydrogen gas jet was used as a stripping target in first realization of charge exchange injection [1,2]. An example of using this gas jet stripping target is shown in Fig. 1 [4,9].

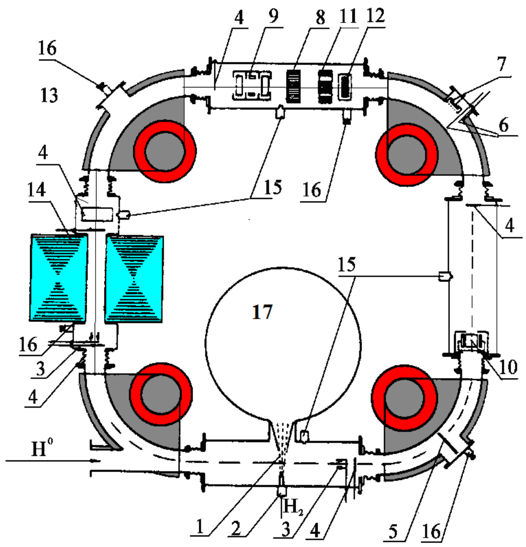

Figure 1: Schematic of storage ring with gas jet stripping target and with diagnostics and control. 1-striping gas target; 2-pulsed gas valve; 3-Faraday Cup; 4-Quartz screen; 5, 6-moving targets; 7-ion collectors; 8-current monitor; 9-Beam Position Monitor; 10-Quadrupol pick ups; 11-magnetic BPM; 12-beam loss monitor; 13-detector of secondary particles density; 14-inductor core; 15-gas pulses; 16-gas leaks, 17-jet receiver and pumping.

The supersonic Hydrogen jet (1) is formed by a Laval nozzle attached to the pulsed valve (2) [10]. The jet cross a vacuum chamber 8x4 cm^2 and collected by a receiving cone attached to the receiver (1) with capacity of 800 litres pumped by a diffusion pump. The Laval nozzle has critical cross section with diameter of 0.2 mm and an exit of 6 mm, a diffuser is 44 mm long. With the valve pressure up to 100 At the jet gas density is up to 10^{19} mol/cm^3,at the nozzle exit and the target thickness up to 10^{17} mol/cm^2 at 4 cm from the nozzle. A Mach number of the jet is up to 12. With the jet duration ~1ms the hydrogen consumption is 0.2 cm^3/pulse and (95% of gas can be collected into the receiver [11]. The stripping cross section in H_2 σ_{01} $=10^{-17}$ cm^2 at energy 1 MeV and decreases inverse proportional to kinetic energy [12]. For Hydrocarbon C_2H_8 σ_{01} $=10^{-16}$ cm^2 [12]. For stripping of 1 MeV H- is enough the jet thickness d~$10^{16}$$cm^{-2}$. Such jet can be used as internal target for generation of products in reaction of circulating beam with elements of jet. An energy loss in target can be compensated by acceleration of circulating particles after jet passing [6, 13].

Possible design of such storage ring is shown in Fig. 2. In design of the storage ring with nonlinear focusing it is good to have possibility for high brightness beam accumulation by charge exchange injection with space charge compensation. For energy ~10 MeV it is possible to use a supersonic gas jet as a stripping target as was in the small scale proton storage ring in BINP [1-6]. RFQ and small linac can be used as injector with H^- beam ~100 mA, 10 MeV. A circulating proton beam ~10 or 100 A can be accumulated. Such beam can be used for realization of resonance reaction induced by circulating ions in thin internal target as shown in Fig. 2. For the resonant reaction $^{13}C(p, \gamma)\,^{14}N$, generating a 9.17 MeV gamma-ray it is need to use a target with isotope ^{13}C.

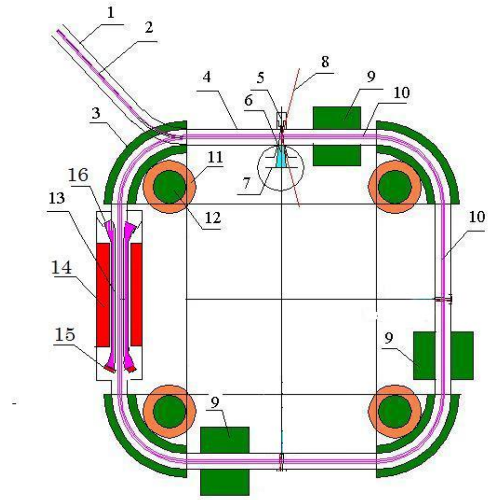

Figure 2: Schematic of resonance reaction production in interaction of circulating proton beam with thin targets accompanied by electron cooling. 1- beam line for transportation of injecting H- beam; 2- injecting beam of H-; 3-bending magnets; 4-vacuum chamber of storage ring; 5- generator of supersonic jet- stripping, reaction target; 6- supersonic jet, stripping-reaction target; 7-pump-recirculator of target jet; 8- cone of resonant gamma rays; 9- iron core for inductor for compensation of beam energy loss in jet target; 10-circulating proton beam; 11- magnetic coil; 12- yoke of bending magnet; 13-cylindrical hollow electron beam; 14- solenoid of electron cooling system; 15- cathode of electron cooling beam; 16-collector of electron beam.

For recirculation of this expensive isotope it is possible to use the jet generator with recirculation as shown in Fig. 3 [14]. The system operation is similar to an oil diffusion pump. The liquid is boiled by heater, the vapour is transported to the nozzle and crossing the aperture with the beam as a narrow jet. The jet material is condensed to the receiving surface and flowing as liquid to the boiler for further evaporation.

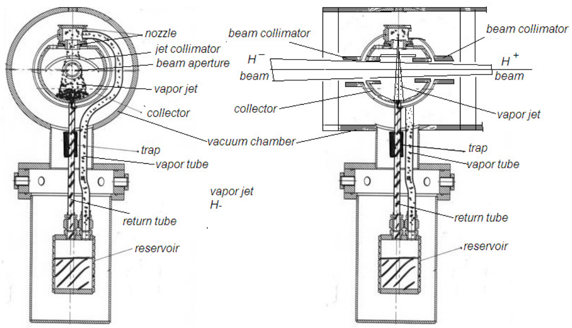

Figure. 3: Jet formation with vapour recirculation [14]

For stripping of ions with higher energy (~GeV) it is necessary much higher target thickness ~0.3 mg/cm^2 or ~10^{19} carbon atoms/cm^2.

The target with high density and good vacuum properties can be produced with using of heavy Hydrocarbon molecules as in diffusion pump oil and cluster formation as was observed in [15, 16]. Plug nozzle with a central body can be used for high dense low divergence jet production as shown in Fig. 4. An efficient Mach number for jets with condensate can be up to several hundred [15].

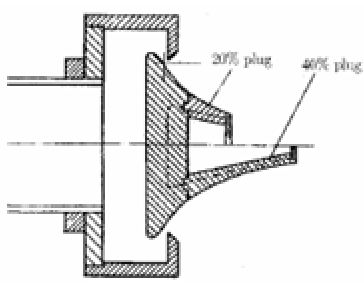

Figure 4: Example of the plug nozzle with a central body for low divergence jet production.

A stripping properties of this supersonic jets with condensate should be similar to the solid carbon foils but without foils limitations.

With gas jet target was observed strong transverse instability induced by interaction of circulating proton beam with compensating electrons [1-6, 17, 18].
Self stabilization of this instability and accumulation of circulating proton beam with intensity far above space charge limit is discussed in [4-6, 9].

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