DIRECT MEASUREMENTS OF SPACE-CHARGE-POTENTIAL IN HIGH INTENSITY H^- BEAM WITH LASER BASED PHOTO NEUTRALIZATION METHOD

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Abstract

Laser wire scanner is considered as the most promising method for profile measurements in high intensity H^- beams [1]. In order to demonstrate the feasibility of laser wire scanner, a Q-switched Nd:YAG laser (1064nm) diagnostic system has been developed in Japan Proton Accelerator Research Complex (J-PARC) linac [2]. In this paper, first experimental results of laser based beam current profile and space-charge potential measurements in J-PARC medium energy beam transport line (MEBT1) are described.

INTRODUCTION

Wire scanners are presently used to measure transverse beam profile in the J-PARC linac, and observed results agree with calculated rms widths within 20% differences [3]. However, measured beam intensity and pulse width has to be restricted by heat load limitations in the scanner wires. The interaction mechanism between thin wire and H^- ions for various beam energies should also be investigated to clarify beam profiles. To avoid these limitations, the photo neutralization method with Nd:YAG laser has been developed as an available candidate for beam intensity profile monitor. Laser stripping technique is also considered as charge exchange procedure for Accelerator-Driven-System (ADS) in J-PARC [4]. An electron of H^- beam can be stripped by fast and intense laser beam with non-destructively, and laser system have advantages of maintenance and radiation hardness in high intensity proton accelerators. The photo neutralization method is also expected as an advanced diagnostic technique to measure space-charge-potential in high intensity negative hydrogen ion beams. The kinetic energy of photo detached electron corresponds to the ion velocity and space-charge potential at stripped location.

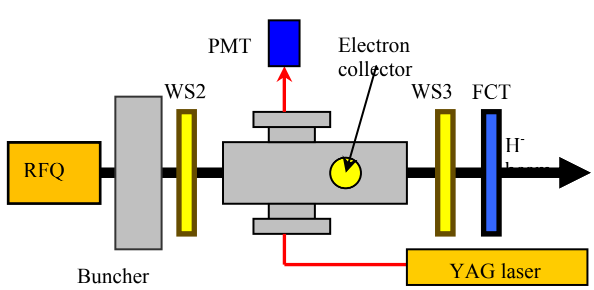

Fig.1: Schematic of laser profile monitor in MEBT1.

EXPERIMENTAL APPARATUS

The 0.5ms long, 30mA pulse beam in the MEBT1 consists of micro bunch of <0.5ns pulse width. The H^- ion beam is accelerated by 324MHz radio frequency quadrupole linac (RFQ) up to the beam energy of 3MeV. Laser profile monitor system was installed on MEBT1 transport line and laser light is horizontally injected into the H^- beam line and scanned across in the vertical direction (Fig. 1). Commercial Nd:YAG laser can produce pulse width of 20ns long, maximum pulse energy of 500mJ, wavelength of 1064nm at repetition rate of 25Hz. Laser beam size was formed to horizontal width of 6mm and height of 0.8mm at the H^- beam line by a pair of 80mm focal length cylindrical lenses. A photomultiplier tube (PMT) observe the laser beam that passing through vacuum chamber after interaction with H^- beam, to confirm laser injection timing, pulse width and optical alignment. Stripped electrons were deflected 90degree by a electromagnetic dipole and collected to a Faraday cup.

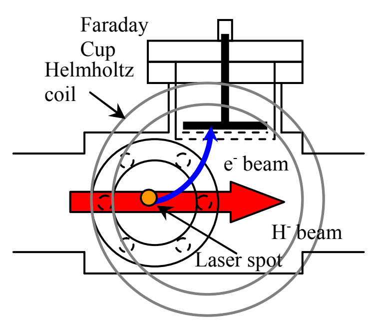

Fig.2: Layout of photo diagnostic box and Faraday cup.

The magnetic field required to deflect 1.63keV electrons is about 50G and its effect on the ion beam is negligible. In order to collect whole stripped electrons diffused by intense space charge, the sufficiently wide area collector plate have been prepared at the nearest location of downstream. The Faraday cup was also designed with electron repeller grid and electrostatic shield mesh (transmission ratio are both 56%, Au coated) in front of the detector. For a high current H^- beam, Lorentz stripping and/or residual gas stripping can contribute to a significant amount of activation. It's also being a source of background in laser wire measurement. Although the high energy component of background electron can be neglected owing to the small cross section of neutralization in the experimental condition of gas pressure of 10^{-6}Pa and magnetic field of 50G, electron cloud like component possibly be a contamination of electron collector. The electron repeller grid can discriminate the background component and also suppress the secondary electron emission from detector plate.

Vertical and horizontal beam profiles at up and downstream of photo interaction chamber are measured by wire scanners, and averaged (30msec) beam pulse signals for each sample positions. The out put signal of WS has been supposed to depend mainly on beam energy, wire diameter and materials. The bias potential have been optimized by measuring the wire signals as a function of bias potential. An expected mechanism of interaction between thin wire and H^- beam is that, as the wire is biased positively, the current component due to the intercepted H^- ion are clearly detected because of a reduction in secondary electron emission. The beam current was also monitored by using a fast current transformer (FCT, ~324MHz) at downstream of laser diagnostic box [5].

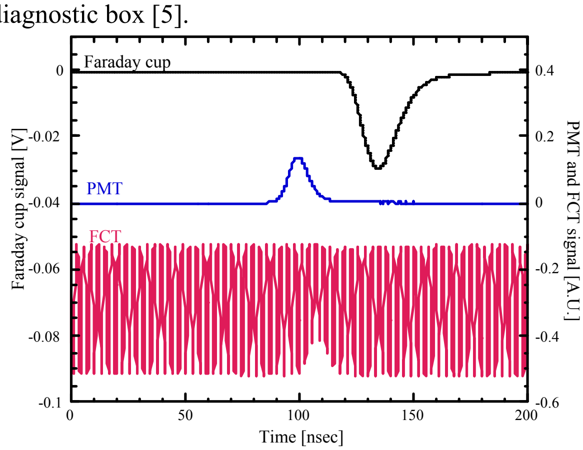

Fig. 3 An example of Faraday cup, PMT and FCT signals during the laser injection timing.

OBSERVATION RESULTS

In Fig. 3, the experimental results are shown as function of time along the beam pulse. Faraday cup signal was passed through 20MHz low pass filter to remove electrostatic 324MHz micro bunch oscillation.

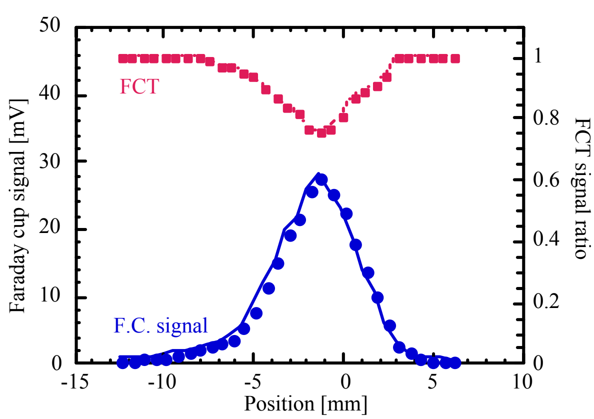

Fig. 4 Faraday cup signal and FCT reduction profile in vertical direction (beam current 15mA). The FCT notch signal corresponds to stripped electron signal.

The signal was clearly observed by averaging 16 pulses, and had about 30nsec delay time from PMT signal due to the difference of cable length and signal transport velocity. The beam current notch was also confirmed in FCT signal at downstream of laser photo neutralization point. The notch depth corresponds to the photo neutralized beam component. For example, about 25% decreasing of 15mA H^- beam equivalent to about 30mV Faraday cup signal by take account of the total 31% transmission efficiency of electron reppeler and shield mesh, 3dB reduction of low pass filter and 50ohm input impedance of oscilloscope. As shown in Fig. 4, the consistent beam current notch level with neutralized electron signal was confirmed.

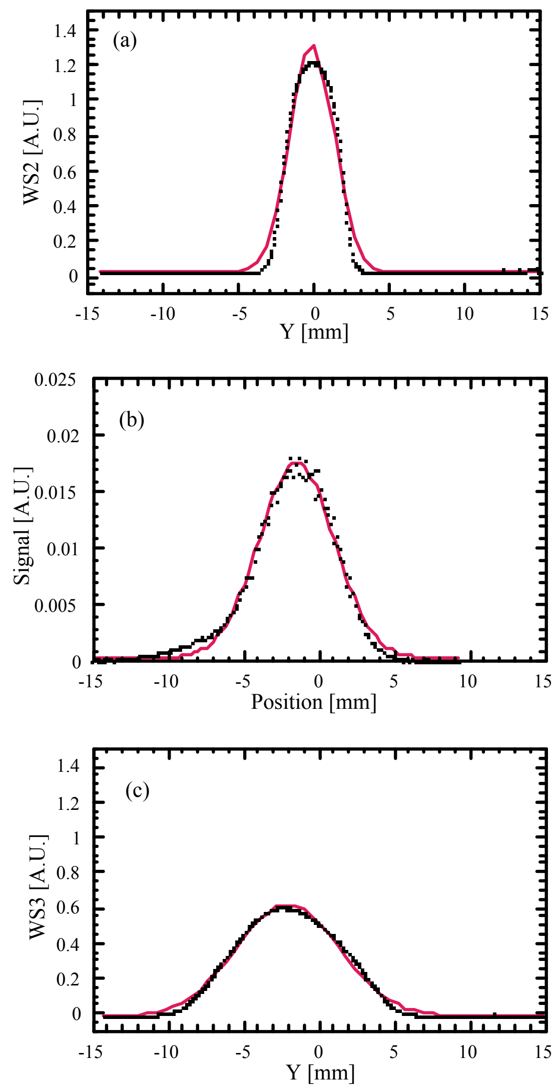

Fig. 5 Vertical beam profiles of (a) upstream at laser injection, (b) laser profile monitor and (c) downstream after photo neutralization for beam current of 20mA. Red thin line shows the Gaussian fitted curve to the measurement.

The radial profile after Abel inversion is also calculated and rms width of the Gaussian fitted vertical profile is σ=2.2mm, the width of the laser beam of 0.8mm intercept about 25% particles at beam center line. Thus the almost complete photo neutralization fraction for a 130mJ (repetition frequency of 5Hz) 1064nm Nd:YAG laser pulse on a 15mA, 3MeV H^- beam could also be confirmed [6]. Beam profiles measured with laser and carbon wire scanners located in the up and downstream of laser injection port are shown in Fig. 5. The Gaussian fitted curve to the laser and carbon wire data has an rms width of σ_{laser}=2.49±0.02mm, σ_{up}=1.45±0.01mm and σ_{down}=3.45±0.1mm for 20mA beam. The beam divergence and position in vertical direction were consistently observed.

The laser photo neutralization method has a capability of direct measurement of space-charge potential by evaluating the photo detached electrons energy. As shown in Fig. 6, the electron will have the energy of E_0 corresponding to m/M (m, M: electron and ion mass) of H^- beam energy at the stripped point, then the photo detached electron at this point will gain the energy of eϕ at the exit point. Therefore, the space-charge potential is directly measured by scanning the electron reppeler grid potential.

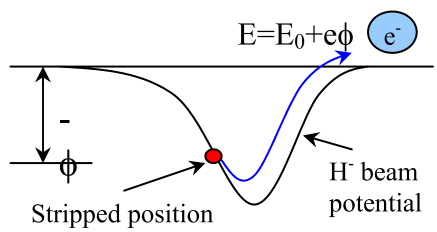

Fig. 6: Principle of space-charge potential measurement.

The bias potential dependence of photo detached electron is shown in Fig. 7. The low energy (<1.63keV) signal component shows that the electron trajectory has finite spread of injection angle into the Faraday cup due to the strong space-charge potential. The main component of electron signals are observed in higher energy region than electron kinetic energy of 1.63keV, and maximum electron energy indicate the space-charge potential at beam center. In the MEBT1 beam line, accelerated particles are confined by micro bunch structure of 324MHz RF potential. The Gaussian profile of 30degree phase width is assumed in longitudinal direction. The maximum space charge potential of about 700V, 500V and 200V are calculated for 20mA, 15mA and 5mA beam respectively by taking into account the experimental results of transverse profiles. Thus, the collected electron will have total energy of 2.3keV, 2.1keV and 1.8keV at the Faraday cup position. The experimental results of bias potential dependence agree with these calculation results.

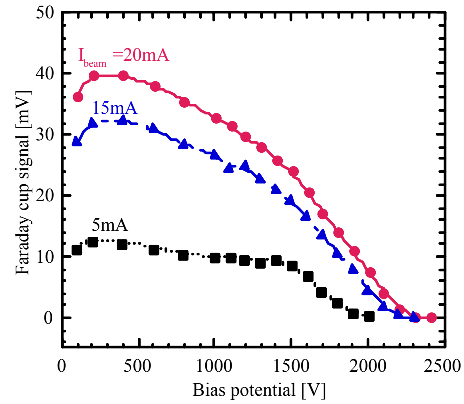

Fig. 7: Faraday cup signals as a function of applied bias potential.

SUMMARY

The Nd:YAG laser based beam profile monitor have been developed to observe the current profile of high intensity H^- beam in the J-PARC MEBT1. It was shown that the photo detached electron signal corresponds to the reduction of H^- beam current. The results of transverse profile measurements also agree with wire scanner signals of up and downstream. The strong space-charge effect is considered as an essential source of emittance blow up for high intensity linac beam. In order to contribute the beam dynamics study, the direct measurement of space-charge potential was also examined. The bias potential dependence is consistent with the calculation results of space-charge potential of micro bunch structure.

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