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MEASUREMENT OF EACH 324 MHz MICRO PULSE STRIPPING EFFICIENCY FOR H⁻ LASER STRIPPING EXPERIMENT IN J-PARC RCS

P.K. Saha*, K. Okabe, A. Miura, N. Hayashi, H. Harada and M. Yoshimoto
J-PARC Center, KEK & JAEA, Japan

Abstract

In 3-GeV RCS (Rapid Cycling Synchrotron) of J-PARC (Japan Proton Accelerator Research Complex), a proof-of-principle experiment for 400 MeV H^- stripping to protons by using only lasers is under preparation. The experiment requires precise measurements of all three charge fractions of only a single H^- micro pulse of 324 MHz at the downstream of laser and H^- interaction point (IP). It is very essential to establish a new measurement method for that purpose, which has not yet been studied anywhere in that direction. We consider measuring BPM (beam position monitor) pickup signal by using a fast oscilloscope with more than 4 GHz bandwidth. To test the system, we have done some experimental studies, where charge-exchange type beam halo scrapper, placed at the L-3BT (linac to 3-GeV beam transport) was used for H^- stripping. The un-stripped H^- and stripped proton (p) separated by bending magnets at the downstream of IP were simultaneously measured by two BPMs. The stripping efficiency of each 324 MHz micro pulse is precisely and separately obtained from the measured H^- and p pulses depending on the scrapper position settings. A detail of the present study results are presented.

INTRODUCTION

In 3-GeV RCS (Rapid Cycling Synchrotron) of J-PARC (Japan Proton Accelerator Research Complex), carbon stripper foil is used for multi-turn H^- stripping injection [1]. The injected beam energy is 0.4 GeV, while it is accelerated up to 3-GeV and simultaneously delivered to the muon and neutron production targets at the Material and Life Science Facility as well as injected into the Main Ring Synchrotron. At present RCS beam power for operation is much lower than its designed 1 MW, and no serious issues yet with foil lifetime. However, real lifetime and rapid foil failure due to overheating of the foil, especially at high intensity are always serious concerns [2]. The real lifetime means, how long a foil can be put in service until when foil degradation is tolerable. Foil degradation such as, change of foil thickness, pinhole formation as well as deformation of the foil deteriorate the stripping efficiency rapidly, resulting a significant increase of the waste beam at the injection beam dump. It is then determine the foil lifetime even if a foil failure does not occur [3]. On the other hand, residual activation near the stripper foil due to foil scattering beam losses during injection is also another uncontrollable factor and a serious issue for facility maintenance [4].

In order to overcome realistic issues and limitations involved in the conventional H^- stripping injection by using stripper foil, a POP (proof-of-principle) experiment for 400 MeV H^- stripping to proton (p) by using only lasers is under preparation at J-PARC [5]. Figure 1 shows a schematic view of present method [6]. Similar to the laser-assisted H^- stripping method [7], it also has 3 steps, but high field magnetic stripping in the 1st (H^- to H^0) and 3rd (H^{0*} to p) steps are replaced by lasers. Widely available high power Nd:YAG lasers can be used for those purposes in order to utilized large photo-detachment and photo-ionization cross sections [8], in the former and later steps, respectively. The 2nd step is an excitation of ground state (n=1) H^0 atoms to two level higher (n=3) states, where we considered ArF Excimer laser of 193 nm for that purpose. The strategy of

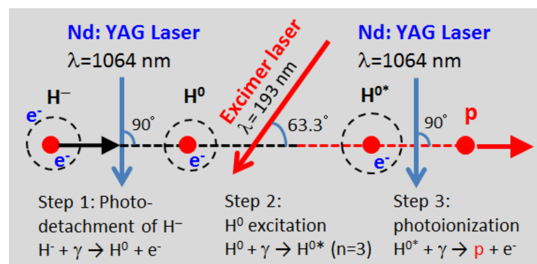

Figure 1: Schematic view of principle for H^- stripping to proton by using only lasers. Noted parameters are typical ones estimated for 400 MeV H^- beam energy.

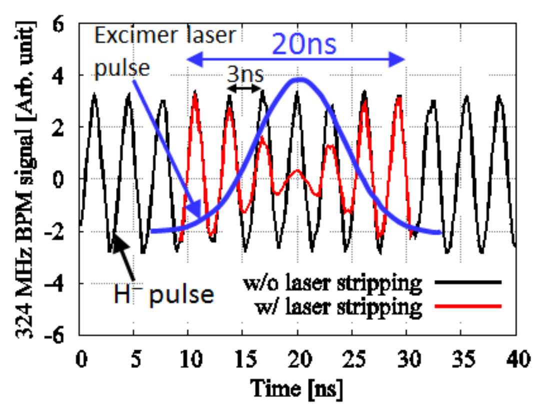

Figure 2: The H^- (black) micro pulse signal measured by BPM pickup. The blue curve is a typical laser pulse. The red curve is an expected H^- signal out of the laser pulses.

POP experiment is to strip only a single H^- micro pulse of 324 MHz. This is because, the whole micro pulses (~ 10^5) can be covered by using laser storage ring [9], which is under development for this purpose. The POP experiment requires precise measurements of not only the stripped protons but also (if any) neutral H^0 and H^- of only a single micro pulse at the downstream of laser and H^- interaction

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* E-mail address: saha.pranab@j-parc.jp

point (IP). For that purpose, we considered using stripline BPM (beam position monitor) pickup signal taken by a fast oscilloscope. Figure 2 shows such a typical measured H^- signal of a BPM pickup (black). If we assume a Gaussian laser pulse like the blue curve, we expect the original H^- will be changed like the red curve, due to its stripping protons at the overlapping region with laser pulses. Here we assume 90% stripping efficiency, estimated based on the laser peak power at the center of the laser pulse, especially for the Excimer laser.

We performed some experimental studies, where at present charge-exchange type beam halo scrapper (carbon foil), placed at L-3BT (linac to 3-GeV beam transport), and near to the IP is used for H^- stripping. The un-stripped H^- and the stripped protons (p) separated by bending magnets at the downstream of IP are simultaneously measured by two BPMs. The stripping efficiency of each 324 MHz micro pulse is precisely and separately obtained from the measured H^- and p pulses depending on the scrapper position settings.

BRIEF CONFIGURATION OF THE STRIPLINE BPM

Figure 3 shows a schematic view for the configuration of 1 stripline pickup out of 4 implemented in each BPM installed at the L-3BT of J-PARC Linac [1]. The shape of the striplines of BPMS at the L-3BT are circular, where striplines are placed just outside of the beam pipe aperture, typically 0.185 m transmission line for the largest BPM types. Transverse beam positions in the horizontal and vertical directions are determined from the difference of the signal of pair pickups in respective directions.

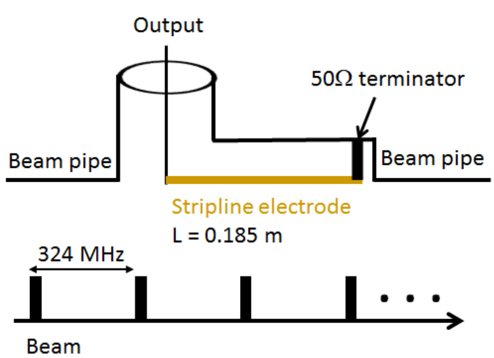

Figure 3: Schematic view of configuration of 1 stripline pickup of the BPM installed in the L-3BT of J-PARC Linac. Four such pickups are implemented in each BPM.

As was shown in Fig. 2, signal of pickup with exactly 324 MHz can be well detected, but due to mainly extremely longer pulse length of more than 200 ps (rms) and also wider momentum spread ($\Delta p/p$), the characteristic features of the pulse shape is not clear. For example, the separation between pulses created at the upstream of the pickup and its reflection with opposite sign as well as separation among 324 MHz pulses. The length of the striplines were also

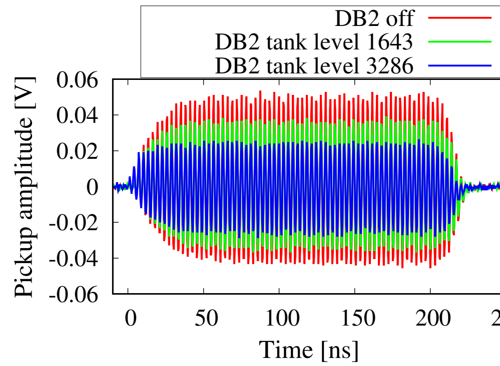

Figure 4: Pickup signal with respect to variation of debuncher amplitude. In this study, data was taken by one 324 MHz BPM placed at the 1st arc section of the RCS.

not particularly optimized for sophisticated purposes, like the present study. However, by using upstream accelerating cavities, the bunch length can be manipulated in order to obtain better time resolution as well as relative change of the bunch length, which is important for the POP experiment. As the magnitude of the output pulse of the pickup depends on the image current times the characteristic impedance of the stripline, amplitude of the output pulse can be used for relative optimization of the longitudinal beam parameters. Experimental studies on that direction are also in progress.

Figure 4 shows preliminary data taken by varying amplitude of the 2nd debuncher (DB2) in order to manipulate $\Delta p/p$ of the H^- beam. The DB2 is placed several 10 meters upstream of the IP, which is mainly used for manipulating $\Delta p/p$ of the H^- beam as required for the RCS. The present data was taken by using a similar BPM, but it is placed in RCS 1st arc section. The signal amplitude increases as DB2 tank level is decreased, and it is thus maximum when DB2 is kept off. Although absolute values of $\Delta p/p$ can not be determined from this data, but one can obtained information of relative change of the longitudinal bunch length.

MEASUREMENT PRINCIPLE OF MICRO PULSE STRIPPING EFFICIENCY

Figure 5 shows a schematic view of the end of L-3BT of J-PARC Linac, where POP experimental devices for H^- stripping by using lasers will be installed at the red rectangular box. Downstream of the IP (laser and H^- interaction point), all three charge fractions can be simultaneously measured. The stripped p and un-stripped H^- separated by bending magnets at the downstream of IP go to 100-degree beam dump and RCS injection BT, respectively. The neutral charge H^0 (if any) goes to the 90-degree beam dump, and those can be measured by further stripping them to p by installing a stripper foil at the upstream of 90-degree in future.

At present, instead of laser, we used one scrapper for stripping H^- to protons, placed near the IP [10]. The scrapers are charge-exchange type and used for cleanup halo or unexpected long tail in the H^- beam. The scrapped H^- are

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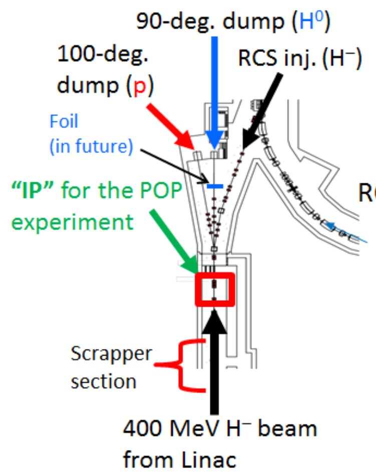

Figure 5: Schematic view of the end section of L-3BT. The H^- laser stripping experimental devices will be installed at the red rectangular box. All three charge fractions can be simultaneously measured at the downstream of IP.

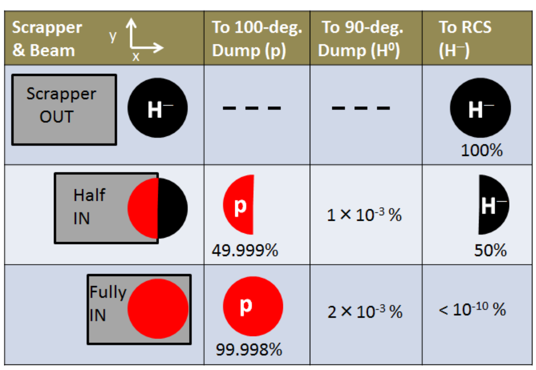

Figure 6: Schematic view of expected charge fractions at the downstream of IP as a function of scrapper insertion.

stripped to p, and dumped to the 100-degree beam dump (see Fig. 5). The scrapper foil is thick enough (600 µg/cm^2) to strip more than 99.998% of H^- to protons, if intercepted by the scrapper [11]. In order to check the measurement principle, we used one horizontal scrapper as a charge-exchange foil. Figure 6 shows a schematic view of the scrapper insertion for H^- scrapping and the corresponding charge fractions in downstream beam lines. Similar situation can be expected when inserting a vertical scrapper.

MEASUREMENT RESULT

In this experiment, a horizontal scrapper was gradually inserted to the beam line and BPM pick signals of stripped p un-stripped H^- were simultaneously measured by two independent BPMs at 100-degree beam dump and RCS injection BT, respectively. Figure 7 shows raw signals of p (left) and H^- (right) measured by BPM pickups for different position of the scrapper. The horizontal axis is time, where vertical axis is the pickup signal. The data is taken for one typical intermediate pulse of the H^- beam, where a more than 600 of such pulses are injected into the RCS. The non-flatness

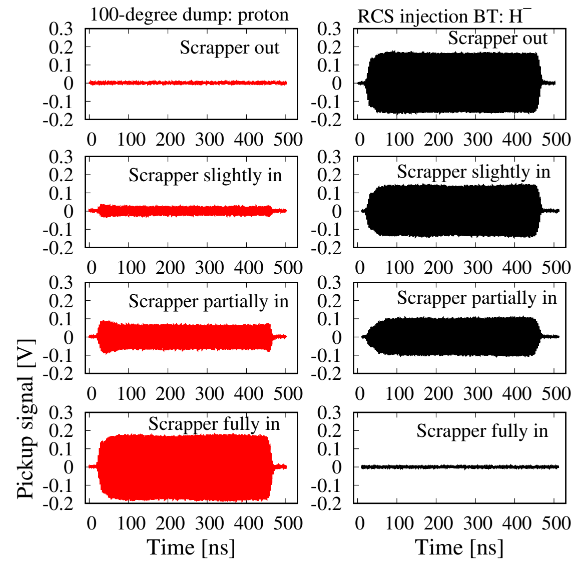

Figure 7: Simultaneously measured p and H^- raw signals for different positioning of the scrapper. The stripping/scrapping efficiency was independently obtained by using FFT analysis of the whole bunch as well as by integration of each pulse.

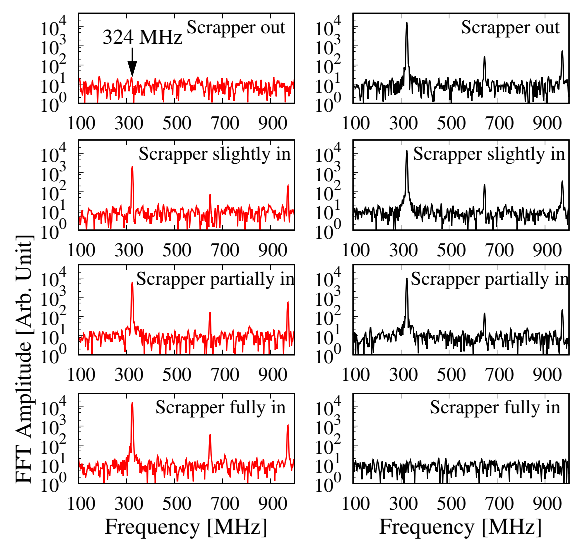

Figure 8: FFT spectra of proton and H^- raw signals shown in Fig. 7. The FFT amplitude corresponds to the micro pulse frequency of 324 MHz was used for the analysis.

at the beginning and at the end of the pulse might be due to character behavior of the chopper system and/or due insufficient beam loading compensation. The response of the signal with respect to the scrapper position can easily be seen. A similar situation is thus expected for H^- stripping by using lasers.

Figure 8 FFT (Fast Fourier Transformation) analysis of the raw signals, used for obtaining independent charge fractions from the FFT amplitude at 324 MHz. Figure 9 shows p and H^- fractions as a function of scrapper position as obtained from the FFT spectra. The stripped p and remaining un-

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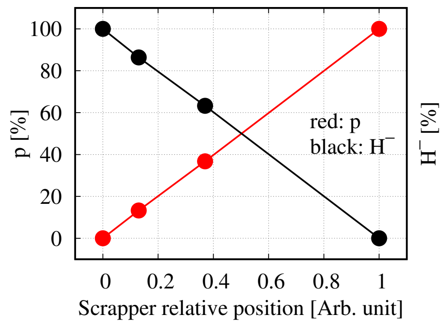

Figure 9: Stripping/scrapping efficiencies as a function of scrapper position as obtained from the FFT spectra. The fraction of scraped p were found to be consistent with expected un-stripped H^- fractions for any scrapper positions.

stripped H^- were precisely measured independently. The sum of p and H^- was obtained be to almost expected 100%, as neutral H^0 fraction was estimated be negligibly small.

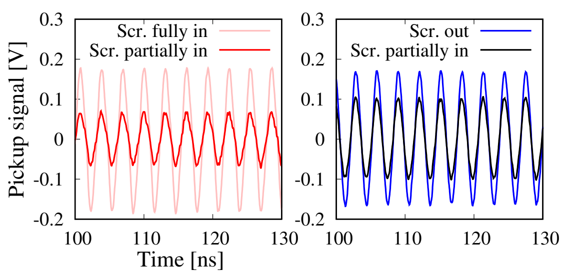

Figure 10: Expanded view of raw signals for some micro pulses, used to calculate individual charge fractions.

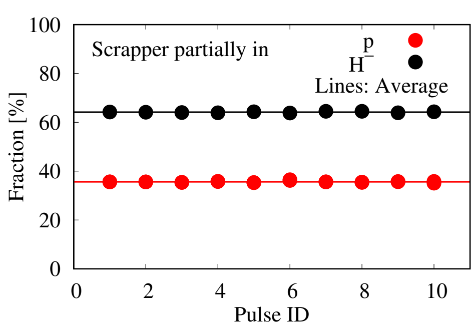

Figure 11: The p and H^- charge fractions of each individual micro pulse were was as obtained from the ratio of integrated yields with different scrapper position as shown in Fig. 10.

Next, we extracted stripping efficiency of each 324 MHz micro pulse, which is essential for the POP experiment as shown in Fig. 2. Figure 10 shows, expanded views of raw signals with and without scrapper, together with partially inserting the scrapper. The p charge fraction for each pulse was obtained from the ratio of integrated yields with scrapper partially in (red) to that with scrapper fully in (pink). The H^- fraction for were also individually obtained in the same day (ratio of data with black and blue). Figure 11 shows p and H^- charge fractions for some typical pulses, when the scrapper was partially inserted. The solid lines are averages values for these 10 pulses and were obtained to be 35.67±0.26%, and 64.15±0.25%, for p and H^-, respectively.

The present measurement technique can be thus demonstrated to obtain precise information of each 324 MHz micro pulse. The present method can be successfully utilized for the POP experiment of H^- stripping by using lasers, in order to precisely measure stripping efficiency of a single micro pulse. On the other hand, measurement of each individual micro pulse is also useful for optimization and adjustment of both H^- beam and laser pulses in the POP experiment. Such an individual measured information each micro pulses can be also used for multi-dimensional purposes, such as beam dynamics studies, optimization of micro level H^- beam, any any other purposes.

SUMMARY

The POP (proof-of-principle) experiment for H^- stripping by using only lasers, which is under preparation at J-PARC, requires precise measurements of all three charge fractions of only a single H^- micro pulse of 324 MHz at the downstream of IP. In order to obtain stripping efficiency of each individual micro pulse, we established a method measuring BPM pickup signal by using a fast oscilloscope. Instead of laser, we used charge-exchange type beam halo scrapper, and simultaneously measured the stripped p and un-stripped H^-. The p and H^- charge fractions as a whole with respect to scrapper positions were precisely obtained by using FFT analysis, where those for each individual micro pulses were also accurately obtained based on integration yields of each micro pulse. In order to obtain better time resolution, further better oscilloscope can be used, but the present measurement method can already be successfully utilized for the POP experiment.

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